Study and Analysis of Postures and Ergonomic Design Tool to Minimize the Work-Related Musculoskeletal Disorder (WRMSD) of Construction Workers in The States of Maharashtra and West Bengal In India

Thesis submitted by

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PROFORMA – 1

"Statement of Originality"

I Manoj Tarachand Gajbhiye registered on 30th April 2019 do hereby declare that this thesis entitled **"Study and Analysis of Postures and Ergonomic Design Tool to Minimize the Work-Related Musculoskeletal Disorder (WRMSD) of Construction Workers in The States of Maharashtra and West Bengal In India"** contains literature survey and original research work done by the undersigned candidate as part of Doctoral studies.

All information in this thesis have been obtained and presented in accordance with existing academic rules and ethical conduct. I declare that, as required by these rules and conduct, I have fully cited and referred all materials and results that are not original to this work.

I also declare that I have checked this thesis as per the "Policy on Anti Plagiarism, Jadavpur University, 2019", and the level of similarity as checked by iThenticate software is 07 %.

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PREFACE

An individual's efficiency and job excellence are directly dependent upon the working postures, good health, and safety of the workers at workplaces. In view of this, identification and assessment of hazards or risk factors should be the high priority to control. Ergonomics, on the other hand, means fitting the task to the individual and not the individual to the task, encouraging compatibility between human and work system. It is a science of designing the jobs and workplaces that fit the workers. It is studied that the workplace design, equipment, machine, tools, products, environment, and system, taking into consideration the human's physical, physiological, biomechanical, and psychological capabilities, should optimize the effectiveness and productivity of work systems while assuring the safety, health, and well-being of the workers. The aim of human factors and ergonomics is to give a safe and productive workplace to the individual. It is also assumed and explored that all types of physical and mental stress are associated with the work and work environment. Work-related musculoskeletal disorders (WRMSDs) are common in the workplaces and construction sites. The muscles, nerves, tendons, ligaments, joints, and spinal cord are affected due to awkward working postures. Though, the automation and automated machines and tools are available to minimize human intervention in an industry. However, manual work is still required and plays a major role in industries. Also, the healing treatment of WRMSDs is costlier; hence, it is necessary to take precautionary measures before it's too late. High work efficiency without human efforts allows that the worker can be in good health and working postures. Awkward body posture influences Occupational injuries, muscular diseases, imbalance of muscles, and tissues. Hence, systematic observation, assessment, and remedies may decrease the risk of WRMSDs. From the study, lower back pain is the common spinal disease that restricts the movement of individuals. In view of above all, the present research work has been proposed, planned, and designed for the assessment of postures of different construction workers working in Maharashtra and West Bengal.

This thesis is prepared in well-organised manner into seven chapters. A brief summany of the each chapter is given below.

1. An overview of work-related musculoskeletal disorders, construction work and related occupations, causes, contributory factors of WRMSDs, the role of ergonomics, the requirement for postural analysis, ergonomic assessment methods, a literature review

of previous work using various ergonomic assessment techniques, the research gap, and objectives are discussed in Chapter One.

2. Data collection, data analysis and methods used in this research work are discussed in chapter two.
3. In Chapter 3, postural analysis of excavation workers, including the background, methods, analysis of traditional working postures, design of an Iron-pan for material handling, and postural analysis after modification, are discussed.
4. In Chapter 4, postural analysis of laborers (for concreting work), including the background, methods, analysis of traditional working postures, design of a collection and eviction table, and postural analysis after modification, are discussed.
5. In Chapter 5, postural analysis of rebar workers, including the background, methods, analysis of traditional working postures, design of a Foldable Multitasking Workable Platform, and postural analysis after modification, are discussed.
6. In Chapter 6, postural analysis of masons, including the background, methods, analysis of traditional working postures, a Prototype Design Proposal for a Multi-Tasking Portable Workbench, and postural analysis after modification, are discussed.
7. In Chapter 7, general conclusions are discussed, along with recommendations for future scope.

It is evident that the current research work on the "Study and Analysis of Postures and Ergonomic Design Tool to Minimize the Work-Related Musculoskeletal Disorder (WRMSD) of Construction Workers in The States of Maharashtra and West Bengal In India" will provide useful information and guidance to researchers regarding construction work, construction workers executing various construction occupations, the working environment, and the most vulnerable occupations within construction work, along with remedial solutions.

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(Manoj T. Gajbhiye)

VITA

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Dedicated to my parents, mentors and family….

**My strength and source of inspiration for their trust in me,
my learning, never-ending support, love and encouragement.**

TABLES OF CONTENTS

	Page No
TITLE SHEET	i
LIST OF PUBLICATIONS	ii
CERTIFICATE OF ORIGINALITY	vi
CERTFICATE FROM THE SUPERVISORS	vii
PREFACE	viii
ACKNOWLEDGEMENT	x
VITA	xii
DEDICATION	xiii
TABLE OF CONTENTS	xiv
LIST OF FIGURES	xxi
LIST OF TABLES	xxviii
LIST OF ABBREVIATION	xxxi
WORKERS ASSESSMENT QUESTIONNAIRE SHEET	xxxvi

Chapter 1 INTRODUCTION 1 - 87

1.1	Background	1
1.2	Construction Work, Related Occupations And Related Risk Factors	6
1.2.1	Excavation Worker (Manual)	7
1.2.2	Unskilled Worker /labour (Coolie)	9
1.2.3	Formwork (Centering/ Shuttering)	15
1.2.4	Rebarer	17
1.2.5	Mason (Brick layer /plasterer)	19
1.2.6	Electrician	24
1.2.7	Plumber	26
1.2.8	Tilers	28
1.2.9	Carpenter	30
1.2.10	Painter	32
1.3	Overview Work-Related Musculoskeletal Disorders (WRMSD)	35
1.3.1	Ergonomics	35
1.3.2	Musculoskeletal Disorders	35
1.3.3	Work- related musculoskeletal disorders (WRMSD)	35
1.3.4	Postural Analysis	36
1.4	Factors Contribute To The Development Of WRMSD	37
1.4.1	Causes Of WRMSD	37
1.4.2	Symptoms, Cause and Diseases of WRMSD in Construction Work	39
1.4.3	Sign And Symptoms Of WRMSD	43
1.4.4	Role Of Ergonomics In Construction	44

1.4.5 Requirement Of Postural Analysis Of Construction Worker 44
1.5 Ergonomic And Methods Of Assessment 45
1.5.1 Self-Report Method 46
1.5.2 Simple Observational Method 46
1.5.3 Advance Observational (Computer Based) Method 47
1.5.4 Direct Measurement Methods 48
1.5.5 Computer Modeling Techniques Using DHM 50
1.6 Construction Work And Previous Research 51
1.6.1 Previous research work on construction and WRMSD using Self-Report Methods 53
1.6.2 Previous research work on construction and WRMSD usingSimple Observation Methods 58
1.6.3 Previous research work on construction and WRMSD using Advance observation (computer based) Methods 61
1.6.4 Previous research work on construction and WRMSD using Direct Measurement Methods 64
1.6.5 Summary of Previous Research work 71
1.7 Research Gap 84
1.8 Aim, Objectives And Scope Of Present Research Work 86
1.8.1 Aim of the Present Research Work 86
1.8.2 Scope of the Present Research Work 86
1.8.3 Objectives of the Present Research Work 87

Chapter 2 METHODOLOGY 88-143

2.1 Data Collection Analysis And Postural Analysis For Various Occupations 88
2.1.1 Data Collection (Field Observation / Survey/ Questionnaires/Video Recording) 88
2.1.2 Participants 89
2.1.3 Result And Data Analysis 89
2.1.4 Summary 106
2.2 Description Of Risk/Exposure Assessment Technique Applied 108
2.2.1 Ovako Working Posture Analysis System (OWAS) 108
2.2.2 Standardized Nordic Musculoskeletal Questionnaire (NMQ) 111
2.2.3 Rapid Upper Limb Assessment Method (RULA) 114
2.2.4 Rapid Entire Body Assessment (REBA) 119
2.2.5 Quick Exposure Check (QEC) 124
2.2.6 Evaluation Del Riesgo Individual/Individual Risk Assessment (ERIN) 128
2.2.7 Assessment Of Repetitive Tasks Of The Upper Limbs (ART) 130
2.2.8 Workplace Ergonomic Risk Assessment (WERA) 132

2.2.9 Novel Ergonomic Postural Assessment Method (NERPA) 136
2.2.10 PUSH-PULL Analysis using CATIA V5R19 139
2.2.11 Revised Job Strain Index (JSI) 140

Chapter 3 **POSTURAL ANALYSIS OF EXCAVATION WORKERS AND NOVEL DESIGN OF IRON-PAN FOR MATERIAL HANDLING** 144-191

3.1 Background 144
3.2 Various Task Performed by the excavation workers 146
3.2.1 Excavation of soil using pic-axe (Job-1) 146
3.2.2 Soil collection in the Iron-pan (Job-2) 146
3.2.3 Lift the Iron-pan (Job-3) 146
3.2.4 Throwing of soil outside the pit / pass the Iron-pan to outside labourer (Job-4) 147
3.2.5 Receive Iron-pan by outside labourer (Job-5) 147
3.2.6 Throwing soil to dump by the outside labourer (Job-6) 147
3.3 Results 150
3.4 Result Of RULA, REBA, Biomechanical And Lifting Analysis For Traditional Working Postures Of All Task 153
3.4.1 Result of RULA and REBA Method for Traditional Working Postures 153
3.4.2 Biomechanical Analysis for Traditional Methods adopted 156
3.4.3 Lifting Analysis for Traditional Methods adopted 162
3.5 Design concept and working techniques for Excavation workers 164
3.5.1 Proposed Design Concept Of Crowbar And Working Techniques For Excavation Task (Job-1) 164
3.5.2 Novel Design of Iron-Pan for Material Handling and Working Postures Techniques for Job-2 to Job-4 164
3.5.3 Fabrication of Novel Design of Iron-Pan for Material Handling 169
3.5.3.1 Model of Novel Design of Iron-Pan 169
3.5.3.2 Requirement of Materials with specification 169
3.5.3.3 Different Parts of the Novel Design of Iron-Pan for Material Handling and their functions 169
3.5.3.4 Fabrication of Novel Design of Iron-Pan for Material Handling 170
3.5.3.5 Total Cost of Manufacturing/Fabrication 170
3.6 Postural Analysis And Biomechanical Analysis Using Novel. Design Of Iron-Pan For Material Handling And Proposed Methods 171
3.6.1 Postural Analysis for Excavation Task (JOB-1) after Modification 171

3.6.1.1 RULA Analysis for Proposed Design Concept of Crowbar and Working Technique for Excavation Task (Job-1) 171
3.6.1.2 Biomechnical Analysis for Proposed Design Concept of Crowbar and Working Technique for Excavation Task (Job-1) 172
3.6.2 Postural Analysis, Biomechanical Analysis and Lifting Analysis for Other Task (JOB-2 to JOB-5) using Novel Design of Iron-Pan after Modification 174
3.6.2.1 Postural and Biomechnical Analysis of Collection of Soil in the Novel Designed Iron-Pan for Material Handling (Job-2) 175
3.6.2.2 Postural and Biomechanical analysis for Lifting of Novel Designed Iron-Pan for Material Handling from ground level (Job-3) 176
3.6.2.3 Postural and Biomechanical Analysis for throwing of soil or passing of Novel Designed Iron-Pan for Material Handling to outside labour (Job-4) 178
3.6.2.4 Postural and Biomechanical Analysis for Receiving of Novel Designed Iron-Pan for Material Handling by the outside labourer (Job-5) 180
3.6.2.5 Lifting Analysis as per NIOSH 1991 using new prototype Iron-pan (Job-3, Job-4 and Job-5) 183
3.7 Summry 189

Chapter 4 **POSTURAL ANALYSIS OF UNSKILLED WORKERS (LABOUR) AND PROTOTYPE DESIGN PROPOSAL OF MATERIAL COLLECTION AND EVICTION TABLE FOR SLAB CONCRETING WORK** 192-222

4.1 Introduction 192
4.2 Task Performed by the Un-skilled worker (Labour) for concreting work 194
4.2.1 Transporation of concrete materials to concrete mixture machine from dumpyard 194
4.2.2 Mixing of concrete by operator using Concret Mixture machine 196
4.2.3 Elevate the mixture to Slab Level 196
4.2.4 Unloading the mixture from Elevator 196
4.2.5 Collection and Transfer the Mixture by the Labour 201
4.2.6 Uniform distribution of the concrete mixture on the Slab Centering 202
4.3 Results 203
4.4 Results obtained by using ERIN, NERPA and WERA methods 207
4.5 Design of Concrete Collection and Eviction Table 210
4.5.1 Design of Model of Concrete Collection andEviction Table 210

	4.5.2	Description of Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work	211
4.6		Postural Analysis Using Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work	213
	4.6.1	ERIN, RULA and REBA Score using Prototype Design Proposal of Material Collection and Eviction Table for Slab Concreting Work	213
	4.6.2	Biomechanical Analysis Using Prototype Design Proposal of Material Collection and Eviction Table for Slab Concreting Work for different weight	216
	4.6.3	Lifting Analysis Using Newly Proposed Design Concrete Collection and Eviction Table For Different Weight as Per NIOSH 1991	218
4.7		Summary	221
Chapter 5		**POSTURAL ANALYSIS OF REBAR AND DESIGN OF FOLDABLE MULTI-TASKING WORKABLE PLATFORM FOR REBAR WORK**	223-251
5.1		Introduction	223
5.2		Various Task Performed By The Rebar	225
	5.2.1	Task 1: Rebar Straightening (R1)	225
	5.2.2	Task 2: Rebar Cutting to required length (R2)	225
	5.2.3	Making of Stirrups / Ties (R3):	225
	5.2.4	Task 4: Making of reinforcement / rebar steel cage for column (R4)	226
	5.2.5	Task 5: Tying stirrups in plinth and beam (R5)	226
	5.2.6	Task 6: Tying of Slab reinforcement / Rebar using wires (R6)	226
	5.2.7	Task 7: Bending column bar to attach new rebar for extension (R7)	226
5.3		Results	231
5.4		Results Of NERPA, ART And JSI Methods For Traditional Working Postures	234
	5.4.1	Result Of NERPA Method For Traditional Working Technique	234
	5.4.2	Result Of ART Method For Traditional Working Technique	235
	5.4.3	Result Of JSI Method For Traditional Working Technique	236
5.5		Design Of Foldable Mutlitasking Workable Platform For Rebar Work	237
	5.5.1	Design Model Of Foldable Mutlitasking Workable Platform For Rebar Work	237
	5.5.2	Fabrication Of Foldable Mutlitasking Workable Platform For Rebar Work	240

		5.5.2.1	Requirment oF Materials With Specification	240
		5.5.2.2	Different Parts Of The Foldable Mutlitasking Workable Platform For Rebar And Their Functions	240
		5.5.2.3	Fabrication Of Foldable Mutlitasking Workable Platform For Rebar Work	242
		5.5.2.4	Total cost of manufacturing/Fabrication	245
5.6			Postural Analysis Using Newly Designed Foldable Mutlitasking Workable Platform	246
	5.6.1		Result of NERPA Method For Newly Designed Foldable Mutlitasking Workable Platform after Modification	250
	5.6.2		Result of ART Method For Newly Designed Foldable Mutlitasking Workable Platform	251
	5.6.3		Result Of JSI Method For Newly Designed Foldable Mutlitasking Workable Platform	251
5.7			Summary	252
Chapter 6		**POSTURAL ANALYSIS OF MASONS AND PROTOTYPE DESIGN PROPOSAL OF MULTI-TASKING PORTABLE WORKBENCH**		254-287
6.1			Introduction	254
6.2			Various Task Performed By The Masons	255
	6.2.1		Masons' / Masons' nature of job and ergonomic risks	255
	6.2.2		Task 1: Bricklaying	255
	6.2.3		Task 2: Plastering	257
6.3			Results	259
6.4			Results of REBA, ERIN, WERA AND QEC Methods For Traditional Working Postures	265
	6.4.1		Result Of REBA, ERIN, WERA And QEC methods for Bricklaying Work Posture	265
	6.4.2		Result of REBA, ERIN, WERA and QEC methods for Plastering Posture	270
6.5			Prototype Design Proposal Of Multi-Tasking Portable Workbench	275
	6.5.1		Design Model of Multi-Tasking Protable Workbench for Masonry Work	275
6.6			Postural Analysis Using Newly designed Multi-Tasking Portable Workbench for Masonry Work	280
	6.6.1		REBA Score after Modification for both working postures	282
	6.6.2		WERA socre after Modification for both working postures	282
6.7			Summary	284

Chapter 7 **GENERAL CONCLUSION AND FUTURE SCOPE** 288-290

7.1 Conclusion 288
7.2 Future Scope 290

Chapter 8 **REFERENCE** 291-317

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LIST OF FIGURES

Sl. No.	Figure No.	Description	Page No.
1	1.1	Work-related musculoskeletal disorders and contribution factors	37
2	1.2	Fish bone diagram of Work-related musculoskeletal disorders and contribution factors	38
3	1.3	Flow Diagram of Literature Review	52
4	2.1	Percentage of Male and Female feeling pain in different body parts (n=465)	92
5	2.2	Percentage of male and female feeling pain at various progression of day	93
6	2.3	Number of workers feeling pain according to age group (n=465)	96
7	2.4	Number of workers feeling pain (n=465) according to Occupation group	96
8	2.5	Number of workers feeling pain (n=465) according to working experience	97
9	2.6	Percentage of construction worker feel pain in different body parts of different age group (n=465)	101
10	2.7	Percentage of worker feel pain at different time zone by different age group construction workers (n=465)	102
11	2.8	Percentage of construction workers working in awkward posture, work with pace, doing pervasive jobs, meet with traumatic incidents and consume alcohol (n=465)	103
12	2.9	Occupation and complaint of pain in body parts by different occupational workers	105
13	2.10	Worksheet of OWAS	110
14	2.11	Nordic Musculoskeletal Questionnaire (NMQ)	113
15	2.12	Rapid Upper Limb Assessment Method Worksheet (RULA)	118
16	2.13	Rapid Entire Body Assessment (REBA) Worksheet	123
17	2.14(a)	QUICK EXPOSURE CHECK (QEC)	126
18	2.14(b)	QUICK EXPOSURE CHECK (QEC)	127
19	2.15	Evaluation Del Riesgo Individual/Individual Risk Assessment Worksheet **(**ERIN)	129

20	2.16	Assessment of Repetitive Tasks of the Upper Limbs (ART) Worksheet	131
21	2.17(a)	Workplace Ergonomic Risk Assessment (WERA)	134
22	2.17(b)	Workplace Ergonomic Risk Assessment (WERA)	135
23	2.18	Novel Ergonomic Postural Assessment Method (NERPA) worksheet	138
24	2.19	Job Strain Index (JSI) – Revised Strain Index	143
25	3.1	Actual images of labour performing excavation and associated work	148-149
26	3.1(i)	Labourers performing excavation work using pick-axe (Loosen the soil) (Job-1) (P-1) (P-2)	148
27	3.1(ii)	Labourer performing collection of soil in Iron-pan (Job-2)	148
28	3.1(iii)	Labourer performing lifting of Iron-pan (Job-3)	148
29	3.1(iv)(a)(b)	Labourer performing soil throwing / passing Iron-pan to outside labourer (Job-4)	149
30	3.1(v)	Outside labour receive Iron-pan from Inside labour (Job-5)	149
31	3.1(vi)(a)(b)	Outside labourer dumping soil (Job-6)	149
32	3.2	Number and percentage of worker reply to pain/discomfort	153
33	3.3	Biomechanical analysis for all Six Jobs designed in CATIA.	158-161
34	3.3(i)(a)	Biomechanical analysis of first position with worker holding pick-axe above shoulder height (Job-1) (P-1)	158
35	3.3(i)(b)	Biomechanical analysis of second position with worker holding pick-axe below shoulder height (Job-1) (P-2)	158
36	3.3(ii)	Soil collection in the Iron-pan (Job-2)	159
37	3.3(iii)	Lifting of pan (Job-3)	159
38	3.3(iv)	Throwing of soil outside the pit / pass the iron-pan to outside labourer (Job-4)	160
39	3.3(v)	Receiving of iron-pan by the outside labourer (Job-5)	160
40	3.3(vi)	Throwing of soil by the outside labourer (Job-6)	161
41	3.4	Result of lifting of pan as per NIOSH 1991 guidelines designed in CATIA	162
42	3.5	Proposed working posture using crow bar	164
43	3.6	Novel Design of Iron-Pan for Material Handling	165-168
44	3.6(i)	Novel Design of Iron-Pan for Material Handling (2D)	165

45	3.6(ii)	Novel Design of Iron-Pan for Material Handling (3D)	166
46	3.6(iii)(a)(b)(c)	Parts of Nevel Designed Iron-pan	166
47	3.6(iv) (a)(b)	Fabricated Iron-pan	167
48	3.6(v)(a)(b)	Labour working with Novel Design of Iron-Pan	168
49	3.7	Proposed working posture using crow bar, RULA and Biomechanical Scores	173
50	3.7(a)	RULA score of left side of the proposed working posture using crow bar	173
51	3.7(b)	RULA score of left side of the proposed working posture using crow bar	173
52	3.7(c)	Biomechanical analysis of proposed working posture using crow bar	173
53	3.8	Collection of soil in the Novel Design of Iron-Pan for Material Handling (Job-2)	175
54	3.9	Lifting of Novel design of Iron-pan from ground level (Job-3)	176-177
55	3.9(i)	Lifting of Iron-pan from ground level (for 20 kg) (Job-3(a))	176
56	3.9(ii)	Lifting of Iron-pan from ground level (for 15 kg) (Job-3(b))	177
57	3.9(iii)	Lifting of Iron-pan from ground level (for 10 kg) (Job-3(c))	177
58	3.10	Throwing of soil or passing of Novel Design Iron-pan to outside labourer (Job-4)	179
59	3.10(i)	Throwing of soil labour/ passing Iron-pan to outside labour (Iron-pan at shoulder level - 20kg) (Job-4(a))	179
60	3.10(ii)	Throwing of soil labour/ passing Iron-pan to outside labour (Iron-pan at shoulder level - 15kg) (Job-4(b))	179
61	3.10(iii)	Throwing of soil labour/ passing Iron-pan to outside labour (Iron-pan at shoulder level - 10kg) (Job-4(c))	179
62	3.11	Receiving of Iron-Pan by outside labour	180-181
63	3.11(i)	Receiving of pan by the outside labourer (20 kg) (Job-5(a))	180
64	3.11(ii)	Receiving of pan by the outside labourer 15 kg) (Job-5(b))	181
65	3.11(iii)	Receiving of pan by the outside labourer (10 kg) (Job-5(b))	181
66	3.12	NIOSH 1991 Lifting result lifted from ground level (Job-3)	185
67	3.12(i)	Lifting result when time per lift is 120 second for lifting 20 kg weight	185

68	3.12(ii)	Lifting result when time per lift is 120 second for lifting 15 kg weight	185
69	3.12(iii)	Lifting result when time per lift is 120 second for lifting 10 kg weight	185
70	3.13	NIOSH 1991 Lifting result when iron-pan at chest level of the inside labourer (Job-4)	186-187
71	3.13(i)	Lifting result when time per lift is 120 second for lifting 20 kg weight when pan at shoulder level	186
72	3.13(ii)	Lifting result when time per lift is 120 second for lifting 15 kg weight when pan at shoulder level	186
73	3.13(iii)	Lifting result when time per lift is 120 second for lifting 10 kg weight when pan at shoulder level	187
74	3.13(iv)	Lifting result when time per lift is 120 second for lifting 5 kg weight when pan at shoulder level	187
75	3.14	NIOSH 1991 lifting result for outside labourer (Job-5)	188
76	3.14(i)	Lifting result of external laborer when time per lift is 120 second for lifting 20 kg weight	188
77	3.14(ii)	Lifting result of external laborer when time per lift is 120 second for lifting 15 kg weight	188
78	3.14(iii)	Lifting result of external laborer when time per lift is 120 second for lifting 10 kg weight	188
79	4.1	Transportation of materials to concrete mixture machine	194-196
80	4.1(i)	Collecting, Lifting and Transportation of Gravels	194
81	4.1(ii)	Collecting, Lifting and Transportation of Sand	195
82	4.1(iii)	Lifting, Transportation and unloading of cement sack	195
83	4.1(iv)	Mixture Operator collecting water from barrel	196
84	4.2 (a)(b) (c)	Unlocking and locking of Hopper	197
85	4.3	Figure of Elevator	198-199
86	4.3(i)	Real time elevator with vertical distance (at first floor)	198
87	4.3(ii)	Real time Elevator (view from ground)	199
88	4.4	Figure of elevator with hopper at first floor and collection of concrete	200-201
89	4.4(i)	Figure of real time elevator with hopper releasing concrete on floor (unloading of concrete mixture)	200
90	4.4(ii)	Laborers collecting concrete in the iron-pan	201
91	4.5	Real time images of collectiong, lifting and holding of iron-pan on head	202
92	4.5(a)	Collection of Concrete in the Iron-pan	202
93	4.5(b)	Lifting of Iron-Pan	202
94	4.5(c)	Lifting and holding Iron-Pan on head	202
95	4.6	Labourers Reaction About Pain in Different Body Parts	205

96	4.7	Percentage of Laborers having Pain in Different Body Parts	208
97	4.8	Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work	210
98	4.9	Lifting of Iron-pan from the height of 1000 mm and 500 mm	212
99	4.9(i)	Person lifting Iron-Pan from Height of stand 1000 mm	212
100	4.9(ii)	Person lifting Iron-Pan from Height of stand 500 mm	212
101	4.10	RULA Score (Obtained in CATIA) from Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work	213-214
102	4.10(a)	RULA Scores for left side of the manikin after Modification	213
103	4.10(b)	RULA Scores for right side of the manikin after Modification	214
104	4.11	Biomechanical Analysis for different weight using Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work	217-218
105	4.11(a)	Biomechanical analysis score for 10 kg	217
106	4.11(b)	Biomechanical analysis score for 12 kg	217
107	4.11(c)	Biomechanical analysis score for 15 kg	218
108	4.11(d)	Biomechanical analysis score for 20 kg	218
109	4.12	Lifting analysis scores for different weight using Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work	219-220
110	4.12(a)	NIOSH Lifting analysis score for 10 kg	219
111	4.12(b)	NIOSH Lifting analysis score for 12 kg	219
112	4.12(c)	NIOSH Lifting analysis score for 15 kg	220
113	4.12(d)	NIOSH Lifting analysis score for 20 kg	220
114	5.1	Various Task performed by the Rebarers	227-230
115	5.1(i)(a)(b)(c)	Rebar Straightning (R1)	227
116	5.1(ii)(a)(b)	Rebar Cutting (to required length) (R2)	227
117	5.1(iii) (a)(b)	Making of Stirrups / Ties (R3)	228
118	5.1(iv)	Making of reinforcement / rebar steel cage for column (R4)	228
119	5.1(v)	Tying stirrups in plinth and beam (R5)	229
120	5.1(vi)	Tying of Slab reinforcement / Rebar using iron wires (R6)	229

121	5.1(vii)	Straightning of column rebar for extension of column (R7)	230
122	5.2	Number and percentage of worker reply to pain/discomfort	233
123	5.3	Detailed 2D Drawing of Foldable Mutlitasking Workable Platform for Rebar work	238
124	5.4	Detailed 3D Drawing of Foldable Mutlitasking Workable Platform for Rebar work (Isometric view)	239
125	5.5	Fabricated Foldable Mutlitasking Workable Platform for Rebar work	242-244
126	5.5 (a)	Fabricated Foldable multitasking workable plateform	242
127	5.5 (b)	Fabricated Foldable multitasking workable plateform (Folded)	243
128	5.5 (c)	Fabricated Foldable multitasking workable plateform (Opened)	244
129	5.5 (d)	Fabricated Foldable multitasking workable plateform (Arrangement for making stirrups)	244
130	5.6	Rebar Cage tying with newly designed Foldable Mutlitasking Workable Platform	246
131	5.7	Rebar Cage tying with newly designed Foldable Mutlitasking Workable Platform	247
132	5.8	Cutting of Rebar using newly design foldable multitasking workable platform	248
133	5.9	Stirrups making with newly designed newly design Foldable Mutlitasking Workable Platform	248
134	5.10	Newly design foldable multitasking workable platform with weight	249
135	6.1	Real time images of Masons' performing bricklaying work	256
136	6.1(a)	Collect mortar from iron pan (BL-1)	256
137	6.1(b)	Laying of mortar bed (BL-2)	256
138	6.1(c)	Filling bricks gap(BL-3)	256
139	6.1(d)	Adjust level (BL-4) String Line (Adjust Level and line)	256
140	6.1(e)	Picking of Brick (from ground) (BL-5)	256
141	6.1(f)	Laying of Brick (BL-6)	256
142	6.1(g)	Breaking of Brick (BL-7)	256
143	6.2	Real time images of Masons' performing plastering work	258
144	6.2(a)	Applying mortar to ceiling (PL-1)	258
145	6.2(b)	Level /Plan the mortar (PL-2)	258
146	6.2(c)	Applying mortar on wall (for inside plastering) (PL-3)	258

147	6.2(d)	Level/plain the mortar (for inside plastering) (PL-4)	258
148	6.2(e)	Picking mortar for plastering (to apply on wall) (for outside plastering) (PL-5)	258
149	6.2(f)	Applying mortar on wall (for outside plastering) (PL-6)	258
150	6.2(g)	Level / plain the mortar (for outside plastering) (PL-7)	258
151	6.3	Feeling Pain in different body parts by Mason	262
152	6.4	Percentage of body part feeling pain by Mason	263
153	6.5	Pain at different time zone by all Masons	264
154	6.6	Details of pain due to other parameter complaint by Masons	264
155	6.7	Detailed 2D Drawing of Proposed Multi-Tasking Portable Workbench (Parts)	276
156	6.8	Drawing of Multi-Tasking Portable Workbench (with Top view, Front view, Side view and Isometric view)	277
157	6.9	Drawing of Multi-Tasking Portable Workbench with BOM and Maximum height (1200 mm)	278
158	6.10	Multi-Tasking Portable Workbench with minimum height (400 mm)	279
159	6.11	Manikin working in sitting position with resting its foot on foot rest.	281
160	6.12	Manikin working on standing position with resting its foot on foot rest	281
161	6.13	Manikin working on standing position on top	282

LIST OF TABLES

Sl. No.	Table No.	Description	PAGE NO.
1	1.1	Types of WRMSD Diseases and relevance to construction	40
2	1.2	Body Parts and External and Internal Symptoms of WRMSD	43
3	1.3	Previous Research work using Self-report method in construction	53
4	1.4	Previsous Research work using Simple observation method in construction	58
5	1.5	Previous Research Work using Advance observation (computer based) method in construction	61
6	1.6	Previous Resarch work using Direct measurement methods in construction	64
7	2.1	Somatic characteristics of construction workers (n=465)	91
8	2.2	Number of Male and Female feeling pain in different body parts (n=465)	92
9	2.3	Feeling of pain at various progression of day (n=385)	93
10	2.4	Characteristics of construction workers (n=465)	94
11	2.5	Number of workers feeling pain (n=465)	95
12	2.6	Total number of workers in different construction occupation at different age group (n=465)	97
13	2.7	Number of workers feeling pain in different construction occupation at different age group (n=465)	98
14	2.8	Details of pain while working in awkward postures, doing work with pace, doing pervasive jobs, after traumatic incidents and when consume alcohol/ chewing tobacco/smoke by all workers (n=465)	99
15	2.9	Percentage of construction worker feel pain in different body parts of different age group (n=465)	101
16	2.10	Percentage of worker feel pain at different time zone by different age group construction workers (n=465)	102
17	2.11	Percentage of construction workers working in awkward posture, work with pace, doing pervasive jobs, meet with traumatic incidents and consume alcohol (n=465)	103
18	2.12	Occupation and complaint of pain in body parts by different occupational workers	104
19	2.13	Proposed priority levels for Quick Exposure Check scores	125
20	2.14	Comparison of joint angle value of RULA and NERPA method	137
21	2.15	Risk Factors and its Multiplier	141

22	3.1	Somatic Characteristics of workers (Excavation)	151
23	3.2	Worker reply to pain/discomfort (N=54) (Excavation)	152
24	3.3	RULA Scores for Traditional Working Postures of Excavation	154
25	3.4	REBA Scores for Traditional Working Postures of Excavation	155
26	3.5	Biomechanical analysis results of all six jobs for Traditional Working postures of Excavation	157
27	3.6	Lifting pan from ground for Traditional Working Postures of Excavation	163
28	3.7	RULA scores for first, second and new proposed conceptual body position (Excavation)	171
29	3.8	Biomechanical analysis on the spinal segment of L4/L5 of first, second and proposed conceptual body position (Excavation)	172
30	3.9	RULA score after modification (Job-2, Job-3, Job-4, Job-5)	182
31	3.10	REBA Scores after modification (Job-2, Job-3, Job-4, Job-5)	182
32	3.11	Biomechanical analysis results after modification (Job-2, Job-3, Job-4, Job-5)	183
33	3.12	Lifting analysis results after modification (Job-3, Job-4, Job-5)	184
34	4.1	Somatic Characteristics of workers (N=68)	204
35	4.2	Laborers' reaction about pain/discomfort in body (N=68)	205
36	4.3	Laborers' reaction about pain/discomfort in different time zone	206
37	4.4	ERIN Score for Traditional Working Postures	207
38	4.5	RULA Score for Tranditional Working Postures	208
39	4.6	REBA Score for Tranditional Working Postures	209
40	4.7	ERIN Score using Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work	214
41	4.8	RULA Score using Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work	215
42	4.9	REBA Score using Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work	216
43	4.10	Biomechanical analysis score using Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work	217
44	4.11	Result of lifting-lowering analysis by CATIA after Modification	218
45	5.1	Somatic Characteristics of Rebar workers (N=48)	232
46	5.2	Rebarer reply to pain/discomfort (N=48)	232

47	5.3	Ergonomics Risk Scores Of NERPA Method For Traditional Working Postures	234
48	5.4	Ergonomics Risk Scores of Assessment of repetitive tasks of the upper limbs (ART) Method For Traditional Working Postures	235
49	5.5	Ergonomics Risk Scores Of Revised Job Strain Index (JSI) Method For Traditional Working Postures	236
50	5.6	NERPA and ART Score after using Newly Designed Foldable Multitasking Workable Platform	250
51	5.7	Revised Job Strain Index Score after using Newly Designed Foldable Multitasking Workable Platform	251
52	6.1	Demographic characteristics of Masons' (n=64)	259
53	6.2	Number of Masons' feeling pain (n=64)	260
54	6.3	Feeling Pain in different body parts by the Masons (n=64)	261
55	6.4	Pain at different time zone by all Masons	261
56	6.5	Details of pain due to other parameter are mentioned below	262
57	6.6	Ergonomics Risk Scores of REBA (Bricklaying Work)	266
58	6.7	Ergonomics Risk Scores of ERIN (Bricklaying Work)	267
59	6.8	Ergonomics Risk Scores of WERA (Bricklaying Work)	268
60	6.9	Ergonomics Risk Scores of QEC (Bricklaying Work)	269
61	6.10	Ergonomics Risk Scores of REBA (Plastering Work)	271
62	6.11	Ergonomics Risk Scores of ERIN (Plastering Work)	272
63	6.12	Ergonomics Risk Scores of WERA (Plastering Work)	273
64	6.13	Ergonomics Risk Scores of QEC (Plastering Work)	274
65	6.14	Ergonomic risk score of REBA and WERA Methods (for Bricklyaing and Plastering Work) after modifications	283
66	6.15	Comparative result of REBA, ERIN, WERA and QEC for Bricklaying work for Traditional working Postures	285
67	6.16	Comparative result of REBA, ERIN, WERA and QEC for Plastering work for Traditional working Postures	286

LIST OF ABBREVIATION

Sl. NO.	ABBREVIATION	DESCRIPTION
1	OWAS	OVAKO WORKING POSTURE ANALYSIS SYSTEM
2	NMQ	STANDARDIZED NORDIC MUSCULOSKELETAL QUESTIONNAIRE
3	RULA	RAPID UPPER LIMB ASSESSMENT
4	REBA	RAPID ENTIRE BODY ASSESSMENT
5	QEC	QUICK EXPOSURE CHECK
6	ERIN	EVALUATION DEL RIESGO INDIVIDUAL/ INDIVIDUAL RISK ASSESSMENT
7	ART	ASSESSMENT OF REPETITIVE TASKS OF THE UPPER LIMBS
8	WERA	WORKPLACE ERGONOMIC RISK ASSESSMENT
9	NERPA	NOVEL ERGONOMIC POSTURAL ASSESSMENT METHOD
10	JSI	REVISED JOB STRAIN INDEX
	RULA	
11	UA	Upper Arm
12	LA	Lower Arm
13	W	Wrist
14	WT	Wrist Twist
15	SC(A)	Score in Table-A
16	M	MUSCLE SCORE
17	F	Force
18	SC(C)	Score in Table-C
19	N	Neck
20	BK/T	Back/Trunk
21	L	Legs
22	SC(B)	Score in Table-B
23	SC(D)	Score in Table-D
24	RLS	RULA Score
	REBA	
25	N	Neck
26	BK/T	Back/Trunk
27	L	Legs
28	PS(A)	Posture score in Table A
29	F	Force
30	TS(A)	Total Score of A
31	UA	Upper Arm
32	LA	Lower Arm
33	W	Wrist
34	PS(B)	Posture score in Table B
35	CP	Coupling Score

36	TS(B)	Total Score of B
37	TS(C)	Total score from Table C
38	A	Activity Score
39	RBS	REBA Score
	BIOMECHANICAL ANALYSIS	
41	M	Moments about L4/L5
42	C	Compression on L4/L5
43	BLC	Body load compression
44	ATC	Axial Twist compression
45	F/EC	Flexion/Extension compression
46	JS	Joint shear about L4/L5
47	AF	Abdominal force
48	AP	Abdominal pressure
	LIFTING ANALYSIS	
49	RWL	Recommended weight limit
50	LI	Lifting Index
	ERIN	
51	BK	Back
52	T	Trunk
53	S	Shoulder
54	UA	Upper Arm
55	LA	Lower Arm
56	H	Hand
57	W	Wrist
58	N	Neck
59	L	Legs
60	R	Rhythm
61	IOE	Intensity Of Effort
62	SA	Self-Assessment
63	GR	Global Risk
	NERPA	
64	BP	Body Parts
65	UA	Upper Arm
66	LA	Lower Arm
67	W	Wrist
68	WT	Wrist twist
69	PS-A	Posture Score in Table-A
70	M	Muscle score
71	F	Force/Load score
72	N	Neck
73	LB	Lower Back/Trunck
74	L	Legs
75	PS-B	Posture Score in Table-B
76	M	Muscle Score

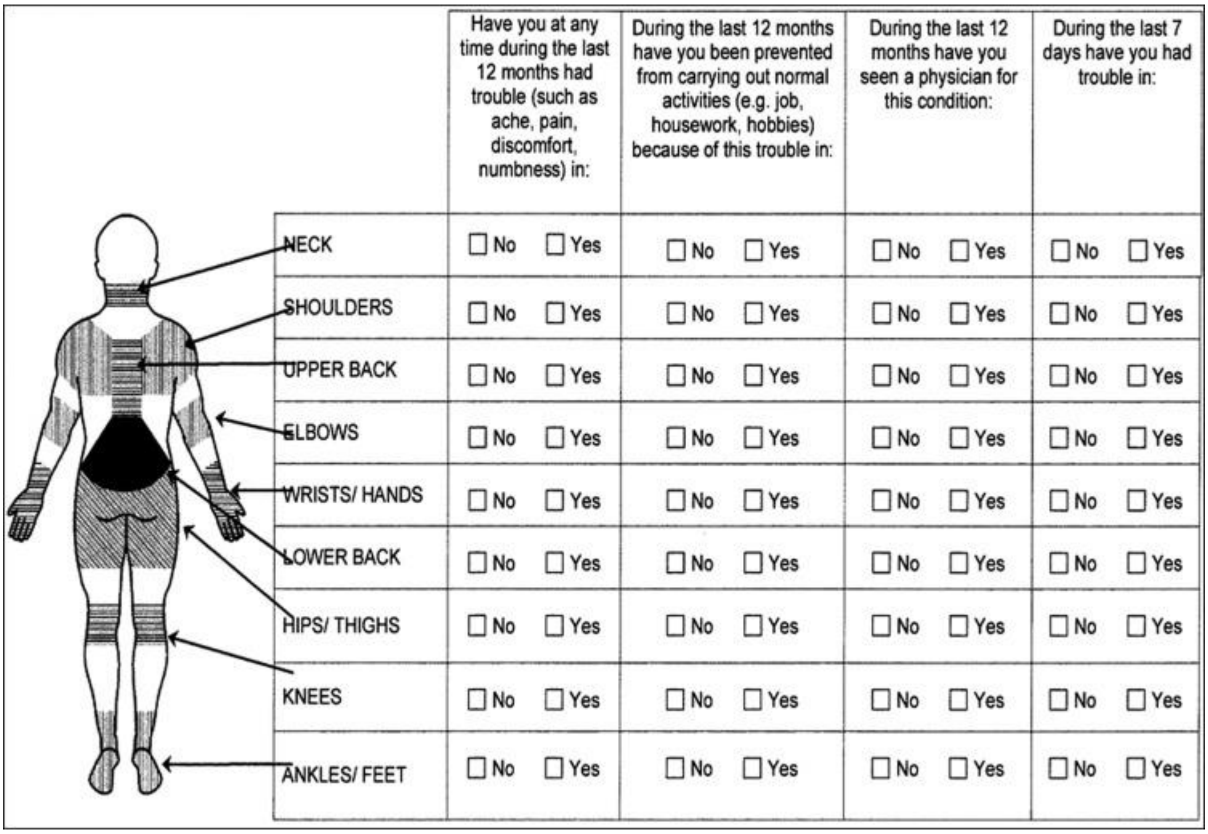
77	F	Force/load Score
78	TS-C	Posture Score in Table-C
79	FS	FINAL SCORE
80	RL	RISK LEVEL
	ART	
81	A1	Arm Movements
82	A2	Repetition
83	B	Force
84	C1	Head/Neck Posture
85	C2	Back Posture
86	C3	Arm Posture
87	C4	Wrist Posture
88	C5	Hand/Finger grip
89	D1	Breaks
90	D2	Work Pace
91	D3	Other Factors
92	TS	Task Score
93	D4	Duration Multiplier
94	ES	Exposure Score
95	RL	Risk Level
	JSI	
97	JS	Job Strain
	WERA	
98	**Part A**	
99	**S**	Shoulder
100	**W**	Wrist
101	**BK/T**	Back
102	**N**	Neck
103	**L**	Leg
104	**PART B**	
105	**LD/F**	Froceful
106	**V**	Vibration
107	**CST**	Contact Stress
108	**TD**	Task Duration
109	**FS**	Final Score
	QEC	
110	**BK/T**	Back
111	A	When performing the task, is the back (select worse case situation) A1 Almost neutral? A2 Moderately flexed or twisted or side bent? A3 Excessively flexed or twisted or side bent?

112	B	For seated or standing stationary tasks. Does the back remain in a static position most of the time? B1 No B2 Yes
113	**S/LA/UL**	Sholder/Arms
114	C	When the task is performed, are the hands (select worse case situation) C1 At or below waist height? C2 At about chest height? C3 At or above shoulder height?
115	D	D Is the shoulder/arm movement D1 Infrequent (some intermittent movement)? D2 Frequent (regular movement with some pauses)? D3 Very frequent (almost continuous movement)?
116	**W/H**	Wrist/Hand
117	E	Is the task performed with (select worse case situation) E1 An almost straight wrist? E2 A deviated or bent wrist?
118	F	Are similar motion patterns repeated F1 10 times per minute or less? F2 11 to 20 times per minute? F3 More than 20 times per minute
119	N	Neck
120	G	When performing the task, is the head/neck bent or twisted? G1 No G2 Yes, occasionally G3 Yes, continuously
121	H	H Is the maximum weight handled MANUALLY BY YOU in this task? H1 Light (5 kg or less) H2 Moderate (6 to 10 kg) H3 Heavy (11 to 20kg) H4 Very heavy (more than 20 kg)
122	J	J On average, how much time do you spend per day on this task? J1 Less than 2 hours J2 2 to 4 hours J3 More than 4 hours
123	K	K When performing this task, is the maximum force level exerted by one hand? K1 Low (e.g. less than 1 kg) K2 Medium (e.g. 1 to 4 kg) K3 High (e.g. more than 4 kg)
124	L	L Is the visual demand of this task L1 Low (almost no need to view fine details)? *L2 High (need to view some fine details)? * If High, please give details in the box below
125	M	M At work do you drive a vehicle for M1 Less than one hour per day or Never?

		M2 Between 1 and 4 hours per day? M3 More than 4 hours per day?
126	N	N At work do you use vibrating tools for N1 Less than one hour per day or Never? N2 Between 1 and 4 hours per day? N3 More than 4 hours per day?
127	P	P Do you have difficulty keeping up with this work? P1 Never P2 Sometimes *P3 Often * If Often, please give details in the box below
128	Q	Q In general, how do you find this job Q1 Not at all stressful? Q2 Mildly stressful? *Q3 Moderately stressful? *Q4 Very stressful? * If Moderately or Very, please give details in the box below
129	EB(S)	Exposure to back (Static)
130	EB(M)	Exposure to back (Moving)
131	ESA	Exposure to shoulder/arm
132	EWH	Exposure to wrist/hand
133	EN	Exposure to neck
134	EDR	Exposure while driving
135	EVT	Exposure when work with vibration tool
136	EWP	Exposure due to work pace
137	TSE	Total stress exposure
138	$	Low Risk
139	@	Medium Risk
140	#	High Risk
141	*	Very High Risk

WORKERS ASSESSMENT QUESTIONNAIRE SHEET

Name:		Age:
Working Experience:		Height:
Description of work:		Weight:
Sex: Male / Female		
Marital Status: Single / Married		
Education: Illiterate/primary/Secondary/Intermediate/Diploma/ITI/Graudation		
Migrated: Yes / No		
Q.N.	Questions	Responses
1	Do you have any pain in your body in any time since you are working?	Yes / No
2	Where do you have pain?	
3	Do you visit to doctor when pain?	Yes / No.
4	Do you take medicine on your own?	Yes / No
5	Do you exercise daily?	Yes / No
6	Do you know work-related musculoskeletal disorder?	Yes / No
7	Do you addicted to Alcohol/Tobacco/Smoking	Yes/No
8	When do you have the more pain?	During working/ After Working/ During sleeping/ In the Morning.
9	Have you ever experienced a traumatic event in your life while working?	Yes/No
10	Do you get tingling hands and/or feel while working or after working?	Yes/No
11	Do you have Swollen veins?	Yes/No
12	Do you exercise every day?	Yes/No
13	Are workers working in higher speed? (Observer Assessment)	Yes / No
14	Are workers performs various jobs? (Observer Assessment)	Yes/No
15	Are workers working in awkward postures more than standard time? (Observer Assessment)	Yes / No.



	Have you at any time during the last 12 months had trouble (such as ache, pain, discomfort, numbness) in:		During the last 12 months have you been prevented from carrying out normal activities (e.g. job, housework, hobbies) because of this trouble in:		During the last 12 months have you seen a physician for this condition:		During the last 7 days have you had trouble in:	
NECK	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes
SHOULDERS	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes
UPPER BACK	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes
ELBOWS	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes
WRISTS/ HANDS	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes
LOWER BACK	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes
HIPS/ THIGHS	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes
KNEES	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes
ANKLES/ FEET	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes

CHAPTER – 1

INTRODUCTION

1.1 BACKGROUND:

Work-related musculoskeletal disorders (WRMSDs) are an increasing problem across the globe in construction workers. According to Punnett et al. (2004), nearly 77% of the population working in construction are suffering from WRMSDs, whereas 33% of the general population is suffering from occupational illness. WRMSDs are the main problem facing construction workers, which often starts at an early age [1][2].

The main cause of work-related disability, injuries, and work loss due to sickness are WRMSDs, which not only hamper productivity but also the efficiency of the workers. The construction industry is the most important industry that employs a large number of people and plays a vital role in the construction of buildings, roads, and bridges [3].

Construction work varies with working conditions such as residential, commercial, working at multiple sites, geographical location, work under different employers, and weather conditions. This variability in construction work makes it difficult to find the relation between work, working situation, and WRMSD. The factors that play a role in this relationship include poor working conditions, lack of proper training, prolonged working hours, poor working posture, poor health condition, improper breaks, pressure for timely completion of tasks, and monotonous work. Work-related musculoskeletal disorders influence health with repetitive work injuries, physical injuries, sick absences, delayed healing, lost workdays, which affect the productivity of work and increase the economic burden due to healthcare costs, insurance, and compensation [1][4].

Working techniques related to WRMSDs include working in awkward postures, repetitive movements, maintaining static body positions, lifting and carrying heavy materials, applying heavy force to different body parts, using vibrating tools and equipment, exposure to temperature extremes, working at high speeds, and having insufficient recovery time.

The risk of WRMSDs increases with: increased job demands, stress, low job satisfaction, lack of support from employers, co-workers, and supervisors, and poor diet and inadequate supplementation [5].

According to Chang et al. (2009), workers who perform heavy physical labor have a high prevalence of WRMSDs in various body parts [6].

The construction work is strongly allied with human factor exposures, and these exposures exist in their regular job tasks. In India, most of the houses (in rural areas) are individually constructed by hiring skilled and unskilled workers manually, often referred to as 'Mistries' and 'Coolies'. Only in urban areas are people forced to live in apartments/flats constructed by builders, contractors, and promoters. In both cases, most of the construction work is carried out manually; however, there also exist duly sophisticated equipment and machinery. The manual work consists of material handling, working in awkward poses, repetitive work, lifting and pushing/pulling heavy materials, and working within the constraints of the workplace. Workers in the construction industry range in age from 20 to over 60 and perform a variety of construction tasks. These workers often suffer from work-related musculoskeletal disorders (WRMSDs) unknowingly, and the prevalence of these disorders is high. As construction work is largely carried out manually, it has an adverse effect and a high prevalence of work-related symptoms among workers. Although construction work has a high prevalence of WRMSDs and significant adverse effects, the literature shows that studies that have highlighted the impact of WRMSDs are inadequate in India. Rahman et al. (2018) state that lower and upper back MSD problems are common across all gender categories and occupations. Age has a mild effect of WRMSDs for lifting and lowering tasks in the construction industry [7].

A work-related musculoskeletal disorder (WRMSD) is a distressing disorder of muscles, tendons, nerves, joints, cartilage, and ligaments. Ergonomic risks include working in awkward postures, improper working sites, forceful exertion, heavy lifting or lowering, repetitive work movements, static and dynamic working conditions, extreme cold and heat, frequency of work, lack of recovery time, vibration, contact stress, improper tool design, improper working techniques, duration stress, and carrying multiple jobs. Work-related musculoskeletal disorders do not build up at a glance, but they develop over time. From the literature, it is evident that there is a close relation between physical exposure and musculoskeletal health. This relationship is due to awkward postures, force, repetition of work, vibration, static load, contact stress, extreme temperature, fatigue, and the cumulative load on the worker's body. Biomechanical exposures, psychosocial stresses, and individual risk factors are the main risk factors that cause WRMSDs due to Physical Exposure [8].

Again, from the definition of NIOSH, "WRMSDs are those diseases and injuries affecting the musculo-skeletal, peripheral nervous, and neurovascular systems that are caused or aggravated by occupational exposure to ergonomic hazards. Ergonomic hazards relative to WRMSDs refer to physical stressors and workplace conditions that pose a risk of injury or illness to the musculoskeletal system of the worker. Ergonomic hazards include repetitive motions, forceful motions, vibration, temperature extremes (especially cold), and awkward postures caused by improper design of workstations, tools, or equipment, and improper work methods [9].

Every task has a risk, and any type of risk, pain, or disorder in the body is an early sign of WRMSD that can lead to serious injury or health problems. Pain or disorder for a prolonged period can reduce the quality of life. It is important to identify and categorize the risks, which will help to reduce exposure to risk. [10]

Cho et al., 2018 [11] pointed out that 16% of construction workers have WRMSDs compared to other workers. Mgbemena et al., 2020 [8] pointed out that 41% of construction workers had WRMSDs in 2015-2016. Forty percent of WRMSDs affected the upper limb, and 53% affected the lower back, according to reports from 2009-2016 for MMH. Jebelli et al., 2018 [12] pointed out that 68% of workers are suffering from excessive stress. Rahman et al., 2018 [7] pointed out that 40% of workers filed WRMSD claims for lower and upper back problems in Australia (2000-2013). Yan et al., 2018 [13] reported that 56% of rebar workers suffer from low back problems in the US. Kim, In-Ju., 2017 [14] reported that 25% of workers complained about backache and 23% of workers complained about muscular pain in European Union countries, whereas in the US, absenteeism is the biggest problem due to WRMSDs. Wang et al., 2015 [15] reported that 33% of occupational injuries and illnesses account for WRMSDs and absenteeism in the US. According to the ILO, 35-40% of fatalities occur in construction work, which employs 10% of the total workforce. [16] Due to this, the loss of days in construction work is 34% in Great Britain [8] and 40% in the US. [17]

In India, every year, nearly 48,000 workers die due to work-related accidents. Out of these 48,000, construction alone contributes 24.2%. [18] Also, the study of Patel et al., 2016 [19] reveals that, as per the 2011 census, 53,455,595 people were employed in the construction sector all over India in 2012, and 24.4% of construction workers die due to occupational injuries and accidents, which is higher than the fatality rates in the UK, Singapore, and Taiwan.

Ergonomics, on the other hand, is meant for fitting the task to the individual and not the individual to the task, meaning it encourages compatibility between humans and work systems. As per the definition of ergonomics given by Fernandez, J.E., "The design of the workplace, equipment, machine, tool, product, environment, and system, taking into consideration the human's physical, physiological, biomechanical, and psychological capabilities and optimizing the effectiveness and productivity of work systems while assuring the safety, health, and well-being of the workers.", the objective of human factors and ergonomics is to provide a secure and productive workplace for individual comfort. Also, the healing treatment of WRMSDs is costlier, hence it is necessary to take precautionary measures before it is too late. [8] [10]

The construction workers are under occupational risk whose main effect can be observed on functional impairment, loss of productivity, or permanent disability, which is mainly due to biomechanical risk factors. Prevention can minimize the problem of exposure, but it should be taken when the alarm is raised. [20]

This is only due to physical exposure and overexertion of the workers due to the need for money. This now-a-days is causing a problem of non-availability of construction workers and laborers in India. The present data shows that Indian workers are at a significant level of physical exposure to work-related musculoskeletal disorders in the construction work they do. They are at a level 50 percent higher than other workers. An acquaintance of accurate physical exposure is essential for the selection of proper assessment tools and for remedies for work-related musculoskeletal disorders. Assessment of WRMSDs is a crucial part of ergonomics and human factors to minimize WRMSDs and improve health, which can be achieved through proper knowledge of risks and techniques for solving them.

Indian construction is basically dependent upon manual work. About more than 90 percent of construction work in India is carried out manually in hazardous conditions. In India, construction work is the only work that is carried out and jobs are available throughout the year in which skilled, semi-skilled, or unskilled workers work. Construction work is labor-intensive and cannot depend solely on machines. Further, the results of this study can be used to target specific hazardous tasks for ergonomic interventions and confirm the need to use a task-based exposure assessment strategy to properly assess ergonomic risk profiles for non-structured jobs such as construction. [21]

Health and physiological aspects, such as imbalanced postures, are affected by different aspects like anatomy, age, physiology, pathology, occupation, recreation, environment, social/cultural factors, and temporarily adopted postures. [22]

Abundance of work has been carried out to assess the physical exposure and work-related musculoskeletal disorders in construction workers in different areas all over the world, and it has been found that construction workers are suffering from WRMSDs tremendously.

1.2 CONSTRUCTION WORK, RELATED OCCUPATIONS AND RELATED RISK FACTORS:

From the study, it is revealed that Indian construction workers are working under heavy risk; lifting heavy loads and working under heavy stress and unpleasant conditions can lead to the development of work-related musculoskeletal disorders. The construction workers are not entirely skilled but gain knowledge and skills from on-site work and experience.

The workers are classified into three types:

1. **Unskilled workers:** Unskilled workers are those who work as laborers for the skilled workers. They are basically called "Coolies."
2. **Semi-skilled workers:** Semi-skilled workers are those who assist the skilled workers and sometimes work as skilled workers for all occupations.
3. **Skilled workers:** Skilled workers are those who are trained in their work. They include Brick Masons (Brick layers/Plasterers), Rebar workers, Form workers, Electricians, Plumbers, Tilers, Painters, and Carpenters, etc.

The following section highlights various construction occupations with details of the work performed in the particular occupation by the workers, the tools used for the particular task, the general body posture while performing that task, the exposed body parts, which include (Head/Neck/Shoulders/Elbows/Arms/Hands/Wrists/Thumbs/Eyes/Back (Middle or Lower)/Thighs/Legs/Knees/Ankles/Feet/Toes), the risks of work-related musculoskeletal disorders, which include (Awkward Posture, Static/Dynamic exertion, Repetitive exertion, Forceful exertion, Frequency of Movement, Duration, Recovery, Vibration, Mechanical Compression, Environmental Conditions, Teamwork, Visual Demands, Psychosocial factors, Individual factors), and real-time images of the tasks."

1.2.1 Excavation Worker (Manual):-

i)	**Description of Occupation:**	A worker performs the activity of excavating (Trenching) the soil for pit of the column.
i)	**Work perform by the construction worker:**	1) Loosening of Soil using pick-axe for column pit. 2) Collecting Soil in Head Pan 3) Lifting the pan from ground 4) Throw soil outside pit. or pass the pan to the outside worker
ii)	**Tools used for the particular task:**	1) Pick-Axe, 2) Spade/Shovel, 3) Head pan, 4) Measuring Tape
iii)	**General body posture while performing that task:**	1) Head/Neck - Flexion/ Extension, Rotation Left/Right 2) Shoulder- Flexion /Extension, Elevation/Depression 3) Upper Arms- Flexion/ Extension, Abduction/Adduction 4) Lower Arms- Flexion/Extension, Pronation/Supination 5) Hand/wrist- Flexion/Extension, Radial/Ulnar Deviation 6) Fingers/Thumbs - Flexion/Extension, Radial/Ulnar Deviation, Abduction /Adduction 7) Thoracic- Flexion /Extension, Lateral Left/Right, Rotation Right/Left 8) Lumbar - Flexion /Extension, Lateral Left/Right, Rotation Right/Left 9) Thigh- Flexion, Abduction 10) Leg - Flexion- Medial /Lateral Rotation 11) Foot- Dorsi Flexion 12) Toes - Hyper extension 13) Lifting/Lowering 14) Reaching/ work overhead
iv)	**Exposed body parts:**	Whole body
v)	**Risk of work-related**	1) Awkward Posture, 2) Repetitive exertion, 3) Forceful exertion, 4) Frequency of Movement, 5) Mechanical Compression,

musculoskeletal disorder:	6)Environmental Conditions, 7)Team Work, 8) Psychosocial factor, 9) Individual factors


[redacted] [redacted] [redacted] [redacted]

1.2.2 Unskilled Worker /labour (Coolie) : -

i)	**Description of Occupation:**	An unskilled worker or laborer is someone who performs physical work and various tasks to assist other trades positions. These workers also erect scaffolds to support masons and other workers.
i)	**Work perform by the construction worker:**	1) Fetch/Carry Bricks, Sand, Gravels, Cement bag, Stones, Blocks, Rock, Pebbles, Water, Mortar, concrete mortar etc 2) Make/Mix the Mortar or Concrete mortar 3) Help Mason to supply materials. 4) Facilitate other skilled workers. 5) Sand/Pebble sieving. 6) Watering the House (If asked) 7) Disposal of Waste **Scaffold**: 1) Cut bamboo or round-shaped centering wooden poles (Balli) of the required size for posts. 2) Erect the poles for posts and fix another round-shaped bamboo or wooden pole in support with the wall. 3) Put a horizontal platform made up of bamboo on the erected frame and tie it securely.
ii)	**Tools used for the particular task:**	All Purpose:- 1) Pick-Axe, 2) Spade/ Shovel, 3) Head pan, 4) Water Can, 5) Sieve **Scaffold**:- 1) Bamboo or round shaped wooden poles of Nilgiri tree (Balli) for (Vertical column) (available in 10’, 12’ 14’ height), 2) Wooden poles for horizontal support against the wall 3) Use bamboo for constructing the platform 4) Coconut coir rope

iii)	**General body posture while performing that task:**	1) Head/Neck - Flexion/ Extension, Lateral Left/Right, Rotation Left /Right 2) Shoulders- Flexion /Extension, Elevation/ Depression 3) Upper Arms- Flexion/ Extension, Abduction/Adduction, Medial/Lateral Rotation 4) Lower Arms- Flexion/Extension, Pronation/ Supination 5) Hand/wrist- Flexion/Extension, Radial/ Ulnar Deviation 6) Fingers/Thumbs - Flexion/Extension, Radial/Ulnar Deviation, Abduction/ Adduction 7) Thoracic- Flexion /Extension, Lateral Left/Right, Rotation Right/Left 8) Lumbar - Flexion /Extension, Lateral Left/Right, Rotation Right/Left 9) Thigh- Flexion/Extension, Abduction/ Adduction, Medial/ Lateral Rotation 10) Leg- Flexion/Extension, Medial /Lateral Rotation 11) Foot- Dorsi Flexion /Planter Flexion, Eversion/ Inversion 12) Toes - Flexion/Hyper-Extension 13) Walking/climbing, 14) Lifting/lowering 15) Holding head pan (on head/hand) (Intermittently) 16) Working Overhead / Reaching 17) Standing/Stooping 18) Applying force/load
iv)	**Exposed body parts:**	Whole body
v)	**Risk of work-related musculoskeletal disorder:**	1) Awkward Posture, 2) Static exertion, 3) Repetitive exertion, 4) Forceful exertion, 5) Frequency of Movement, 6) Duration, 7) Recovery, 8) Vibration 9) Mechanical Compression 10)Environmental Conditions, 11)Team Work, 12) Visual Demands, 13) Psychosocial factor, 14) Individual factors

1.2.3 Formwork (Centering/ Shuttering) :-

i)	**Description of Occupation:**	Workers are responsible for fixing the centering, fixing column box etc to support column and roof concrete.
i)	**Work performed by the construction workers:**	1) Cut centering wooden pole of required size 2) Cut Rafter of required size 3) Prepare vertical support for formwork plates 4) Making and fixing of Plates for formwork for column. 5) Carry out centering/slab formwork work.
ii)	**Tools used for the particular task:**	1) Hand Cutter Machine 2) Hammer 3) Measuring Tape
iii)	**General body posture while performing that task:**	1) Head/Neck - Flexion/ Extension 2) Shoulders- Flexion /Extension, Elevation/Depression 3) Upper Arms- Flexion/ Extension, Adduction, Medial/Lateral Rotation 4) Lower Arms- Flexion, Pronation/ Supination 5) Hand/wrist- Flexion/Extension, Radial/ Ulnar Deviation 6) Fingers/Thumbs - Flexion, Radial /Ulnar Deviation 7) Thoracic- Flexion /Extension, Rotation Right/Left 8) Lumbar - Flexion /Extension, Rotation Right/Left 9) Thigh- Flexion, Abduction 10) Leg- Flexion, Medial /Lateral Rotation 11) Foot- Dorsi Flexion 12) Toes - Hyper-Extension 13) Walking/Climbing 14) Lifting/Lowering 15) Squatting/stooping 16) Working overhead 17) Apply force

iv)	**Exposed body parts:**	1) Shoulder, 2) Elbow, 3) Lower Back, 4) Wrist
v)	**Risk of work-related musculoskeletal disorder:**	1) Awkward Posture, 2) Repetitive exertion, 3) Forceful exertion, 4) Vibration 5) Environmental Conditions, 6) Team Work, 7) Psychosocial factor, 8) Individual factors

1.2.4 Rebarer:-

i)	**Description of Occupation:**	A Rebar worker is responsible for tieing of iron bars for column and slab reinforcement.
i)	**Work perform by the construction worker:**	1) Straightening of Rebar 2) Cutting of Rebar of different size (some places use cutter and some places use Hammer and chisel) 3) Tieing of Rebar 4) Making of ring (stirrups)of different size 5) Making rebar cage for column 6) fixing of rebar cage for column 7) fixing of steel rebar on slab formwork for Reinforcement 8) Manual tieing (fastening) steel rebar using iron wire.
ii)	**Tools used for the particular task:**	1) Rebar cutter (power operated) 2) Iron Chisel and hammer 3) (Rebar bending for making rings) - use local arrangement "Thiyya" 4) Rebar bender (Iron bar with 'C' shape at end 5) Rebar tie wire twister tool (local Made)
iii)	**General body posture while performing that task:**	1) Head/Neck - Flexion/ Extension, 2) Shoulders- Flexion, Depression 3) Upper Arms- Flexion, Abduction/Adduction, Medial/Lateral Rotation 4) Lower Arms- Flexion/Extension, Pronation/ Supination 5) Hand/wrist- Flexion/Extension, Radial/ Ulnar Deviation, twisting 6) Fingers/Thumbs - Flexion/Extension, Radial/Ulnar Deviation, Abduction/ Adduction, twisting 7) Lumbar - Flexion /Extension, Rotation Right/Left 8) Thigh- Flexion, Abduction/ Adduction, Medial/ Lateral Rotation 9) Leg- Flexion, Medial /Lateral Rotation 10) Foot- Planter Flexion, Inversion 11) Toes - Hyper-Extension 12) Lifting/lowering 13) Standing/Stooping/squatting 14) Applying force/load
iv)	**Exposed body parts:**	1) Neck, 2) Shoulders, 3) Wrist, 4) Fingers, 5) Lower Back, 7) Right Arm /Hand

v)	**Risk of work-related musculoskeletal disorder:**	1) Awkward Posture, 2) Repetitive exertion, 3) Forceful exertion, 4) Duration, 5) Vibration, 6)Environmental Conditions, 7) Psychosocial factor, 8) Individual factors

1.2.5 Mason (Brick layer /plasterer) :–

i)	**Description of Occupation:**	Mason is a skilled worker engaged in bricklaying work, plastering work and concreting work.
i)	**Work performed by the construction workers:**	1) Pouring and Spreading of mortar with the help of Brick trowel. 2) Lying brick to form a wall 3) Pouring concrete in column and slab 4) Check level and right angle at the corner with the help of mason square 6) Check vertical alignment / equivalence of water- level of brick wall with the help of Plumb Bob. 7) Plastering the wall with the help of plasterer Trowel, wooden/metal Float and aluminum channel 8) Applying mortar on wall and spread and level it for plastering (inside/outside)) 9) Properly pouring of Concrete on Slab formwork. 10) Spreading and smooth finishing the concrete etc
ii)	**Tools used for the particular task:**	1) Brick Towel, 2) Metal/wooden float, 3) Aluminum channel, 4) Mason Square, 5) Plumb bob, 6) Water Level, 7) Spirit level, 8) Line Dori, 9) Measuring tape, 10) Concrete Vibrator
iii)	**General body posture while performing that task:**	1) Head/Neck - Flexion/ Extension, Lateral Left/Right, Rotation Left /Right 2) Shoulders- Flexion, Elevation/ Depression 3) Upper Arms- Flexion/ Extension, Abduction, Medial/Lateral Rotation 4) Lower Arms- Flexion, Pronation/ Supination 5) Hand/wrist- Flexion/Extension, Radial/ Ulnar Deviation 6) Fingers/Thumbs - Flexion/Extension, Radial/Ulnar Deviation, Abduction/ Adduction 7) Thoracic- Lateral Left/Right, Rotation Right/Left

		8) Lumbar - Flexion /Extension, Lateral Left/Right, Rotation Right/Left 9) Thigh- Flexion, Abduction, Medial/ Lateral Rotation 10) Leg- Flexion, Medial /Lateral Rotation 11) Foot- Planter Flexion, 12) Toes - Hyper-Extension 13) Lifting/Lowering 14) Standing/stooping/squatting 15) Overhead 16) Apply force/load
iv)	**Exposed body parts:**	For Brick work:- 1) Legs, 2) Hand, 3) Fingers, 4) lower back, 5) Wrist, 6) Elbow, 7) Arms For plastering:- 1) Legs, 2) Hand, 3) Wrist, 4) Neck, 5) Shoulder, 6) Fingers, 7) Eyes, 8) Arms, 9)Lower back For Concreting:- 1) Legs (Calf), 2) Hands, 3) Wrist, 4) Shoulders, 5) Knees 6) Lower back , 7) Toes
v)	**Risk of work-related musculoskeletal disorder:**	1) Awkward Posture, 2) Repetitive exertion, 3) Forceful exertion, 4) Frequency of Movement 5) Duration, 6)Environmental Conditions, 7) Visual Demands, 8) Psychosocial factor, 9) Individual factors

1.2.6 Electrician:-

i)	**Description of Occupation:**	Skilled worker engaged in casing the wall for installation of electrical conduit and wiring. Electrician and semi-skilled electric worker assist for this work. They are also performing the work of cutting the wall of required size for conduit.
i)	**Work performed by the construction workers:**	1) Carry materials to workstation. 2) Marking the Electrical Line as per diagram on wall, Ceiling and other part of house using scale and tape. 3) (Grooving channel) Chasing wall for concealed wiring in electrical conduit using Electric Cutter, Chisel and Hammer. (Should use Wall chaser) 4) Installed conduit (If in plan or required) on the wall. 5) Fitting conduit in the chase (groove). 6) Cutting conduit as per required length. 7) Connect all conduits to junction box and fixture position. 8) Install wiring 9) Install lighting system and fixtures 10) Install/connect wiring
ii)	**Tools used for the particular task:**	1) Cutter machine, 2) Chisel, 3) Hammer, 4) Cable Cutter, 5) Pliers, 6) Tester, 7) Screw Driver, 8) Drill Machine
iii)	**General body posture while performing that task:**	1) Head/Neck - Flexion/ Extension, 2) Shoulders- Flexion /Extension, 3) Upper Arms- Flexion/ Extension, Abduction, 4) Lower Arms- Flexion/Extension, Pronation/ Supination 5) Hand/wrist- Flexion, Radial/ Ulnar Deviation 6) Fingers/Thumbs - Flexion, Radial/Ulnar Deviation, 7) Thoracic- Lateral right/left, Rotation Right/Left 8) Lumbar - Flexion /Extension, Lateral Left/Right, Rotation Right/Left 9) Thigh- Flexion, Abduction, Medial/ Lateral Rotation

		10) Leg- Flexion, Lateral Rotation 11) Foot- Dorsi Flexion /Planter Flexion, 12) Standing / Reaching (when work for ceiling) 13) Lifting/ Pulling / pushing with hand 14) Apply force/load
iv)	**Exposed body parts:**	1) Lower back, 2) Shoulder, 3) Arms, 4) Hand, 5) Wrist
v)	**Risk of work-related musculoskeletal disorder:**	1) Awkward Posture, 2) Static exertion, 3) Repetitive exertion, 4) Forceful exertion, 5) Frequency of Movement, 6) Duration, 7) Recovery, 8) Vibration, 9) Mechanical Compression 10)Environmental Conditions, 11)Team Work, 12) Visual Demands, 13) Psychosocial factor, 14) Individual factors

1.2.7 Plumber:-

i)	**Description of Occupation:**	A plumber is someone who installs, water piping and draining. Plumber and semi-skilled worker assist for this work. They are also performing the work of cutting the wall of required size for conduit.
i)	**Work performed by the construction workers:**	1) Carry plumbing materials to workstation. 2) Marking the Line as per diagram on wall, floor and other part of house using tape. 3) Chase cutting for concealed using Electric Cutter, Chisel and Hammer. (Grooving channel) (Should use Wall chaser) 4) Installed water pipes in chase cutting. 5) Installed fixtures 6) Install pipe hangers at wall outside and inside. 7) Install sanitary sewer pipes and gas pipes etc 8) Install Tapes and equipments.
ii)	**Tools used for the particular task:**	1) Cutter machine, 2) Chisel, 3) Hammer, 4) Hacksaw, 5) PVC Glue
iii)	**General body posture while performing that task:**	1) Head/Neck - Flexion/ Extension, 2) Shoulders- Flexion /Extension, Elevation/ Depression 3) Upper Arms- Flexion/ Extension, Abduction, 4) Lower Arms- Flexion/Extension, Pronation/ Supination 5) Hand/wrist- Flexion, Radial/ Ulnar Deviation 6) Fingers/Thumbs - Flexion, Radial/Ulnar Deviation, 7) Thoracic- Lateral right/left, Rotation Right/Left 8) Lumbar - Flexion /Extension, Lateral Left/Right, Rotation Right/ Left 9) Thigh- Flexion, Abduction, Medial/ Lateral Rotation 10) Leg- Flexion, Lateral Rotation 11) Foot- Dorsi Flexion /Planter Flexion, 12) Toes - Hyper-Extension

		13) Stooping/squatting 14) Apply force/load
iv)	**Exposed body parts:**	1)Legs (Calf), 2) Knee, 3) Shoulder, 4) Hand, 5) Wrist, 6) Lower back, 7) Feet/toes
v)	**Risk of work-related musculoskeletal disorder:**	1) Awkward Posture, 2) Static exertion, 3) Repetitive exertion, 4) Forceful exertion, 5) Frequency of Movement 6) Duration, 7) Recovery, 8) Vibration, 9) Mechanical Compression, 10)Environmental Conditions, 11)Team Work, 12) Visual Demands, 13) Psychosocial factor, 14) Individual factors

1.2.8 Tilers:-

i)	**Description of Occupation:**	Tilers now a day install vitrified tiles in the house. In the early age, instead of tiles flooring was carried out which was carried out by the mason himself. The tilers are also fit the stone, marble or granite in the kitchen.
i)	**Work performed by the construction workers:**	1) Level the floor surface 2) Mark the Level pad 3) Pouring of cement slurry 4) Scratch cement slurry 5) Bring Tiles and Mount tile on floor/wall 6) Level tile by light tamping 7) Cut the tile (if required) 8) Filled the joint with white cement
ii)	**Tools used for the particular task:**	1) Tile Cutter, 2) Hammer/Mallet, 3) Water Level, 4) Brick Towel, 5) Mixing Bucket, 6) Mug, 7) Water level, 8) Spirit level
iii)	**General body posture while performing that task:**	1) Head/Neck - Flexion/ Extension 2) Shoulders- Flexion, Elevation 3) Upper Arms- Flexion, Abduction 4) Lower Arms- Flexion, Pronation/ Supination 5) Hand/wrist- Flexion, Radial/ Ulnar Deviation 6) Fingers/Thumbs - Flexion, Radial/Ulnar Deviation 7) Thoracic- Flexion /Extension, Lateral Left/Right, 8) Lumbar - Flexion /Extension, Lateral Left/Right, 9) Thigh- Flexion, Abduction, Medial/ Lateral Rotation 10) Leg- Flexion, Medial /Lateral Rotation 11) Foot- Planter Flexion, Eversion/ Inversion 12) Toes -Hyper-Extension 13) Lifting/lowering 14) Stooping/squatting/kneeling 15) Applying force/load

iv)	**Exposed body parts:**	1) Legs (Calf), 2) Knees, 3) Lower back, 4) Hand, 5) Wrist, 6) Toes
v)	**Risk of work-related musculoskeletal disorder:**	1) Awkward Posture, 2) Repetitive exertion, 3) Visual Demands, 4) Psychosocial factor, 5) Individual factors

1.2.9 Carpenters: -

i)	**Description of Occupation:**	A carpenter work is to make furniture, cabinets, modular kitchens sets, doors and windows etc.
i)	**Work performed by the construction workers:**	1) Marking Ply, Wood and wooden block as per design 2) Cutting of Ply, Wood and Wooden Block / Plate 3) Wood surface /wooden block Planning 4) Making the fitting arrangement in Ply, Wood, Wooden bloc as per requirement 5) Applying Glue 6) Fitting the structure 7) Fixing with the help of screw or nails or wooden nails 8) Screwing using screw driver or Hand Drill machine 9) Cutting Mica as per requirement 10) Fix on Ply as per requirement 11) Fitting/fixing edge binder. 12) Polishing using hand or Spray machine
ii)	**Tools used for the particular task:**	1) Chisel, 2) Handsaw, 3) Screwdrivers, 4) Measuring Tape, 5) Carpenter Pencil, 6) Hammer with nail Puller, 7) Try Square, 8) Plier, 9) Jack (wood/ metal), 10) Surface Planer (Randa), 11) Circular Saw Machine, 12) Table Cutting machine, 13) Cut off Machine, 14) Grinder Machine, 15) Hand Zik Zak machine, 16) Meter Saw machine, 17) Table Saw machine, 18) Carpenter shuttering clamp, 19) Table Drill Machine, 20) Hand Drill machine, 21) Hand Cutting machine, 22) Hand Grinding machine, 23) Spray Machine, 24) Sand Paper, 25) Marking Gauge

iii)	**General body posture while performing that task:**	1) Head/Neck - Flexion/ Extension, 2) Shoulders- Flexion /Extension, Elevation/ Depression 3) Upper Arms- Flexion/ Extension, Abduction, 4) Lower Arms- Flexion/Extension, Pronation/ Supination 5) Hand/wrist- Flexion, Radial/ Ulnar Deviation 6) Fingers/Thumbs - Flexion, Radial/Ulnar Deviation, 7) Thoracic- Flexion, Lateral right/left, Rotation Right/Left 8) Lumbar - Flexion /Extension, Lateral Left/Right, Rotation Right/ Left 9) Thigh- Flexion, Abduction, Medial/ Lateral Rotation 10) Leg- Flexion, Lateral Rotation 11) Foot- Dorsi Flexion /Planter Flexion, 12) Toes - Hyper-Extension 13) Stooping/squatting/kneeling 14) Lifting/lowering 15) Apply force/load
iv)	**Exposed body parts:**	1) Hand, 2) Shoulder, 3) Knees, 4) Hand, 5) Wrist, 6) Neck, 7) Lower back
v)	**Risk of work-related musculoskeletal disorder:**	1) Awkward Posture, 2) Static exertion, 3) Repetitive exertion, 4) Forceful exertion, 5) Vibration, 6)Environmental Conditions, 7)Team Work, 8) Visual Demands, 9) Psychosocial factor, 10) Individual factors

1.2.10 Painters: -

i)	**Description of Occupation:**	Putting work and Painting indoor and outdoor building wall and iron frames of door and windows.
i)	**Work perform by the construction worker:**	1) Mix Putty 2) Apply on Wall or Ceiling using Steel plate. 3) Mix the Required paint using paint and putty Sprayers 4) Apply Paint on wall or Ceiling using Paint brush
ii)	**Tools used for the particular task:**	1) Paint, 2) Putty, 3) Putty steel plate, 4) Paint Brush, 5) Paint Roller, 6) Spray Gun
iii)	**General body posture while performing that task:**	1) Head/Neck - Flexion/ Extension, Lateral Left/Right, 2) Shoulders- Flexion, Elevation 3) Upper Arms- Flexion, Abduction, 4) Lower Arms- Flexion, Pronation/ Supination 5) Hand/wrist- Flexion/Extension, Radial/ Ulnar Deviation 6) Fingers/Thumbs - Flexion, Abduction 7) Thoracic- Flexion /Extension, Rotation Right/Left 8) Lumbar - Flexion /Extension, Lateral Left/Right, Rotation Right/Left 9) Thigh- Flexion, Abduction, Medial Rotation 10) Leg- Flexion, Medial /Lateral Rotation 11) Foot- Planter Flexion, Eversion/ Inversion 12) Toes - Hyper-Extension 13) Standing/Stooping/Squatting/Climbing, 14) Lifting/lowering 15) Working Overhead / Reaching 16) Applying force/load
iv)	**Exposed body parts:**	1) Hand, 2) Wrist, 3)Fingers /Thumbs, 4) Shoulder, 5) Lower back, 6) Eyes

v)	**Risk of work-related musculoskeletal disorder:**	1) Awkward Posture, 2) Repetitive exertion, 3) Frequency of Movement, 4)Environmental Conditions, 5)Team Work, 6) Visual Demands, 7) Psychosocial factor, 8) Individual factors

1.3 OVERVIEW WORK-RELATED MUSCULOSKELETAL DISORDERS (WRMSD):

1.3.1 Ergonomics:

The word "Ergonomics" comes from two Greek words "ergon," meaning work, and "nomos," meaning "laws." Today, however, the word is used to describe the science of "designing the job to fit the worker, not forcing the worker to fit the job." Ergonomics covers all aspects of a job, from the physical stresses it places on joints, muscles, nerves, tendons, bones and the like, to environmental factors which can affect hearing, vision, and general comfort and health.
Ergonomics, as defined by the Board of Certification for Professional Ergonomists (BCPE), "is a body of knowledge about human abilities, human limitations and human characteristics that are relevant to design. Ergonomic design is the application of this body of knowledge to the design of tools, machines, systems, tasks, jobs, and environments for safe, comfortable and effective human use".

Ergonomics (or human factors) is the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimize human well-being and overall system performance.

1.3.2 Musculoskeletal disorders:

A musculoskeletal disorder is a condition where a part of musculoskeletal system is injured over time. This disorder occurs when the body part is called on to work harder, stretch farther, impact more directly or otherwise functions at a greater level then it is prepared for. Note that the immediate impact may be the term musculoskeletal disorder identifies a large group of conditions that result from traumatizing the body in either a minute or major way over a period of time. It is the accumulation of trauma that causes the disorder.

1.3.3 Work- related musculoskeletal disorders (WRMSD):

Work-related musculoskeletal disorders (WRMSDs) are a set of painful disorders of bones, muscles, tendons, ligament, Joints, Spinal cord and nerves. It includes strain, sprain, soreness, pain, tenderness etc with connecting tissue injuries. In the beginning of 1800 century, musculoskeletal disorders were recognised as an occupational etiological factor and have been examined till 1970 using etiological factors and started using as an occupational factors for epidemiologic methods. [85]

Work-related musculoskeletal disorders (WRMSDs) are a common health problem throughout the industrialized world and a major cause of disability. WRMSDs are conditions of the nerves, tendons, muscles, and supporting structures of the musculoskeletal system that can result in fatigue, discomfort, pain, local swelling, or numbness and tingling. WRMSDs usually develop from cumulative damage resulting from months or years of exposure to excessive levels of physical and psychosocial stressors at work. Scientific evidence has shown that physical and psychosocial factors are critical in the development of WRMSDs.

The major risk factors for WRMSDs in the workplace include:

- Heavy manual handling
- Repetitive and forceful actions
- Vibration
- Awkward static postures that arise from badly designed workstations, tools, equipment, working methods
- Poor work Organisation.

Exposure to such factors produces effects within the worker’s body (e.g. decreased blood flow or local muscle fatigue). If adequate recovery does not occur, it can lead to the development of WRMSDs.

1.3.4 Postural Analysis:

Posture provides valuable insights into the natural state of the body's tissues. Through postural analysis, it's possible to identify areas experiencing greater strain than others and pinpoint the muscle groups contributing to this strain.

Causes of postural imbalance:

There are four main contributors to postural imbalances

- Repetitive activities
- Postural habits
- Trauma
- Structural factors: Inherited and Acquired

1.4 FACTORS CONTRIBUTE TO THE DEVELOPMENT OF WRMSD:

1.4.1 CAUSES OF WRMSD:

Only a single element is not enough to cause the risk of WRMSD. It requires enough more to this. There are three influencing factors which are responsible for increasing work-related musculoskeletal disorder (WRMSD). These influencing factors are Intensity, Duration and Frequency. When these three factors meet with the risk factors, are responsible for the development of WRMSD. (Table 1) The physical exposure to be quantified should include these three factors for the assessment of workers exposure. Rate of movement and vibration, variation in posture, psychosocial factors and organisation factors are the other ones which are to be recorded for the measurement of exposure factors.

Risk Factors		**Influencing factors**		**Effect**
Awkward Posture Load/Force (Intensity of effort) Static exertion Repetitive exertion (Speed of work) Forceful exertion (Wt. of the object to be lifted) Frequency of movement Duration (Time) Recovery(Rest/Break) Vibration Mechanical Compression Environmental Conditions Team Work Visual Demands Psychosocial factor Individual factors Load Coupling Workplace	X	Intensity Duration Frequency	=	Work-related Musculoskeletal Disorders

Figure 1.1 Work-related musculoskeletal disorders and contribution factors

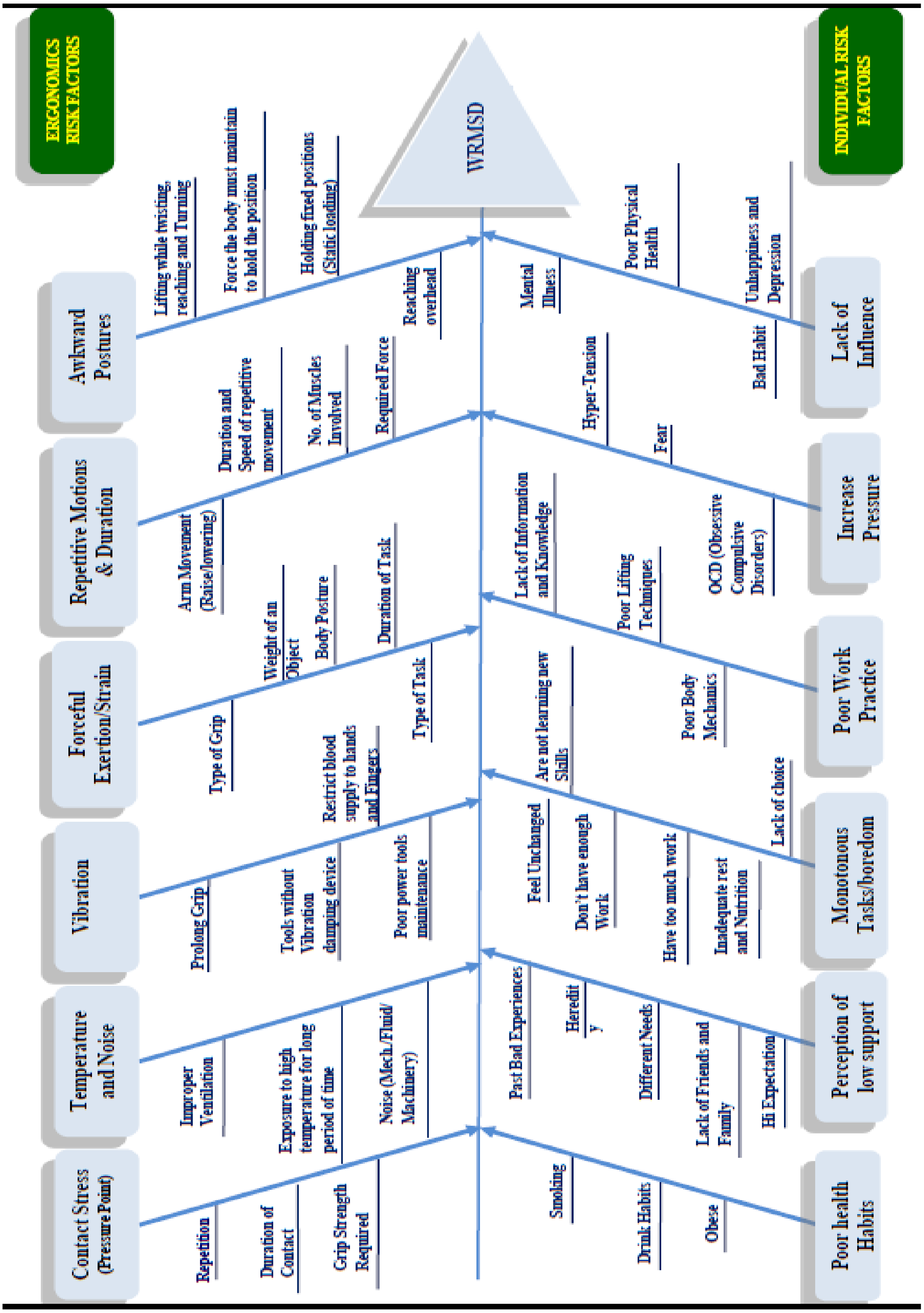
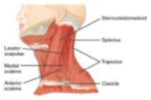
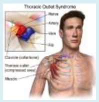


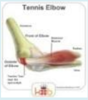
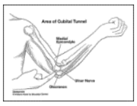
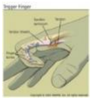
Figure 1.2 Fish bone diagram of Work-related musculoskeletal disorders and contribution factors

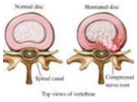
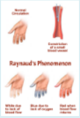
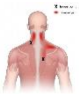
1.4.2 Symptoms, Cause and Diseases of WRMSD in Construction Work:

Work-related musculoskeletal disorders (WRMSDs) arise gradually but exhibit some symptoms. A single factor alone is not responsible for the development of WRMSD; multiple factors contribute. When physical risk factors (Awkward Posture, Load/Force, Static exertion, Repetitive exertion, Forceful exertion, Frequency of movement, Duration, Recovery, Vibration, Mechanical Compression, Environmental Conditions, Team Work, Visual Demands, Psychosocial factors, Individual factors, Load Coupling, Workplace) and influencing factors (Intensity, Duration, and Frequency) combine repeatedly, are ignored, and persist for long periods of time, WRMSDs arise. Table 1 shows 18 types of diseases with descriptions, causes, body parts affected, symptoms, and relevance to construction work, followed by a figure illustrating different parts of the body to provide an at-a-glance overview of symptoms to workers, laborers, and readers to correlate the symptoms. Table 2 shows body parts and their associated external and internal systems related to work-related musculoskeletal disorders."

Table 1.1 Types of WRMSD Diseases and relevance to construction

S. N.	Disease Name	Description	Causes	Affected body parts	Symptoms	Figure	Relevance to construction work
1	Carpal Tunnel Syndrome	Narrowed tunnel surrounding the flexor tendons swell, putting pressure on the median nerve	Heredity/repetitive hand use/hand and wrist position/ pregnancy	Hand and Arms	Pain/numbness/tingling/burning/shock sensation in thumb and index, middle and ring fingers. Pain or tingling fells in forearm. weakness in hand		e, k
2	Tendonities	An inflammation of a tendon.	Repetitive work, serious injury due to accidents and sports.	Base of thumb/ elbow/ shoulder/ knee	Pain in affected areas /loss of motion and frozen in the affected area.		a, b, c, d
3	Muscle/Tendon Strain	It is a twist, pull and /or tear of a muscle and / or tendon.	Overuse and overstretching of muscles and tendons, strain, excessive muscle contraction.	Any part of the body	Pain/muscle spasm/muscle weakness/swelling/ inflammation/cramping		All
4	Ligament Spain	It is stretch or tear in a ligament.	Falls, twists or hit in a way that forces the body out of its normal position.	Ankle/foot/ knee/wrist/ thumb	Pain/muscle spasm/muscle weakness/ inflammation/ cramping		All
5	Tension neck syndrome	Neck muscle injured and irritated from overuse and postural problems	Repetitive motion/poor posture/ use of computer and phone/teeth grinding/exercise and sports/poor sleep position/ heavy lifting/ stress/trauma/ tension	Neck	Muscle tightness/ muscle spasms/ muscle stiffness/difficulty turning head in certain directions/pain that worsens in certain positions,		a, b, e
6	Thoracic outlet compression	Group of disorders that occurs when blood vessels or nerves in the space between collarbone and first rib are compressed.	Poor posture/trauma/ repetitive activity /pressure on joints/work in pregnancy.	Shoulders/ neck/ fingers	Pain/ache/swell in neck/shoulder/hand/ arm. Cold fingers. Hands or arms with fatigue. Numbness or tingling in your fingers/ weakness in gripping.		a, b, e, k
7	Rotator cuff tendonitis	Affects the tendons and muscles that help move shoulder joint.	Lifting by arm over the head/ static shoulder/ sleeping on shoulder every night/swimming/ pitching	Shoulder	Pain/swelling/stiffness in front of the shoulder and side of arm. Pain in arm triggered when raise or lower. Mobility and strength loss in the affected arm.		a, b, e

8	Tennis elbow (Epicondylitis)	An inflammation or overuse of the tendons that join the forearm muscles on outside of the elbow.	Overuse, repetitive, weight lifting, age and vigorous use of the forearm muscle.	Elbow	Pain or burning on the outer part of elbow. Weak grip strength.		h, j, k
9	Cubital / Radial tunnel syndrome	Intermittent compression on radial nerve from radial head to the inferior border of supinator muscle without weakness in obvious extensor.	Repeatedly lean on elbow / bend elbow for sustained periods.	Elbow	Pain and numbness in the elbow. Pain in forearm. Tingling in the ring and little fingers. Weak ring finger, pinching ability and hand grip.		a, b, e
10	Digital Neuritis	Entrapment of a plantar inter-digital nerve as it passes under the transverse metatarsal ligament.	Neuritis can be caused by injury, infection or autoimmune disease.	Hands or foot	Numbness, prickling or tingling feet or hands and spread upward into legs and arms. Sharp jabbing, throbbing, freezing or burning pain, extreme sensitive to touch.		a, b, e, f, k
11	Trigger finger/ Thumb	Painful condition causes fingers or thumb to catch or lock when bend. Affect any finger or more.	Repeated movement or forceful use of finger or thumb.	Fingers and thumb	A painful clicking or snapping on bend or straighten finger. stiffness in finger especially in the morning.		a, b, c, d, e, f, g, h
12	DeQuervain's Syndrome	Painful swelling on tendons in wrist and lower thumb. Cause pain when rub.	Repetitive motion of hands.	Wrist and lower thumb	Pain along the back of thumb. swelling and pain at the base of thumb/wrist and affect grasping		a, b, c, d, e, f, g, h
13	Mechanical back syndrome	Pain trigged by the action of the spine. Include ligaments, tendons muscles, inter vertebral discs.	Back or neck sprain and strain. Disc Herniation, VCF, LSS, Spinal osteoarthritis (spondylosis), spondylolisthesis.	Spinal Cord	Localized back pain without any radiation, tenderness or spasm in the back, severe back stiffness, sudden onset back pain.		All
14	Degenerative Disc Disease	Spinal disk show sign of wear and tear, not work properly.	Dry out and cracks in the spinal cord.	Spinal cord	Sharp or constant pain in upper and lower back/neck /hip/thighs. Transitory and severe pain for few days to months. Worsen when sit/ bend /lift/twist and better when move or change positions.		All

15	Ruptured/ Herniated/slip disk	Rubbery cushions (Disk) between the individual bones (Vertebrae) that stack up to make spine. Occurs when jelly pushes out through a tear in the tougher exterior.	A gradual wear and tear. Less flexible and more prone to tearing or rupturing with even a minor strain or twist.	Spinal cord	Arms or legs Tingling/pain/ numbness/weakness.		All
16	Raynaud's syndrome	Spasm of arteries cause incident of reduced blood flow. Fingers/toes affected.	Inflamed blood vessels in the hands and feet.	Hands and feet	Colour of fingers or toes or skin changes response to cold or stress. Numb, prickly feeling or stinging pain. Stress relief when warn or heat treated.		All
17	Myfascial pain in the neck and upper back	A chronic pain disorder occurs when pressure on sensitive points in muscles causes pain in the muscles and sometimes in seemingly unrelated part of body	Injuries or overuse of muscles.	Muscles, tendon, nerves	Deep, aching pain in a muscle. a tender knot in a muscle. Difficulty in sleeping due to pain.		All
18	Shoulder bursitis	Inflammation of a bursa.	A bursa become inflamed due to injury, infection or underlying rheumatic condition	Shoulder	Localized pain or swelling tenderness and pain with motion of the tissue in the affected area.		a, b, c, e, j, k, m

a) Labourers (excavation of soil), b)Labourers (construction work) c) Centering workers d) steel bar tying/Rebar workers e) Masons (Brick layer /plaster) f) Concrete Finishers g) Electricians h) Plumbers i) Flooring/Tiles Installers j) Carpenters k) Painters l) Marble workers m) Welders

1.4.3 SIGN AND SYMPTOMS OF WRMSD:

Table 2 Body Parts and External and Internal Symptoms of WRMSD

Sr. No.	Body Parts	External symptoms of WRMSD	Internal symptoms of WRMSD
1	Neck	1) Swelling or Inflammation, 2) Stiff Neck 3) Neck Muscles spasm	1) Stiffness, 2) Muscles Spasms 3) Shooting/Radiating Pain
2	Shoulders	1) Not able to raise arm above shoulder level 2) Swelling or Inflammation	1) Stiffness, 2) Loss of Mobility, 3) Pain
3	Elbows	1) Difficulty in Walking and Climbing 2) Swelling	1) Pain, 2) Swelling 3) Stiffness, 4) Soreness
4	Arms	1) Shaking Arms 2) Difficulty in moving Arms	1) Shooting Pain 2) Radiating Pain 3) Tingling, 4) Numbness
5	Hands	1) Shaking Hands 2) Swelling in hand	1) Loss of Strength 2) Numbness, 3) Pain
6	Wrists	1) Shaking Wrist 2) Swelling in Wrist	1) Loss of Strength 2) Numbness, 3) Pain
7	Fingers	1) Difficulty in Movement of fingers 2) Loss of Strength 3) Swelling in Finger	1) Mobility and Feeling 2) Jerking Movement 3) Loss of Strength
8	Thumbs	1) Swelling on Thumb 2) Loss of Strength	1) Pain at Base
9	Eyes	1) Dry eyes	1) Smarting (Shrunken) eyes 2) Burning, 3) Strain
10	Back (Middle/ Lower)	1) Swelling or Inflammation 2) Stiff Back, 3) Back Muscle spasm	1) Shooting Pain 2) Radiating Pain
11	Thighs	1) Stiffness 2) Difficulty in Walking	1) Shooting Pain 2) Radiating Pain
12	Legs	1) Shaking legs 2) Difficulty in Walking	1) Shooting Pain, 2) Radiating Pain, 3) Tingling, 4) Numbness
13	Knees	1) Difficulty in Walking and Climbing 2) Swelling	1) Pain, 2) Swelling , 3) Stiffness 4) Soreness
14	Ankle, Feet and Toes	1) Difficulty in Walking 2) Swelling or Inflammation	1) Numbness 2) Burning Sensation 3) Tingling, 4) Stiffness

1.4.4 ROLE OF ERGONOMICS IN CONSTRUCTION:

According to Kim, In-Ju (2017) [23], construction work is manual physical demanding and workers dependent work which requires working in

1. i) Awkward postures,
2. ii) Manual lifting and handling of heavy and irregular-sized loaded materials,
3. iii) Repeated twisting and bending of the body,
4. iv) Work over the shoulder height,
5. v) Work below the knee,
6. vi) Work in static position for prolong,
7. vii) Climbing and descending,
8. viii) Pushing and pulling of loaded materials etc

which are the primary reasons for WRMSD in the construction and not possible to avoid. Due to these reasons, workers are exposed to work-related injuries. Construction work is more hazardous than other work, accounting for 34% of nonfatal injuries and more than 50% of workers suffering from WRMSD, despite the existence of sophisticated tools and equipment. [23] Human factors and ergonomics are crucial for preventing occupational injuries and fatalities in the workplace.

1.4.5 REQUIREMENT OF POSTURAL ANALYSIS OF CONSTRUCTION WORKER:

Work-related Musculoskeletal Disorders (WRMSDs) are conditions that affect the musculoskeletal system, encompassing muscles, tendons, nerves, joints, cartilage, and ligaments. They arise from prolonged exposure to ergonomic risk factors such as prolonged static postures (e.g., prolonged sitting or standing), repetitive movements, awkward postures (e.g., reaching overhead, working in flexed positions), forceful exertions, vibration, and exposure to cold temperatures. These factors, over time, can lead to the development of WRMSDs.

The development and implementation of ergonomic risk assessment tools are essential for identifying and mitigating these risks. Ergonomics plays a critical role in any industry by enhancing worker safety and health, improving productivity, increasing product quality, reducing costs, and fostering a safer and more comfortable work environment. By implementing ergonomic principles, organizations can create workplaces that are better suited to human capabilities, reducing the risk of injuries and improving overall employee well-being. In recent years, there has been a significant increase in the development and implementation of ergonomic risk assessment tools, reflecting a growing awareness of the importance of ergonomics in preventing WRMSDs.

Construction work presents unique challenges due to its physically demanding nature. Workers frequently encounter heavy lifting and lowering, repetitive tasks, awkward postures, and exposure to extreme conditions. These factors contribute to a high prevalence of WRMSDs among construction workers, including pain in the neck, shoulders, back, arms, and legs. Lower back pain is particularly common due to frequent bending, lifting, and carrying heavy loads.

The objective of this research is to assess the prevalence of Work-related Musculoskeletal Disorders (WRMSDs) and associated pain/discomfort in different body parts of construction workers engaged in various occupations. This assessment will provide valuable data to inform the development and implementation of targeted interventions to improve worker safety and health.

1.5 ERGONOMIC AND METHODS OF ASSESSMENT:

Over the years, numerous tools and techniques have been developed for the assessment of ergonomic risk. These techniques aim to identify and mitigate ergonomic hazards, thus safeguarding human well-being. While the formal development of ergonomic assessment tools can be traced back to the 1970s, methods like video recording were utilized as early as the 1900s.

Various evaluation methods have been developed for the correct and reliable assessment of ergonomic risk factors. These methods can be categorized into self-report methods, simple observational methods, advanced observational methods, direct measurement methods (which include Inertial Measurement Units (IMUs), biomechanical methods, remote sensing methods, and vision-based methods), and computer modeling methods (both software and hardware-based) [15] [25] [26].

For accurate risk assessment, selecting the appropriate method is crucial. Effective ergonomic intervention and the selection of suitable assessment tools are essential to accurately determine the level of risk exposure to work-related musculoskeletal disorders.

Ergonomic principles have been successfully applied in diverse sectors, including healthcare, manufacturing (automobile, dairy, textile, leather, metal), agriculture, livestock, fishing, forestry, transportation, inventory management systems, administration, teaching, artistic and entertainment fields, sports, and many more [27][28][29].

1.5.1 SELF-REPORT METHOD:

A self-report method that was primarily developed for the assessment of WRMSD in a wide variety of ergonomics risk which includes diaries, interviews, questionnaires, self evaluation, check list, body map, etc, [25] [30] [31] [32] [33] [34] The method can be used to collect data directly from the workers using diaries, face to face interviews, questionnaires and video recording. This method is use to collect physical as well as psychosocial aspect. [25] Formerly, many questionnaires also have been developed for the assessment of WRMSD in which NMQ [21] and rating scale like Borg scale [16] [35] [36] are the popular tool. The Nordic musculoskeletal Questionnaire does not differentiate symptoms of self report of work-related or non-work-related and need to be carried out cautiously since this is survey based technique. [37] Many development has been made with time in these methods. [38] [39] [40] [41]

This method help to collect data regarding demographic variability, sign, symptoms and level of pain or discomfort, physical observation by visiting to site or workplace and allowing for video recording for future reference. The method is simple and easy for variety of work with minimum investment, but need to visit many place to collect large amount of data and difficult to rely on data because of variation in individuals experience and subjective in nature.

1.5.2 SIMPLE OBSERVATIONAL METHOD:

Observation method is a systematic observation of working postures at workplace with the help of assessment sheet. Several numbers of simple observational methods have been developed in last five decade and before. The observational methods were developed for the efficient recording of workplace exposure using experience observer and worksheet. [25] The different observational method provides different exposure factors i.e. some method provides exposure to body parts and some provides critical exposure like load/force, coupling, task duration, intensity, vibration, contact stress etc. [34] The simple observational methods are POSTUREGRAM, Posture Targetting, HAMA [30], CHECKLIST, Strain Index, OCRA, Manual Handling Guidance L23, FIOH Risk Factor Checklist, ACGIH TLVs, LUBA, Upper

Limb Disorder Guidance HSG60, MAC [25], OWAS, RULA, NIOSH, PLIBEL, QEC, REBA [25] [30], POSTURE ANALYSIS [42], FSS [43], PErforM [44], MAPO [45], HARM [46], HAT TOOL [47], KILA [48], ROSA [49], ERIN [50][51], EAWS [52], ALLA [53], KIM I, II, III [54] [55], RAMP [56], WERA [57], SERA [58], PERA [59], AULA [60]**,** EAWA [61], WRAP [62][46], ART, CTD, HAL, KC [63].

The simple observational methods are economical and can be used for wide range of static and repetitive risk assessment. These categorical methods do not disturb the workers. This method's scoring system is hypothetical in nature and the Different aspect is weighted and connection between the factors is to be measured. More than one method can be used for the group of exposure that can be allowable risk boundary.

1.5.3 ADVANCE OBSERVATIONAL (COMPUTER BASED) METHOD:

Advance observational method includes video-based observational method that are developed for the evaluation of dynamic, static, non-repetitive, force, velocity, prolong observation and high frequency postural instants. [15] [25] [26] [34] Advance observation methods includes methods like ROTA, TRAC, HARBO, PEO, Video analysis for different purpose [25] [30], COWAS [64], WOPALAS [65], PATH [66], CUBE MODEL [67], SIMI MOTION [68], SNOOK TABLE [69], VIDAR [70], NERPA [71], CERA [72], ERGAN (ARBAN) [73], AUVAfit [74] and VIRA [30].

These methods record the data using video and computer and analysed using customized software subsequently. For analysis of the working postures the worker's postural instances have been video recorded in real time and all measurements like distance of movements, angular changes, velocity and acceleration are measured and noted down. This method includes biomechanical models and use anthropometric, postural and hand load data for calculation of inter-segmental moment and force for analysis. The advance observational method requires high technical support and system having considerably high cost. The process of this method is time consuming and not suitable for practical scenario. [15] [25] [26]

1.5.4 DIRECT MEASUREMENT METHODS (INTEGRATED WITH SENSOR, INERTIAL MEASUREMENT UNITS (IMU'S), BIOMECHANICAL, REMOTE SENSING AND VISION BASED METHOD):

All the direct measurement methods are sensor based. Accelerometer, gyroscope, magnetometer, electromyography (EMG), optical markers, goniometer, inclinometers, optical scanners and sonic sensors are electronic devices use to measure and report body's specific force, angular rate and unsafe posture at work place since long time. Accelerometer measures the physical accelerations of the object in translational movements like sway, surge and heave. Gyroscope measures the orientations of the object which consists of row, yaw and pitch. Magnetometer measures the directions of the magnetic field. It measures static angular displacement with respect to g-line, linear accelerations and angular velocities of an object in orthogonal directions. Electromyography (EMG) measures muscle tension and fatigue. It reveals nerve dysfunction, muscle dysfunction or problems with nerve-to-muscle signal transmission. Goniometer measures angular displacement. Inclinometers measures angles of slope, elevation, or depression of an object with respect to gravity's direction. An Optical scanner scan and digitally convert images, codes, text or objects as two-dimensional (2D) digital files and sends them to computers and sonic sensors measures the distance of a target object by emitting ultrasonic sound waves, and converts the reflected sound into an electrical signal. [15] [25]

When the devices like accelerometer, gyroscope and magnetometer are integrated, the newly designed device is known as Inertial Measurement Units (IMU). The IMU is robust, low cost and provide data with high quality. These IMUs is a self-contained system which measures linear and angular movements which is a triad of gyroscopes and accelerometers. The IMUs are generally called as rate-integrating gyroscopes and accelerometers that are sensor based. Recently, many scientist and researchers are using Inertial Measurement units and developing new advance devices for measuring physical exposure of human body. These are light weight sensors and can directly attach to the human body for recording different parameters generally 3D joints motion and body segments. Different direct measurement devices are available commercially.

Biomechanical on the other hand is use to estimate joint load responsible for WRMSD. The joint load is force or moment that has been applied on a weight-bearing or load-bearing joint while doing any task. Biomechanical are used to evaluate human resources movements of tissues and estimate joint load on body. According to the biomechanical model, higher the load, more the risk. The biomechanical model can be used for post-analysis and human movement analysis; therefore, currently this technique is used for the post processing of data of human motion collected through direct measurement. However, this method requires more money and time to collect large amount of individual and motion data at the same time possibility of variation and error in data. [15] Remote sensing technique is a sensor based biomechanical analysis method that requires range, image or video sensors to record and capture human motions. In this technique, sensors do not fixed on the human body, hence the human being to be evaluated will be visible to the expert for real time assessment. [15]

Vision based technique is also a sensor based method with uses depth sensors and multiple video camera's for 3D reconstruction of human motions. This technique is specifically used for extraction of skeleton and tracking of motion of object. The motion data like rotation angles, joint angles, position vectors and movement direction etc are used for evaluation. Microsoft Kinect, stereo camera and wearable sensor systems, Joint angle measurement system, real-time location system, physiological status monitor sensor are use for evaluation of risk using vision based techniques. [15] Direct measurement method includes methods like BODY POSTURE SCANNING SYSTEM [75], CYBERGLOVE, EMG, LMM [25] [30], FORCE MEASUREMENT [76] [77], GONIOMETER [78], Inclinometer, Accelerometer, sonic system, electromagnetic system [30] and IMU [15].

Direct measurement system requires sophisticated instruments that provide detailed information about the worker however cost of the equipment is high, requires high storage device and time consuming but provides high accuracy with simple post-processing. The system is not suitable for onsite measurement of risk exposure as bodily attached sensors change the behavior and performance of the workers. [15]

1.5.5 COMPUTER MODELING TECHNIQUES USING DHM:

Computer modeling techniques is popular and widely used method for the evaluation of ergonomic risk. An evaluation of working postures for risk factors are carried out by developing Digital Human Model (DHM) by using computer software, computation algorithms for configuring and driving mannequin and thereby simulating and analyzing. Computer modeling technique found an effective tool in the area of development of assessment of ergonomics risk method since it does not obstruct the work at workplace and different analysis can be carried out. [8] [79] This is an upcoming technique which uses the principal of redesigning of product and workplace as per human comfort and safety to evaluate risk which was developed early in the 1960 after CAD which was design for aerospace and automobile industries. Subsequently various computer modeling ergonomic risk evaluation tools was invented and developed to create Digital Human Model (DHM), called as computer manikin. The computer modelling ergonomic risk evaluation software found worthy and most efficient which permit real-time modeling, simulation and evaluation of object and workplace.

The computer modeling methods that are used to create manikin are MannequinPro, Jack (Tempus), Ramsis, Safework, Sammie, Delmia (CATIA) are the modern DHM based ergonomic tools whereas Anybody, 3DSSPP, Tecnomatic, SantosHuman, HumoSim, HandiMan, Hadrian, Santos and Ergonaut etc are the tools and software used for virtual environmental evaluation. [8] [79] With development of computer modeling method, recognition of ergonomics risk and evaluation become easy, fact and eliminates the physical intervention of human being for real testing due to integration of simulation. This allows ergonomist and researchers to change the posture, design, working environment and improvisation virtually for analysis thereby saving cost, time and man-hour's losses. As the analysis carried out by virtual simulation hence no destruction, injury and damage to the real work scenario, workplace as well as human being. [79] Detailed review on computer modeling techniques are presented by Mabemena et al., 2020 and Raghunathan at el., 2016. The methods has been adopted initially by [9] [71] [80] [81] [82] [83] [84] for various analysis using computer modelling technique specially CATIA.

1.6 CONSTRUCTION WORK AND PREVIOUS RESEARCH:

As per the Jaffar et al., 2011, ergonomic risk factor is categorized as 1) Biomechanical exposure 2) Psychosocial and 3) Individual risk factors. The level of exposure normally assessed with respect to work intensity (or magnitude) and Contact stress (Pressure Points) on body parts. The above mentioned three factors are causing work-related musculoskeletal disorders (WRMSD) in human being. Among these three factors, Biomechanical exposure is most common factor for work related musculoskeletal disorders among the workers or combination of all. [86]

With the development of assessment methods, work-related musculoskeletal disorders (WRMSD) assessment has been started in the construction work also. All types of methods being used for the assessment of work-related musculoskeletal disorder amongst the construction workers. Table 4 - 7 provides detailed review of construction field assessment using different methods.

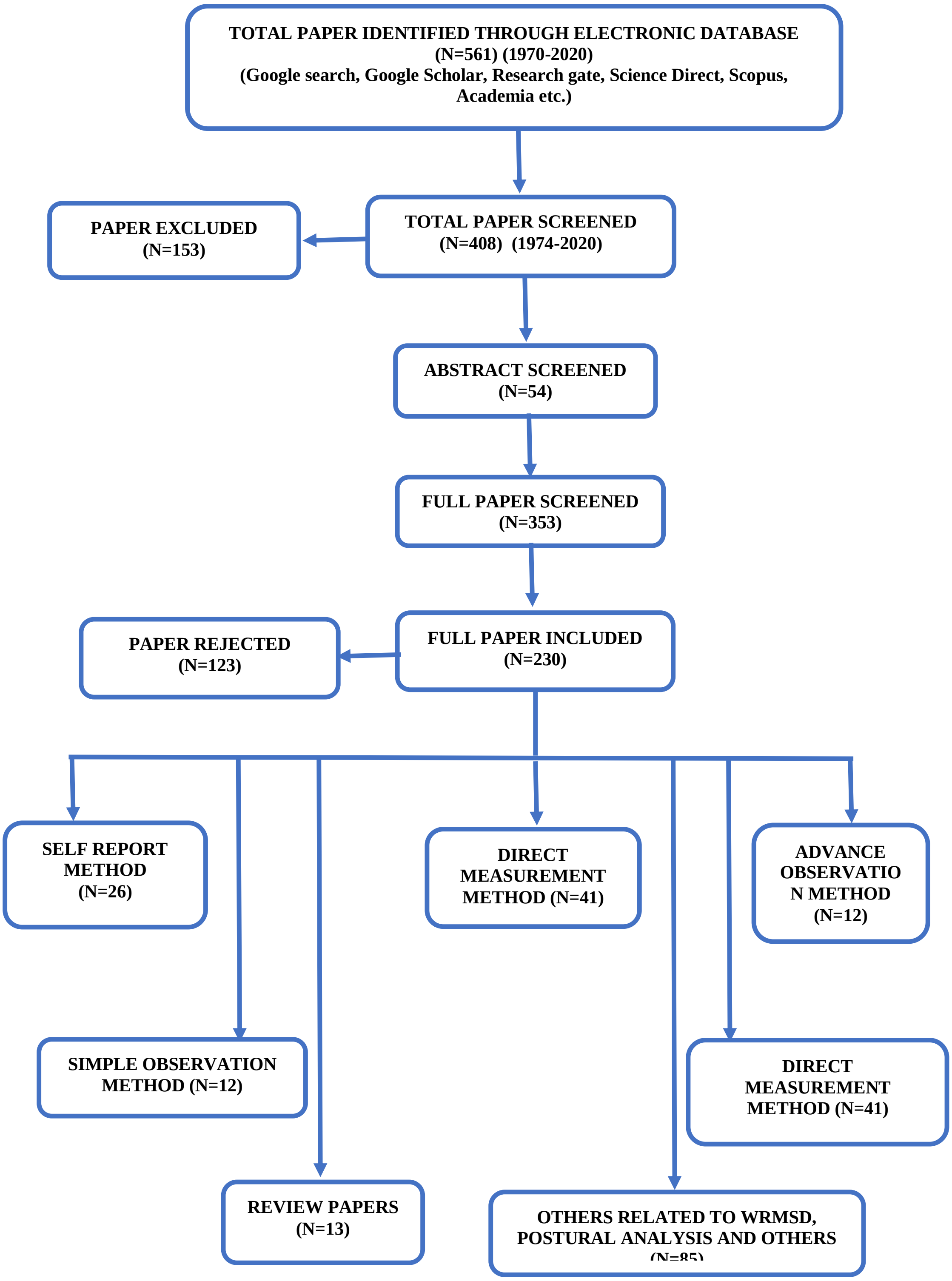


Figure 1.3 Flow diagram of Leterture Review

1.6.1 Previous research work on construction and WRMSD using Self-Report Methods:

Table 1.3 Previous Research work using Self-report method in construction

Sr. No.	Ref.	Target group	Specific task assessed	Studied Area	Risk assessment / data analysis Method	Objective	Group size	Findings/ Result
1	[87]	Plumbers, Carpenters, Floor tile	Plumbing, Furniture, Floor tiling - Stretching and exercises, use of PPE, working methods, and material storage and movement	Field	Observation, Interview, Percentage	Evaluate use of ergonomics based on stretching and exercises, personal protective equipment, working methods, material movement, ergonomic designed hand tools.	40 Carpenters, 40 Plumbers and 40 Floor tile layers	All three are Facing WRMSD problems. Not using PPE, no training and do not use props.
2	[88]	Painters and Tilers	Painting and Tiling	Field	NMQ-E/ PPR/CI	To Find WRMSD reasons due to physical load and psychosocial risk	24 painters and 31 tilers	Workers are suffering from Physical load risk as well as Psychosocial risk and avoiding individuals health.
3	[7]	Unskilled Workers	MMH (Lifting / Lowering)	Field	Structured questionnaire survey, Multinomial logistic regression analysis, Krushal-Wallis tests, OR, Chi-Square test results and R-square	Develop model to predict acute and chronic LBD and UBD of material handling (MH).	Carpenters - 155, Bricklayers - 107, Plumbers - 93, Wall and floor tilers - 33, Roof slaters/ tilers - 23, Plasterers - 13, and Structural steel welders -8	The developed model is found to be good predictable capabilities that can be useful for improvement of health and safety of workers involve in Material handling of lifting and lowering.
4	[89]	Masons, Carpenters, Rebarers, Fitter, Plumbers, Elctricians, Crane Operators and Unskilled Workers	Stress - Masons and Concrete, Carpenters, Loading-unloading, Reinforcement, Skilled Workers, and Fitters, Plumbers, Electricians, Crane operators, Roofers)	Field	OSI, NMQ, WHOQoL-BREF Questionnaire, One way ANOVA	Measure occupational stress in manually intensive work and its relationship with development of MSDs and QoL by considering worker's safety.	268 workers	Workers are under high level of stress at the workplace and living with low QoL.

5	[90]				Snowball sampling, NMQ and Work Ability Index, recording by using a Dictaphone, NVivo10, SPSS, Chi Square, Fishers Exact Test and One Way ANOVA.	Surevy workers' understanding of their health at work and ways of making their jobs easier, safer or more comfortable.	80 workers	All workers are sufering from WRMSD risk.
6	[91]		Safety - Fatigue	Lab. study	Interview, FASCW (Fatigue Assessment Scale for Construction Workers), t-test	Study the fatigue effect on safety performance of construction workers’	20 male rebar workers	As the fatigue increases, an error increases.
7	[92]	Tilers	Floor laying and general work		General secondary data (Insurance claim data), SAS Software V.9.1	Compare construction worker and general workers for medical insurance claims for WRMSD (particularly for floor layerers)	Claims between 2006 -2010	Floor layerer claimed more medical insurances and have high rates of MSD
8	[93]	Carpenters	Furniture work		Questionnaire, Odd Ratio and 95% CI	Impact and risk factors for WRMSD among carpenters.	522 carpenters	WRMSD in Upper part of body
9	[94]				Questionnaire, IBM SPSS Statistics 20	Evaluate advantage of ergonomic measures and MSD among construction workers.	1130 workers	No relationship between the use of ergonomic measures and MSD.
10	[31]	Rebarers (Women)	Rebar work		Self Report, Questionnaire, SPSS, Chi-square test and multiple logistic regression analysis.	Find prevalence of WMSD symptoms and risk factors among women rebar workers	272 Women	High prevalence of WMSD

11	[95]	All workers	Manual work	Field study	Self report and Questionnaire, SPSS, Chi-square (p-value)	To find MSD risk factors, prevalence and relation with muscles	60 male	High prevalence of MSD found in Elbows, wrists/hand, ankles/feet and association found between duration and lower limb.
12	[96]	Rebar workers	Rebar		Monte Carlo simulation Crystal Ball, Chi-Square test	Minimize heat stress to optimize labour productivity.		Heat stress not only from outdoor but also due to confined spaces affecting labour productivity.
13	[32]	Mason and Supervisors	Bricklayer and supervisors		Self report, Dutch Questionnaire-test, CI	Assessment and relation between psychosocial and mental health complaints	1500 workers	Supervisors are under high psychosocial risk and mental health risk than brick layerers but both are under psychosocial risk factor.
14	[20]	Supervisors and Masons	Supervisory work and bricklayers.		Questionnaire, Univariate logistic regression analysis, t-test, SPSS	Review the MSD symptoms frequency among bricklayers and supervisors.	1500 workers (750 bricklayers and 750 supervisors)	Both bricklayers and supervisors have high MSD
15	[97]	Masons	Mason work		Interview and observation	Identify and analyse masonry activities, events and incidents that has high frequency and severity of injuries	141 incidents	Incidents: overexertion, struck by objects and contacts; Activities: (1) block laying, (2) material handling, and (3) erecting and dismantling scaffold; Labour are at high risk than masons.
16	[98]	Manual labourers, carpenters, brick layers painters, electricians, plumbers and welders.	Manual material handling, carpentry, brick laying painting, electrical, plumber and welding.	Field study	Questionnaire, PASW (SPSS) software (Logistics Regression, chi-square test, 95% CI)	To study epidemiological study of MSD	211 workers	80% construction workers suffering from MSD with age, working hours and work duration.

17	[99]		posture stability		Self report, One-way nonparametric Krushal–Wallis tests, Mann–Whitney test,	Factors influences worker perception to postural stability when suddenly come to standing position from a awkward working posture and identify risky working postures associated with lower stability ratings.	186 workers	Non-erect postures results in the largest self-reports of instability whereas postural stability differs depending on the postures required to perform tasks.
18	[100]	Roofer	Roof work		Phone interview, Student t-test, ANOVA, Krushal–Wallis test, Chi-square test, Cochran–Mantel–Haenszel test, Cochran–Armitage est, multivariable regression model, Hosmer–Lemeshow goodness- of-fit statistical analysis, SAS	Find association in work demands, chronic medical and musculoskeletal conditions, aging, and the ability to remain on the job	979 workers	Strong association
19	[6]	Scaffolders, Rebarers, formworkers, electrician-plumbers, concreters and miscellaneous workers	Scaffolding, steel fixers, form working, electrical, plumbing, miscellaneous work	Field study	Questionnaire, One-way ANOVA, McNemar's, Chi-square test, Fisher's exact test,	To find work fatigue and physiological work effect at high elevation affected by occupation among construction workers.	302 workers	A symptom varies with occupation but most affect work is projection of physical impairment and need more attention towards older workers.

20	[101]	Carpenters, Electricians, Plumbers, Other	Carpentry work, Electrical, Plumbing and Other	Field	Questionnaires, Multivariate logistic regression model, Statistical Analysis System (SAS), One way ANOVA	Measures work compatibility of physical and psychosocial variables using Demand–Energizer Instrument (DEI) and find relation with symptoms of MSD and stress.	23 carpenters, 55 electricians, 40 plumbers, and 29 others workers	In construction psychosocial factor play a vital role as well as Work environment, physical task, performance, and job satisfaction are associated with MSD and stress.
21	[102]		Occupational disability	Secondary data	office record of disability pension, Standardized incidence ratios (SIR), confidence intervals	Carry out detailed study of nature work pattern, causes and level of work-related disability.	14474 male	Construction workers have prevalence high risk of disability due to disorders of MSD system, accidents, age and period of service.
22	[103]			Survey	Questionnaire, Chi-square test and logistic regression	Co-relations between job, age, and other life style and conditions with causes and severity of occupational injuries.	880 male	Risks of occupational injuries are due to job, age, BMI, hearing and sleep disorders and lack of exercise.
23	[104]		Exercise for shoulder at home	Survey and clinical	Self report, Shoulder Rating Questionnaire (SRQ), Shoulder Pain and Disability Index (SPADI) questionnaire, ANOVA	Evaluate a remedial exercise proposed for reducing pain and improve shoulder function.	67 Male	Home exercises for shoulder reduce symptoms and improve functional status of shoulder
24	[105]	All workers	Age and Occupation	Health check up data about 1989–1992	Self-administered questionnaires, Odds ratios, Confidence intervals	Illustrate musculoskeletal disorder in connection to age and occupation in construction work.	85191 Males (73,631 construction workers, 8,603 foremen, and 2,957 office workers)	Work-related musculoskeletal disorder increases with age.

25	[2]	Sheet metal workers, Electricians, Plumbers, Operating engineers)	MSD systems among apprentice	Survey	Questionnaire, self report (NMQ), Statistical Analysis Software for PC V 8.0., Odds ratios and confidence intervals, Chi-square test	Evaluate prevalence of MSD symptoms and find occupational and personal factors associated with symptoms among construction apprentices.	996 apprentice (929 Male and 67 Female)	MSD is the major problem started at the early stage among young construction workers and increase with age and year of work especially in female than male.
26	[106]	Masons	Masonary work	Survey	Questionnaire, Self report, NMQ, Kappa, Chi-square test	Find magnitude and musculoskeletal injury characteristics of MSD among masons in low back pain.	300 Masons	Masons' are suffering from MSD of low back pain.

1.6.2 Previous research work on construction and WRMSD using Simple Observation Methods:

Table 1.4 Previsous Research work using Simple observation method in construction

Sr. No.	Ref.	Target group	Specific task assessed	Studied Area	Risk assessment / data analysis Method	Objective	Group size	Findings/ Result
1	[107]	Unskilled Workers	Material Handling	Field	NMQ,GHQ, REBA, OWAS, Chi square test	discomfort levels of the specific operational stance	164 (Male) Field	Skilled Workers suffering from WRMSD
2	[108]	Masons, Tilers, Form workers, Unskilled workers	Grinite, Brisk work, Shuttering, Plastering, Material transport	Field	REBA, RULA	To evaluate level of ergonomics risk of various tasks of construction work.	54 Male	Workers are suffering from WRMSD in each task of construction work.
3	[109]	Masons	Brick field		NMQ, REBA, statistical package Primer of Biostatistics	Find prevalence of WMSD among brick field workers.	104 male and 112 female	Works in awkward postures and risk of MSD.

4	[110]	All workers	Road	Field	Questionnaire, Video, RULA, REBA, SI, SAS 9.1, One way ANOVA	Evaluate potency of RULA, REBA and SI for assessment of Non fixed work.	14 Male	SI found more effective
5	[111]	Masons	Wall plastering		Self report, WERA , Chi-Square test, SPSS	Investigate WMSD among wall plastering workers	43 workers	Workers suffering from wrist, shoulder and lower back pain.
6	[112]	Masons	Wall plastering, bricklaying and floor concreting		Video, self report, WERA, Chi-square test	Reliability and validity of WERA tool.	130 workers (wall plastering - 43, bricklaying - 45 and floor concreting – 42)	Method found reliable and can apply in industry and epidemiological studies.
7	[113]	Masons	Roofing and concrete paving operation		Task Demand Assessment (TDA)	Measuring safety risk of construction activities and analyze accidents possibilities after making changes in operation parameters	2 roof workers and crew for upgrading of airport taxiways	Useful for measuring safety risk of complex activities and provides several risk and task demand factors as well as applicable for analysis and designing of construction operations.
8	[57]	Masons	Plastering, bricklaying, floor concreting		Video, WERA, Chi-square test, kappa analysis	Development of the Workplace Ergonomic Risk Assessment (WERA) tool.	Plastering - 43 workers, bricklayer - 45 workers and floor concreting - 42 workers	WERA found to be a easy, quick and reliable method for physical risk factors.
9	[114]		Scaffolding - MMH	Field	NIOSH, Arbouw, practitioners', OWAS	Compare different manual material handling methods (manual lifting) in scaffolding work.	26 for NIOSH/ Arbouw/Practitioners and other and 61 for Observation = 87	Simple and complicated methods have same results and in scaffolding work the risk is high with increasing pain in low back.
10	[115]		Mechanical (Piping/HVAC) and Electrical installation	Interview, Questionnaire, observation,	NIOSH	Implementation of ergonomics intervention in piping, heating, ventilation and air conditioning (HVAC), and electrical systems of M/EI to reduce MSD loading.	Electrical - 11 , Pipe - 12, Sheet metal - 9 and others - 7	Identified measures and hazardous task which needed to be developed the control measure to improve controls

11	[116]	Unskilled workers	Scaffold frame disassembly	Lab.	NIOSH, SAS general linear model (GLM), ANOVA, Newman–Keuls multiple comparison	Find best possible hand location for a lifting tool to reduce ergonomic risk of postural imbalance and overexertion while disassembling of scaffold.	44 Male	A 46 cm distance of hands between the elbow and chest heights is found to be optimal hand location
12	[117]	Unskilled workers	Brisk manufacturing (Forming, heating and Packing processes)	Survey and Lab. work	Questionnaire, Survey, NIOSH (1991),	Evaluate the lifting task to minimize low back risk factors in fire brisk manufacturing.	20 Males and 6 Females	Ergonomically redesigning of tasks is required

1.6.3 Previous research work on construction and WRMSD using Advance observation (computer based) Methods:

Table 1.5 Previous Research Work using Advance observation (computer based) method in construction

Sr. No.	Ref.	Target group	Specific task assessed	Studied Area	Risk assessment / data analysis Method	Objective	Group size	Findings/ Result
1	[118]	Painters, Masons, Tilers, Security, Cook, Drivers, Unskilled workers and other	Painting/ Sentry/ Ceramic work/ Cooking/ Safety officer/ Driving/ Wall builder/ Scaffolding/ Plastering/ Administration/ Restoration/ Forging/ Windows installer/ False ceiling/ Cement work/ Executive engineer/ Electrician/ QC expert/ Piping/ Technical expert/ Carpentry	Field	Interview/ NMQ/PATH/ MMH /SPSS, chi-square test and general linear models	To evaluate the risks of ergonomic factors procreated musculoskeletal disorders	357 male from different construction sites	Significant pain in the different body parts and both methods found efficient for assessment of construction indutry expossure evaluation.
2	[119]	Form workers, Tilers, Carpenters and Unskilled Workers	Excavation, Centering, Tile work, Furniture and Marble polishing	Field	Observation, Videos, Photos, Questionnaire survey, PATH and RII	To find level of ergonomics risk and suggest corrective measures in construction work	19 Male	All workers are under high risk of WRMSD.
3	[120]	All workers	Delay cause		Interview, questionnaire, RII, SPSS	Assessment of factors causes delay in building construction project and its effects.	All stakeholders	All stakeholders contribute in delay due to different causes
4	[121]	Masons	Drywall		PATH, SPSS	Assessment of physical exposures to drywall workers.	6621 PATH observations	Drywall panel installation workers suffering from MSD
5	[122]	Masons and unskilled workers	Foundation work		Video, OWAS	Analysis of working posture	3 Male	Three jobs of foundation work found in risk
6	[123]	Unskilled workers, Carpenters, Ironworkers, Plasterers, and Tilers	Highway tunnel		PATH ,Chi-square test	Ergonomic risk factors and frequency for major jobs and operations in highway construction work.	120 workers (laborers, carpenters, ironworkers, plasterers, and tilers)	Highway tunnel construction worker are exposing ergonomic risk factors.

7	[124]	Stone Cutter	Stone Cutting		NMQ, OWAS, OSHA ergonomics checklist, Wright's mini peak flow meter, WBGT, psychometric chart, A sound level meter, t-test, chi-square test	Prevalence of MSD among male stonecutters of West Bengal, India	60 workers	Working in awkward posture and under low illumination, high sound and dust.
8	[125]	Workers	Iron work - Crane Assembly, Finishing, Revolving Door installation, Caisson Cage construction, Rod Work, Building erection and Struts installation	Survey	Observation, PATH, Work-sampling, Specialty-task-activity-based, chi-square test	Evaluate ergonomic exposure due to machinery moving/rigging, ornamental, reinforcing, structural work in construction ironwork (CI).	13821 observations	The construction Ironworker spend most of the work time in non-neutral trunk position with both arm above shoulders and stood on uneven or unstable surfaces exposing to ergonomic risk.
9	[21]	All workers	Ironworkers (Highway construction site)	Field	Observational work sampling, PATH, OWAS, Statistical Analysis System (SAS), Chi-square test	Evaluate ergonomic risk of concrete reinforcement work at large heavy highway construction site.	2128 Observations of 16 Male and 1 Female ironworkers	The workers are working in many ergonomic risks at large heavy highway construction while concrete reinforcing as non-neutral posture varied with work and most of the time engaged in manual material handling.

10	[126]	Unskilled workers	Carrying wood beams into and out of a construction pit, shoveling and moving crushed rock, sweeping and shoveling dirt, drilling concrete, spreading mortar on concrete and moving bricks and concrete blocks.	Lab. Exp. - simulation	PATH (Old and new version), accelerometers, LMM, electronic inclinometers, Video, Observation, SAS, frozen-frame analysis, simulated real-time analysis (IMU), Proportion of agreement (P(a)) and kappa (k) coefficient, CI	Study the validity of PATH and a simplified version of PATH to assess trunk, should and knee of construction workers by comparing observational approaches and discrete reference measurements between observational and continuous direct measurements	5 Male	Results of both methods are closely approximate to each other to estimate shoulder, trunk and leg posture.
11	[127]			Field study	Video, OWAS, Computerized Chinese OWAS (CCOWAS), CCOWAS	Evaluate and recommend improvement of postures for formwork, iron reinforcement, cements and scaffold jobs	16 workers	Sawing, positioning and hammering of form work, positioning and wire-tying in iron rods, brick laying and manual handling in scaffold is found to be most stressful work.
12	[24]	All workers	Roof boarding, concrete form preparation, clamping support braces, assembling roof frames, roof joisting, shelter form preparation, and fixing fork clamps.	Field study	Computerized OWAS (COWAS)	To identify the most problematic postures in hammering tasks	18 workers	The most problematic posture found in roof joisiting, concrete form preparation and roof frames construction

1.6.4 Previous research work on construction and WRMSD using Direct Measurement Methods:

Table 1.6 Previous Resarch work using Direct measurement methods in construction (integrated with sensor, inertial measurement units (IMU's), biomechanical, remote sensing and vision based)

Sr. No.	Ref.	Target group	Specific task assessed	Studied Area	Risk assessment / data analysis Method	Objective	Group size	Findings/ Result
1	[11]	Unskilled Workers	Material Handling	Lab. Exp. (Test)	Wearable IMU (pneumaticall-powered exoskeleton system)	body postures while performing material handling	4 (Male) Indoor (laboratory) test	Waist bending angles at a different height, shoulder twisting angles and the distance between a tip of foot and blocks are in danger.
2	[12]	Electrician and Unskilled Workers	Electrical and Material handling	Field / Lab.	Electroencephalogram (EEG) with supervised learning algorithms stress, k-Nearest Neighbors (k-NN), Gaussian Discriminant Analysis (GDA), Support Vector Machine (SVM), Hidden Markov Models (HMM), decision tree, and Logistic Regression approaches	Automatically recognize workers' stress	11 male (Laboratory)	Fixed windowing approach and the Gaussian Support Vector Machine (SVM) gives high classification accuracy with minimal body motion and can be used for early stress detection.
3	[128]	Unskilled Workers, Rebarer, Masons	Material handling, Rebar, and Plastering	Field/Lab.	IMU (Computer vision and smart insole (with planter pressure sensor) -based joint-level ergonomic workload calculation methodology and 3D pose estimator), 3DSSPP	To replace manually visual observation, on body sensors and accurately record workload on body	3 Male (laboratory)	Help to replace on body sensors by using smart insole. Non-invasive force monitor, provide detailed information about posture, exteral load and pattern of posture and load.

4	[13]	Rebarers	Rebar iron work	Field	IMU (Personalized WIMU-based mHealth system), OWAS, t-test test	Ii presented a worker-centric data-driven personalized trunk posture recommended method to help rebar workers in personal healthcare and self-management of work-related postural ergonomic hazards.	5 Male rebar workers	The proposed method help rebar workers in preventing and controlling postural ergonomic hazards during construction rebar ironwork.
5	[17]	Unskilled Workers	Overhead working, squatting, stooping, semi-squatting, and one-legged kneeling	Lab.	IMU (Wearable insole), MATLAB, ANN, DT, KNN, and SVM)	To develop a novel and non-invasive method that automatically detect and classify awkward working postures based on foot plantar pressure using wearable insole pressure system.	10 Male	The wearable insole pressure system is found useful to monitor health, detect unsafe condition, alert warning alarm.
6	[129]	Unskilled Workers	Working overhead, squatting, stooping, kneeling, Flexion, neck bend, reaching etc	Computer program	IMU (Supervised motion tensor), BVH file format, machine learning algorithms, MATLAB	To introduce abstract and efficient motion tensor decomposition approach to compress and reorganize the motion data with a multi-classification algorithm for analysis	Laboratory work	Method able to differentiate various posture and recognized postures with less computation and memory.
7	[16]	Unskilled workers	Material handling	Lab. - Simulation / Algorithms	IMU (Wearable sensor, heart rate monitor, infrared temperature sensors and an EEG sensor). Borg's RPE for level of fatigue.	Investigate the thermoregulatory changes for assessment of fatigue (Physical and mental). Also physiological changes for the purpose of predicting the level of physical fatigue.	12 male	Physical fatigue can be monitored using wearable sensors with thermoregulation changes.

8	[130]				Self Report, Observation, and IMU's, t-test, deviation analysis, critical incident analysis, epidemiological analysis	Identify prominent risks leading to heat illness in summer	216 workers and 26 site	Heat stress risks are socially constructed and can be managed.
9	[131]	Motions of all construction workers	All workers motions	Lab.	IMU (Wearable and Wireless) (AT-BAN)	Human body motions study, review of existing assessment Methods and compared with IMU, introduction of new detection system and demonstration through experiments	Laboratory	Found positive results and IMU found to be non-invasive, long-term and ubiquitous tracking of body postures and motions
10	[132]	Electricians	Electrical		Inclinometers and a data logger (Logger Teknologi HB, Åkarp), SPSS version 11.5	Quantify the postures of electricians working in the construction industry (Brazilian and Norwegian).	24 Male	Electricians are exposed to high levels of upper arm elevation and head extension, mainly due to overhead work.
11	[133]		Prefabricated walls		load cells (AMTI MC3A-6), surface electromyography (sEMG), electrodes, AnyBody^{TM} modelling system, multiple logistic regression model, NIOSH, REBA, Borg’s CR-10 scale, repeated measures ANOVA (RANOVA)	MSD risks evaluation during common panel erection tasks and the influence of panel mass and size	24 workers	WMSD risks is found to be high.

12	[134]		Stilts		A force plate, Kistler charge amplifier, Motus Analog Acquisition Module, SAS/STAT software, F-tests, MANOVA and ANOVA	Find the loss of balance when using stilts in construction for standing position.	20 workers	Higher the stilts were elevated, the greater the postural instability
13	[135]		Factors of accidents	Field	Site data, interviews, review documents (EC Framework Directive, RIDDOR),	Find the causes (factors) of construction accidents	100 accidents	Poor safety, Poor site layout and housekeeping, improper design and selection of tools, equipment and materials, poor design and use of PPE, poor risk management, lack of learning from past experience are the main causes.
14	[136]	Unskilled workers	Concrete delivery	Field	Participatory Ergonomics - LMM, Tri-axial electro-goniometer, Dynamometer, Video, Questionnaire, LMM Ballett software, Regression analysis	Evaluate PE intervention to reduce low back exposure in concrete placing work by using skid plates by concrete laborers for horizontal movement of concrete-filled hoses.	10 laborers	Use of skid plate has decreases the risk of LBD and LMM can be use in construction assessment.
15	[137]	Carpenters	Furniture work	Lab.	Video, Continuous assessment of back stress (CABS) methodology, NIOSHLE, LMM and 3DSSPP	Identify and developed prototype design to reduce low back stress of framing carpenters.	15 workers and 22 workers	The newly developed pneumatic wall lift, an extension handle for a pneumatic nail gun and a vertical lumber handling system has reduced the risk of low back increasing productivity.

16	[138]	Unskilled Workers	Muscles force (pushing/ pulling)	Lab.-scale experiments-Simulation	Video, IMU - ubiquitous Smartphone (iTunes App Store) sensor (accelerometer /EMG-based neuromuscular / gyroscope/ supervised machine learning algorithms), Baltimore Therapeutic Equipment (BTE) Simulator II, Artificial Neural Network (ANN)/ Python	Calculate human force and acceleration using wearable smart phone sensor with relation between force and acceleration created by workers for pushing and pulling activities,	10 experiments	Calculation for force level can be done by trained model with accuracy.
17	[139]	Unskilled Workers	Lifting and Lowering (Trunk posture)	Lab.	Video recording, IMU (SPMWS, ActiGraph GT9X Link, MPMWS, Zephyr BioHarness™3) and Lab view written software for analysis.	To find the effect of placement of sensor on body using two off-the-shelf systems.	One	Wearable sensors are useful than direct observation and video analysis of construction activities for postural analysis.
18	[140]	Unskilled Workers	Repetitive lifting (muscle activity and muscle fatigue)	Lab. Simulation	IMU (Normalised RMS sEMG - surface electromyography), signals recorded using the Noraxon MR 3.8 software, for data analysis Saphiro-Wilk test and Mixed model ANOVA	To evaluate the effect of repetitive lifting task of different weights and effects on postures on spinal biomechanics (i.e. muscle activity and muscle fatigue)	20 Male	In the repetitive lifting, increased lifting weights increased sEMG activity and muscle fatigue of BB, BR, LES, and MG muscles but not the RF muscle.
19	[141]	Rebarers	Rebar		Questionnaires, InBody 230 body analyzer, HEM-712C blood pressure monitor, K4b2, COSMED portable metabolic analyzer, QUESTemp 36 Area Heat Stress Monitors t-test	Measure physical workloads and compare physiological and perceptual responses between bar benders and bar fixers.	6 bar benders and 33bar fixers	All are higher. This sutyd helps to calculation of daily energy expenditure of rebar work.

20	[36]	Unskilled workers	Manual task on scaffold - chipping of concrete		Wearable pressure measuring insoles (F-Scan), heart rate monitor (Polar 810i),Borg scale, Video, MANOVA and ANOVA	Evaluate postural stability, cardiovascular stress, and maintenance of postural balance by new and expert Skilled Workers working on scaffold at different heights.	8 worker (4 new and 4 expert)	Stress of working at higher height and absent of handrails reduces postural stability and increase cardiovascular stress and difficulty in maintaining balance to new Skilled Workers than experts.
21	[142]	Labour	Lifting (Concrete)	Field and lab.	Observation, stop watch, Pacer heart rate monitor, Sphygmomanometer, treadmill, Hygrometer, Kata thermometer, psychometric chart, NIOSH, ANOVA	Find different risk factors in lifting operations by female.	11 Female	Poor safety measures and rest, higher workload, risky field working conditions with accident prone and need to consider occupational health status.
22	[143]	Labour	Manual Material Handling	Lab. - Simulation	Rig, Load cell plate form, beckman dyno graph, MANOVA, factorial design analysis, Multiple regression analysis, SPSS	Effect of lifting frequency, load weight and vertical lifting distance on heart rate.	10 Female	Work-stress factors can understand properly if interaction effects between different lifting parameters studied.
23	[144]	Masnos, Scaffolders, Carpenters, Plumbers and Painters	Bricklaying, Scaffolding, Furniture, Plumbing and Painting work	Field	AEB, ADAB	Find structure of physical workload in different construction work that causes MSD and rank different works according to the load on lumbar spine.	Bricklayers - 123, Scaffolders -30, Carpenters - 33, Plumbers - 31, and Painters -30	To reduce the high pressure on the lumbar spine, more bricklaying machines and elevators should be introduced. In addition current scaffolds should be replaced by lighter constructions.
24	[145]	Painters	Ceiling fitting	Lab. study	Questionnaire, MyoGuard, Intometer, EMG electrodes, t-test	Calculate physical load, muscular load and postures of ceiling fitting workers and compare with laboratory studies.	16 Male	Work performs in upright position with both arms increasing risk of shoulder pain due to rotator cuff tendinitis.

25	[146]		Kinect™ range camera with OpenNImiddle ware	Develop automated approach to evaluate and categories posture for analysis.	Laboratory	This system can be develop for posture analysis, training and online monitoring for analysis of workers behavior.
26	[147]		SSVR, Optotrak (model 3020), Matlab algorithm, randomly-vibrating insoles, SemmeseWeinstein monofilaments (Touch-Test Sensory Evaluators), stabilogram diffusion analysis (SDA) technique, ANOVA, Statistical Analysis System (SAS), Bonferroni method.	Find effect of sensory vibration at different height levels on planter while standing on narrow surface under threaten condition. (simulation approach).	12 workers	Sensory vibration at elevated levels increases the danger of losing balance.
27	[23]	Shoulder injury	Magneto resistive joint angle sensor - measure human joint angles	Designing low cost sensing system		A bench-top version of the External Musculoskeletal Joint Angle sensor was developed is simple, low-cost, sensing solution which automatically monitoring undesirable movements and patterns of motion.

1.6.5 Summary of Previous research work:

The feasibility of the direct measurement method is not limited, and it has been applied to other areas as well. In 2013, Vignais et al. [148] developed an innovative system for real-time ergonomic assessment in industrial manufacturing. In this system, the evaluation was done by referring to the scoring sheet of RULA, and joint angles and orientations were calculated using IMU units. The IMU units were placed on the upper arm, forearm, head, trunk, and pelvis. The upper body of the worker was interpreted in a biomechanical model with 20 degrees of freedom, and a goniometer synchronized the networking of IMU units. The results showed that the IMU had advantages in movement freedom and in-field application. In this system, the authors found that there was magnetic disturbance from the IMU units during evaluation.

In 2014, Li et al. [149] presented a Smart Safety Helmet (SSH) to detect the ergonomic risks of workers in industries. The Smart Safety Helmet consisted of IMU units and EEG sensors. The IMU units were deployed to measure the head gestures of the users, and EEG sensors were deployed to determine the brain activity or mental state of the users. The overall system was controlled by the artificial intelligence module, which interpreted and evaluated the risk factors of the workers based on the raw data received from the sensors. The risk factors considered were the probability of occurrence, the severity of the mishap, and exposure. The results showed that the SSH was able to identify the relationship between the head movements and the mental state of the workers. The disadvantage of this device was that it was unable to provide information on body movement and posture.

Chen et al. [150] proposed a coupled system that incorporated the Kinect and IMU units, which complement each other’s limitations and provide a more seamless system. The system was designed to detect manual lifting hazards in the construction industry. Kinect was used to synchronize the motion of the workers with the skeletal tracking system using its 3D-mapping function and also to evaluate height and body shape. In this system, Kinect's drawbacks were overcome by IMUs, which allowed them to work independently and collect motion data in low-light conditions. The results showed that the overall performance of the system improved by using the joint utilization of Kinect and IMUs for posture measurement.

Peppoloni et al. [151] developed an upper limb wearable device in 2014 for the assessment and measurement of force exerted by the muscles and the postures of the upper limb. For this, the authors used Inertial Measurement Units (IMU) and Electromyography (EMG) sensors.

The IMU was used to measure the motion and posture of the subject, while the EMG was used to assess the force exerted by the muscles. The authors proposed a novel wired system for assessing muscular effort and posture of the upper limb for ULWMSD assessment. In this study, the authors considered the upper limb as a kinematic chain and incorporated 3 degrees of freedom (DoF) for the shoulder, 2 DoF for the elbow, and 2 DoF for the wrist. The EMG observed the forearm flexor muscles. The recorded results from each sensor showed the correlation between the force exerted by the muscles and the postures of the upper limb. The results showed that both devices measured the ULWMSD risk, but only for limited parts of the upper limb.

Schall et al. [152] in 2015 compared the IMU with LMM for directly measuring thoracolumbar trunk motion with the aim to: 1) compare estimates of thoracolumbar trunk motion obtained with a commercially available IMU system with estimates of thoracolumbar trunk motion obtained with a field-capable reference system, the LMM, and 2) explore the effect of alternative sensor configurations and processing methods on the agreement between LMM and IMU-based estimates of trunk motion during a simulated Manual Material Handling task with both systems. The ACUPATH™ Industrial Lumbar Motion Monitor™ (Biomec Inc., Cleveland, OH) and the I2M Motion Tracking System (series SXT IMUs, Nexgen Ergonomics, Inc., Pointe Claire, Quebec) were used to measure angular displacements of the thoracolumbar region of the trunk in the positions of flexion and extension, lateral bending, and axial rotation. A custom LabVIEW program was used to control the simulation of the MMH task, which was developed in MATLAB (r2013b, The MathWorks, Inc., Natick, MA). The statistical analysis was carried out using angular displacement waveforms obtained from the LMM and a custom MATLAB program, which identified the maximum peak value of different postures and the corresponding four seconds before and after each peak. The results showed that the IMU system is useful for estimating trunk angular displacement from the LMM. However, it is recommended that multiple IMUs using fusion algorithms should be preferred over a single IMU for better results. The present system cannot be used for complex joints and dynamic working conditions.

Yan et al. [153] in 2017 developed real-time motion warning personal protective equipment (PPE) that allows workers to become self-aware and self-manage ergonomics hazard prevention using wearable inertial measurement units (WIMUs). The authors proposed a wearable IMU-based real-time motion warning system to raise awareness among construction workers to prevent musculoskeletal disorders of the lower back and neck. In this system, a smartphone application was used for automatically detecting and warning of discomfort posture to the workers. This smartphone application provided a real-time data processing algorithm and a warning threshold algorithm for automatic risk assessment and warnings. The real-time data processing algorithm collected and processed the raw posture data. The warning threshold algorithm sent a warning signal to the worker if the analyzed data crossed the threshold limit. The system was tested and validated in the laboratory and field and worked well with construction workers, but it operates for a short time. This device provided construction workers with a solution to prevent WMSDs due to physical exposure.

Planard et al. [154] carried out their work to evaluate and validate the assessment method using Kinect data in real workplace conditions. The authors proposed and evaluated a RULA method in real work using occlusion-resistant Kinect skeleton data correction, which is marker- and calibration-free. The new method calculates RULA scores at 30 Hz using Kinect skeleton data and assesses its relevance in ergonomic analysis. The results showed that the Kinect data presented more accurate RULA scores. The developed method assesses WRMSDs of a dynamic nature with 30 Hz continuous information, which is assessed offline in real-time.

Hiroyuki et al. [155] developed and used a novel lightweight lumbar-motion measurement device (LMMD) with stretchable strain sensors to measure the risk of lower back pain. This device helps diagnose lower back pain by being mounted on the lower back of the workers. It is lightweight, low in elasticity, highly durable, and has good repeatability, with stretchable strain sensors that form a parallel sensor mechanism capable of measuring rotation angles of lumbar motion in three-axis directions using six sensors. The results revealed that this prototype device effectively measures lumbar motion over time without disturbing the work task. The accuracy is slightly lower, so the authors plan to improve the device by changing its shape to an arc shape, allowing it to fit properly on the waist of the user.

Shahvarpur et al. 2018 [156] studied the effect of wearing a lumbar belt for biomechanical and psychological assessment of flexion, extension motion, and manual material handling. The authors examined the effect of wearing lumbar belts (LB), both extensible and non-extensible, on the segmental trunk range of motion (ROM) and compared coordination during trunk maximum forward bending (flexion) and maximum backward bending (extension) in manual material handling. Healthy participants and those with low back pain were tested for pain intensity, pain fear, and catastrophizing during activities. In both cases, the authors found that the lumbar belts reduced lumbar range of motion and also reduced pain, pain fear, and catastrophizing in workers with low back pain, helping them to maintain their activities. It also helped reduce disability prevention (gradual exposure to physical risk) and maintain regular activities. This LB device may work as protection against various injuries and reduce pain intensity during work.

Chen et al. 2018 [157] proposed an automatic system to identify and visualize work-related musculoskeletal disorder (WMSD) risk factors by using a wearable and connected gait analytics system (WCGAS) and Kinect skeletal models. The authors developed this system to identify risk factors such as overexertion, awkward postures, excessive repetition, and their combinations. The postures, force exertions, and repetitions of work were recorded by plantar pressure using an insole-shaped wearable device with the help of WCGAS and recognized with sequential minimal optimization (SMO) and long short-term memory (LSTM) algorithms. Work-related musculoskeletal disorder risk factors were identified using Kinect skeletal models. The algorithms were applied for quasi-static postures and force exertions like lifting, carrying, bending, pulling, and pushing with variable loads. CNN and LSTM algorithms were applied for sequential and repetitive posture identification. The results showed that the use of WCGAS and Kinect skeletal models can be useful for identifying and visualizing WMSD risk factors using SMO, CNN, and LSTM algorithms.

Fang et al. 2017 [158] designed an accelerometer-based fall warning detection system using hierarchical threshold-based algorithms for tiling operations in construction with a smartphone. Four accelerometers were connected to the chest, waist, arms, and hands of tilers working on scaffolds under normal, drunken, and drowsy conditions. Once the system detects a fall warning, such as a loss of balance or sudden swaying, it informs the workers about their susceptibility. The authors used SVM, VA, and hierarchical-based algorithms with different configurations of accelerometers. The results showed that detecting fall warnings is significantly simpler than avoiding false warnings. The authors also pointed out that accuracy is a more critical factor than the detection rate for recognizing fall warnings.

Akanmu et al. 2017 [159] state that whenever construction workers are exposed to work-related musculoskeletal disorder risks or injuries, they are reassigned to other simpler tasks on construction sites. The authors proposed an ergonomic analysis framework to measure the risk factors affecting body parts during construction work, aiming to reassign tasks that minimize strain on the affected body parts. The authors used the Inertia 3D motion capture suit, which incorporated a 3D miniature inertial motion unit (IMU) and was equipped with an onboard signal processor and data fusion algorithms to capture full human body motion. For demonstration, the authors conducted a laboratory experiment on workers with knee problems who were lifting and stacking wooden boards, performing plumbing work, and electrical work to evaluate motions, postures, body parts, joints, and environmental conditions. The findings indicated that the data could be optimized and used to predict construction tasks with minimal impact on the affected body parts.

The practical approach of the direct measurement system is relatively complex and requires computational analysis with a 3D biomechanical model in practical scenarios. Hence, some software-based methods have been developed and applied for risk assessment in recent years. Recently, research has focused on the automation and optimization of observational and other risk assessment techniques using IMUs, various computer programming and hardware-software interface techniques, machine learning, metaheuristics, CNN, and multi-objective optimization [160] [161] [96] [162] [163].

COMPUTER MODELING TECHNIQUES using DHM are employed for designing and evaluating ergonomic risks. However, this method has not been applied in the field of risk assessment for construction work and workplaces, despite its wide application. Only Das et al. [164], in 2016, used CATIA to present a conceptual trowel for plastering work and a material handling device with an adjustable height to hold an iron pan.

Since the 1900s, and specifically since the 1970s, a range of methods have been developed for evaluating and measuring the exposure rate to physical risk factors that lead to the development of WRMSDs. As discussed in Section 3, self-reported methods, simple observational methods, advanced observational (computer-based) methods, direct measurement methods, and computer modeling (software and hardware-based) methods have been developed and implemented in various areas.

Since 2011, various ergonomic assessment methods have been revealed in this review. These include Workplace Ergonomic Risk Assessment (WERA) [57] and Agricultural Upper-Limb Assessment (AULA) [60] in 2011, Rapid Office Strain Assessment (ROSA) [49] and Working Posture Risk Assessment Tool (WRAP 1.0) [62][46] in 2012, Evaluation Del Riesgo

Individual/Individual Risk Assessment (ERIN) [50], Novel Ergonomic Postural Assessment Method (NERPA) [71], and European Assembly Worksheet (EAWS) in 2013 [52], Push-Pull Analysis using CATIA V5R19 [80] and Fatigue Assessment Scale for Construction Workers (FASCW) [91] in 2014, Image Processing-Aided Working Posture Analysis (I-OWAS) [165], Revised Job Strain Index (JSI) [166], A Computer-Based Expert System (SONEX) [9], and Simple Ergonomics Risk Assessment (SERA) [58] in 2016, PRASAD (Predictive Risk Assessment for Safe Assembly Design) [167] and Postural Ergonomic Risk Assessment (PERA) [59] in 2017, and Allgemeine Unfallversicherungsanstalt - the Austrian Workers' Compensation Board (AUVA fit) [74] and Composite Office Ergonomic Risk Assessment (CERA) [72] in 2018. Since 2011, many research and evaluation works have been carried out using direct measurement methods, particularly Inertial Measurement Units (IMU), Kinect, and ANN, KNN, optimization techniques, biomechanical models, etc.

Various authors and researchers have also reviewed methods of risk assessment over the last three decades and presented their views. The following is a review of ergonomic risk assessment methods, including their applications, advantages, disadvantages, and limitations.

Pinzke, S. (1997) conducted a review study in 1997 on the available observational methods developed for the evaluation of posture. The author carried out this review to assess the applicability of evaluation methods for agricultural working stances. The author identified three categories of evaluation methods: direct measurement, observational, and self-report methods, and described them in detail. The paper provides a comprehensive review of each method (OWAS, WOPALAS, TRAM, ARBAN, RULA, Keyserling, PWSI, VIRA, PEO, HAMA, TRAC, Observer, Graf, Stetson, Cube model, Forman, AET, EWA, and PLIBEL), categorizing them as manual, computer-based, direct, video, task sample, time sample, or real-time. The author also highlighted the relevant body parts, other components, applications, and suitability for agriculture, while suggesting improvements in the observational methods [34].

Guangyan et al. (1999) presented a review paper in 1999 on posture-based methods for assessing physical exposure to WRMSDs. The authors reviewed self-report methods, observation methods based on pen and paper, video tape and computer analysis methods, and direct measurement methods, highlighting their applications, benefits, and limitations. In this review, the authors found that all the methods reviewed were based on principles developed in the 1970s and needed further development for more precise investigations [30].

David G.C. concluded that the selection of a method depends on the objective, nature of the investigation, and relevance to the area. David G.C. (2005) also highlighted the features, functions, and exposure factors assessed by different methods and recommended observational methods. The author categorized the methods into three categories: 1) self-report, 2) observational (simple and advanced), and 3) direct measurement [25].

Costa et al. (2009), in their review, classified and categorized WRMSDs according to body parts, type of risk (biomechanical, psychosocial, and individual), and level of exposure (strong, reasonable, and insufficient). From the review, the authors revealed that awkward postures, heavy lifting, repetition of work, high physical/psychosocial workload, high BMI, and smoking addiction are the most common risk factors. However, less rational data showed a correlation with the growth of WRMSDs [168].

Takala et al. (2010) carried out a review of methods used for the assessment of biomechanical exposures and identified 30 methods, of which 19 methods were compared with others. In this paper, the authors presented general methods (such as OWAS, AET, Posture Targeting, ERGAN, TRAC, PEO, HARBO, PLIBEL, PATH, QEC, REBA, Washington State ergonomic checklists, VIDAR, LUBA, and Chung's postural workload evaluation), methods for upper limb assessment (including HSE for upper limbs, Stetson's checklist, RULA, Keyserling's cumulative trauma checklist, Strain Index, OCRA, ACGIH HAL, Washington State ergonomic checklists, and Ketola's upper-limb expert tool), as well as methods for material handling (NIOSH lifting equation, Arbouw, New Zealand code for material handling, MAC, Washington State ergonomic checklists, ManTRA, ACGIH lifting TLV, and back exposure sampling tool). The authors provided the target exposure, dimensions, metrics, observation strategy, and recording mode for these methods. The authors revealed that although many studies had carried out similar assessments, no single method was found to be the best. They suggested that ergonomists or researchers should define the need and select the appropriate method accordingly [169].

Wang et al. (2015) reviewed the currently available methods for WRMSD risk evaluation in construction work and stated their advantages, limitations, applicability, efficiency, cost, and labor requirements. The authors' review paper shows that the methods are grouped into self-report, observational, direct measurement, remote sensing, biomechanical, and vision-based assessment methods, with an emphasis on wearable sensor and vision-based methods for construction work assessment. In this review, the authors revealed that a single method is not sufficient for effective evaluation. It is better to use multiple methods depending on the study's requirements, severity, and situation. The authors also highlighted that direct measurement methods are not relevant for risk assessment in all circumstances (e.g., fieldwork and dynamic tasks), where wearable sensors may disturb the work and reduce speed. Therefore, using multiple methods can address this issue [15].

Raghunathan et al. (2016) presented this review paper to examine the advancements in computer-aided ergonomic design and the application of Digital Human Models (DHM). The authors reviewed 1) ergonomic interventions and ergonomic design, 2) ergonomic analysis and tools, and 3) Digital Human Models (DHM) and virtual ergonomics. The review reveals that in virtual ergonomics, the development of DHMs with virtual reality and virtual manufacturing is gaining popularity and has significant potential for incorporating computers into product and work system design. The authors emphasized that Human Factors Engineering (HFE) and DHMs should be integrated, aiming to align human-machine compatibility. They suggested that product lifecycle software designs, work-system design, and design academicians should collaborate to enhance human well-being [79].

Sukadarin et al. (2014) and Sukadarin et al. (2016) presented a simple observational method based on pen and paper. In this review paper, the authors reviewed six methods: WERA, QEC, REBA, OWAS, PATH, and PLIBEL. The authors presented and highlighted work activity, risk levels, joint angles, and the ranges of motion for joints of all body parts (such as upper arms, lower arms, shoulders, elbows, wrists, neck, trunk, and legs), categorizing them into 5 to 10 risk levels used in these methods and their adverse effects on the body. The authors revealed that while these methods have potential for assessing risk, they also have some limitations [170][171].

Kolgiri et al. (2016) conducted a review of ergonomic risk factors (ERFs) related to the power loom industry and found that working in awkward postures, vibration, force, repetition, insufficient recovery time, extreme temperatures, static postures, and contact stress are responsible for damage. Proper workplace design, production line balancing, healthy working conditions, work systems, and safety measures can reduce fatigue. Stress and strain, capacity, efficiency, work simplification, and quality products can help minimize ergonomic risks. The authors also discussed in detail ERFs such as awkward posture, force, repetition, vibration, static loading, contact stress, extreme temperature, and sound, and summarized various risk factors with examples [10].

Kale et al. (2016), in their review, presented that researchers have studied single tools, compared tools, and used different methods on the same area. They concluded that selecting a single tool for ergonomic analysis is a complex task. The authors discussed the comparison, major studied areas, and the application of methods in industries. According to the authors' review, when selecting a particular tool for a specific evaluation, it is necessary to define the specific setting, required accuracy, field of analysis, data needed, complexity, costs, ease of use, and other factors that can provide the best solution [172].

ee et al. (2017) highlighted several observational and direct measurement methods. In this review paper, the authors compared previous work conducted by different researchers, assessing their methods and devices, field of application, parameters, postures, materials, cost, reliability, and accuracy of survey-based observational methods and direct measurement methods, particularly REBA, RULA, IMU, and Kinect. The authors found that all methods have their own application areas; however, IMU-based methods showed promising results compared to the others. The authors also emphasized the importance of workers being aware of risk factors, which can help minimize risks and injuries in the workplace [173].

Grooten et al. (2018) explored three main factors indicating ergonomic exposure: intensity, frequency, and duration, and how they relate to body parts or risk factors that cause WRMSDs. The authors specifically explained several observational methods (ALLA, ART, CTD Risk Index, HAL, HARM, KC, KIM-I/II, KIM-III, LUBA, OCRA, OWAS, PATH, PLIBEL, QEC, RAMP, REBA, RULA, SI, WERA) and the main factors that contribute to the development of WRMSDs. According to the authors, all methods assess the intensity of posture but not biomechanical factors (frequency and duration), which can be measured by SI, HAMR, KIM-I/II, KIM-III, RAMP, and WERA. Among these, the WERA method measures the biomechanical risk for the whole body. The authors found that no single method can assess all types of risks; however, it is crucial to acquire knowledge of all available methods and apply the most appropriate one based on the specific requirements [63].

Badhe et al. (2018) presented a paper on postural assessment. The authors focused on three approaches: sensor-based approaches, manual goniometric approaches, and digital photography/photogrammetric approaches, and discussed posture assessment, its importance, and its applications. The authors also described various assessment methods and their limitations, such as visual observational methods, X-ray examinations, flexible rulers, radiologic data, scanners with laser/video cameras/triangular sensors, photography, filming, and software. The authors found different limitations for each of these methods. For example, visual observation only provides details and detects deviations, while X-ray exposes the subject to radiation. Flexible rulers, being low-cost and non-invasive, are more favorable than X-rays, whereas scanners and photography are limited to detecting analytical deviations. Software, on the other hand, provides 2D images using 3-6 cameras and converts them into 3D analysis, but it is costly, complex, and requires calibration every time [22].

The authors observed postural variations across all age groups, and noted that all the described methods are still in the development stage. They also encountered issues with the availability and high cost of the software. Corel Draw, AutoCAD, and Photoshop require calibration, and no method was found that can assess the whole body. Additionally, the authors found that nearly all methods are still in development, and no strong evidence has been found to clarify the procedure for the assessment of photographic postural evaluation.

Mgbemena et al. (2020) emphasized the computer modeling method for manufacturing shop floors. The authors highlighted the use of ergonomic modeling and evaluation tools (software) and hardware technology. They revealed that computer modeling is an effective technique for numerous applications of risk assessment and can be utilized by computer software for various application areas. Construction work is physically demanding and cannot be fully substituted by machinery. The OWAS [25] and WERA [57] methods are specifically developed for the analysis of construction work assessments.

As per the review of this study and Wang et al. (2015) [15], numerous research works have been carried out in the construction area using direct measurement methods (integrated with sensors, inertial measurement units (IMU), biomechanical methods, remote sensing, and vision-based techniques) for various assessments of construction occupations, which is also found in the present review study (Section 3). This study highlights various research works in the field of construction for evaluating ergonomic risk. Over the past 10 years, direct measurement methods used in construction work include IMU, Kinect, biomechanical methods, artificial neural networks (ANN), k-nearest neighbors (KNN), optimization, computer modeling methods using Digital Human Models (DHM), and hardware/software applications. These include lifting and lowering risk exposure evaluation using 3D sensing and IMU [150], real-time motion warning for PPE using WIMU [153], truck posture assessment using SPMWS and MPMWS [139], awkward posture identification using machine learning algorithms and canonical polyadic decomposition systems, SVM and IMU [129], stress assessment using EEG [12], detection and classification of awkward posture using wearable insoles with simulation using ANN, DT, KNN, and SVM [17], evaluation of motion and postures while lifting using robotic wearable exoskeletons with IMU and CANE [11], fall warning detection systems for tilling work using hierarchical threshold-based algorithms with SVM and VA [158], reassignment of work for minimal strain on the body using 3D motion capture suits, onboard signal processors, data fusion algorithms, and IMU [159], and muscle force assessment for pushing and pulling using smartphones, work simulators, and ANN [138].

From this review, the paper identifies that over the last five decades or more, various ergonomics risk assessment methods have been developed and implemented in many areas. However, each method has its own pros and cons.

The self-report method is easy, economical, and applicable in all situations. Primary data, such as personal information and individuals' experiences with work-related pain or discomfort, can be collected from a large number of participants. However, the reliability of this method is somewhat doubtful, as the gathered information can vary from individual to individual. At the same time, data collection is robust, as it requires visiting different locations [15][25].

The simple observational method, or pen-and-paper-based observational method, is simple, inexpensive, mostly posture-based, and used in many applications. This method does not disturb workers and can be carried out in compact workplaces. The methods involved in simple observational assessments are capable of evaluating body postures along with other factors, but they may not evaluate all factors accurately at the same time. These methods also do not consider load/force, repetition, duration of movement, vibration, psychosocial and individual factors, or the interaction/combination of these factors. Additionally, they are not suitable for evaluating dynamic work postures (i.e., they assess only static postures or simple repetitive movements) [30]. Another drawback of this method is that it may be subject to both intra- and inter-observer variability [25].

The advanced observational method is based on a video-based observational approach, where dynamic working postures are recorded using videotape and analyzed afterward. This method records real-time postures, which can be captured by an observer or any other person. The video recordings are then analyzed by a trained analyst (usually an ergonomist) using a scoring sheet, and the analysis applies to the kinetic chain of articulated links of the human body, joint segments, distance of movements, angular changes, velocities, accelerations, forces, and moments, using anthropometric, postural, and hand load information. However, the method is expensive, time-consuming, and requires a specialized, trained person for analysis. Additionally, continuous assessment is not possible [25][63].

Direct measurement methods integrated with sensors, inertial measurement units (IMUs), biomechanical tools, remote sensing, and vision-based methods have gained popularity and application in the field of ergonomic risk evaluation. In this method, sensors are directly attached to the worker's body for exposure assessment, providing highly accurate data on a range of exposure variables in large quantities. The main drawback of this method is that it requires expensive sensors, high-capacity storage devices, sophisticated equipment, and more time for execution and analysis. Additionally, attaching sensors to the body can cause discomfort to the worker, alter their behavior, and reduce performance and efficiency. This method is primarily applicable for laboratory evaluations and not for field use [15][25].

Computer modeling techniques using Digital Human Models (DHM) are popular with a wide variety of applications in the area of ergonomic risk assessment. These methods are fast, easy, and do not require physical intervention. However, the method has some limitations, such as not evaluating time factors, requiring high costs and infrastructure, demanding competence in mathematical modeling and programming, and needing extensive technical support. Despite these limitations, the method shows promising results in the field of ergonomic risk evaluation [8][79].

Another method showing significant results and improvements in the field of ergonomic risk evaluation is "Ansys," developed in the early 1970s. "Ansys" is a mechanical finite element analysis (FEA) software used for engineering simulation. It simulates computer models of structures, electronics, or machine components to evaluate factors such as strength, toughness, elasticity, temperature distribution, electromagnetism, and fluid flow over time [174][175][176].

Construction work is hard, dynamic, and physically demanding. Workers frequently perform tasks in awkward postures, involving prolonged standing and sitting, forward bending, repetitive movements, and forceful manual material handling. Other factors include lifting and lowering, long working hours, vibration, contact stress, working under pressure (e.g., completing tasks within a set time), lack of rest periods, limited knowledge and awareness, working in adverse environmental conditions, multitasking, physical and financial weaknesses, and inadequate nutrition. Based on a review of research in the construction field, it is clear that all tasks in construction present ergonomic risks.

Multiple methods are available for evaluating physical exposure, but rather than relying on a single method, integrating multiple methods can yield better results for ergonomists and researchers. Computer modeling methods also show promising outcomes for the design, development, and analysis of real-world risk evaluations in virtual scenarios.

Early detection of ergonomic risks not only helps identify problems but also minimizes the development of work-related musculoskeletal disorders, improving work hours and reducing costs associated with injuries and fatalities. The review reveals that, even though various methods have been developed over the years, each has its own advantages, disadvantages, and limitations. Not every method is suitable for every situation, so basic knowledge is necessary to select the proper method. The method should be chosen according to the prerequisites of the study, work, and workplace.

Since construction work is robust and dynamic, and in India it is influenced by locally available tools and equipment, workers often work in irregular, complex, uneven, and confined spaces where the use of wearable sensors or other direct measurement devices may not be possible. For construction workers, self-reported methods and simple observational methods are best suited for primary investigations. For more detailed investigations, direct measurement methods can be implemented as needed, and computational modeling methods can be used for modeling and analysis of variations. Therefore, construction work requires multiple solution methods for the evaluation of ergonomic risks.

1.7 RESEARCH GAP AND SCOPE OF THE PRESENT RESEARCH WORK: -

Researchers worldwide have explored various approaches to improving the management of Work-Related Musculoskeletal Disorders (WRMSDs) among workers by optimizing different parameters. However, these research efforts exhibit several limitations, as outlined below:

1) Researchers commonly attempted to develop and compare methods for assessing postural risk factors associated with different types of Work-Related Musculoskeletal Disorders (WRMSDs) among construction workers.
2) A standardized methodology for assessing and managing Work-Related Musculoskeletal Disorders (WRMSDs) among construction workers has not been consistently established.
3) Sufficient research has not yet been conducted to develop a comprehensive system for the prevention and management of Work-Related Musculoskeletal Disorders (WRMSDs) among construction workers.
4) While significant research focuses on assessing postural stress, translating these assessments into actionable postural analyses and remedial interventions remains largely unexplored.
5) Limited research specifically addressing the challenges faced by construction workers in Maharashtra and West Bengal has been found in the available literature. Furthermore, there is a significant gap in health and safety awareness among construction workers in both states.
6) No design solution has been suggested for various occupations for construction workers to reduce Work-related Musculoskeletal Disorder (WRMSD).
7) It has been observed that no proper ergonomic tools have been suggested for construction workers to reduce Work-related Musculoskeletal Disorder (WRMSD).
8) Exploring applicable ergonomic methods for evaluating different postures of construction workers performing construction work and suggesting proper ergonomic design tools is the main aim that remains untouched to date in the present scenario.

This study is related to various works on house building construction. Most of the injuries, stresses, and strains occur due to over-exertion and repetitive work actions. The study will be carried out on workers employed as laborers for house construction work in the state of Maharashtra and West Bengal, India. The respondents for the study will be selected from those involved in house construction work, including excavation of soil for foundations, lifting of different materials such as soil, sand, gravels, cement bags, and water, carrying/fetching of different materials used in construction work, mixing of mortar, rebar work, reinforcing concrete, brick wall construction, plastering, electrical work, plumbing work, wall care putty and painting work, windows and doors manufacturing and fitting work, tile fitting and tile polishing, carpentry work, and fitting of scaffolding and centering.

The study will focus solely on the working styles and postures of the workers for the different work activities mentioned above. Videos and photographs and personal interviews will be conducted for postural analysis, measurement, and assessment. While capturing the videos, the workers will not be disturbed, and the videos and photographs will be taken during their natural work routines to accurately capture their postures.

Based on the videos, photographs, personal interviews, and observations, the results will be analyzed to assess the working postures and movements of the workers and identify potential work-related musculoskeletal disorders (WRMSDs). Subsequently, ergonomic design tools or corrective measures will be suggested to minimize the risk of WRMSDs among house building construction workers by utilizing various exposure assessment methods and techniques within the field of Human Factors and Ergonomics.

The proposed research aims to bridge the gap between past and present studies and suggest ergonomic design tools for high-risk construction occupations to minimize Work-related Musculoskeletal Disorders (WRMSDs) among construction workers involved in various construction tasks in the states of Maharashtra and West Bengal, India.

1.8 AIM, OBJECTIVES AND SCOPE OF PRESENT RESEARCH WORK:

1.8.1 AIM OF THE PRESENT RESEARCH WORK:

The aim of this research is,

1. To study and analyze (assess) the level of physical exposure on the body of house building construction workers to minimize the risk of Work-related Musculoskeletal Disorders (WRMSDs) among construction workers in the states of Maharashtra and West Bengal, India.
2. To develop and implement ergonomically designed tools and/or suggest corrective measures to minimize Work-related Musculoskeletal Disorders (WRMSDs) among construction workers.

1.8.2 SCOPE OF THE PRESENT RESEARCH WORK:

This study is related to various works on house building construction. Most of the injuries, stresses, and strains occur due to over-exertion and repetitive work actions. The study will be carried out on workers employed as laborers for house construction work in the state of Maharashtra and West Bengal, India. The respondents for the study will be selected from those involved in house construction work, including excavation of soil for foundations, lifting of different materials such as soil, sand, gravels, cement bags, and water, carrying/fetching of different materials used in construction work, mixing of mortar, rebar work, reinforcing concrete, brick wall construction, plastering, electrical work, plumbing work, wall care putty and painting work, windows and doors manufacturing and fitting work, tile fitting and tile polishing, carpentry work, and fitting of scaffolding and centering.

The study will focus solely on the working styles and postures of the workers for the different work activities mentioned above. Videos and photographs and personal interviews will be conducted for postural analysis, measurement, and assessment. While capturing the videos, the workers will not be disturbed, and the videos and photographs will be taken during their natural work routines to accurately capture their postures.

Based on the videos, photographs, personal interviews, and observations, the results will be analyzed to assess the working postures and movements of the workers and identify potential work-related musculoskeletal disorders (WRMSDs). Subsequently, ergonomic design tools or corrective measures will be suggested to minimize the risk of WRMSDs among house building construction workers by utilizing various exposure assessment methods and techniques within the field of Human Factors and Ergonomics.

1.8.3 OBJECTIVES OF THE PRESENT RESEARCH WORK:

1. To record working postures of construction workers performing various house construction work (like Excavation work, Labor work, Masonry work, Form work, Rebar work, Electric work, plumbing work, Tiling/flooring work, painting work etc) using video recording, photographs, personal interview and observations in the states of Maharashtra and West Bengal.
2. To select appropriate methods and techniques for postural analysis (assessment) of selected working postures in various construction occupations.
3. To investigate and analyze the working postures of construction workers to assess their risk of developing Work-Related Musculoskeletal Disorders (WRMSDs) by employing appropriate ergonomic methods and techniques.
4. To suggest corrective measures and develop ergonomically designed tools to minimize Work-Related Musculoskeletal Disorders (WRMSDs) among various house building construction workers to increase their efficiency.

CHAPTER – 2

METHODOLOGY

2.1 DATA COLLECTION ANALYSIS AND POSTURAL ANALYSIS FOR VARIOUS OCCUPATIONS.

The construction work consists of various occupations like i) Excavation for column erection, ii) Rebar work, iii) Form Work, iv) Brick work, v) Plastering work, vi) Concreting work, vii) Electrification, viii) Plumbing ix) Putting and Painting, x) Tiling xi) Carpentry work (Furniture).

To perform this activity, it requires-

a) Unskilled workers are those who work as laborers/helpers to skilled workers. They are commonly referred to as "coolies" in India.

b) Semi-skilled workers are those who assist skilled workers and sometimes work as skilled workers in occupations in which they are proficient.

c) Skilled workers are those who are experts in the above-mentioned tasks. They include masons (who perform bricklaying/plastering/concreting work), rebar workers, form workers, electricians, plumbers, tilers, painters, carpenters, etc.

The following methods have been adopted for this research work.

2.1.1 Data Collection (Field Observation / Survey/ Questionnaires/Video Recording):

The data was collected through observations, interviews, and video recordings during work without disturbing the workers, by visiting different construction sites. A designed questionnaire was filled out by the workers. Self-reported questionnaires were given to construction workers, consisting of general questions to be answered with 'Yes' or 'No.' Pain in different body parts, pain occurring at various times of the day, traumatic incidents, and addiction to alcohol/tobacco/smoking were recorded using the questionnaire, discussions, and interviews with workers. These were conducted while workers were performing tasks in awkward postures, working at a fast pace, and doing physically demanding jobs, all of which were observed and recorded. During discussions, symptoms and exposure conditions related to their work were also recorded. The questionnaire was explained to the workers, and their answers were recorded on the sheet.

Personal information such as name, age, work experience, education, marital status, native place, and habits was asked and noted. Height and weight were measured using an anthropometric scale and a digital weighing machine, respectively. BMI was calculated from these data. The average working hours were 8.5 hours, and the average duration of rest was 1.2 hours. The number of working days in a week was seven.

2.1.2 PARTICIPANTS:

Four hundred and forty-one male and fifty-one female construction workers performing various manual construction tasks were randomly observed, interviewed, and video recorded at different construction sites. The workers who participated in this survey were above 20 years of age and grouped into four age groups: 21-30, 31-40, 41-50, and over 50. Prior consent was obtained from house owners, contractors, and individual workers to conduct the study. The workers typically work for 7-8 hours per day, including a recess, for 7 working days a week.

2.1.3 RESULT AND DATA ANALYSIS:

The somatic characteristics of construction workers (male and female) with mean ± SD of age, height, weight, experience, BMI, and their distribution concerning gender are presented in Table 2.1. Table 2.2 and Figure 2.1 show the number of male and female workers experiencing pain in body parts. Table 2.3 and Figure 2.2 show the number of male and female workers who experienced pain at various times of the day.

During the survey, out of 465 workers, 385 (82.80%) reported pain in different body parts. Among the 385, 334 (71.82%) are male, and 51 (10.97%) are female. From Table 2.1, it is revealed that 76.56% of workers are working in an awkward posture, 91.61% of workers are married, 7.53% of workers are illiterate, 62.37% of workers migrated, and 62.15% of workers are addicted to alcohol/smoke/tobacco. Females are found to be more illiterate (31.37%), with no education beyond secondary school, and more addicted to alcohol/smoke/tobacco than males. Females are not as much addicted to alcohol but consume more tobacco. It is also revealed that 67.31% of workers completed primary education and 21.51% completed secondary education. Workers in the construction sector tend to leave their education at the primary level.

From Table 2.2, the highest prevalence of pain is observed in the lower back (72.90%), followed by the shoulders (49.68%), arms (47.31%), wrists (30.75%), legs (26.67%), neck (24.09%), fingers (23.23%), and knees (16.13%). The highest prevalence of pain in the lower back (74.15%) is observed in males, while the shoulders (74.51%) are more affected in female workers. Males report pain in arms/hands (46.86%), shoulders (46.62%), wrists (32.16%), fingers/thumbs (22.71%), legs (22.71%), neck (19.57%), knees (15.46%), elbows (8.94%), chest (8.7%), thigh/hip/buttocks (4.35%), ankle/feet/toes (3.86%), head (3.14%), and upper back (2.9%), while females report pain in the lower back (62.75%), neck (60.78%), legs (58.82%), arms/hands (50.98%), fingers/thumbs (27.45%), head (25.49%), knees, and ankle/feet/toes (21.57%), chest (19.61%), wrists (15.69%), elbows, and thigh/hip/buttocks (13.73%) and upper back (9.8%).

Table 2.3 shows the prevalence of pain at various times of the day. From Table 2.3, it is observed that complaints of pain after work are highest (41.94%) in both males and females. However, females report more pain than males. In males, it is 41.06%, while in females, it is 49.02%, followed by pain in the morning. During working hours, females (27.45%) experience more pain than males (9.42%).

Prevalence for each parameter was analyzed by considering the response of "Yes" to the questions. An analysis was carried out for maximum pain in different body parts (head, neck, shoulders, chest, elbows, arms, hands, wrists, fingers, thumbs, upper back, lower back, thigh/hip/buttocks, legs, knees, ankle/feet/toes), maximum pain at different times of the day (during work, after work, during sleep, and in the morning), working in awkward postures, working at a fast pace, doing physically demanding jobs, encountering traumatic incidents, and consumption of alcohol/tobacco/smoke.

In this study, the largest number of workers belonged to the age group of 41-50 (35.71%) and 31-40 (31.61%), with more than 20 years of experience. The percentage of male workers (89.03%) is higher than female workers (10.97%). Of all participants considered for the study, 54 workers were engaged in excavation work, 107 workers worked as unskilled workers (called “labor” or "coolie"), 38 were form workers, 48 were rebar workers, 64 were masons, 23 were electricians, 31 were plumbers, 30 were tilers, 28 were carpenters, and 42 were painters/fall ceiling workers, which are the most common occupations in construction. Detailed information about the workers is shown in Table 2.4.

Table 2.1 Somatic characteristics of construction workers (n=465)

Participant characteristics	Male	Female	Total
Sex, n (%)	414 (89.03%)	51 (10.97%)	465
Age (Mean ±SD) (yrs)	41.33±9.62	36.37±8.78	40.84 ±9.57
Height (Mean ±SD) (cm)	163.46±5.07	157.02±5.99	162.75±5.55
Weight (Mean ±SD) (kg)	61.82±5.82	50.27±4.46	60.55±6.74
BMI (Mean ±SD) (kg/m^2)	23.13±1.86	20.38±1.31	22.83±2.00
Year of Experience (Mean ±SD)	17.59±9.12	13.06±8.98	17.09±9.21
Experiencing pain	334 (71.82%)	51 (10.97%)	385 (82.80%)
Marital Status, n (%)			
Single	36 (7.74%)	03(0.65%)	39(8.39%)
Married	378 (83.29%)	48(10.32%)	426(91.61%)
Education level			
Illiterate	19 (4.09%)	16(3.44%)	35(7.53%)
Primary	284(61.08%)	29(6.24%)	313(67.31%)
Secondary	94(20.22%)	6(1.29%)	100(21.51%)
Intermediate/Diploma	10(2.15%)	-	10 (2.15%)
ITI	7(1.51%)	-	7 (1.51%)
Migrate			
Yes	247(53.12%)	43(9.25%)	290(62.37%)
No	167(35.91%))	8(1.72%)	175(37.63%)
Addiction to Alcohol / Tobacco/ Smoking			
Yes	255(54.84%)	34(7.31%)	289(62.15%)
No	159(34.19%)	17(3.66%)	176(37.85%)
Pain			
Yes	334 (71.83%)	51 (10.97%)	385 (82.80%)
No	80 (17.20%)	0	80 (17.20%)
Working in awkward posture	314 (67.53%)	42 (9.03%)	356 (76.56%)

Table 2.2 Number of Male and Female feeling pain in different body parts (n=465)

Body Parts	Male	%	Female	%	Total	%
Head	13	3.14	13	25.49	26	5.59
Neck	81	19.57	31	60.78	112	24.09
Shoulders	193	46.62	38	74.51	231	49.68
Chest	36	8.70	10	19.61	46	9.89
Elbow	37	8.94	7	13.73	44	9.46
Arms/Hands	194	46.86	26	50.98	220	47.31
Wrists	135	32.61	8	15.69	143	30.75
Fingers/Thumbs	94	22.71	14	27.45	108	23.23
Upper back	12	2.90	5	9.80	17	3.66
Lower back	307	74.15	32	62.75	339	72.90
Thigh/ hip/	18	4.35	7	13.73	25	5.38
Legs	94	22.71	30	58.82	124	26.67
Knees	64	15.46	11	21.57	75	16.13
Ankles/ feet/toes	16	3.86	11	21.57	27	5.81

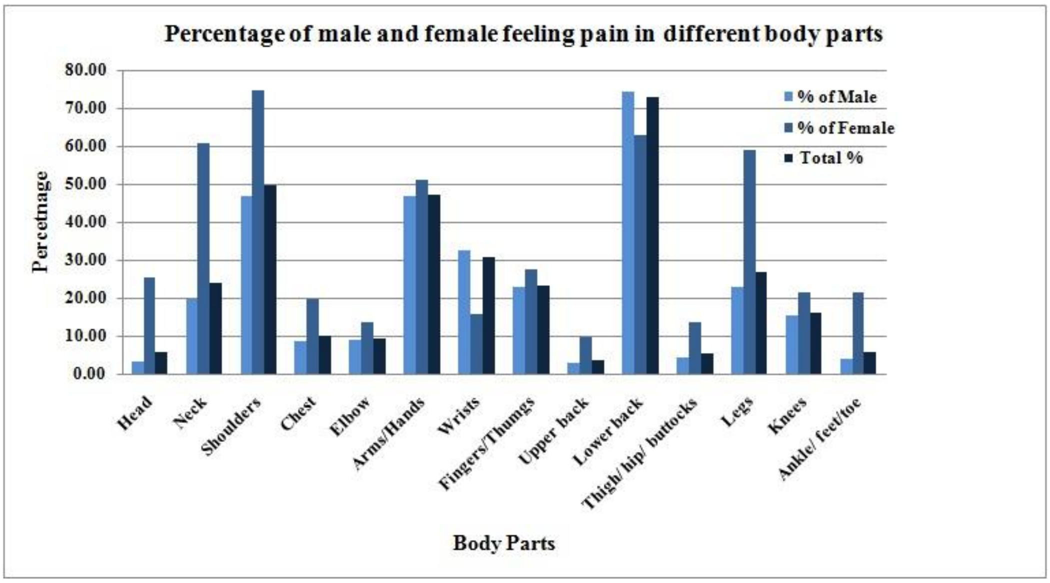


Figure 2.1 Percentage of Male and Female feeling pain in different body parts (n=465)

Table 2.3 Feeling of pain at various progression of day (n=385)

Different time	Male	%	Female	%	Total	%
During working	39	9.42	14	27.45	53	11.40
After working	170	41.06	25	49.02	195	41.94
During sleeping	40	9.66	0	0.00	40	8.60
In the Morning	90	21.74	7	13.73	97	20.86

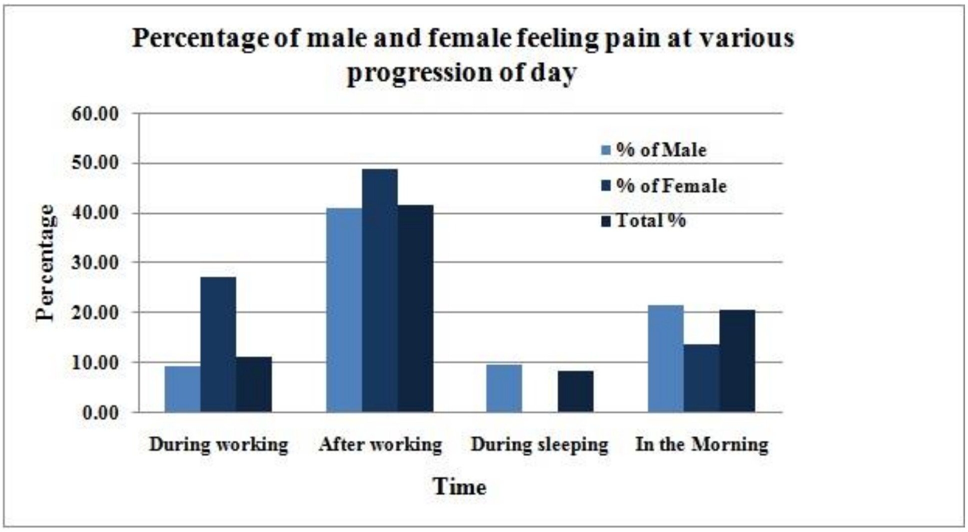


Figure 2.2 Percentage of male and female feeling pain at various progression of day

Table 2.4 characteristics of construction workers (n=465)

			(Mean ± SD)				
Parameter	No. of worker	Percentage	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/m^2)	Experience (yrs)
Age							
21-30	75	16.12	26.49 ± 2.76	162.45 ± 5.99	56.40 ± 6.58	21.34 ± 1.96	4.55 ± 2.64
31-40	147	31.61	35.42 ±3.08	162.68 ± 5.69	59.53 ± 6.71	22.47 ± 1.98	12.06 ± 3.81
41-50	166	35.71	45.67 ± 3.04	162.44 ± 5.17	62.25 ± 5.71	23.57 ± 1.58	21.37 ± 4.38
≥ 51	77	16.56	54.71± 2.78	163.84 ± 5.57	62.87 ± 6.83	23.39 ± 1.96	29.69 ± 6.01
Types of work							
Excavation work	54	11.61	39.67 ± 9.43	161.52 ± 5.75	58.81 ± 6.91	22.52± 2.11	16.22 ± 9.71
Labour work	107	23.01	40.29 ± 9.37	160.97 ± 6.10	57.56 ± 7.73	22.15 ± 2.15	16.43 ± 9.18
Form work	38	8.17	41.16 ± 7.89	164.45 ± 4.03	62.92 ± 5.55	23.27 ± 1.96	17.89 ± 8.04
Rebar work	48	10.32	43.46 ± 8.63	163.75 ± 5.81	61.73 ± 6.51	23.02 ± 2.10	19.35 ± 8.08
Masonry work	64	13.76	42.59 ± 9.09	163.75 ± 4.47	62.39 ± 6.20	23.23 ± 1.69	18.53 ± 9.19
Electrical work	23	4.95	44.57 ± 10.50	164.22 ± 5.18	62.91 ± 5.56	23.32 ± 1.67	21.04 ± 9.97
Plumbing work	31	6.67	40.10 ± 12.41	163.65 ± 5.45	61.62 ± 7.14	22.98 ± 2.13	16.94 ±
Flooring/ Tiling work	30	6.45	46.27 ± 6.64	161.67 ± 5.28	61.32 ± 5.27	23.50 ± 2.04	21.30 ± 6.91
Carpentry work	28	6.02	37.61 ± 9.86	163.54 ± 5.56	61.85 ± 4.50	23.14 ± 1.48	14.39 ± 9.39
Painting /	42	9.03	34.55 ± 8.13	163.45 ± 5.47	60.61 ± 5.48	22.69 ± 1.76	11.17 ± 6.61
Working experience (yrs)							
00 - 10	139	29.89	29.81 ± 4.71	162.74 ± 5.82	57.06 ± 6.47	21.53 ± 2.00	6.32 ± 3.00
11 - 20	168	36.13	40.58 ± 4.71	162.49 ± 5.30	61.59 ± 6.12	23.29 ± 1.62	16.23 ± 2.65
20 - 30	118	25.38	48.85 ± 3.10	163.10 ± 5.67	63.09 ± 5.97	23.69 ± 1.56	25.18 ± 2.73
≥ 30	40	8.60	56.60 ± 2.35	162.85 ± 5.39	60.79 ± 7.53	22.91 ± 2.40	34.35 ± 1.86
BMI (kg/m^2)							
≤ 18	08	1.72	41.38 ± 13.93	165.00 ± 2.32	46.21 ± 1.30	16.99 ± 0.78	17.75 ±
18 - 25	404	86.88	40.24 ± 9.69	162.67 ± 5.64	59.86 ± 6.13	22.59 ± 1.69	16.40 ± 9.16
≥ 25	53	11.40	45.30 ± 6.38	163.02 ± 5.12	67.98 ± 4.65	25.55 ± 0.54	22.28 ± 6.86

Table 2.5 Number of workers feeling pain (n=465)

Parameter	Total number of workers	No. of workers feel pain	Percentage of workers feel pain from respective parameter population	Percentage of workers feel pain from total population (n=465)
Age (yrs)				
21-30	75	63	84	14
31-40	147	126	85.71	28
41-50	166	134	80.72	29
≥ 51	77	62	80.52	14
Gender				
Male	414	334	80.68	72
Female	51	51	100	11
Types of work				
Excavation work	54	50	92.59	11
Labour work	107	100	93.46	22
Form work	38	34	89.47	8
Rebar work	48	39	81.25	9
Masonry work	64	56	87.5	13
Electrical work	23	14	60.87	4
Plumbing work	31	23	74.19	5
Flooring/ Tiling work	30	23	76.67	5
Carpentry work	28	18	64.29	4
Painting /Fall-ceiling work	42	28	66.67	7
Working experience (yrs)				
00 - 10	139	117	84.17	26
Nov-20	168	137	81.55	30
20 - 30	118	95	80.51	21
≥ 30	40	36	90	8
BMI (kg/m^2)				
≤ 18	8	8	100	2
18 - 25	404	336	83.17	73
≥ 25	53	41	77.36	9

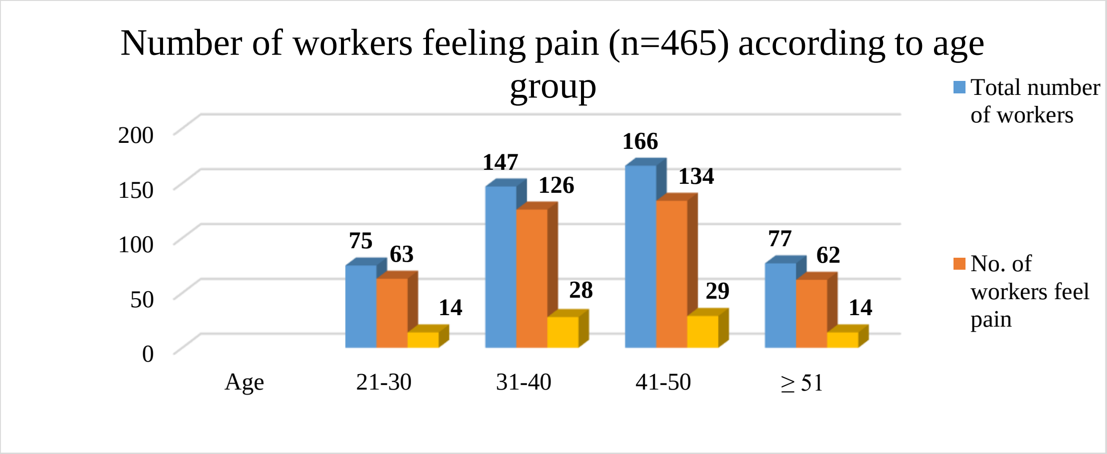


Figure 2.3 Number of workers feeling pain according to age group (n=465)

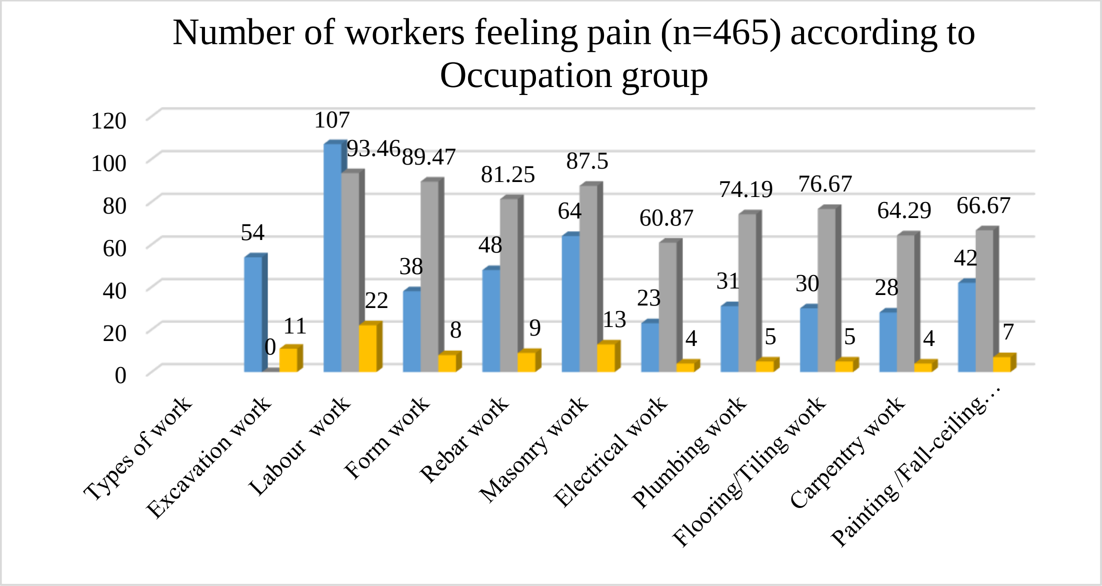


Figure 2.4 Number of workers feeling pain (n=465) according to Occupation group

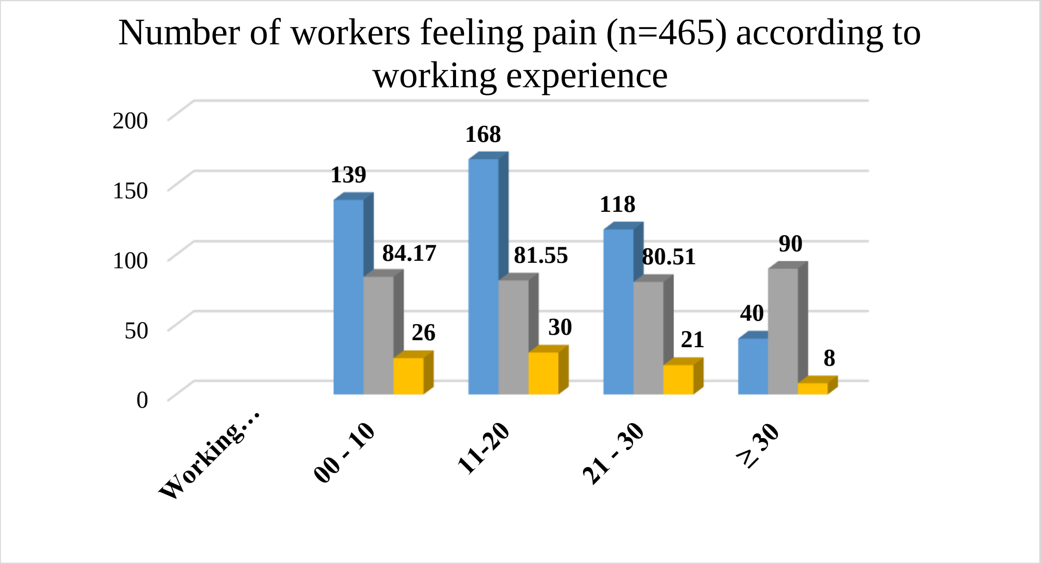


Figure 2.5 Number of workers feeling pain (n=465) according to working experience

Table 2.6 : Total number of workers in different construction occupation at different age group (n=465)

Occupations	Age:21-30 (n=75) (male= 60) (female=15)		Age:31-40 (n=147) (male= 125) (female=22)		Age:41-50 (n=166) (male= 156) (female=10)		Age≥51 (n=77) (male= 73) (female=4)	
	n	%	n	%	n	%	n	%
Excavation work	8	10.67	23	15.65	19	11.45	4	5.19
Labour work	23	30.67	36	24.49	35	21.08	13	16.89
Form work	6	8	9	6.12	23	13.86	0	0
Rebar work	5	6.67	13	8.84	19	11.45	11	14.29
Masonry work	8	10.67	19	12.93	23	13.86	14	18.18
Electrical work	2	2.67	5	3.40	7	4.22	9	11.69
Plumbing work	8	10.67	5	3.40	9	5.42	9	11.69
Flooring/Tiling work	0	0	5	3.40	15	9.04	10	12.99
Carpentry work	7	9.33	11	7.48	6	3.61	4	5.19
Painting /Fall-ceiling work	8	10.67	21	14.29	10	6.02	3	3.90

Table 2.7 Number of workers feeling pain in different construction occupation at different age group (n=465)

	Age:21-30 (n=75)		Age:31-40 (n=147)		Age:41-50 (n=166)		Age≥51 (n=77)	
	(male= 60) (female=15)		(male= 125) (female=22)		(male= 156) (female=10)		(male= 73) (female=4)	
	n	Percentage of workers between age 21-30	n	Percentage of workers between age 31-40	n	Percentage of workers between age 41-50	n	Percentage of workers age above 50
Excavation work	5	6.67	22	14.97	19	11.45	4	5.19
Labour work	23	30.67	34	23.13	35	21.08	8	10.39
Form work	6	8.00	9	6.12	19	11.45	0	0.00
Rebar work	5	6.67	13	8.84	10	6.02	11	14.29
Masonry work	8	10.67	17	11.56	20	12.05	11	14.29
Electrical work	2	2.67	0	0.00	5	3.01	7	9.09
Plumbing work	5	6.67	5	3.40	4	2.41	9	11.69
Flooring/ Tiling work	0	0.00	5	3.40	11	6.63	7	9.09
Carpentry work	5	6.67	7	4.76	4	2.41	2	2.60
Painting /Fall-ceiling work	4	5.33	14	9.52	7	4.22	3	3.90

Table 2.5 shows the number of workers experiencing pain in body parts. Among the workers (n=465), 28% of workers belonging to the age group of 31-40 experience pain in different body parts and at different times, followed by 14% in the 21-30 age group. Twenty-nine percent and 14% of workers experience pain, belonging to the age groups 41-50 and over 50, respectively (Figure 2.3). All female workers interviewed reported complaints of pain, while 72% of male workers complained about pain. By occupation, it is found that 22% of unskilled workers, 11% of workers engaged in excavation work, 8% of form workers, 13% of masons, 9% of rebar workers, 5% of tilers, 5% of plumbers, 7% of painters, 4% of carpenters, and 4% of electricians complain of pain in body parts (Figure 2.4). Eight percent of workers with more than 30 years of experience complain of pain in body parts, followed by 26% of workers with 0-10 years of experience (Figure 2.5).

Table 2.6 shows the total number of workers belonging to different age groups in various occupational groups in construction work. Table 2.7 shows the occupations and the number of workers feeling pain in different age groups. From Table 2.7, it is found that middle-aged workers are suffering from more pain or work-related musculoskeletal disorders (WRMSD). Masons and unskilled workers or "Labor/Coolies" of all age groups are suffering from pain or WRMSD. The percentage of pain reported by rebar workers, masons, plumbers, tilers, and electricians is higher in the age group over 50, followed by other occupational workers. The complaint of pain by workers engaged in excavation work is most common in the age group of 31-40 (14.97%) and 41-50 (11.45%).

From Table 2.8, it is found that 76.56% of workers are working in awkward postures, 63.23% of workers perform physically demanding jobs, 62.15% of workers are addicted to alcohol/tobacco/smoke, 32.69% of workers work at a fast pace, and 13.19% of workers experience traumatic incidents.

Table 2.8 Details of pain while working in awkward postures, doing work with pace, doing pervasive jobs, after traumatic incidents and when consume alcohol/ chewing tobacco/smoke by all workers (n=465)

Parameters	Total	Percentage
Working in Awkward Posture	356	76.56
Pace of work	152	32.69
Pervasive jobs	294	63.23
Traumatic Incidents	61	13.19
Addiction to Alcohol/chewing tobacco/smoke	289	62.15

Table 2.9 and Figure 2.6 show the number and percentage of workers experiencing pain in different body parts, respectively, in each age group. From Table 2.9 and Figure 2.6, 54.67% of workers in the age group 21-30 complain about pain in arms/hands, 45.33% in wrists, 42.67% in neck, 36% in fingers/thumbs, and 20.00% in chest, followed by the age group 31-40. 58.50% of workers complain of pain in shoulders, belonging to the age group 31-40, followed by workers in the 21-30 age group (56%). Maximum pain in the lower back is complained of by workers in the 31-40 age group (81.63%), followed by the age group over 50 (72.73%), the age group 41-50 (69.28%), and the age group 21-30 (64%). Complaints of pain in the legs and knees are reported by more workers in the over 50 age group, followed by other age groups, with

fewer complaints in the younger age groups. Less than 10% of workers in all age groups complain of pain in the head, upper back, thigh/hip/buttocks, and ankle/feet/toes.

Table 2.10 and Figure 2.7 show the number and percentage of workers experiencing pain at different times, respectively, in each age group. From Table 2.10 and Figure 2.7, it is found that the maximum number of workers complain of pain after working, belonging to all age groups. Complaints of morning pain are reported by workers in the over 50 age group (45.45%), followed by the 41-50 age group (30.72%).

Table 2.11 and Figure 2.8 show that workers in all age groups work in awkward postures, but the percentage is higher in the 31-40 age group (82.99%). At the same time, workers in all age groups are addicted to alcohol/tobacco/smoke, but the highest percentage is in the 41-50 age group. Physically demanding jobs are carried out by workers in the 31-40 age group, while a higher number of workers in the over 50 age group work at a fast pace and experience traumatic incidents.

Table 2.12 and Figure 2.9 show the various occupations and complaints of pain in different body parts by various construction workers. From Table 2.12 and Figure 2.9, it is revealed that all workers complain of pain in the lower back, arms/hands, wrists, fingers/thumbs, shoulders, legs, and knees. The construction occupations with the most problems are found to be excavation, materials transportation, masonry work, and rebar work. Tilers and painters, followed by electricians and plumbers, are also facing the problem, but to a lesser extent. Tilers have problems in the lower back, thigh/hip/buttocks, legs (especially the “calf”), and knees, as they are forced to work in squatting and kneeling postures. Painters have more problems in the lower back, shoulders, neck, arms/hands, wrists, and fingers/thumbs.

Excavation work is performed by unskilled workers, who are called excavators for this study. Materials transportation and assistance to skilled workers are performed by laborers called “coolies,” who are referred to as laborers for this study. Masonry work is performed by masons, and rebar work is performed by rebar workers.

Table 2.9 Percentage of construction worker feel pain in different body parts of different age group (n=465)

Body part and other parameters	Age:21-30 (n=75) (male= 60) (female=15)		Age:31-40 (n=147) (male= 125) (female=22)		Age:41-50 (n=166) (male= 156) (female=10)		Age≥51 (n=77) (male= 73) (female=4)	
	n	%	n	%	n	%	n	%
Head	7	9.33	8	5.44	5	3.01	6	7.79
Neck	32	42.67	45	30.61	17	10.24	18	23.38
Shoulders	42	56.00	86	58.50	83	50.00	20	25.97
Chest	15	20.00	19	12.93	10	6.02	2	2.60
Elbow	6	8.00	19	12.93	14	8.43	5	6.49
Arms/Hands	41	54.67	80	54.42	66	39.76	33	42.86
Wrists	34	45.33	46	31.29	45	27.11	18	23.38
Fingers/Thumbs	27	36.00	37	25.17	32	19.28	12	15.58
Upper back	6	8.00	4	2.72	3	1.81	4	5.19
Lower back	48	64.00	120	81.63	115	69.28	56	72.73
Thigh/ hip/ buttocks	4	5.33	5	3.40	10	6.02	6	7.79
Legs	11	14.67	44	29.93	39	23.49	30	38.96
Knees	3	4.00	15	10.20	31	18.67	26	33.77
Ankle/ feet/toe	2	2.67	8	5.44	7	4.22	10	12.99

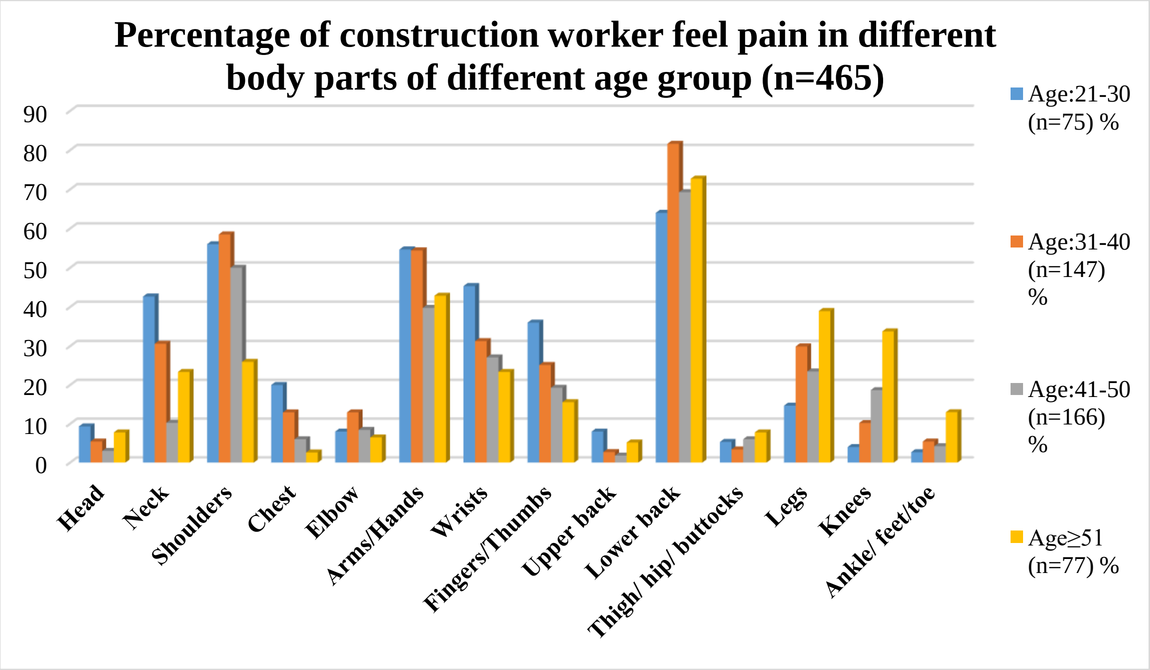


Figure 2.6 Percentage of construction worker feel pain in different body parts of different age group (n=465)

Table 2.10 Percentage of worker feel pain at different time zone by different age group construction workers (n=465)

Time zones	Age:21-30 (n=75) (male= 60) (female=15)		Age:31-40 (n=147) (male= 125) (female=22)		Age:41-50 (n=166) (male= 156) (female=10)		Age≥51 (n=77) (male= 73) (female=4)	
	n	%	n	%	n	%	n	%
During working	22	29.33	19	12.93	11	6.63	1	1.30
After working	26	34.67	84	57.14	62	37.35	23	29.87
During Sleeping	8	10.67	13	8.84	13	7.83	6	7.79
In the morning	3	4.00	8	5.44	51	30.72	35	45.45

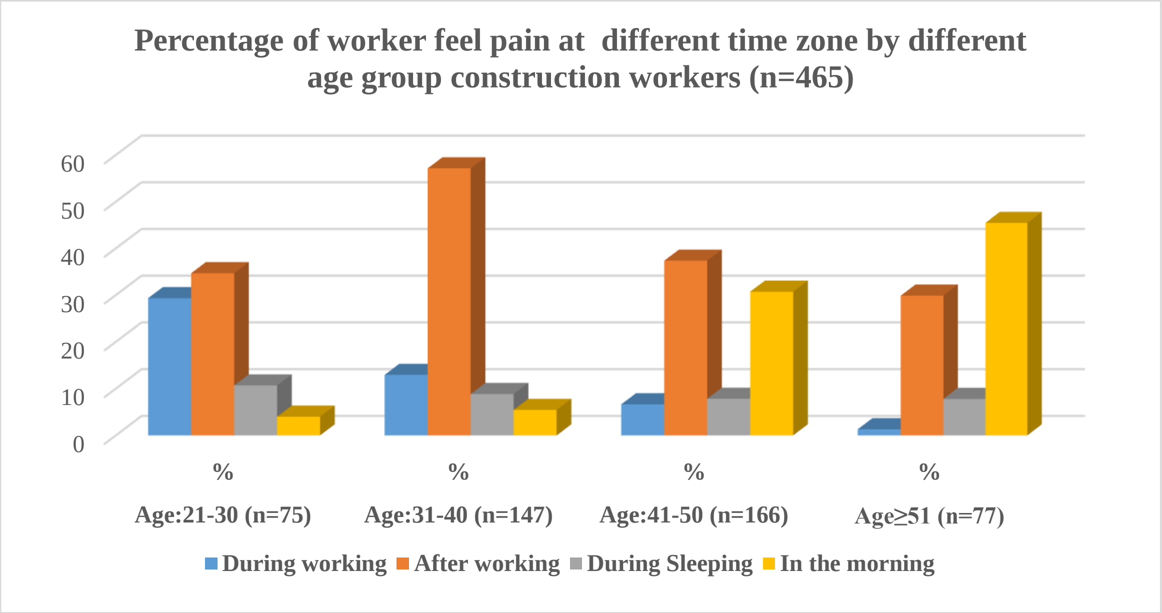


Figure 2.7 Percentage of worker feel pain at different time zone by different age group construction workers (n=465)

Table 2.11 Percentage of construction workers working in awkward posture, work with pace, doing pervasive jobs, meet with traumatic incidents and consume alcohol (n=465)

Body part	Age:21-30 (n=75) (male= 60) (female=15)		Age:31-40 (n=147) (male= 125) (female=22)		Age:41-50 (n=166) (male= 156) (female=10)		Age≥51 (n=77) (male= 73) (female=4)	
	n	%	n	%	n	%	n	%
Working in Awkward Posture	50	66.67	122	82.99	126	75.90	58	75.32
Pace of work	28	37.33	52	35.37	43	25.90	29	37.66
Pervasive jobs	50	66.67	102	69.39	92	55.42	50	64.94
Traumatic Incidents	7	9.33	14	9.52	27	16.27	13	16.88
Addiction to Alcohol	33	44.00	96	65.31	115	69.28	45	58.44

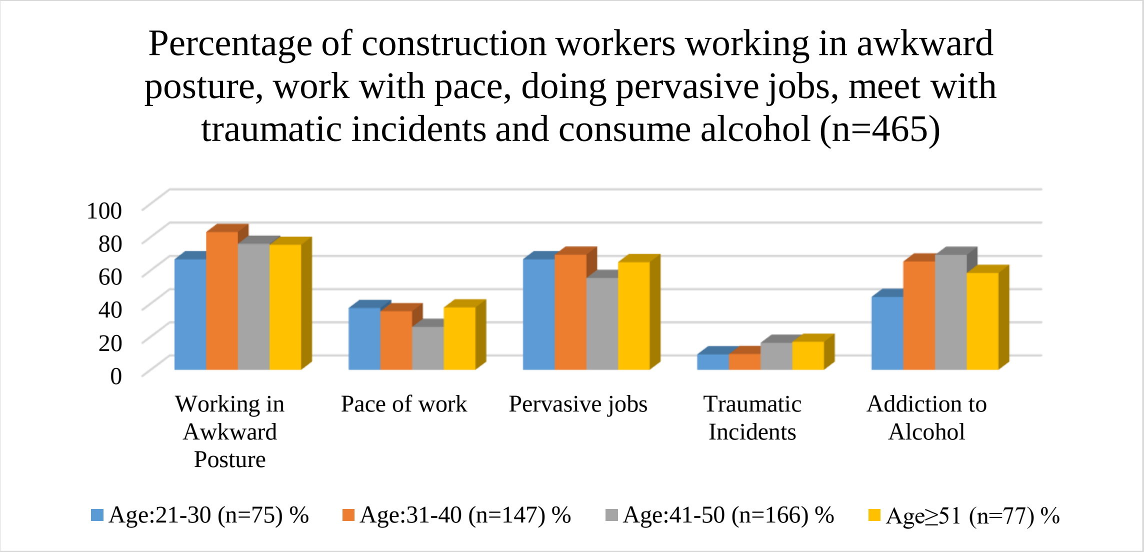


Figure 2.8 Percentage of construction workers working in awkward posture, work with pace, doing pervasive jobs, meet with traumatic incidents and consume alcohol (n=465)

Table 2.12 Occupation and complaint of pain in body parts by different occupational workers

	Excavation work (n=54)		Labour work (n=107)		Form work (n=38)		Rebar work (n=48)		Masonry work (n=64)		Electrical work (n=23)		Plumbing work (n=31)		Flooring/ Tiling work (n=30)		Carpentry work (n=28)		Painting /Fall-ceiling work (n=42)	
Occupations / Body part	Pain in body parts	% of pain in body parts	Pain in body parts	% of pain in body parts	Pain in body parts	% of pain in body parts	Pain in body parts	% of pain in body parts	Pain in body parts	% of pain in body parts	Pain in body parts	% of pain in body parts	Pain in body parts	% of pain in body parts	Pain in body parts	% of pain in body parts	Pain in body parts	% of pain in body parts	Pain in body parts	% of pain in body parts
Head	7	13	15	15	0	0	0	0	4	7	0	0	0	0	0	0	0	0	0	0
Neck	10	19	31	29	24	64	10	21	13	21	9	40	0	0	0	0	0	0	15	36
Shoulders	46	86	72	68	30	79	0	0	51	80	12	53	2	7	0	0	0	0	19	46
Chest	14	26	19	18	0	0	11	23	2	4	0	0	0	0	0	0	0	0	0	0
Elbow	2	4	5	5	0	0	18	38	19	30	0	0	0	0	0	0	0	0	0	0
Arms/Hands	40	75	50	47	27	72	25	53	14	22	2	9	12	39	13	44	18	65	19	46
Wrists	17	32	12	12	12	32	17	36	28	44	12	53	14	46	4	14	8	29	19	46
Fingers/Thumbs	13	25	19	18	8	22	12	25	19	30	10	44	8	26	0	0	0	0	19	46
Upper back	0	0	5	5	0	0	0	0	12	19	0	0	0	0	0	0	0	0	0	0
Lower back	46	86	79	74	32	85	39	82	54	85	11	48	20	65	23	77	18	65	17	41
Thigh/ hip/ buttocks	0	0	7	7	0	0	0	0	0	0	0	0	0	0	18	60	0	0	0	0
Legs	17	32	29	28	18	48	27	57	8	13	0	0	7	23	18	60	0	0	0	0
Knees	0	0	22	21	0	0	30	63	0	0	0	0	0	0	23	77	0	0	0	0
Ankle/ feet/toe	0	0	19	18	0	0	0	0	2	4	0	0	0	0	6	20	0	0	0	0

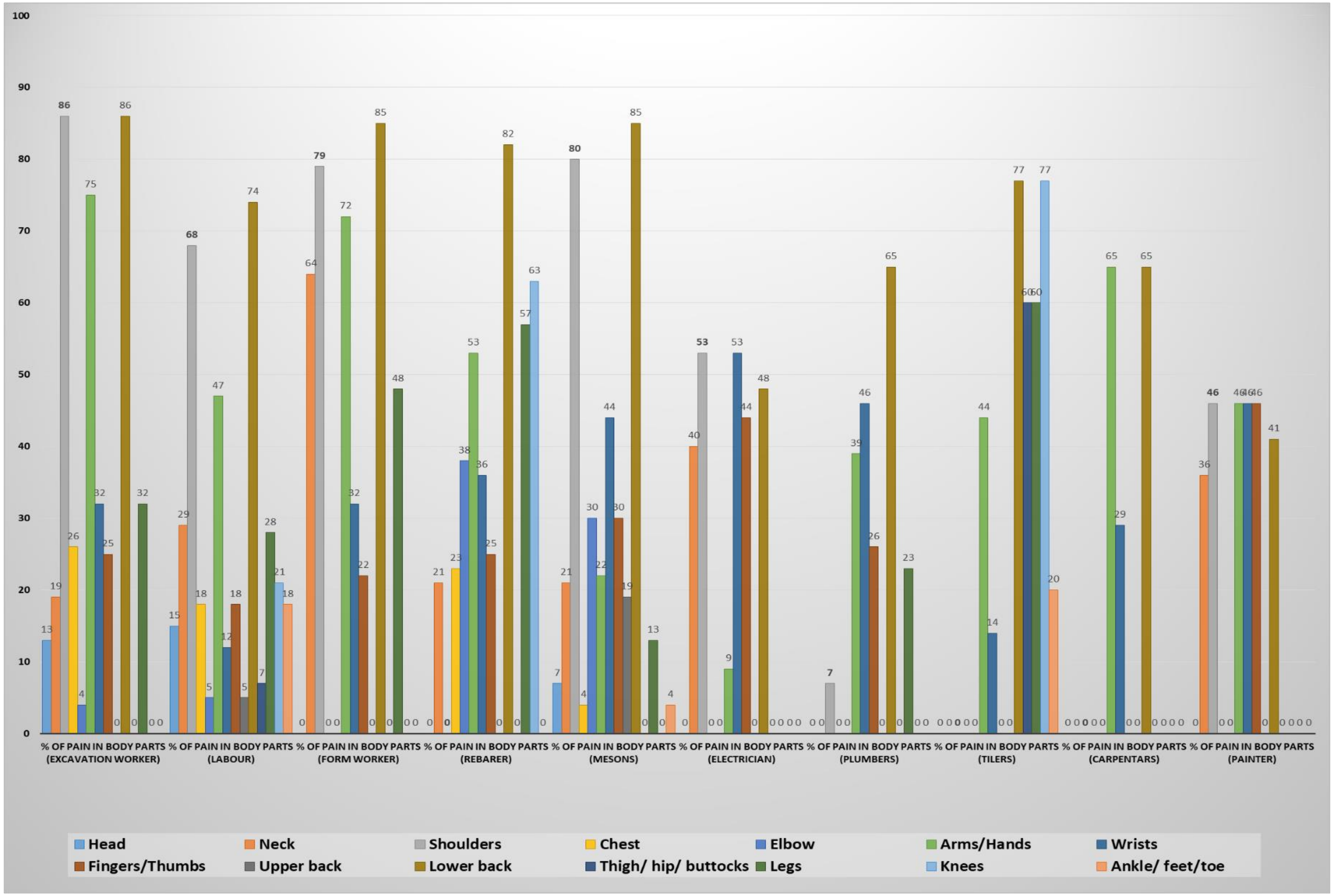


Figure2.9 Occupation and complaint of pain in body parts by different occupational workers

2.1.4 Summary

The individual factors like age, gender, height, weight, BMI, types of work, duration of work, physical load and exertion, and per day working hours are required to be studied to obtain the relation between the influence of incidence and prevalence of work-related musculoskeletal disorders. In this study, body parts, maximum feeling of pain at different times of the day, and types of work have been considered for this study purpose and the effect of age and BMI on these factors. The age groups 21-30, 31-40, 41-50, and ≥ 51, along with 11 different types of construction work, have been studied.

The majority of construction workers have reported high pain and symptoms in the neck, shoulders, arms, wrists, lower back, legs, and knees, while some have reported pain in the chest, elbows, fingers, and thumbs, which have also been reported in previous studies [177][178][179]. The most common body parts to which workers experience pain and risk of WRMSD included the lower back (88.05%), shoulders (60.00%), and arms (54.81%), followed by wrists, legs, and neck. The study revealed that pain in the upper extremities has been most frequently reported by workers in the 21-30 age group, while pain in the lower extremities has been frequently reported by workers who are ≥ 51 years of age. Increasing age and an increase in BMI (weight) are found to be significant for the cause of WRMSD [180]. Nevertheless, the study shows that the percentage of tingling is higher in the older age groups, but the risk begins from an early age, specifically from the 31-40 age group due to working in awkward postures and poor nutrition. The physical risk factors, psychosocial factors, and individual factors are related to construction workers who work for a prolonged period with undue loads in awkward postures without awareness of the threat [181]. The study also revealed that those workers who work in awkward postures, work for prolonged hours, take inadequate rests, carry out repetitive motions with high frequency, and lift heavy materials show a high prevalence of WRMSD. It is also found that as age increases, the pain and symptoms of WRMSD increase during sleep time and in the morning. All age group workers were suffering from pain and/or WRMSD except the 21-30 age group due to age, but the data, study, and analysis show that there is a high risk of experiencing pain and/or WRMSD.

In the recent study, the percentage of males (86.75%) reporting pain was higher than females (13.25%), as females only carried out excavation and labor work (manual material handling work). The number and percentage of workers in the age group 31-40 (32.72%) and 41-50

(34.81%) were higher than in the 21-30 (16.37%) and ≥ 51 (16.10%) age groups. The active age group of construction workers appears to be 31-50 (67.53%), and these workers experience low pain. However, the risk rate of pain and WRMSD increases with age [105]. From previously studied work at different construction sites, it is revealed that almost all manual construction workers experience pain and suffer from WRMSD symptoms [182]. WRMSD is one of the current health problems faced by construction workers worldwide. The incidence of WRMSD symptoms involves pain in different body regions and varies at different times of the day [106]. Awkward working posture and material handling can cause WRMSD and disorders in construction workers, which are associated with the physical workload in construction work [183]. The study also showed that construction workers experience pain in almost all body parts [184], but the high prevalence of complaints about pain is found in the lower back [124][95][185], and lower back pain is significant where the load carried at the workplace is too heavy [186]. The study shows that almost all age group workers suffer from pain and WRMSD, but younger (21-30) and older (≥ 50) workers are more affected. The work-related musculoskeletal disorders in construction workers are extensive and begin at an early age [2]. Consistent with age, workers doing labor work recorded the highest prevalence, followed by workers doing masonry work, excavation work, rebar work, and form work. The most common aspect of all construction workers, including all types of work, is the extreme use of repetitive and forceful exertion of muscles and other body structures, which are used poorly and uninterruptedly. This leads to a high prevalence of work-related musculoskeletal disorders due to stress on different body joints.

Among the construction workers mentioned above, working in awkward postures, addiction to tobacco/smoking/alcohol, traumatic incidents, pervasive jobs, and working with pace show more resemblance to work-related musculoskeletal disorders (WRMSD) among construction workers. Efforts need to be taken to reduce the prevalence and severity of work-related musculoskeletal disorders in construction work by introducing training programs, preventing working in awkward postures, minimizing repetitive movements, avoiding lifting heavy materials, providing material handling devices, proper tools, and medical facilities.

2.2 Description of Risk/Exposure Assessment Technique Applied:

Postural analysis and biomechanical analysis on i) Excavation workers ii) Labourers iii) Rebarers iv) Masons (Bricklaying and Plastering) have been performed using OWAS, NMQ, RULA, REBA, QEC, ERIN, ART, WERA, NERPA, JSI and software like CATIA and SEIMENS. The biomechanical analysis was performed using CATIA. Amongst the methods described in Chapter 1, for the evaluation of postures, the following methods were used, with their details given below:

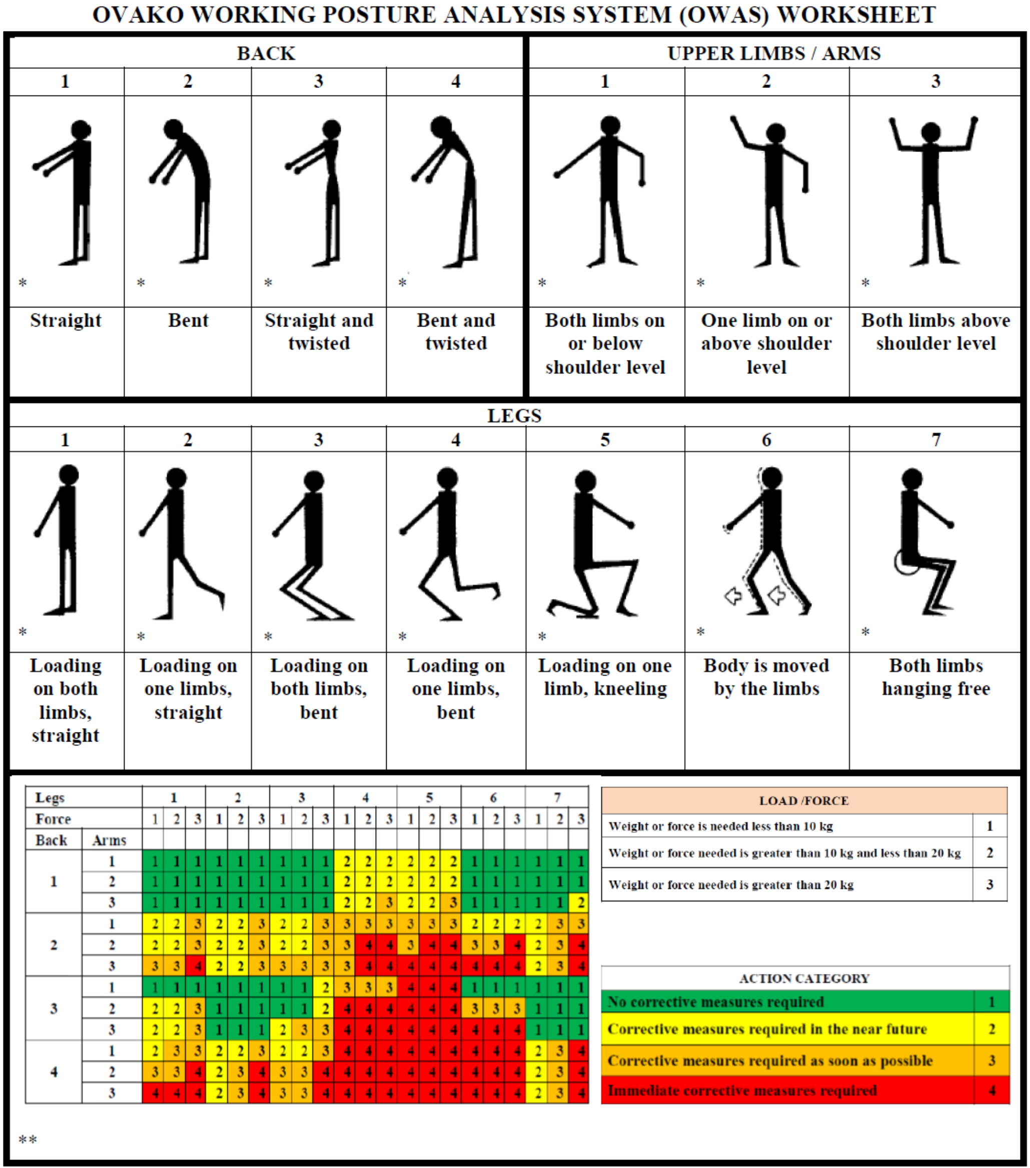
2.2.1 Ovako Working Posture Analysis System (OWAS):

Osmo Karhu, Pekka Kansi, and Ilkka Kuorinka developed a simple observation technique in 1977 with the intention to make it simple, provide unambiguous answers, and offer possibilities to correct the oversimplified ergonomic approach, which is OWAS (Ovako Work Posture Analyzing System). This is a simple method for analyzing and controlling poor postures. The OWAS technique is based on whole-body sampling of working posture that covers the working postures of the back, upper limbs (arms), and lower limbs (legs), as well as the force to be applied by workers [187].

The back includes: 1) Straight, 2) Bent, 3) Straight and twisted, and 4) Bent and twisted. The upper limbs include: 1) Both limbs on or below shoulder level, 2) One limb on or above shoulder level, and 3) Both limbs above shoulder level. The lower limbs include: 1) Loading on both limbs, straight, 2) Loading on one limb, straight, 3) Loading on both limbs, bent, 4) Loading on one limb, bent, 5) Loading on one limb, kneeling, 6) Body is moved by the limbs, and 7) Both limbs hanging free. Code numbers have been assigned to each item, and each posture can be described with a three-digit code. The force is also divided into three parts: 1) ≤ 10 kg, 2) ≥ 10 kg and ≤ 20 kg, and 3) ≥ 20 kg. The posture is described with these three-digit codes in the sequence of the back, upper limb, and lower limb. An example is given below. After rating, it has been reclassified into four categories to interpret the result (Figure 2.1). These are as follows:

1. Postures are under the normal effect of MSD and do not need special attention.
2. Postures are under the little harmful effect of MSD and need some remedial action in the future.
3. Postures are under the extreme effect of MSD and need instant remedial action.

4. Postures are under the tremendous effect of MSD and need immediate corrective action. It is difficult to describe and evaluate postures such as hands, feet, and head, so it cannot be applied everywhere. As OWAS is an observation technique, it requires a few seconds of recording, and random observation can also be applied. The technique is too broad to provide an accurate level of precision for explaining the working posture and ergonomic stresses associated with this. COWAS, the computerized version of OWAS, was developed by Kivi and Mattila in 1991 and was used by Mattila et al. (1993) to estimate the proportion of time that building construction workers spent in various back, arm, and leg postures while performing hammering tasks [64].



OVAKO WORKING POSTURE ANALYSIS SYSTEM (OWAS) WORKSHEET

BACK			
1	2	3	4
*	*	*	*
Straight	Bent	Straight and twisted	Bent and twisted

UPPER LIMBS / ARMS		
1	2	3
*	*	*
Both limbs on or below shoulder level	One limb on or above shoulder level	Both limbs above shoulder level

LEGS						
1	2	3	4	5	6	7
*	*	*	*	*	*	*
Loading on both limbs, straight	Loading on one limbs, straight	Loading on both limbs, bent	Loading on one limbs, bent	Loading on one limb, kneeling	Body is moved by the limbs	Both limbs hanging free

Legs		1			2			3			4			5			6			7		
Force		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Back	Arms																					
1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
	3	1	1	1	1	1	1	1	1	1	2	2	3	2	2	3	1	1	1	1	1	2
2	1	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	2	2	2	2	3	3
	2	2	2	3	2	2	3	2	2	3	3	4	4	3	4	4	3	3	4	2	3	4
	3	3	3	4	2	2	3	3	3	3	3	4	4	4	4	4	4	4	4	2	3	4
3	1	1	1	1	1	1	1	1	1	2	3	3	3	4	4	4	1	1	1	1	1	1
	2	2	2	3	1	1	1	1	1	2	4	4	4	4	4	4	3	3	3	1	1	1
	3	2	2	3	1	1	1	2	3	3	4	4	4	4	4	4	4	4	4	1	1	1
4	1	2	3	3	2	2	3	2	2	3	4	4	4	4	4	4	4	4	4	2	3	4
	2	3	3	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4
	3	4	4	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4

LOAD /FORCE	
Weight or force is needed less than 10 kg	1
Weight or force needed is greater than 10 kg and less than 20 kg	2
Weight or force needed is greater than 20 kg	3

ACTION CATEGORY	
🟩 No corrective measures required	1
🟨 Corrective measures required in the near future	2
🟧 Corrective measures required as soon as possible	3
🟥 Immediate corrective measures required	4

**

*Karhu, O., Kansi, P., & Kuorinka, I. (1977). Correcting working postures in industry: A practical method for analysis. Applied Ergonomics, 8(4), 199–201. DOI:10.1016/0003-6870(77)90164-8

** www.slideserve.com/istas/prevention-of-msds-by-workload-optimization-based-on-external-and-internal-load-assessment-methods

Figure.2.10 Worksheet of OWAS

2.2.2 STANDARDIZED NORDIC MUSCULOSKELETAL QUESTIONNAIRE (NMQ):

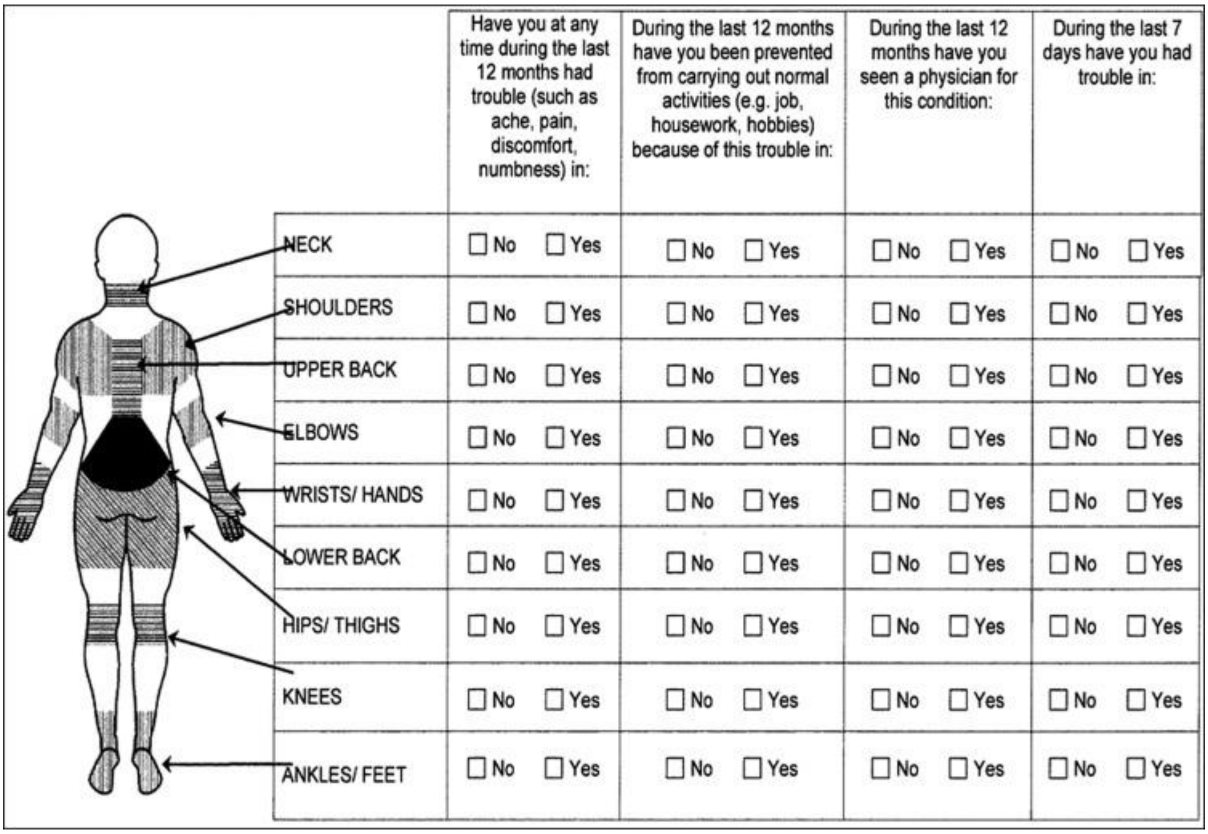
The Nordic Musculoskeletal Questionnaire (NMQ) method was first developed by a research group at the Nordic Council of Ministers, Oslo, by I. Kuorinka, B. Jonsson, A. Kilbom, H. Vinterberg, F. Biering-Sorensen, G. Andersson, and K. Jorgensen in 1987 to analyze and detect musculoskeletal disorders, aiming to standardize the evaluation questions so that the results of different studies could be compared. The method was developed and tested with standardized questionnaires to determine the frequency of musculoskeletal disorders in general, as well as low back and neck/shoulder complaints, for survey purposes. It provides reliable information on musculoskeletal disorders. The questionnaires comprise structured, forced, binary, or multiple-choice questions and are self-declared questionnaires or interviews. General and specific types of questionnaires have been designed for surveys. The general questionnaire was developed for simple survey purposes, while the specific questionnaire was designed for an in-depth survey of the work environment, workstation design, and tool design. The main purpose of designing this questionnaire is to screen for musculoskeletal disorders in an ergonomic situation and for occupational healthcare services or epidemiological studies [180]. A large number of workers and different workplaces can be surveyed, with self-reports of symptoms and postures [188]. The Nordic Musculoskeletal Questionnaire does not differentiate between symptoms of work-related or non-work-related issues and needs to be carried out cautiously since this is a survey-based technique [37].

In the development of the NMQ, the human body was divided into nine anatomical parts, starting with the neck, shoulders, upper back, elbows, lower back, wrists/hands, hips/thighs, knees, and ankles/feet. It includes 28 multiple-choice questions and is divided into two parts: general and specific, as mentioned above. The first part refers to the symptoms of the 9 body parts, including the neck, shoulders, upper back, elbows, lower back, wrists/hands, hips/thighs, knees, and ankles/feet during the last 12 months and 7 days. The second part refers to the symptoms of 3 body parts, including the neck, shoulders, and lower back, for the last 7 working days. The persons whose survey was carried out need to answer the questions that relate to any symptoms they have. The questionnaire was complemented with a supplementary question asking whether there are any symptoms of work-related musculoskeletal disorders. These questions were: (1) The symptoms are solely related to the present work; (2) The symptoms are partly related to the present work and partly not; (3) The symptoms are solely related to other factors than the present work. These questionnaires also included details about age, sex, height, weight, smoking, and leisure time habits, which were not mandatory to answer. Figure 8 (a) (b) [180].

The technique has been adapted in many areas, such as health and social activities, manufacturing industries, automobiles, dairy, textiles, leather, metal, agriculture, livestock, fishing, forestry, transportation, inventory management systems, administration, teaching, artistic endeavors, entertainment, sports, wood, water supply, and many more. [28]

Dickinson et al. (1992) [37] modified the NMQ developed by Kuorinka et al. (1987) to verify the views of technical staff, clerks, data entry operators, and others for improvement and found that considerable improvements were suggested by the respondents. Changes were made accordingly for a standardized version of the NMQ (Figure 8c). Later, in 1998, Kaewboonchoo et al. (1998) [38] compared the NMQ with the Japanese Questionnaire for workers exposed to hand-arm vibration. The authors translated the NMQ into Japanese and found that the NMQ can be used to assess exposure to hand-arm vibration. The authors found that the NMQ identifies the severity, duration, treatment, and disability, excluding finger numbness and blanching. In 2011, Arsalani et al. (2011) [39] used the NMQ, converting it into Persian, to measure nursing working conditions and health problems. The authors found that the NMQ provided reliable information. Kahraman et al. (2016) [40] in 2016 used the NMQ in Turkey to adapt the method linguistically and culturally to examine the psychometric properties. The authors found that the NMQ is suitable for psychometric properties and can be used for screening and epidemiological examination of musculoskeletal symptoms. Hence, the NMQ can be applied in wide areas as mentioned earlier.

In 2014, Franasiak et al. (2014) [41] used the NMQ for ergonomic strain during robotic surgery. Prior to this, the same study had been carried out using RULA and SI, but both methods showed the need for further investigation, leading to the use of the NMQ. The authors used a modified version of the NMQ, which included 38 questions by adding one column to the Kuorinka et al. (1987) Standardized Nordic Musculoskeletal Questionnaire: "During the last 12 months, have you seen a physician for this condition?" They found that the NMQ, with the modified version, is suitable for studying ergonomic strain during robotic surgery (Figure 2.2).



	Have you at any time during the last 12 months had trouble (such as ache, pain, discomfort, numbness) in:	During the last 12 months have you been prevented from carrying out normal activities (e.g. job, housework, hobbies) because of this trouble in:	During the last 12 months have you seen a physician for this condition:	During the last 7 days have you had trouble in:
NECK	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
SHOULDERS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
UPPER BACK	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
ELBOWS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
WRISTS/ HANDS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
LOWER BACK	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
HIPS/ THIGHS	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
KNEES	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes
ANKLES/ FEET	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes	☐ No ☐ Yes

Figure 2.11 Nordic Musculoskeletal Questionnaire (NMQ)

2.2.3 RAPID UPPER LIMB ASSESSMENT METHOD (RULA):

Lynn McAtamney and E. Nigel Corlett in 1993 developed a survey/observation method Rapid Upper Limb Assessment (RULA) for postural analysis with emphasis on upper body disorders, considering biomechanical and postural load requirements. The upper body includes neck, trunk, and upper limbs along with how body muscle's function and how external forces affect the body. This includes how long the body is in a static position, force applied, and repetitive movements. The method was developed to carry out a quick assessment with minimum tools under any circumstances. It is a tool for quick assessment of physical risk exposure to the body while working, mainly focusing on upper body muscles, efforts, exertion of force, static and repetitive movements, which are responsible for muscle fatigue and can be used to assess epidemiological, physical, mental, environmental, and organizational factors related to upper body disorders. The method does not require any equipment, training, or special skills for assessment. The only things required are a clipboard, worksheet, and pen [189].

Chowdury et al., (2014) [190] used RULA in 2014 to analyze the work posture of ceramic industry workers and found that most of the workers are exposed to physical risk factors of the upper extremities due to bad working posture. The authors also found that all working postures in that industry are exposing workers to physical risk factors and need further investigation to minimize the physical risk factor. The authors state that repetitive strain injury (RSI) is due to exposure to work posture, muscle activities, and force. The authors again state that the RULA method was developed to identify physical risk factors that require further attention or investigation rather than giving a guarantee of low or high hazards with the low or high score.

Dockrell et al., (2012) [191] in 2012 used RULA to assess the posture of children working at computers, aiming to study the reliability of RULA with children. The main aim of this study was to examine inter-rater and intra-rater reliability of RULA with children. The authors verified that RULA has higher intra-rater reliability than inter-rater reliability and was more reliable for older children than younger ones.

Recently, Abreu et al., (2017) [192] applied RULA in the precast industry for ergonomic work analysis with OWAS, aiming to provide a healthy environment for workers, as the precast industry requires lots of physical efforts. The authors used RULA and OWAS to identify postures of workers while carrying out different working activities on the job shop and the impact of posture on the body, which increases the physical risk factor. The authors found that poor working conditions and working in awkward postures are contributing to the physical exposure factors. Finally, the authors suggested some recommendations for improvement.

The method uses a sequence of different posture images in various positions of the body parts, and a number score is allocated to each position, as shown in figure 18a. It includes two main groups: Group A and Group B. Group A belongs to arm and wrist analysis, which includes scoring for upper arm, lower arm, wrist position, and twist position, while Group B belongs to neck, trunk, and legs, with the effect of static, repetitive, and forceful actions on the upper arm, lower arm, wrist, neck, trunk, and legs. To get the score for static, repetitive, and forceful exertion, stress on muscles and force for body parts are scored for both groups.

On the basis of the assessment, scores are allotted to each posture in Section A and Section B (Figure 2.3). As soon as the data are collected and the RULA score is calculated, the level of WRMSD risk is checked. The level of WRMSD risk is mentioned in figure 18a at the section RULA score action level.

STEP BY STEP PROCEDURE:

To assess physical exposure using the RULA method, understand the job task and its demands by interviewing the workers and observing the worker’s working movements and postures during work for several working hours. The postures should be selected based on:

a) Most difficult posture
b) Static posture for the maximum period
c) Highest force required
The assessment can be done in real-time or via recording.

Stage 1: Score upper arm position as per the position of the worker's body (POS -1, POS -2, POS -3, and POS -4) from allotted marks 1 to 4, as shown in figure 2.3. Add 1 to the earlier score if the shoulder is raised or the upper arm is abducted, and subtract 1 if the arm is supported or the person is leaning. Note the score in the upper arm score box.

Stage 2: Score lower arm position as per the position of the worker's body (POS -1, POS -2, and POS -3) from allotted marks 1 to 2, as shown in figure 2.3. Add 1 to the earlier score if the arm is working across the midline or out of the body side. Note the score in the lower arm score box.

Stage 3: Score wrist position as per the position of the worker's wrist (POS -1, POS -2, POS -3, and POS -4) from allotted marks 1 to 3, as shown in figure 2.3. Add 1 to the earlier score if the wrist is bent from the midline. Note the score in the wrist score box.

Stage 4: Score wrist twist position as per the position of the worker's wrist (POS -1 and POS -2) from allotted marks 1 and 2, as shown in figure 2.3. Note the score in the wrist twist score box.

Stage 5: From the scores of Step 1 to Step 4, locate the posture score from Table A (figure 2.3). Note the score in the posture score A box.

Stage 6: Score muscle score as per the parameters mentioned in Step 6 of figure 2.3. Note the score in the muscle use score box.

Stage 7: Score force/load score as per the parameters mentioned in Step 7 of figure 2.3. Note the score in the Force/Load box.

Stage 8: Add score values from Stage 5 + Stage 6 + Stage 7 and note the score in the wrist and arm score box.

Stage 9: Score neck position as per the position of the worker's neck (POS -1, POS -2, POS -3, and POS -4) from allotted marks 1 to 4, as shown in figure 2.3. Add 1 to the earlier score if the neck is twisted or side-bent. Note the score in the neck score box.

Stage 10: Score trunk position as per the position of the worker's trunk (POS -1, POS -2, POS -3, and POS -4) from allotted marks 1 to 2, as shown in figure 2.3. Add 1 to the earlier score if the trunk is twisted or side-bent. Note the score in the trunk score box.

Stage 11: Score legs position as per the position of the worker's legs (POS -1 and POS -2) from allotted marks 1 to 2, as shown in figure 2.3. Note the score in the legs score box.

Stage 12: From the scores of Step 7 to 9, locate the posture score from Table B (figure 2.3). Note the score in the posture score B box.

Stage 13: Score muscle score as per the parameters mentioned in Step 13 of figure 2.3. Note the score in the muscle use box.

Stage 14: Score force/load score as per the parameters mentioned in Step 14 of figure 2.3. Note the score in the force/load score box.

Stage 15: Add score values from Stage 12 + Stage 13 + Stage 14 and note the score in the neck, trunk, and leg box.

Stage 16: Locate the RULA final score from the scores obtained from Stage 8 and Stage 15 using Table C (figure 2.3).

Stage 17: Check this RULA final score to find the action level required.

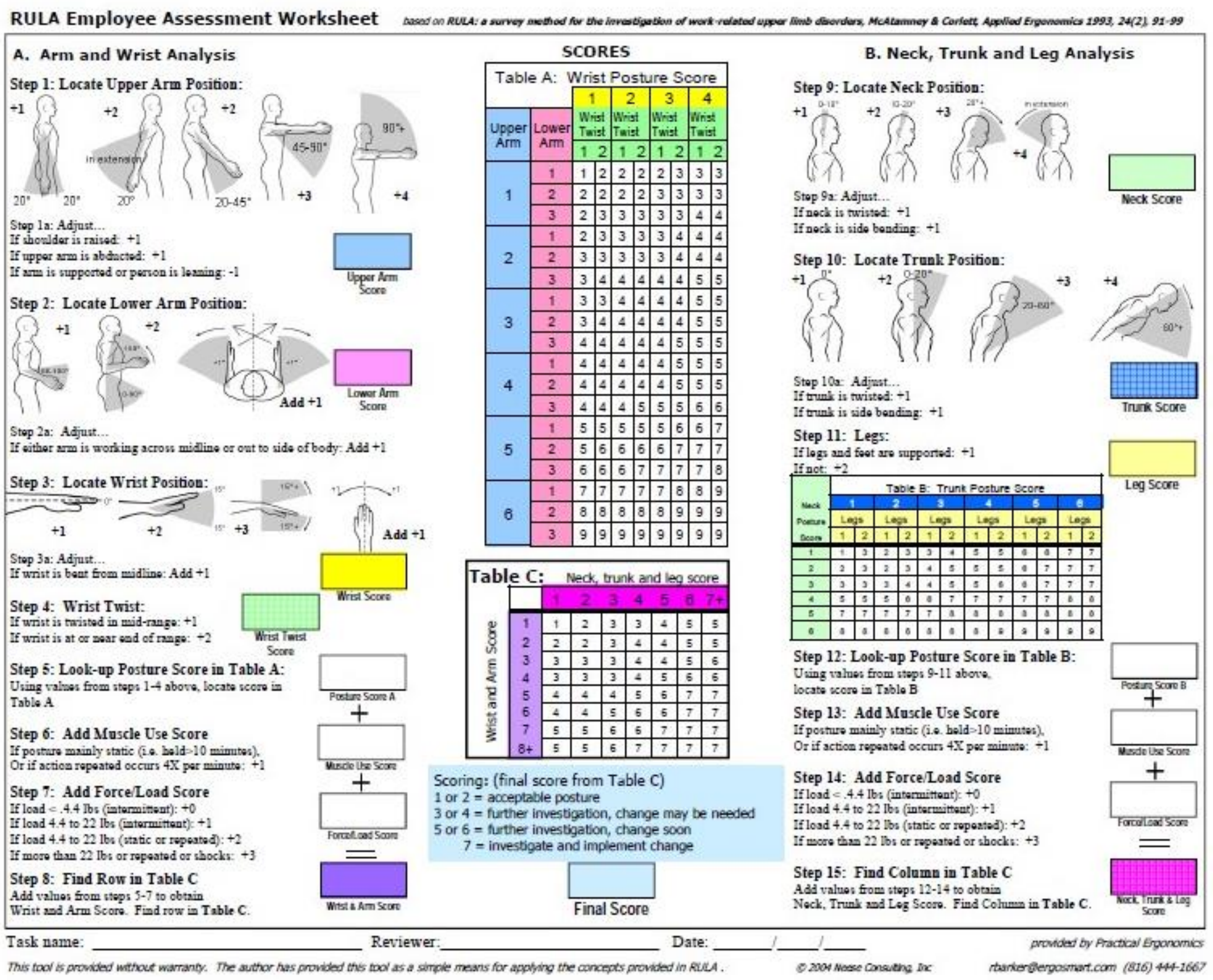
RULA Parameter:

1 or 2 = Acceptable posture

3 or 4 = Further Investigation, Change may be needed

5 or 6 = Further Investigation, Change Soon

7 = Investigation and implement Change



RULA Employee Assessment Worksheet *based on RULA: a survey method for the investigation of work-related upper limb disorders, McAtamney & Corlett, Applied Ergonomics 1993, 24(2), 91-99*

A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position:

Step 1a: Adjust…
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 2: Locate Lower Arm Position:

Step 2a: Adjust…
If either arm is working across midline or out to side of body: Add +1

Lower Arm Score

Step 3: Locate Wrist Position:

Step 3a: Adjust…
If wrist is bent from midline: Add +1

Wrist Score

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is at or near end of range: +2

Wrist Twist Score

Step 5: Look-up Posture Score in Table A:
Using values from steps 1-4 above, locate score in Table A

Posture Score A
+

Step 6: Add Muscle Use Score
If posture mainly static (i.e. held>10 minutes),
Or if action repeated occurs 4X per minute: +1

Muscle Use Score
+

Step 7: Add Force/Load Score
If load < 4.4 lbs (intermittent): +0
If load 4.4 to 22 lbs (intermittent): +1
If load 4.4 to 22 lbs (static or repeated): +2
If more than 22 lbs or repeated or shocks: +3

Force/Load Score
=

Step 8: Find Row in Table C
Add values from steps 5-7 to obtain
Wrist and Arm Score. Find row in Table C.

Wrist & Arm Score

SCORES

Table A: Wrist Posture Score

Upper Arm	Lower Arm	1 Wrist Twist 1	1 Wrist Twist 2	2 Wrist Twist 1	2 Wrist Twist 2	3 Wrist Twist 1	3 Wrist Twist 2	4 Wrist Twist 1	4 Wrist Twist 2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Table C: Neck, trunk and leg score

Wrist and Arm Score	1	2	3	4	5	6	7+
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	5	5	6	6	7	7	7
8+	5	5	6	7	7	7	7

Scoring: (final score from Table C)
1 or 2 = acceptable posture
3 or 4 = further investigation, change may be needed
5 or 6 = further investigation, change soon
7 = investigate and implement change

Final Score

B. Neck, Trunk and Leg Analysis

Step 9: Locate Neck Position:

Step 9a: Adjust…
If neck is twisted: +1
If neck is side bending: +1

Neck Score

Step 10: Locate Trunk Position:

Step 10a: Adjust…
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 11: Legs:
If legs and feet are supported: +1
If not: +2

Leg Score

Table B: Trunk Posture Score

Neck Posture Score	1 Legs 1	1 Legs 2	2 Legs 1	2 Legs 2	3 Legs 1	3 Legs 2	4 Legs 1	4 Legs 2	5 Legs 1	5 Legs 2	6 Legs 1	6 Legs 2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

Step 12: Look-up Posture Score in Table B:
Using values from steps 9-11 above,
locate score in Table B

Posture Score B
+

Step 13: Add Muscle Use Score
If posture mainly static (i.e. held>10 minutes),
Or if action repeated occurs 4X per minute: +1

Muscle Use Score
+

Step 14: Add Force/Load Score
If load < 4.4 lbs (intermittent): +0
If load 4.4 to 22 lbs (intermittent): +1
If load 4.4 to 22 lbs (static or repeated): +2
If more than 22 lbs or repeated or shocks: +3

Force/Load Score
=

Step 15: Find Column in Table C
Add values from steps 12-14 to obtain
Neck, Trunk and Leg Score. Find Column in Table C.

Neck, Trunk & Leg Score

Task name: ______________ Reviewer: ______________ Date: ____/____/____

provided by Practical Ergonomics

This tool is provided without warranty. The author has provided this tool as a simple means for applying the concepts provided in RULA.

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rbarker@ergosmart.com (816) 444-1667

Figure 2.12 Rapid Upper Limb Assessment Method Worksheet (RULA)

2.2.4 RAPID ENTIRE BODY ASSESSMENT (REBA):

Rapid Entire Body Assessment (REBA) is a quick observational and survey method used for the assessment of static and dynamic movements, rapidly changing or unstable body posture, which leads to the development of work-related musculoskeletal disorders. The method was developed by Lynn McAtamney and Sue Hignett in 1995, with the objective of finding risk factors associated with trunk and leg loading, in addition to those on the upper limb, coupling factors while material handling, and muscle activities caused by static, dynamic, or rapidly changing posture. The REBA method was developed using the concepts of RULA, OWAS, and the NIOSH method, in which the authors added the risk of knee, loads/forces, coupling, repetition, and activity of the whole body [193].

Following this, in 2000, Hignett et al. (2000) [194] developed REBA for unpredictable working postures of sensitive tasks in the field, with objectives to develop a postural analysis system applicable to a variety of tasks, divide the body into coded sections, score muscle activities, emphasize the importance of coupling in material handling, use of other material handling equipment, indicate action levels with urgency, and use minimum equipment (i.e., pen and paper method). According to the authors, the availability of task-sensitive field techniques and the recorded posture of work-related musculoskeletal injuries will be helpful to change traditional working procedures for ergonomic workplace assessments.

Hignett et al. (2000) [194] actually first described this method by which body posture can be evaluated by articular angle measurement, force/load observation, movement repetition, and frequency. The body parts like neck, trunk, legs, upper arm, lower arm, and wrist posture are considered in REBA, in which each position range score value is considered to be higher as the distance from the neutral position of the body part increases. The REBA worksheet is divided into two scoring parts: A and B. The scoring part A consists of neck, trunk, legs, as well as force/load score, having a combination of 60 postures. The scoring part B consists of upper arm, lower arm, wrist, as well as coupling score, having a combination of 36 postures. The scoring parts A and B have 144 combinations in Table C, and by adding the activity score, it will give the REBA score. The activity score considers the static posture, which is maintained stable for more than one minute, and movements are repeated four times per minute, large rapid range changes in postures, and an unstable base. The REBA scoring actions are shown in Figure 2.4.

Madani et al. (2016) [195], in 2016, performed a literature review on REBA to provide brief information about its development, applications, validity, and limitations. The authors reviewed several papers related to REBA and found that the technique is popular and broadly used for ergonomics assessment in various sectors and validated the method by comparing it with other methods for its validity and reliability. By using computers, the assessment time and reliability of the method can be increased. The REBA method is applicable to service sectors like information technology, telecommunications, financial services, community services, hospitality services, supermarkets, all types of medical services, real estate or construction, schools and colleges, etc., as well as food industries, grain milling industries, manufacturing and packaging industries, firefighters, etc.

STEP BY STEP PROCEDURE:

To assess physical exposure using REBA method, it is need to identify the work by discussing with workers, observing the work, working movements and awkward posture of workers work for longer time. The postures must be selected on the basis of a) Most awkward posture and hard to work b) working for long period of time and 3) posture which required high force load. As the tool is meant for whole body assessment hence body posture, forceful exertions, movement type, repetition and coupling types should be observed and recorded on real time. Using REBA score worksheet, the various postures and task during working phase without much more time.

To assess physical exposure using the REBA method, it is necessary to identify the work by discussing with workers, observing the work, working movements, and awkward posture of workers who work for longer periods of time. The postures must be selected on the basis of (a) most awkward posture and hard to work with, (b) working for a long period of time, and (c) posture which requires high force load. As the tool is meant for whole-body assessment, hence, body posture, forceful exertions, movement types, repetition, and coupling types should be observed and recorded in real-time. Using the REBA score worksheet, the various postures and tasks during the working phase can be assessed without much more time.

Stage 1: Score the neck position as per the position of the worker's neck (POS -1, POS -2, and POS - 3) from the allotted marks 1 to 2, as shown in figure 2.4. Add 1 to the earlier score if the neck is twisted or side-bent. Note down the score in the neck score box

Stage 2: Score the trunk position as per the position of the worker's trunk (POS -1, POS -2, POS -3, POS -4, and POS -5) from the allotted marks 1 to 4, as shown in figure 2.4. Add 1 to the earlier score if the trunk is twisted or side-bent. Note the score in the trunk score box.

Stage 3: Score the leg position as per the position of the worker's legs (POS -1, POS -2, POS -3, and POS -4) from the allotted marks 1 to 2, as shown in figure 2.4. Add 1 if the leg is bent between 30-60 degrees, and add 2 if the legs are bent more than 60 degrees. Note the score in the leg score box.

Stage 4: From the scores of steps 1 to 3, locate the posture score from Table A. Note the score in the Posture Score A box.

Stage 5: Score the force/load score as per the parameters mentioned in step 5 of figure 2.4. Note the score in the force/load score box.

Stage 6: Add the score values of steps 4 and 5 and note the score in the score A box of the neck, trunk, and legs.

Stage 7: Score the upper arm position as per the position of the worker's body (POS -1, POS -2, POS -3, POS -4, and POS -5) from the allotted marks 1 to 4, as shown in figure 2.4. Add 1 to the earlier score if the shoulder is raised or the upper arm is abducted, and subtract 1 if the arm is supported or the person is leaning. Note the score in the upper arm score box.

Stage 8: Score the lower arm position as per the position of the worker's body (POS -1, POS -2, and POS -3) from the allotted marks 1 to 2, as shown in figure 2.4. Note the score in the lower arm score box.

Stage 9: Score the wrist position as per the position of the worker's wrist (POS -1 and POS -2) from the allotted marks 1 to 2, as shown in figure 2.4. Add 1 to the earlier score if the wrist is bent from the midline or twisted. Note the score in the wrist score box.

Stage 10: From the scores of steps 7 to 9, locate the posture score from Table B. Note the score in the Posture Score B box of the arm and wrist.

Stage 11: Score the coupling score as per the parameters mentioned in step 11 of figure 2.4. Note the score in the coupling score box.

Stage 12: Add the scores of stages 10 and 11 and note the score in the score B box of the arm and wrist.

Stage 13: Locate the score from Table C by using the score values of stages 6 and 12 using Table C and note it down in the Table C score box.

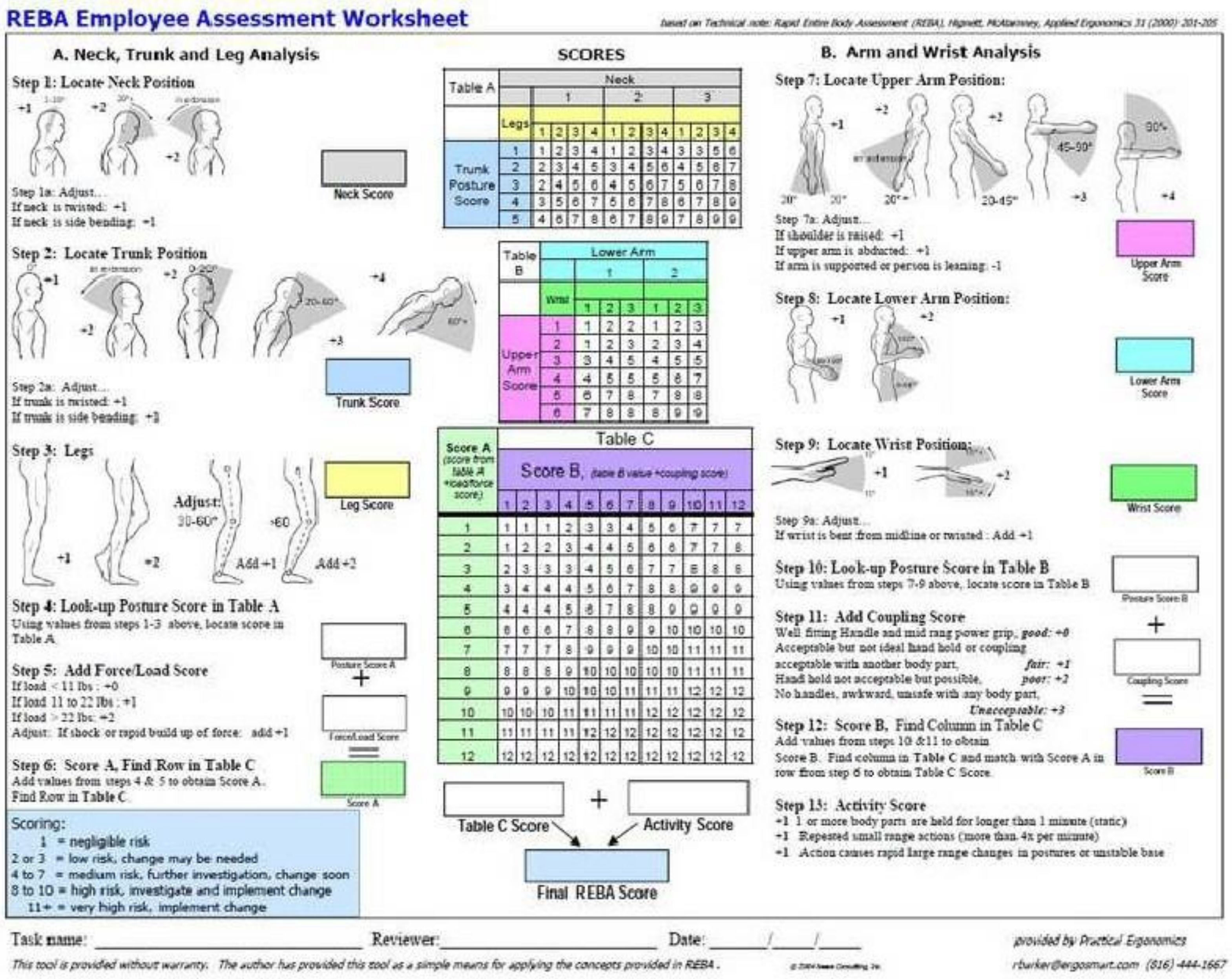
Stage 14: Score the Activity Score as per the parameters mentioned in step 13 and note down the score value in the Activity Score box.

Stage 15: Add the score values of stages 13 and 14 to get the REBA final score.

Stage 16: Check this REBA final score to determine the action level required.

REBA Parameter:

1 = Negligible risk
2 or 3 = low risk, change may be needed.
4 to 7 = Medium risk, Further investigation, change soon
8 to 10 = High risk, investigation and implement change
11 = Very high risk, implement change



REBA Employee Assessment Worksheet

based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Neck Score

Step 2: Locate Trunk Position

Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 3: Legs

Leg Score

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above, locate score in Table A

Posture Score A

+

Step 5: Add Force/Load Score
If load < 11 lbs : +0
If load 11 to 22 lbs : +1
If load > 22 lbs: +2
Adjust: If shock or rapid build up of force: add +1

Force/Load Score

=

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in Table C.

Score A

Scoring:
1 = negligible risk
2 or 3 = low risk, change may be needed
4 to 7 = medium risk, further investigation, change soon
8 to 10 = high risk, investigate and implement change
11+ = very high risk, implement change

SCORES

Table A		Neck											
		1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B		Lower Arm					
		1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Score A (score from table A +load/force score)	Table C Score B, (table B value +coupling score)											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score

Final REBA Score

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 8: Locate Lower Arm Position:

Lower Arm Score

Step 9: Locate Wrist Position:

Step 9a: Adjust...
If wrist is bent from midline or twisted : Add +1

Wrist Score

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B

+

Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, *good:* +0
Acceptable but not ideal hand hold or coupling acceptable with another body part, *fair:* +1
Hand hold not acceptable but possible, *poor:* +2
No handles, awkward, unsafe with any body part, *Unacceptable:* +3

Coupling Score

=

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain Score B. Find column in Table C and match with Score A in row from step 6 to obtain Table C Score.

Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Task name: ______________ Reviewer: ______________ Date: ___/___/___

provided by Practical Ergonomics
rbarker@ergosmart.com (816) 444-1667

This tool is provided without warranty. The author has provided this tool as a simple means for applying the concepts provided in REBA.

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Figure 2.13 Rapid Entire Body Assessment (REBA) Worksheet

2.2.5 QUICK EXPOSURE CHECK (QEC):

Guangyan Li and Peter Buckle in 1998 developed the Quick Exposure Check (QEC) technique. The technique was developed to assess the workplace risk factors exposure for WRMSDs. The technique is posture-based, simple, easy, quick, scientifically based, comprehensive, reliable, and has a high level of sensitivity and usability in various work situations after making some improvements in the technique.

This technique consists of a questionnaire and a scoring sheet. This technique not only allows experts, but workers also play a vital role by filling out the QEC assessment form.

For assessment, a questionnaire sheet is given to the observer and worker for work-related physical exposure. The observer observes the back (trunk) and upper limb joints and assesses: 1) position of the back - (A1/ A2/ A3), 2a) position of back in static position (standing/seating task) – (B1/B2), 2b) lifting, pushing, pulling, carrying the load – (B3/B4/B5), 3) hand position – (C1/C2/C3), 4) shoulder/arm position – (D1/D2/D3), 5) wrist and hand position with repetitive movements – (E1/E2), and 6) position of neck – (G1/G2/G3). The workers answer the questions: 1) maximum weight carried by the worker – (H1/H2/H3/H4), 2) task duration in a day – (J1/J2/J3), 3) maximum force to be applied by a single hand – (K1/K2/K3), 4) requirement of visuality – (L1/L2), 5) driving while working – (M1/M2/M3), 6) vibrating tools used – (N1/N2/N3), 7) difficulty in work tasks – (P1/P2/P3), and 8) individual assessment of the task – (Q1/Q2/Q3/Q4). (Figures 2.5a and 2.5b).

For QEC exposure scoring purposes, the authors have developed a matrix to calculate the total exposure scores for each body part. The sheet is shown in the figure. Now, after scoring, it is necessary to decide whether any ergonomic intervention is required or not, which can be determined by verifying the result with the percentage of score E (%). The percentage of score can be calculated by dividing the total assessment score by the maximum total score, i.e., $E(\%) = X / X_{max} * 100\%$. Where X is the total score obtained from Back + Shoulder/arms + Wrist/hands + Neck; Xmax is the total maximum score of Back + Shoulder/arms + Wrist/hands + Neck, which is constant. Xmax = 176 is constant for manual material handling, and X_{max} = 162 for others [196]. The exposure scoring priority level of QEC is given in Table 2.13.

Table 2.13 Proposed priority levels for Quick Exposure Check scores [197]

Exposure Factor	**Exposure level**			
	Low	Moderate	High	Very High
Back (Static)	8-14	16-22	24-28	30-40
Back (Moving)	10-20	22-30	32-40	42-56
Shoulder/Arm	10-20	22-30	32-40	42-56
Wrist/Hand	10-20	22-30	32-40	42-56
Neck	4-6	8-10	12-14	16-18
Driving	1	4	9	-
Vibration	1	4	9	-
Work place	1	4	9	-
Stress	1	4	9	16

This technique uses the manual observation of workers' movements by experts, workers' answers to the questions, different postures of the workers, and maximum movement of body parts like the back (trunk), arms, neck, and upper limbs responsible for WRMSDs. In addition, this technique also scores the whole-body quick assessment, calculates the risk index of each body part selected, frequency of movement, effort, and duration of the shift per day, stress, vibration, and psychosocial risk factors.

The QEC technique can quickly assess most of the exposure risk factors of WRMSDs and can be applied in all working areas. The technique allows both experts and workers to collaborate in the assessment, thereby encouraging both experts and workers to take part in the assessment process, which ultimately helps to minimize the level of WRMSDs in workers and assists experts in assessing accurately. The technique is basically based on epidemiological data, increasing its reliability, and it is good for initial studies [198] [199] [75] [197] [200].

Worker's name ________________ Date ________

Observer's Assessment

Back

A When performing the task, is the back
(select worse case situation)

A1 ☐ Almost neutral?
A2 ☐ Moderately flexed or twisted or side bent?
A3 ☐ Excessively flexed or twisted or side bent?

B Select ONLY ONE of the two following task options:

EITHER

For seated or standing stationary tasks. Does the back remain in a static position most of the time?

B1 ☐ No
B2 ☐ Yes

OR

For lifting, pushing/pulling and carrying tasks (i.e. moving a load). Is the movement of the back

B3 ☐ Infrequent (around 3 times per minute or less)?
B4 ☐ Frequent (around 8 times per minute)?
B5 ☐ Very frequent (around 12 times per minute or more)?

Shoulder/Arm

C When the task is performed, are the hands
(select worse case situation)

C1 ☐ At or below waist height?
C2 ☐ At about chest height?
C3 ☐ At or above shoulder height?

D Is the shoulder/arm movement

D1 ☐ Infrequent (some intermittent movement)?
D2 ☐ Frequent (regular movement with some pauses)?
D3 ☐ Very frequent (almost continuous movement)?

Wrist/Hand

E Is the task performed with
(select worse case situation)

E1 ☐ An almost straight wrist?
E2 ☐ A deviated or bent wrist?

F Are similar motion patterns repeated

F1 ☐ 10 times per minute or less?
F2 ☐ 11 to 20 times per minute?
F3 ☐ More than 20 times per minute?

Neck

G When performing the task, is the head/neck bent or twisted?

G1 ☐ No
G2 ☐ Yes, occasionally
G3 ☐ Yes, continuously

Worker's Assessment

Workers

H Is the maximum weight handled MANUALLY BY YOU in this task?

H1 ☐ Light (5 kg or less)
H2 ☐ Moderate (6 to 10 kg)
H3 ☐ Heavy (11 to 20kg)
H4 ☐ Very heavy (more than 20 kg)

J On average, how much time do you spend per day on this task?

J1 ☐ Less than 2 hours
J2 ☐ 2 to 4 hours
J3 ☐ More than 4 hours

K When performing this task, is the maximum force level exerted by one hand?

K1 ☐ Low (e.g. less than 1 kg)
K2 ☐ Medium (e.g. 1 to 4 kg)
K3 ☐ High (e.g. more than 4 kg)

L Is the visual demand of this task

L1 ☐ Low (almost no need to view fine details)?
*L2 ☐ High (need to view some fine details)?
* *If High, please give details in the box below*

M At work do you drive a vehicle for

M1 ☐ Less than one hour per day or Never?
M2 ☐ Between 1 and 4 hours per day?
M3 ☐ More than 4 hours per day?

N At work do you use vibrating tools for

N1 ☐ Less than one hour per day or Never?
N2 ☐ Between 1 and 4 hours per day?
N3 ☐ More than 4 hours per day?

P Do you have difficulty keeping up with this work?

P1 ☐ Never
P2 ☐ Sometimes
*P3 ☐ Often
* *If Often, please give details in the box below*

Q In general, how do you find this job

Q1 ☐ Not at all stressful?
Q2 ☐ Mildly stressful?
*Q3 ☐ Moderately stressful?
*Q4 ☐ Very stressful?
* *If Moderately or Very, please give details in the box below*

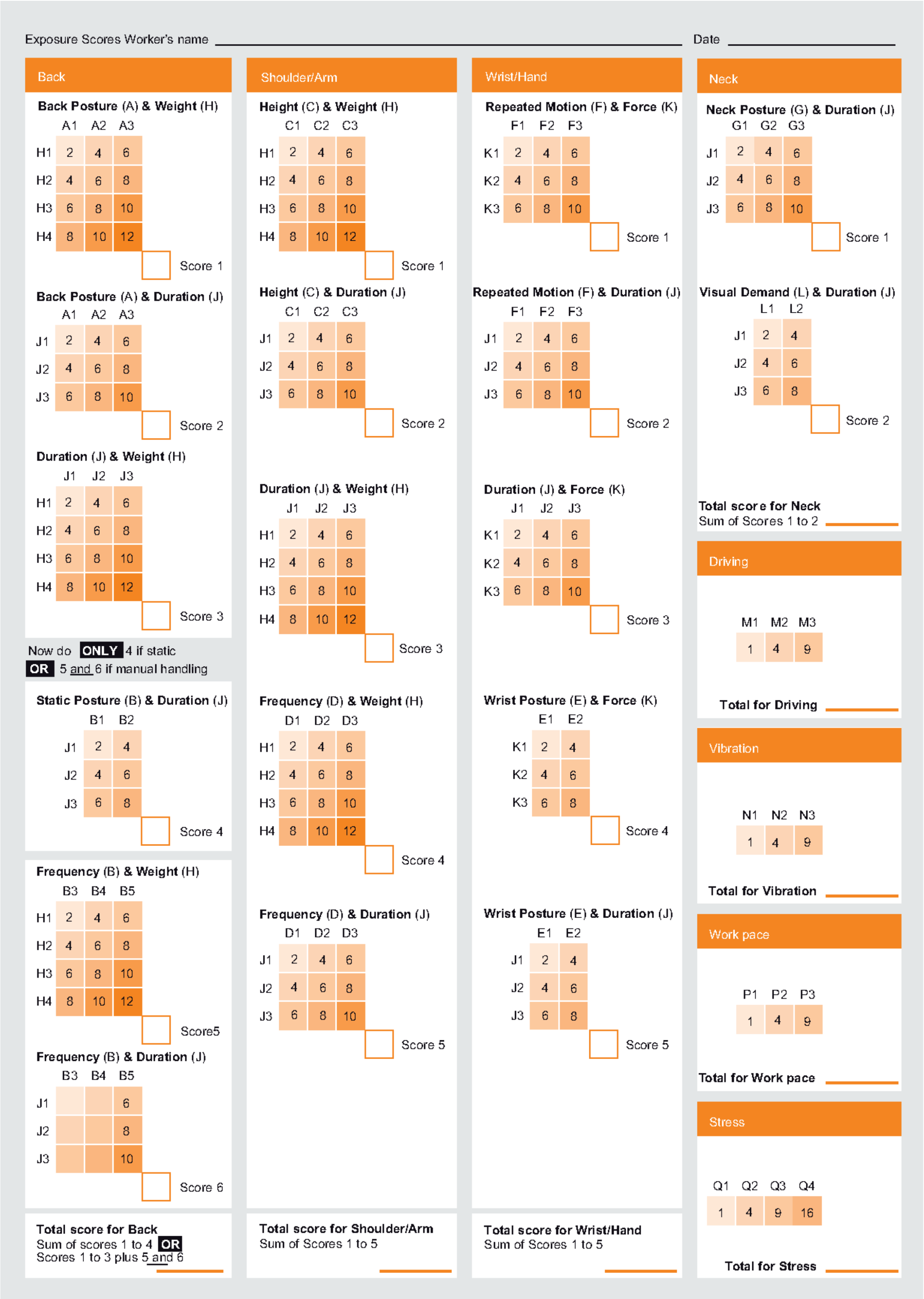
* *Additional details for L, P and Q if appropriate*

* **L**

* **P**

* **Q**

Figure 2.14(a) QUICK EXPOSURE CHECK (QEC)



Exposure Scores Worker's name ____________________ Date __________

Back

Back Posture (A) **& Weight** (H)

	A1	A2	A3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

☐ Score 1

Back Posture (A) **& Duration** (J)

	A1	A2	A3
J1	2	4	6
J2	4	6	8
J3	6	8	10

☐ Score 2

Duration (J) **& Weight** (H)

	J1	J2	J3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

☐ Score 3

Now do **ONLY** 4 if static **OR** 5 and 6 if manual handling

Static Posture (B) **& Duration** (J)

	B1	B2
J1	2	4
J2	4	6
J3	6	8

☐ Score 4

Frequency (B) **& Weight** (H)

	B3	B4	B5
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

☐ Score5

Frequency (B) **& Duration** (J)

	B3	B4	B5
J1			6
J2			8
J3			10

☐ Score 6

Total score for Back
Sum of scores 1 to 4 **OR**
Scores 1 to 3 plus 5 and 6 ________

Shoulder/Arm

Height (C) **& Weight** (H)

	C1	C2	C3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

☐ Score 1

Height (C) **& Duration** (J)

	C1	C2	C3
J1	2	4	6
J2	4	6	8
J3	6	8	10

☐ Score 2

Duration (J) **& Weight** (H)

	J1	J2	J3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

☐ Score 3

Frequency (D) **& Weight** (H)

	D1	D2	D3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

☐ Score 4

Frequency (D) **& Duration** (J)

	D1	D2	D3
J1	2	4	6
J2	4	6	8
J3	6	8	10

☐ Score 5

Total score for Shoulder/Arm
Sum of Scores 1 to 5 ________

Wrist/Hand

Repeated Motion (F) **& Force** (K)

	F1	F2	F3
K1	2	4	6
K2	4	6	8
K3	6	8	10

☐ Score 1

Repeated Motion (F) **& Duration** (J)

	F1	F2	F3
J1	2	4	6
J2	4	6	8
J3	6	8	10

☐ Score 2

Duration (J) **& Force** (K)

	J1	J2	J3
K1	2	4	6
K2	4	6	8
K3	6	8	10

☐ Score 3

Wrist Posture (E) **& Force** (K)

	E1	E2
K1	2	4
K2	4	6
K3	6	8

☐ Score 4

Wrist Posture (E) **& Duration** (J)

	E1	E2
J1	2	4
J2	4	6
J3	6	8

☐ Score 5

Total score for Wrist/Hand
Sum of Scores 1 to 5 ________

Neck

Neck Posture (G) **& Duration** (J)

	G1	G2	G3
J1	2	4	6
J2	4	6	8
J3	6	8	10

☐ Score 1

Visual Demand (L) **& Duration** (J)

	L1	L2
J1	2	4
J2	4	6
J3	6	8

☐ Score 2

Total score for Neck
Sum of Scores 1 to 2 ________

Driving

M1	M2	M3
1	4	9

Total for Driving ________

Vibration

N1	N2	N3
1	4	9

Total for Vibration ________

Work pace

P1	P2	P3
1	4	9

Total for Work pace ________

Stress

Q1	Q2	Q3	Q4
1	4	9	16

Total for Stress ________

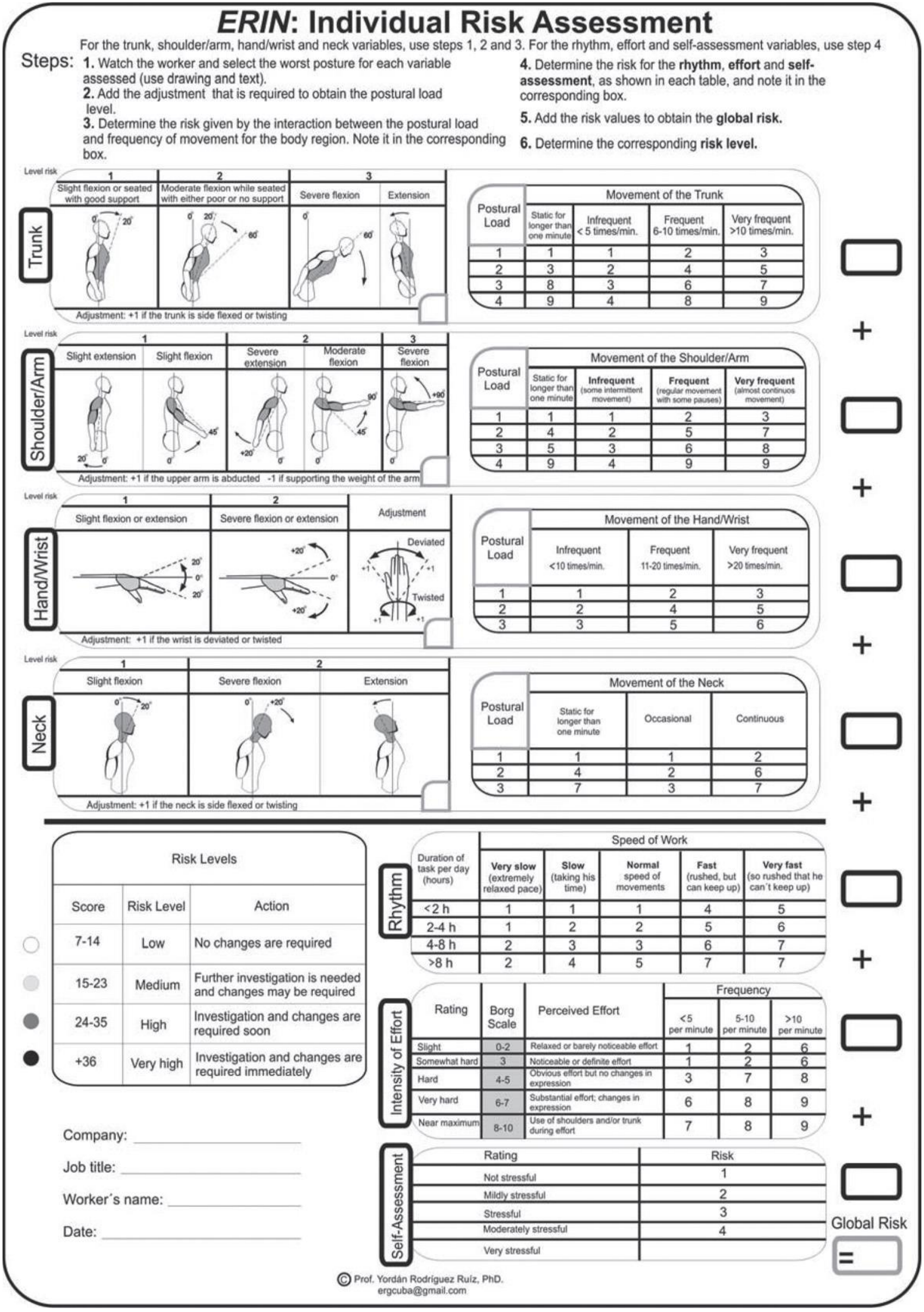
Figure 2.14(b) QUICK EXPOSURE CHECK (QEC)

2.2.6 INDIVIDUAL RISK ASSESSMENT (ERIN):

Yordan Rodríguez, Silvio Vina, and Ricardo Montero in 2013 developed the method Evaluation del Riesgo Individual (Individual Risk Assessment) (ERIN). The method was developed on the basis of available ergonomic tools and epidemiological data. The method was developed with the view that it should be used to evaluate static and dynamic work assessments by non-expert persons, requiring less training and without the use of any equipment **[50].** This method is basically focused on factors like workplace and worker assessment. The worksheet of ERIN has been designed using available ergonomic tools like RULA, REBA, SI, QEC, OCRA, and OWAS. This method measures posture, frequency of movement of the trunk, shoulder/arm, hand/wrist, and neck, which results from speed of work, task duration, intensity of effort, and self-assessment **[51].** The method was developed by considering all the factors that are required by ergonomists. This method is simple, easy to use, understand, and learn, based on science, comprehensive, can measure levels of exposure, does not need instruments, can involve the workers, and can be applied to any work situation.

For fast decision-making, the ergonomist or researcher can observe a number of body joints and postures simultaneously. The non-experts can select the worst posture for each body part and assess when the body is continuously in motion, and the greatest intensity of effort and frequency of movement should be selected if different types of efforts are present during the assessment. The scoring of the ERIN is very simple and easy to score. The reliability and validity of the method have been tested by the author Ruiz, Y.R. (2018) **[201]** and can be applied to any work area for the assessment of physical exposure. The ERIN worksheet is shown in Figure 2.6. To determine the ERIN score, follow the steps below **[50]:**

1. Observe the work and worker and select the worst posture of the worker for each variable.
2. Score the risk values for each variable and, if required, make the adjustments necessary to obtain the postural load level.
3. Determine the risk provided by the interaction between postural load and frequency of movement for the body region, which is available in the front box.
4. Determine the risk for the rhythm, given by the intersection of the duration of the task per day and speed of work; effort, given by the intersection of rating and frequency; and self-assessment, given by the intersection of rating and risk.
5. Add all the risk values to obtain the global risk.
6. Determine the corresponding risk level based on the global risk."



***ERIN*: Individual Risk Assessment**

For the trunk, shoulder/arm, hand/wrist and neck variables, use steps 1, 2 and 3. For the rhythm, effort and self-assessment variables, use step 4

Steps:
1. Watch the worker and select the worst posture for each variable assessed (use drawing and text).
2. Add the adjustment that is required to obtain the postural load level.
3. Determine the risk given by the interaction between the postural load and frequency of movement for the body region. Note it in the corresponding box.
4. Determine the risk for the **rhythm**, **effort** and **self-assessment**, as shown in each table, and note it in the corresponding box.
5. Add the risk values to obtain the **global risk.**
6. Determine the corresponding **risk level.**

Trunk

Level risk	1	2	3	
	Slight flexion or seated with good support	Moderate flexion while seated with either poor or no support	Severe flexion	Extension

Adjustment: +1 if the trunk is side flexed or twisting

Postural Load	Movement of the Trunk			
	Static for longer than one minute	Infrequent < 5 times/min.	Frequent 6-10 times/min.	Very frequent >10 times/min.
1	1	1	2	3
2	3	2	4	5
3	8	3	6	7
4	9	4	8	9

\+

Shoulder/Arm

Level risk	1		2		3
	Slight extension	Slight flexion	Severe extension	Moderate flexion	Severe flexion

Adjustment: +1 if the upper arm is abducted -1 if supporting the weight of the arm

Postural Load	Movement of the Shoulder/Arm			
	Static for longer than one minute	**Infrequent** (some intermittent movement)	**Frequent** (regular movement with some pauses)	**Very frequent** (almost continuos movement)
1	1	1	2	3
2	4	2	5	7
3	5	3	6	8
4	9	4	9	9

\+

Hand/Wrist

Level risk	1	2	
	Slight flexion or extension	Severe flexion or extension	Adjustment

Adjustment: +1 if the wrist is deviated or twisted

Postural Load	Movement of the Hand/Wrist		
	Infrequent <10 times/min.	Frequent 11-20 times/min.	Very frequent >20 times/min.
1	1	2	3
2	2	4	5
3	3	5	6

\+

Neck

Level risk	1	2	
	Slight flexion	Severe flexion	Extension

Adjustment: +1 if the neck is side flexed or twisting

Postural Load	Movement of the Neck		
	Static for longer than one minute	Occasional	Continuous
1	1	1	2
2	4	2	6
3	7	3	7

\+

Risk Levels

	Score	Risk Level	Action
○	7-14	Low	No changes are required
○	15-23	Medium	Further investigation is needed and changes may be required
●	24-35	High	Investigation and changes are required soon
●	+36	Very high	Investigation and changes are required immediately

Company: ____________________

Job title: ____________________

Worker´s name: ____________________

Date: ____________________

Rhythm

Duration of task per day (hours)	Speed of Work				
	Very slow (extremely relaxed pace)	**Slow** (taking his time)	**Normal** speed of movements	**Fast** (rushed, but can keep up)	**Very fast** (so rushed that he can´t keep up)
<2 h	1	1	1	4	5
2-4 h	1	2	2	5	6
4-8 h	2	3	3	6	7
>8 h	2	4	5	7	7

\+

Intensity of Effort

Rating	Borg Scale	Perceived Effort	Frequency		
			<5 per minute	5-10 per minute	>10 per minute
Slight	0-2	Relaxed or barely noticeable effort	1	2	6
Somewhat hard	3	Noticeable or definite effort	1	2	6
Hard	4-5	Obvious effort but no changes in expression	3	7	8
Very hard	6-7	Substantial effort; changes in expression	6	8	9
Near maximum	8-10	Use of shoulders and/or trunk during effort	7	8	9

\+

Self-Assessment

Rating	Risk
Not stressful	1
Mildly stressful	2
Stressful	3
Moderately stressful	4
Very stressful	

Global Risk

=

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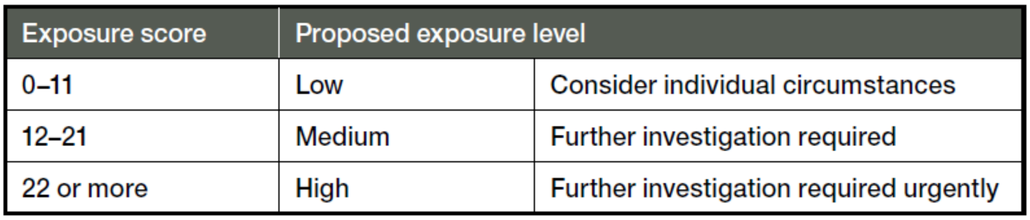
Figure 2.15 Evaluation Del Riesgo Individual/Individual Risk Assessment Worksheet **(**ERIN)

2.2.7 ASSESSMENT OF REPETITIVE TASKS OF THE UPPER LIMBS (ART):

Assessment of repetitive tasks of the upper limbs (the ART tool) began development in early 2007 by the Health and Safety Executive and was presented in 2009. The aim was to develop a reliable and accurate tool for disseminated inspection. The criteria for designing this tool are the same as those used for the MAC tool and are used to identify physical risk factors that cause WRMSD in the upper limb due to repetitive work, repetitive tasks, symptoms, indications, exposure to current risks, and areas for improvement. It uses a flowchart process sheet for assessment and a traffic-light system for grading risk levels. This ART method is used where repetition of work occurs every few minutes, more frequently, or at least 1-2 hours per day per shift. This method assesses the risk levels of frequency and repetition of movement, force/power, awkward postures, and influencing factors such as duration, recovery, perceived workplace, environmental factors, etc., of the hand, wrist, arms, shoulders, neck, and back. The details of the scoring sheet are given in Figure 43 [202][203][204].

Steps of ART Score:

1. Encircle the score of A1, A2, B, C1, C2, C3, C4, C5, D1, D2, D3, and D4.
2. Note down all scores in final scoring section and calculate task score.
3. Note down duration multiplier.
4. Calculate final exposure score by multiplying task score with duration multiplier.
5. Check the exposure score with proposed exposure level and suggest accordingly.
6. To Score Force, score kindly refer Figure 2.16: Level of force exerted with hands.
7. Mention psychosocial factor if any
8. Exposure score is proposed as below.



Exposure score	Proposed exposure level	
0–11	Low	Consider individual circumstances
12–21	Medium	Further investigation required
22 or more	High	Further investigation required urgently

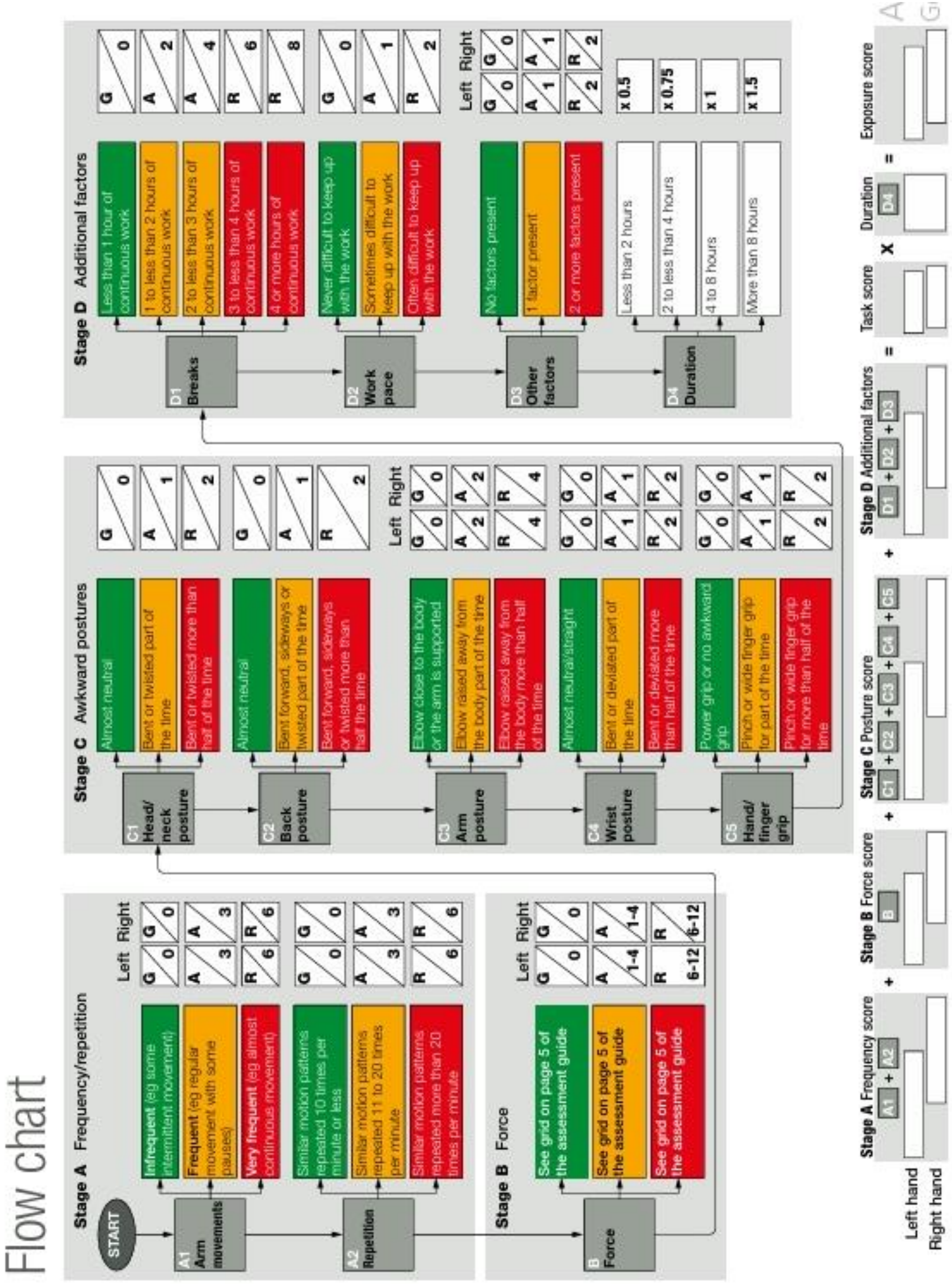


Figure 2.16 Assessment of Repetitive Tasks of the Upper Limbs (ART) Worksheet

2.2.8 WORKPLACE ERGONOMIC RISK ASSESSMENT (WERA):

The Workplace Ergonomic Risk Assessment (WERA) method was developed by Md. Nasrull Abdol Rahman, Mat Rebi Abdul Rani, and Jafri Md. Rohini in 2011. It was developed to find the WRMSD amongst wall plastering, brick laying, and floor concreting workers in the construction industry (Figure 2.17(a) and 2.17(b)). This developed method is a quick observational method designed to provide a screening approach for working tasks related to physical risk factors associated with WRMSD. The WERA method comprises six types of physical risk factors: posture, repetition, force, vibration, contact stress, and task duration, affecting five body parts: neck, shoulder, wrist, back, and leg. The WERA is a pen-and-paper method, requiring no special equipment, and has a scoring system with action levels that provide guidelines for risk levels and actions needed for conducting more detailed assessments. The method can be used in any space of workplaces without disturbing the workforce [57].

Further, in 2012, the authors conducted a validity and reliability test of the WERA method and presented it at the International Conference on Industrial Engineering and Operations Management, Istanbul. Reliability was assessed using video recordings of workplace tasks, and validity was established by correlating it with the Body Discomfort Survey (BDS). The authors found that the WERA method is applicable for the assessment of WRMSD in any body part [112]. In the same year, the WERA method was used to assess WRMSD among wall plastering workers by the same authors [111] [205].

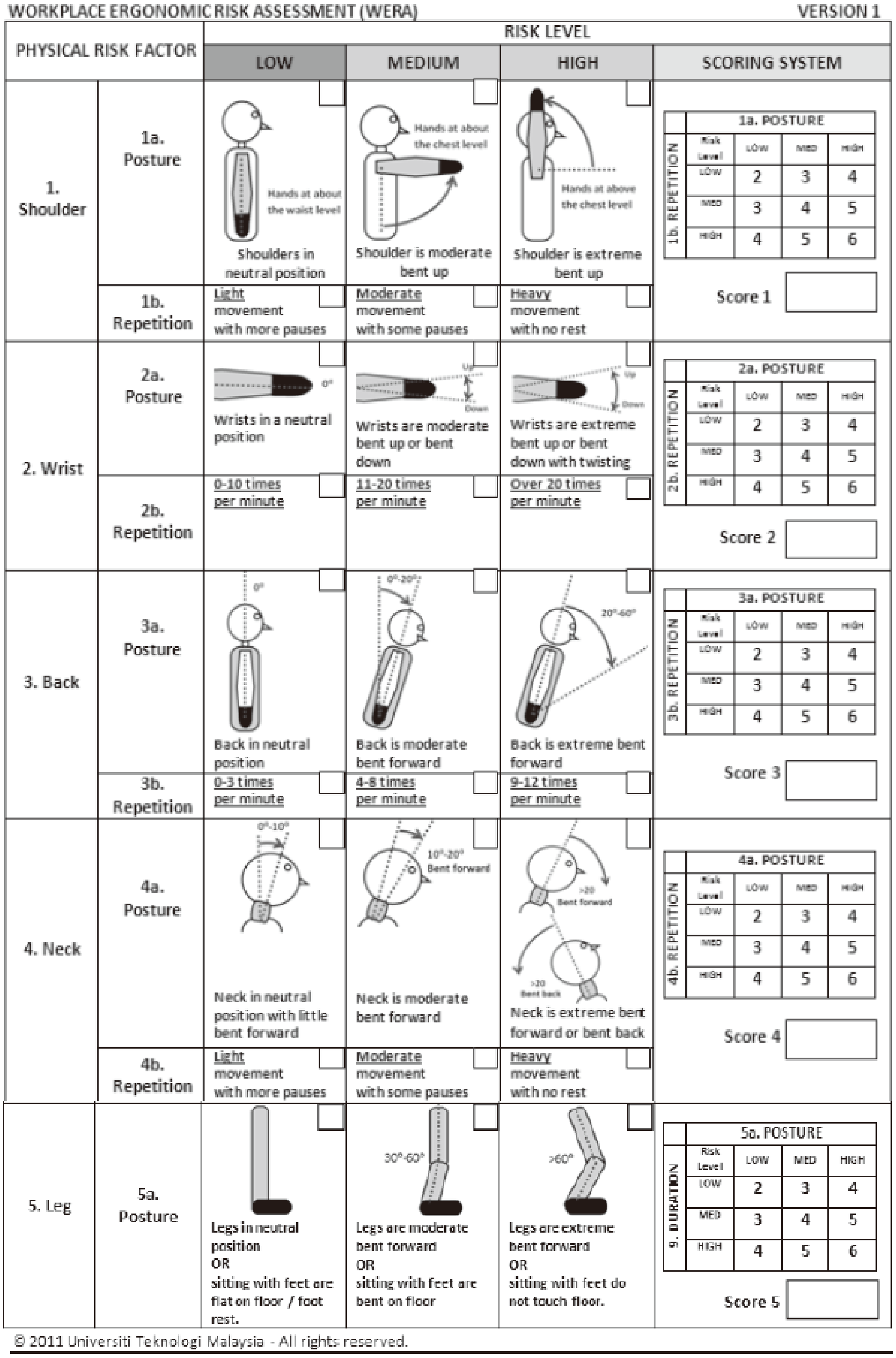
The procedure for using WERA [57 [111]:-

1. Observe the task/job:
    a. Observe the task/job to formulate a general ergonomic workplace assessment, including the impact of work layout and environment, use of equipment, and behaviour of the worker with respect to risk taking. If possible, record data using photograph or a video camera.
2. Select the task/job for assessment.
    a. Decide which task/job to analyze from the observation in step one. The following criteria can be used:-
        - Most frequently repetitive work of task/job.
        - Extreme, unstable, or awkward posture

        - The task/job known to cause discomfort by worker.
        - Required the greatest forces, contact stress and use of vibration tool.

3. Score the task/job.
    a. Using the WERA tool, score for each items of risk factor include Part A and B (Item No. 1-9).
        - Part A (Item No. 1-5) consist a five main body areas include the shoulder, wrists, back, neck and legs. This part cover two physical risk factor for each body parts include posture and repetition.
        - Part B (Item No. 6-9) consist a four physical risk factor include forceful, vibration, contact stress and task duration.
4. Calculation of exposure scores.
    a. Calculate the score for each items (Part A and B) and the total final score. Mark the numbers at the crossing point of every pair of circled number (columns vs. rows).
        - In part A, for the Item No. 1-5 based on pair of the posture and repetition. For example: Item No. 1 - Shoulder Posture (1a) vs. Shoulder Repetition (1b)
        - In part B, for the Item no 6-8, the rows side based on the posture following in part A. For example: Item No. 6 – Forceful (6) vs. Shoulder Posture (3a). And for the Item No. 9, the rows side based on the Forceful (6).

    After score for each items of risk factor (Item No. 1-9), calculate the total final score.
5. Consideration of actions level.
    a. The total final score will be indicated whether the task is accepted (final score of 18-27, low risk level) or still accepted, further investigate & required change (final score of 28-44, medium risk level) or not accepted in which need to immediately change (final score of 45- 54, high risk level).



WORKPLACE ERGONOMIC RISK ASSESSMENT (WERA) VERSION 1

PHYSICAL RISK FACTOR		RISK LEVEL			SCORING SYSTEM
		LOW	MEDIUM	HIGH	
1. Shoulder	1a. Posture	☐ Shoulders in neutral position	☐ Shoulder is moderate bent up	☐ Shoulder is extreme bent up	Score 1 ☐
	1b. Repetition	☐ Light movement with more pauses	☐ Moderate movement with some pauses	☐ Heavy movement with no rest	
2. Wrist	2a. Posture	☐ Wrists in a neutral position	☐ Wrists are moderate bent up or bent down	☐ Wrists are extreme bent up or bent down with twisting	Score 2 ☐
	2b. Repetition	☐ 0-10 times per minute	☐ 11-20 times per minute	☐ Over 20 times per minute	
3. Back	3a. Posture	☐ Back in neutral position	☐ Back is moderate bent forward	☐ Back is extreme bent forward	Score 3 ☐
	3b. Repetition	☐ 0-3 times per minute	☐ 4-8 times per minute	☐ 9-12 times per minute	
4. Neck	4a. Posture	☐ Neck in neutral position with little bent forward	☐ Neck is moderate bent forward	☐ Neck is extreme bent forward or bent back	Score 4 ☐
	4b. Repetition	☐ Light movement with more pauses	☐ Moderate movement with some pauses	☐ Heavy movement with no rest	
5. Leg	5a. Posture	☐ Legs in neutral position OR sitting with feet are flat on floor / foot rest.	☐ Legs are moderate bent forward OR sitting with feet are bent on floor	☐ Legs are extreme bent forward OR sitting with feet do not touch floor.	Score 5 ☐

1b. REPETITION	1a. POSTURE			
	Risk Level	LOW	MED	HIGH
	LOW	2	3	4
	MED	3	4	5
	HIGH	4	5	6

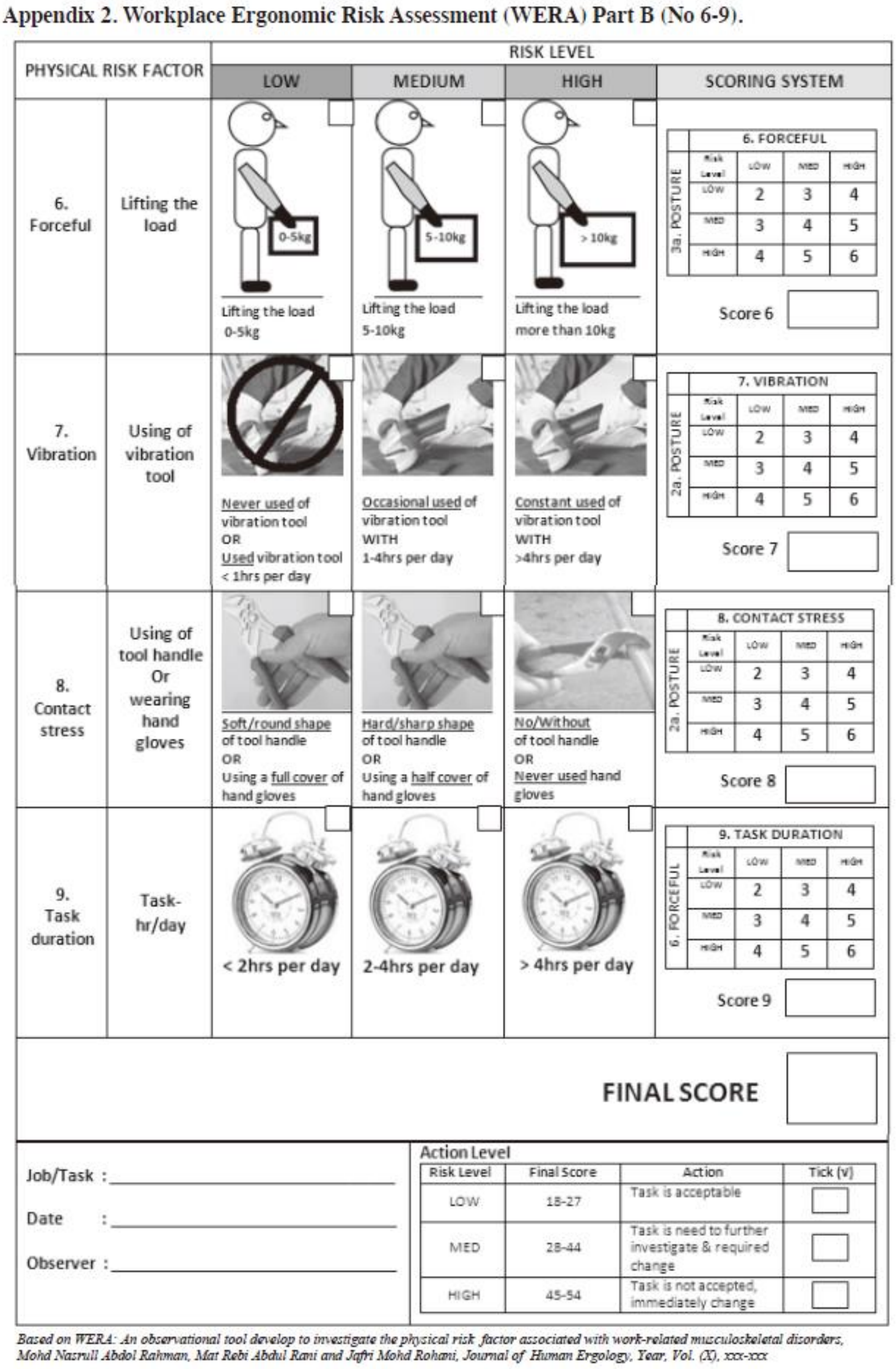
2b. REPETITION	2a. POSTURE			
	Risk Level	LOW	MED	HIGH
	LOW	2	3	4
	MED	3	4	5
	HIGH	4	5	6

3b. REPETITION	3a. POSTURE			
	Risk Level	LOW	MED	HIGH
	LOW	2	3	4
	MED	3	4	5
	HIGH	4	5	6

4b. REPETITION	4a. POSTURE			
	Risk Level	LOW	MED	HIGH
	LOW	2	3	4
	MED	3	4	5
	HIGH	4	5	6

9. DURATION	5a. POSTURE			
	Risk Level	LOW	MED	HIGH
	LOW	2	3	4
	MED	3	4	5
	HIGH	4	5	6

Figure 2.17(a) Workplace Ergonomic Risk Assessment (WERA)



Appendix 2. Workplace Ergonomic Risk Assessment (WERA) Part B (No 6-9).

PHYSICAL RISK FACTOR		RISK LEVEL			
		LOW	MEDIUM	HIGH	SCORING SYSTEM
6. Forceful	Lifting the load	☐ 0-5kg Lifting the load 0-5kg	☐ 5-10kg Lifting the load 5-10kg	☐ > 10kg Lifting the load more than 10kg	6. FORCEFUL Score 6 ☐
7. Vibration	Using of vibration tool	☐ Never used of vibration tool OR Used vibration tool < 1hrs per day	☐ Occasional used of vibration tool WITH 1-4hrs per day	☐ Constant used of vibration tool WITH >4hrs per day	7. VIBRATION Score 7 ☐
8. Contact stress	Using of tool handle Or wearing hand gloves	☐ Soft/round shape of tool handle OR Using a full cover of hand gloves	☐ Hard/sharp shape of tool handle OR Using a half cover of hand gloves	☐ No/Without of tool handle OR Never used hand gloves	8. CONTACT STRESS Score 8 ☐
9. Task duration	Task-hr/day	☐ < 2hrs per day	☐ 2-4hrs per day	☐ > 4hrs per day	9. TASK DURATION Score 9 ☐

6. FORCEFUL

3a. POSTURE	Risk Level	LOW	MED	HIGH
	LOW	2	3	4
	MED	3	4	5
	HIGH	4	5	6

Score 6 ☐

7. VIBRATION

2a. POSTURE	Risk Level	LOW	MED	HIGH
	LOW	2	3	4
	MED	3	4	5
	HIGH	4	5	6

Score 7 ☐

8. CONTACT STRESS

2a. POSTURE	Risk Level	LOW	MED	HIGH
	LOW	2	3	4
	MED	3	4	5
	HIGH	4	5	6

Score 8 ☐

9. TASK DURATION

6. FORCEFUL	Risk Level	LOW	MED	HIGH
	LOW	2	3	4
	MED	3	4	5
	HIGH	4	5	6

Score 9 ☐

FINAL SCORE ☐

Job/Task :____________________________

Date :____________________________

Observer :____________________________

Action Level

Risk Level	Final Score	Action	Tick (v)
LOW	18-27	Task is acceptable	☐
MED	28-44	Task is need to further investigate & required change	☐
HIGH	45-54	Task is not accepted, immediately change	☐

Based on WERA: An observational tool develop to investigate the physical risk factor associated with work-related musculoskeletal disorders, Mohd Nasrull Abdol Rahman, Mat Rebi Abdul Rani and Jafri Mohd Rohani, Journal of Human Ergology, Year, Vol. (X), xxx-xxx

Figure 2.17(b) Workplace Ergonomic Risk Assessment (WERA)

2.2.9 NOVEL ERGONOMIC POSTURAL ASSESSMENT METHOD (NERPA):

The method Novel Ergonomic Postural Assessment Method (NERPA) has been developed by Alberto Sanchez-Lite, Manuel Garcia, Rosario Domingo, and Miguel Angel Sebastian in 2013. It was developed using a digital human model (DMH) jointly with a 3D CAD tool suitable for product-process designing, used in aeronautical and automotive industries. This NERPA method is a modified version of RULA, which was developed for use in the automotive industry for manual assembly work, with the aim to overcome its drawbacks. In this method, suitable changes have been made to the corresponding scores of the body parts according to ergonomic standards. According to the authors, 3D visualization of the actual assembly sequence in a virtual situation and ergonomic workstation design can improve the functional performance of the manual assembly work [71].

The authors have made some changes in the RULA worksheet for NERPA, as shown in Figure 2.18. The NERPA method focuses on arms, neck, trunk, and wrists, and not on legs.

NEPRA Assessment Worksheet:

In Upper arm assessment, NERPA uses three positions for bending the arm instead of four positions, with three ranges of scores instead of four. The first level is the same, the second level has been increased by 150 to achieve better flexibility, the third level has decreased by 300, and the fourth level is eliminated, with four possible additives. The gravity remained unchanged for postures.

In Wrist assessment, NERPA gives 150 of flexion or extension to the wrist for the first level, thereby increasing to 450 for the second, and the third level position is increased by 300 compared to the RULA method. A radial and ulnar deviation is set as 100.

In Neck arm assessment, NERPA uses the same positions and values of flexion and extension as RULA; the only angular values related to twisting and lateral bending have been set to 100.

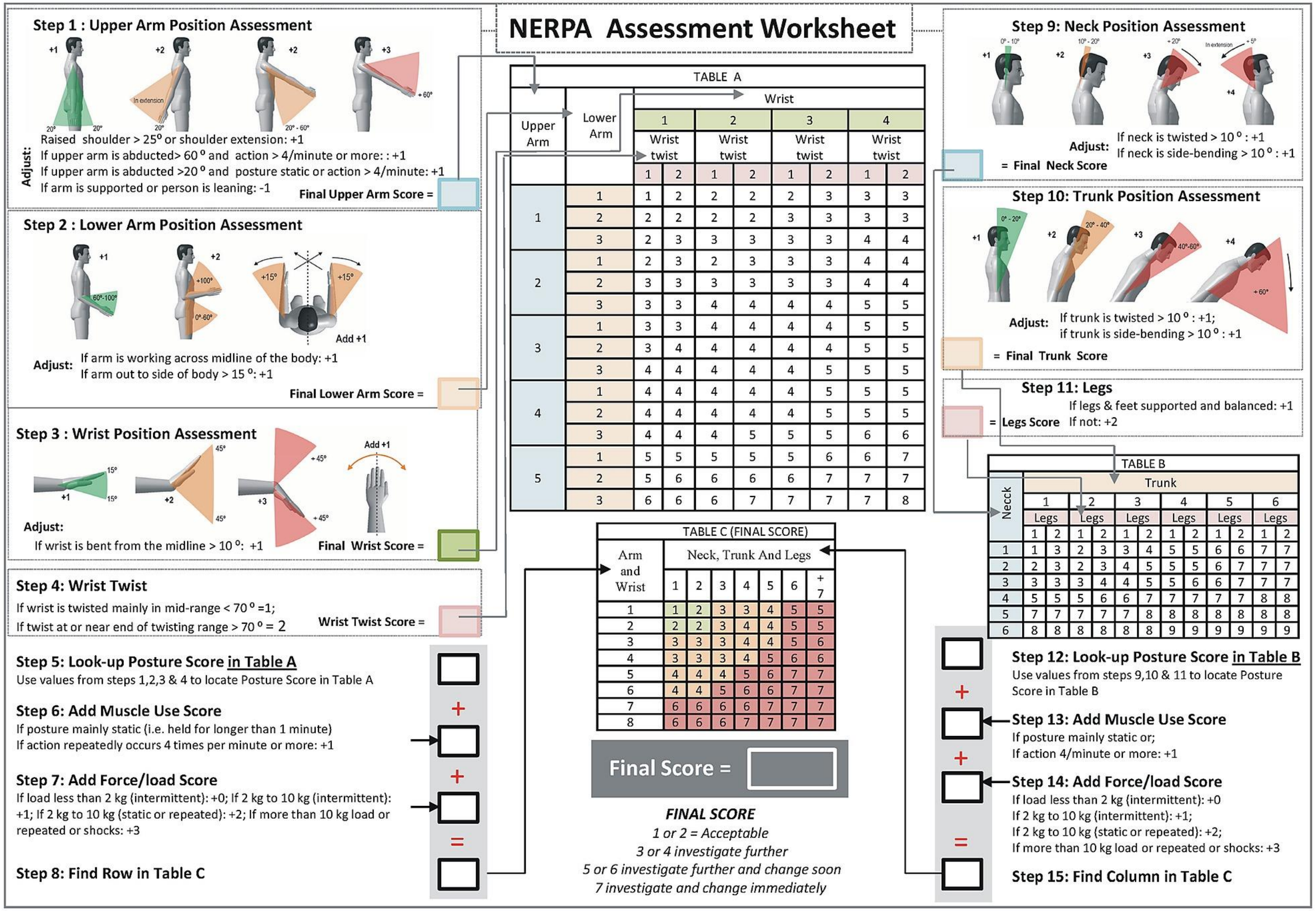
In Trunk assessment, the first level has been increased by 100, the second level has been increased by 200, and in the third level, the upper limit remains the same, whereas the lower limit has been increased by 100. The angular values related to twisting and lateral bending have been set to 100.

The comparison of joint angle values between RULA and NERPA is shown in Table 2.14. The other parameters, like muscle score, force score, and final score, are the same as RULA. The

NERPA method is found to be more significant than RULA for assessment purposes in different industries.

Table 2.14 Comparison of joint angle value of RULA and NERPA method [71]

Movement	Range	Upper Arm		Lower Arm		Wrist		Neck		Trunk	
		RULA	NERPA	RULA	NERPA	RULA	NERPA	RULA	NERPA	RULA	NERPA
Flexion	**Green**	$0-20^0$	$0-20^0$	$0-20^0$	$0-20^0$	0	$0-15^0$	$0-10^0$	$0-10^0$	$0-20^0$	$0-20^0$
	Orange	-20^0-0	20^0-60^0	-20^0-0	20^0-60^0	$0-15^0$	15^0-45^0	10^0-20^0	10^0-20^0	20^0-60^0	20^0-60^0
	Red	$>45^0$	$>60^0$	$>45^0$	$>60^0$	$>15^0$	$>45^0$	$>20^0$	$>20^0$	$< 0^0$	$0^0<$
Extension	**Green**	$0-20^0$	$0-20^0$	$0-20^0$	$0-20^0$	0	$0-15^0$	$0-10^0$	$0-5^0$	$0-20^0$	$0-20^0$
	Orange	20^0-45^0	20^0-60^0	20^0-45^0	20^0-60^0	$0-15^0$	15^0-45^0	10^0-20^0	10^0-20^0	20^0-60^0	20^0-60^0
	Red	$>90^0$	$>60^0$	$>90^0$	$>60^0$	$>15^0$	$>45^0$	$>20^0$	$>5^0$	$>60^0$	$>60^0$
Radial Deviation	**Green**					0	$0-10^0$				
	Orange					0	$>10^0$				
	Red					>0	$>10^0$				
Ulnar Deviation	**Green**					0	$0-10^0$				
	Orange					0	$>10^0$				
	Red					>0	$>10^0$				
Abduction	**Green**	0	$0-20^0$	0	$0-20^0$						
	Orange	>0	20^0-60^0	>0	20^0-60^0						
	Red	>0	$>60^0$	>0	$>60^0$						
Adduction	**Green**	0	$0-20^0$	0	$0-20^0$						
	Orange	>0	20^0-60^0	>0	20^0-60^0						
	Red	>0	$>60^0$	>0	$>60^0$						
Rotation	**Green**	-	-	-	-			0	-		
	Orange	-	-	-	-			-	-		
	Red	>0	$>15^0>60^0$	>0	$>15^0>60^0$			>0	$-10^0<10^0$		
Lateral Bend	**Green**							0	-	0	$0-10^0$
	Orange							-	-	>0	-
	Red							>0	$-10^0< >10^0$	>0	$>10^0$
Upward/ Downward Rotation	**Green**									0	$0-10^0$
	Orange									>0	-
	Red									>0	$>10^0$



NERPA Assessment Worksheet

Step 1 : Upper Arm Position Assessment

Adjust:
Raised shoulder > 25° or shoulder extension: +1
If upper arm is abducted> 60 ° and action > 4/minute or more: : +1
If upper arm is abducted >20 ° and posture static or action > 4/minute: +1
If arm is supported or person is leaning: -1

Final Upper Arm Score =

Step 2 : Lower Arm Position Assessment

Adjust: If arm is working across midline of the body: +1
If arm out to side of body > 15 °: +1

Final Lower Arm Score =

Step 3 : Wrist Position Assessment

Adjust:
If wrist is bent from the midline > 10 °: +1

Final Wrist Score =

Step 4: Wrist Twist

If wrist is twisted mainly in mid-range < 70 ° =1;
If twist at or near end of twisting range > 70 ° = 2

Wrist Twist Score =

Step 5: Look-up Posture Score in Table A
Use values from steps 1,2,3 & 4 to locate Posture Score in Table A

+

Step 6: Add Muscle Use Score
If posture mainly static (i.e. held for longer than 1 minute)
If action repeatedly occurs 4 times per minute or more: +1

+

Step 7: Add Force/load Score
If load less than 2 kg (intermittent): +0; If 2 kg to 10 kg (intermittent): +1; If 2 kg to 10 kg (static or repeated): +2; If more than 10 kg load or repeated or shocks: +3

=

Step 8: Find Row in Table C

TABLE A

Upper Arm	Lower Arm	Wrist							
		1		2		3		4	
		Wrist twist		Wrist twist		Wrist twist		Wrist twist	
		1	2	1	2	1	2	1	2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	2	3	3	3	4	4
	2	3	3	3	3	3	3	4	4
	3	3	3	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8

TABLE C (FINAL SCORE)

Arm and Wrist	Neck, Trunk And Legs						
	1	2	3	4	5	6	+ 7
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	6	6	6	6	7	7	7
8	6	6	6	7	7	7	7

Final Score =

FINAL SCORE
1 or 2 = Acceptable
3 or 4 investigate further
5 or 6 investigate further and change soon
7 investigate and change immediately

Step 9: Neck Position Assessment

Adjust: If neck is twisted > 10 ° : +1
If neck is side-bending > 10 ° : +1

= Final Neck Score

Step 10: Trunk Position Assessment

Adjust: If trunk is twisted > 10 ° : +1;
if trunk is side-bending > 10 ° : +1

= Final Trunk Score

Step 11: Legs

If legs & feet supported and balanced: +1
= Legs Score If not: +2

TABLE B

Necck	Trunk											
	1		2		3		4		5		6	
	Legs		Legs		Legs		Legs		Legs		Legs	
	1	2	1	2	1	2	1	2	1	2	1	2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	9	9	9	9	9	9

Step 12: Look-up Posture Score in Table B
Use values from steps 9,10 & 11 to locate Posture Score in Table B

+

Step 13: Add Muscle Use Score
If posture mainly static or;
If action 4/minute or more: +1

+

Step 14: Add Force/load Score
If load less than 2 kg (intermittent): +0
If 2 kg to 10 kg (intermittent): +1;
If 2 kg to 10 kg (static or repeated): +2;
If more than 10 kg load or repeated or shocks: +3

=

Step 15: Find Column in Table C

Figure 2.18 Novel Ergonomic Postural Assessment Method (NERPA) Worksheet

2.2.10 PUSH-PULL ANALYSIS USING CATIA V5R19:

Norhidayah et al. (2014) [206] executed push-pull analysis in the aerospace industry. In this study, the authors studied the awkward postures of workers while performing pushing and pulling activities in manual material handling (MMH) with the objective of evaluating the maximum tolerable initial force and sustained force during these activities carried out by workers. At the same time, the authors evaluated the activity tolerated for a longer period between pushing or pulling activities and the comfort level of awkward postures. The authors found that the tasks carried out by workers were repetitive, involving frequent movement and a large degree of freedom. The acceptable initial and sustained forces were evaluated using push-pull analysis, and the comfort level was assessed using the RULA method. Both of these evaluations were carried out using an ergonomic design and analysis tool, the Computer-aided Three-dimensional Interactive Application version 5 release 19 (CATIA V5R19) software, and the study was conducted on 6 production workers. This analysis revealed that pushing activities tolerated more force than pulling activities, in both maximum acceptable initial and sustained force, with the maximum comfort level score. This caused back pain problems for workers in the aerospace industry, which were influenced by the work activity, work load, work duration in awkward postures, and the distance between workplaces. In this study, CATIA V5R19 proved to be a future tool for the analysis of ergonomic diseases [80].

2.2.11 REVISED JOB STRAIN INDEX (JSI) (2016):

The Job Strain Index (JSI) was developed by J. Steven Moore and Arun Garg in the year 1995. It is an observational technique that identifies physical risk exposure associated with the upper limbs, primarily the hands and wrists [207]. This technique is based on existing knowledge and physiological theory, biomechanics, and epidemiology of distal upper extremities (DUE). This DUE includes carpal tunnel syndrome (CTS), tendinitis, bursitis, and other disorders related to the hands and wrists. It is related to muscle tendons and narrows the nerves of the elbow, forearm, wrist, and hands.

The Job Strain Index evaluates six parameters that cause work-related musculoskeletal disorders and their magnitude. These six parameters are:

1. Intensity of Exertion
2. Duration of Exertion
3. Efforts per Minute
4. Hand/Wrist posture
5. Speed of Work
6. Duration of Task per day

Each parameter consists of five different variable criteria for exposure and can be obtained from the time-motion study (Figure 2.19).

The Job Strain Index not only predicts the disorder but also indicates the magnitude of risk factor exposure related to work.

Calculation of Job Stress Index:

The Job Stress Index is the product of all these parameters/variables with the multipliers, as mentioned in equation no. 1. Table 2.15 explains this, and Figure 2.19 is used to score and evaluate the Job Strain Index.

JSI = (Intensity of exertion) x (Duration of work) x (Efforts/Minute) x (Hand/Wrist Posture) x (Speed of work) x (Duration of Task per day) - Eq. 1

Table 2.15 Risk Factors and its Multiplier

Rating	Intensity of exertion (Multiplier)	Duration of work (Multiplier)	Efforts/ Minute (Multiplier)	Hand/Wrist Posture (Multiplier)	Speed of work (Multiplier)	Duration of Task per day (Multiplier)
1	Light (Barely noticeable or relaxed effort) (1)	<10% (0.5)	<4 (0.5)	Very Good (Perfectly neutral) (1.0)	Very Slow (1.0)	<1 (0.25)
2	Somewhat hard (Noticeable or definite effort) (3)	10 – 29 % (1.0)	4 – 8 (1.0)	Good (Near neutral) (1.0)	Slow (1.0)	1-2 (0.50)
3	Hard (Obvious effort, Unchanged facial expression) (6)	30-49% (1.5)	9-14 (1.5)	Fair (Non neutral) (1.5)	Fair (1.0)	2-4 (0.75)
4	Very hard (Substantial effort, changes facial expression) (9)	50-79% (2.0)	15-19 (2.0)	Bad (Marked deviation) (2.0)	Fast (1.5)	4-8 (1.0)
5	Near Maximal (Uses shoulder or truck to generate force) (13)	≥80 % (3.0)	≥20 (3.0)	Very Bad (Near Extreme) (3.0)	Very Fast (2.0)	≥8 (1.5)

For doing this analysis, it is necessary to collect the data for the above parameters, rate the values, select multipliers, calculate the SI Score, and carry out the analysis on the following factors:

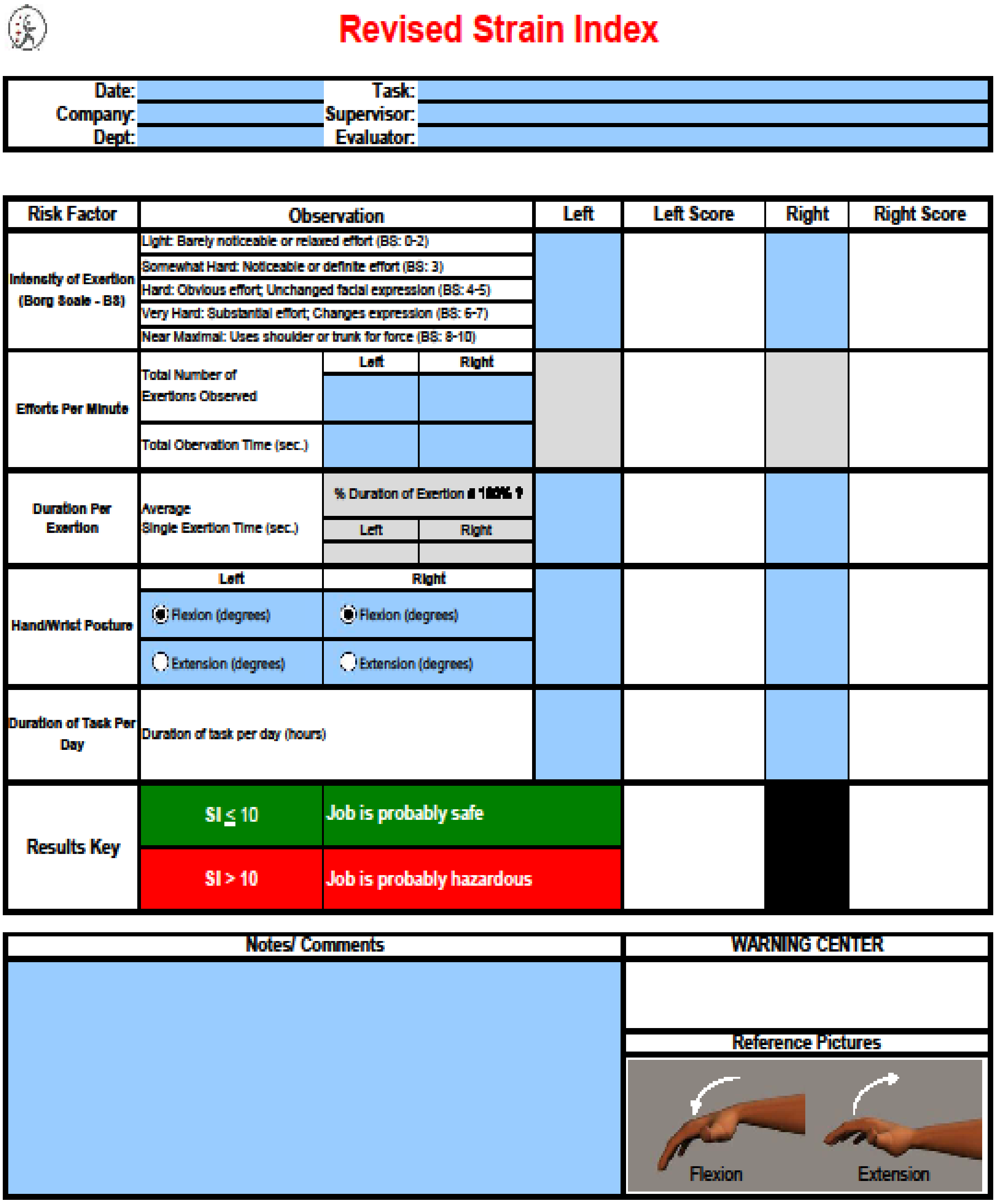
1. If the SI Scores are less than or equal to 3, they are probably safe.
2. If the SI Scores are greater than or equal to 7, they are probably hazardous.
3. The mechanical compression should be considered separately. Moore and Garg (1995) also carried out work within the pork processing industry and suggested that the job or task is hazardous if the SI score is equal to or greater than 5, and safe if the score is less than 5 **[207].** Further, a three-level hazard criterion has been used by many users, suggesting that the job or task is safe if the score is less than 3.0, the job or task is unsafe or needs some intervention if the score is between 3.0 and 7.0, and the job or task is hazardous if the score is greater than 7.0 [208][209][210][211][212][27].

The method Job Strain Index was designed to assess physical risk exposure for cyclic and single exertion jobs and not for multiple task ratings. Attempts have been made to score and rate multiple tasks by different authors [213][211] [204], for which Moore and Garg (1995) suggested that a team of two or more persons should analyze the task together. Another limitation with the Job Strain Index is that it does not consider mechanical compression or other vibration risk factors, for which many upgrades and work have been carried out in this Job Strain Index. Recently, in 2016, Garg et al. (2016) [166] developed a new assessment model, namely the Revised Strain Index (RSI) (Figure 2.19), for distal upper extremity exposure. This model is based on five variables rather than six, which are: Intensity of exertion (Force), Duration of work (Duration per exertion), Efforts per minute (Frequency), Hand/Wrist posture (Wrist Flexion or Extension), and Duration of task per day (Hours per day), using continuous variables and multipliers. This model is similar to the old SI but slightly different. It omits the speed of work and includes the duty cycle rather than duration per exertion. The parameters—intensity of exertion, efforts per minute, and hours of exposure per day—are the same as the old ones, but there is a difference in the hand/wrist postural variable, where gripping/pinching force is applied to wrist flexion/extension. The duty cycle has been replaced with duration per exertion, though these variables are interrelated. The duty cycle does not distinguish between tasks of the same duty cycle but different exertion durations.

The formula to calculate RSI and the details of the Revised Strain Index rating and associated multipliers are given below:

RSI = (Intensity of exertion/Force) x (Duration of work/Duration per Exertion) x (Efforts/Minute/Frequency) x (Hand/Wrist Posture/Wrist Flexion or Extension) x (Duration of Task per day/Hours per day)

If the final outcome is less than 10, then the job is safe; if the final RSI score is more than 10, then the job is hazardous and needs some improvements [166].



Revised Strain Index

Date:		Task:	
Company:		Supervisor:	
Dept:		Evaluator:	

Risk Factor	Observation			Left	Left Score	Right	Right Score
Intensity of Exertion (Borg Scale - BS)	Light: Barely noticeable or relaxed effort (BS: 0-2) Somewhat Hard: Noticeable or definite effort (BS: 3) Hard: Obvious effort; Unchanged facial expression (BS: 4-5) Very Hard: Substantial effort; Changes expression (BS: 6-7) Near Maximal: Uses shoulder or trunk for force (BS: 8-10)						
Efforts Per Minute		Left	Right				
	Total Number of Exertions Observed						
	Total Obervation Time (sec.)						
Duration Per Exertion	Average Single Exertion Time (sec.)	% Duration of Exertion ≤ 100% ?					
		Left	Right				
Hand/Wrist Posture	Left	Right					
	● Flexion (degrees)	● Flexion (degrees)					
	○ Extension (degrees)	○ Extension (degrees)					
Duration of Task Per Day	Duration of task per day (hours)						
Results Key	SI ≤ 10	Job is probably safe					
	SI > 10	Job is probably hazardous					

Notes/ Comments	WARNING CENTER
	Reference Pictures

Reference: Arun Garg, J. Steven Moore & Jay M. Kapellusch (2016): The Revised Strain Index: an improved upper extremity exposure assessment model, Ergonomics, DOI: 10.1080/00140139.2016.1237678

Figure 2.19 Job Strain Index (JSI) – Revised Strain Index

CHAPTER – 3

POSTURAL ANALYSIS OF EXCAVATION WORKERS AND NOVEL DESIGN OF IRON-PAN FOR MATERIAL HANDLING

3.1 BACKGROUND

The foundation is the primary function of all construction work, as it supports the house. It is at least 1500 mm deep from the surface. This includes digging the ground to create a pit for placing the foundation and subsequently erecting the column pit. In India, a large number of construction works are performed manually, and excavation is one of the activities, although new and modern technologies have been developed to carry out construction work. However, construction work in India still requires human involvement, which demands heavy physical labor.

During construction, laborers must work in awkward postures, perform repetitive tasks, lift and lower materials, transport materials, work in a standing position, work overhead, endure high and low temperatures, and work without support, among other frequent tasks. Additionally, these workers are suffering from WRMSDs due to a lack of knowledge, proper training, guidance, properly designed ergonomic tools and equipment, as well as poor habits.

While performing excavation work, laborers experience all of the aforementioned issues. Studies have shown that these activities lead to severe accidents and the development of work-related musculoskeletal disorders (WRMSDs) [140][129][214][131][215]. In India alone, 24.20% of casualties occur every year due to various construction risk factors [19].

When excavation is in progress, the laborers have to excavate soil (dig/trench), collect the excavated soil in an iron pan, lift the iron pan, throw the excavated soil outside the pit, or pass the head pan to the laborer standing at the surface of the pit when working deep inside the pit. All of these tasks are dynamic in nature and require high physical exertion for excavation and lifting. In India, both men and women manually perform this dangerous, forceful, and dynamic work.

A single laborer performs all the activities of excavation and throwing soil outside the pit; however, extra laborers are deployed when working deep inside the pit. This work takes three to four days to dig/trench a pit of size 1500mm x 1500mm x 1800mm by a single laborer. Laborers use an axe to dig the soil, an iron pan, and spades to collect the excavated soil in the iron pan.

The laborers lift the iron pan by hand from the ground level to throw the soil outside the pit. When the laborer is unable to perform the throwing operation, extra laborers are deployed and hand the iron pan to him so he can throw the excavated soil while standing near the pit at the surface level.

Evaluating such dynamic, forceful, and repetitive work is not possible without the use of computer software that can design, perform simulations, and carry out assessments of working postures. Factors such as intense lifting, monotonous and repetitive work, insufficient rest periods, forceful physical effort, and performing activities in awkward postures for prolonged periods are responsible for exerting high biomechanical forces on the laborers' bodies. These factors also contribute to the development of work-related musculoskeletal disorders, permanent or quasi-disabilities, and casualties on construction sites.

Assessment of such biomechanical forces is not feasible manually and requires computer intervention. CATIA is capable of providing various ergonomic analyses covering all aspects of both machines and humans. Many older methods have also been upgraded as needed to achieve better results [165] [64] [82] [9] [71] [83] [84].

The RULA, REBA, and CATIA provide a comprehensive evaluation of stresses on different body parts in practical scenarios. This paper uses a computer-aided three-dimensional interactive application (CATIA), a human simulation software that validates a three-dimensional (3D) model for detailed body posture analysis.

Therefore, in this work, RULA worksheets, REBA worksheets, and CATIA software are used in an attempt to assess the ergonomic risks associated with the real-life awkward postures of Indian excavation laborers. Additionally, biomechanical and lifting analysis was performed on the real-life work postures of the laborers by developing a manikin of the real-life postures of the excavation laborers in CATIA. Later, a new iron pan was designed in CATIA, and the analysis was performed on the manikin while using the newly developed iron pan to observe the differences in the results. RULA and REBA analyses were performed using worksheets on the manikin, and biomechanical and lifting analyses were conducted on the manikin using CATIA software tools for various excavation tasks with the newly designed iron pan.

3.2 VARIOUS TASK PERFORMED BY THE EXCAVATION WORKERS

3.2.1 Excavation of soil using pic-axe (JOB-1):

During this task, workers perform excavation work by extending the shoulder, trunk extension, sometimes twisting of the trunk, both arms above the shoulder, radial deviation of the wrist when both arms are above the shoulder, ulnar deviation of the wrist when both arms are below the shoulder, legs in a flexed position (bent) at the knees between 30°-60°, and leg abduction. Figure 3.1(i)(a) - 3.1(i)(b) shows a real image. In Figure 3.1(i)(a), in this position, the person is raising the shoulder with a pickaxe to hit the ground and loosen the soil. In the other position, Figure 3.1(i)(b), the person is hitting the ground. If the soil is dry, the pickaxe comes out quickly; otherwise, it gets stuck in the ground and requires more force to remove it.

3.2.2 Soil collection in the Iron-pan (JOB-2):

In this job, laborers use a spade to collect the excavated soil in an iron pan to throw it out of the pit of the column. During this job, the trunk of the laborers is in forward flexion at the lumbar region with an angle greater than 90°. Both arms/hands of the laborers are below shoulder level, while the wrist is under ulnar deviation. The legs are in an abducted position at the thighs and in a flexed position with the knees at an angle of 30°-60° (Figure 3.1(ii)).

3.2.3 Lift the Iron-pan (JOB-3):

After collecting the soil in the iron pan, the laborer has to lift the iron pan from the ground. The laborer throws the soil outside the pit. When the laborer cannot throw the collected soil outside the pit, the iron pan is given to the laborer standing outside the pit at the surface. In this work, the laborers lean forward from the lumbar region at an angle greater than 90°, and their arms are below shoulder level. The laborer often works in a twisted position from the lumbar region. The laborer works with the trunk, neck, and wrist extended at angles greater than 45°. When lifting the iron pan, the entire load of the iron pan falls on the hands of the laborers. Laborers hold the iron pan at elbow height, then at shoulder height, and then at the top of the shoulder. Both legs are in an abducted position at the thighs and a flexed posture at the knee (>60°) (Figure 3.1(iii)).

3.2.4 Throwing of soil outside the pit / pass the Iron-pan to outside labourer (JOB-4):

In this work, the laborer picks up the iron pan and pours the soil out of the column pit when the pit is shallow. As soon as the column pit becomes deep, the laborer gives the iron pan to the laborer standing near the column on the surface. While performing this, the laborers are in an extended posture of the vertebra, with their arms above shoulder height and the neck in an extended position. The legs are abducted at the thighs (Figure 3.1 (iv) (a)(b)).

3.2.5 Receive Iron-pan by outside labourer (JOB-5):

When the pit is deep and the laborers are unable to remove the soil out of the column pit, the laborer standing near the surface of the column pit takes the iron pan from the laborer working in the column pit. During this task, the laborer bends about 60° in the flexion position with more than 20^0 vertebral rotations. The spine and neck are in extended postures while the arms are perpendicular and raised above the shoulders. One of the legs is at the plain surface through 30°-60° of flexion and the other is above the dumped soil with a 60° flexion posture. The right leg is slightly abducted at the thigh and flexed to 90° at the knee (Figure 3.1(v)).

3.2.6 Throwing soil to dump by the outside labourer (JOB-6):

The posture of this job is shown in Figure 3.1(vi)(a)(b), in which it appears that the surface becomes rough and uneven after pouring the soil. The outside laborer is standing on an uneven plane, one foot on a flat plane and the other one and a half feet above the flat plane. In this posture, the laborer's right leg is in an upright position, while the left leg is in a flexed position and abducted at the thigh, with flexion at the knee. The hands are holding the iron pan above shoulder level, and the wrists are in an extended posture.

(a)- Position – 1 (P-1)

(b) – Position – 2 (P-2)

Figure (i): Labourers performing excavation work using pick-axe (Loosen the soil) (Job-1)

Figure (ii): Labourer performing collection of soil in Iron-pan (Job-2)

Figure (iii): Labourer performing lifting of Iron-pan (Job-3)

(a) (b)

Figure (iv): Labourer performing soil throwing / passing Iron-pan to outside labourer (Job-4)

Figure (v): Outside labour receive Iron-pan from Inside labour (Job-5)

(a) (b)

Figure (vi): Outside labourer dumping soil (Job-6)

Figure 3.1: Actual images of labour performing excavation and associated work

3.3 RESULTS:

Over four weeks, 54 laborers were studied, observed, recorded, and interviewed at various construction sites. The laborers' information and feelings of discomfort, along with other related issues, were discussed with the laborers using a simple questionnaire. Additionally, the weight of the empty and filled iron pan, and the weight of the spade, were measured and recorded. The questionnaire was designed to help determine the frequency of WRMSD and other discomforts in body parts. RULA and REBA worksheets were used to evaluate the ergonomic risks of excavation laborers while performing various excavation tasks. CATIA V5 software was also used to develop and analyze selected high-risk manikins based on real-time images of the laborers. The work for the following tasks was developed and analyzed on the manikin in CATIA: 1) Excavation of soil (Job-1), 2) collection of soil in the iron pan (Job-2), 3) lifting of the iron pan (Job-3), 4) throwing soil outside the pit or passing the iron pan to the outside laborer (Job-4), 5) receiving the iron pan by the outside laborer (Job-5), and 6) throwing and dumping soil by the outside laborers (Job-6). After obtaining the results from RULA, REBA, and CATIA, a new iron pan was designed and modeled in CATIA. The manikin was also developed in CATIA, and various postures were created and analyzed for different working positions using the newly proposed crowbar for excavation and the novel design of the iron pan for material handling.The evaluation of RULA, REBA, biomechanical, and lifting was performed on the following tasks: 1) Excavation of soil (Job-1), 2) collection of soil in the novel design of the iron pan for material handling (Job-2), 3) lifting of the novel design of the iron pan for material handling from the ground level for weights of 20kg, 15kg, and 10kg (Job-3), 4) throwing soil by the inside laborer or passing the novel design of the iron pan for material handling to the outside laborer when the head pan is at the shoulder level for weights of 20kg, 15kg, and 10kg (Job-4), 5) receiving the novel design of the iron pan for material handling by the outside laborer for weights of 20kg, 15kg, and 10kg (Job-5), and 6) lifting analysis of the manikin for Job 2, Job 3, and Job 4 for the same weight lifting. For the analysis, repetition, static muscle load, force, working postures, and lack of break time were considered while developing the computer manikin. The standard rules of anthropometry were followed as per the guidelines. Green, yellow, orange, and red colors were designated for "acceptable posture," "need further investigation and change," "need further investigation and change soon," and "need investigation and change immediately," respectively [216].

The studied workers were doing manual excavation work at different construction sites. Table 3.1 shows the workers' age (years), height (cm), weight (kg), experience (years), BMI (kg/m²), working hours, and rest hours. The duration of working hours depends on the demand for work, but the standard daily working hours are 9 (± 1) hours, and rest is 1 (± 30 minutes). Workers' BMI was found to be in the range of 18 to 25 kg/m²; however, six workers were found to be above the BMI limit (> 25 kg/m²).

Table 3.1: Somatic Characteristics of workers (Excavation)

Characters	**Mean (±SD)**
Age (years)	39.67 (± 9.43)
Height (cm)	161.52 (± 5.74)
Weight (kg)	58.81 (± 6.91)
Work Experience (years)	16.22 (± 9.71)
BMI (kg/m2)	22.52 (± 2.11
Working hours/day (hours)	9 (±1)
Rest hours/day (hours)	1 (± 30min)

According to Table 3.2, the most affected body parts are the lower back (85%), shoulders (85%), and arms/hands (74%). Trauma was also reported in the wrist (31%), chest (26%), fingers/toes (24%), and neck (19%). Figure 3.1 also shows that among all the body parts, the lower back (22%), shoulders (22%), and arms/hands (19%) are the most affected. From the video recording, it was also observed that all laborers were working in awkward postures. When the laborers worked deep inside the column pit, it was noticed that they were having trouble breathing. From the survey report, it was observed that about 90% of the laborers had migrated from other states; about 80% of the laborers were addicted to tobacco, alcohol, or smoking. Almost all age groups of laborers reported pain in different body parts except the upper back, thigh, hip, buttocks, knees, ankles, feet, and toes. The study also revealed that 48.15% of laborers have pain after working, 18.52% have pain in the morning, 14.81% have pain during working, and 11.11% have pain while sleeping.

Table 3.2: Worker reply to pain/discomfort (N=54) (Excavation)

Body Parts	Number of workers	% of workers
Head	7	13
Neck	10	19
Shoulder	46	85
Chest	14	26
Elbow	2	4
Arms/Hands	40	74
Wrist	17	31
Fingers/Thumbs	13	24
Upper Back	0	0
Lower Back	46	85
Thigh/Hip/Buttock	0	0
Legs	17	31
Knees	0	0
Ankle/Feet/Toe	0	0

For evaluation, six postures were selected for the study: 1) Excavation of soil using a pick-axe (Job 1), 2) Soil collection in the iron pan (Job 2), 3) Iron pan lifting (Job 3), 4) Throwing of soil outside the pit or passing the iron pan to the outside laborer (Job 4), 5) Iron pan received by the outside laborer (Job 5), and 6) Dumping of soil by the outside workers (Job 6). The laborers perform the work of loosening soil, collecting soil, lifting the pan, and throwing the soil themselves. An additional laborer is required when the worker is unable to throw the excavated soil out of the column. Figures 3.1(i) to 3.1(vi) show the real-time images of excavation work and jobs considered for analysis.

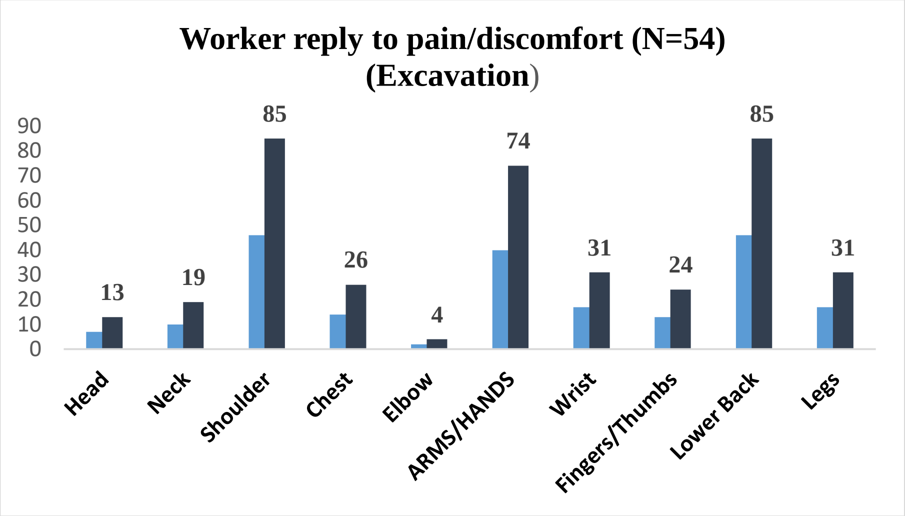


Figure 3.2 Number and percentage of worker reply to pain/discomfort

3.4 Result of RULA, REBA, Biomechanical and Lifting Analysis for Traditional Working Postures of all Task:

3.4.1 Result of RULA and REBA Method for Traditional Working Postures:

For Job 1, the score obtained from the RULA and REBA sheets shows that this job is at very high risk and needs instant change. For Job 2, the score obtained from the RULA and REBA shows that this job is at very high risk and needs instant change. For Job 3, the score obtained from the RULA and REBA shows that this job is at very high risk and needs instant change. For Job 4, the RULA and REBA scores obtained for this job show that this job is also at very high risk and needs immediate change. For Job 5, the RULA and REBA scores for this job show that this job is also at very high risk and needs immediate change. For Job 6, the RULA and REBA scores for this job show that this job is also at very high risk and needs immediate action to change the working posture.

Overall, the RULA and REBA scores were monitored with job repetitions, static load on muscle groups, awkward working postures, and no rest time. Tables 3.3 and 3.4 show the final scores of RULA and REBA for all six tasks. RULA's results were found to be more than 7 for all jobs and 11 for REBA, which revealed that they require investigation and immediate change. The RULA and REBA scores show that the neck, trunk, and legs are mainly affected on both the left and right sides of the body while performing Job 1 (P-1) & (P-2), Job 2, Job 3, and Job 5. Job 4 mostly affects the wrists and hands, while Job 6 affects the lumbar and shoulder. The RULA and REBA scores indicate that the neck, trunk, lumbar region, and legs are mainly affected by working in awkward postures.

Table 3.3 RULA Scores for Traditional Working Postures of Excavation

BP	**Job 1-P1**		**Job 1 -P2**		**Job 2**		**Job 3**		**Job 4**		**Job 5**		**Job 6**	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R
UA	3	3	3	3	3	2	3	3	5	5	4	4	4	4
LA	2	2	2	2	3	3	2	2	2	2	2	2	2	2
W	4	3	4	3	3	3	3	3	4	4	3	3	3	3
WT	1	1	1	1	2	2	2	2	2	2	2	2	2	2
SC(A)	5	4	5	4	5	4	4	4	7	7	5	5	5	5
M	1	1	1	1	1	1	1	1	1	1	1	1	1	1
F	3	3	3	3	1	1	3	3	3	3	3	3	3	3
SC(C)	**9**	**8**	**9**	**8**	**7**	**6**	**8**	**8**	**11**	**11**	**9**	**9**	**9**	**9**
N	4		4		5		5		5		5		5	
BK/T	6		6		5		5		2		5		4	
L	1		1		2		2		2		2		2	
SC(B)	8		8		8		8		7		8		8	
M	1		1		1		1		1		1		1	
F	1		1		1		3		3		3		3	
SC(D)	**12**		**12**		**10**		**12**		**11**		**12**		**12**	
RLS	**>7***		**> 7***		**> 7***		**> 7***		**> 7***		**> 7***		**> 7***	

Table 3.4 REBA Scores for Traditional Working Postures of Excavation

	Job 1-P1	Job 1 – P2	Job 2	Job 3	Job 4	Job 5	Job 6
N	3	2	3	3	3	3	3
BK/T	4	4	5	5	3	5	4
L	3	4	3	4	2	4	4
PS(A)	8	8	9	9	6	9	9
F	1	1	1	2	2	2	2
TS(A)	9	9	10	11	8	11	11
UA	2	2	2	2	5	5	3
LA	2	2	1	2	2	2	2
W	2	2	2	2	2	2	2
PS(B)	3	3	2	3	8	8	5
CP	1	1	0	2	2	2	2
TS(B)	4	4	2	5	10	10	7
TS(C)	10	10	10	12	11	12	12
A	1	1	1	1	1	1	1
RBS	11*	11*	11*	13*	12*	13*	13*

3.4.2 Biomechanical Analysis for Traditional Methods adopted:

Overall, from the postures of the manikin designed in CATIA, the biomechanical analysis was performed to calculate and report lumbar spinal loads such as moments about L4/L5, compression on L4/L5, body load compression, axial twist compression, flexion/extension compression, joint shear about L4/L5, abdominal force, abdominal pressure, and body movements developed for real-time posture. All the output of the designed model is based on scientific research data. Tables 3.5 and Figure 3.3 (i) to (vi) show the results of the biomechanical single action analysis for all six jobs of the excavation work.

For Job 1, the biomechanical result shows that the moment about L4/L5 (M) is 258 Nm, compression on L4/L5 (C) is 5044 N, and joint shear about L4/L5 (JS) is 164 N (A), while abdominal force (AF) and abdominal pressure (AP) for the real-time posture developed are 92 N and 3 N/m^2, respectively, for position 1. The biomechanical result for position 2 shows that the moment about L4/L5 (M) is 132 Nm, compression on L4/L5 (C) is 2213 N, and joint shear about L4/L5 (JS) is 550 N (A), while abdominal force (AF) and abdominal pressure (AP) for the real-time posture developed are 84 N and 3 N/m^2, respectively.

For Job 2, the biomechanical result shows that the moment about L4/L5 (M) is 75 Nm, compression on L4/L5 (C) is 1063 N, and joint shear about L4/L5 (JS) is 385 N (A), while abdominal force (AF) and abdominal pressure (AP) for the real-time posture developed are 48 N and 2 N/m^2, respectively.

For Job 3, the biomechanical result shows that the moment about L4/L5 (M) is 156 Nm, the compression on L4/L5 (C) is 2587 N, and joint shear about L4/L5 (JS) is 379 N (A). Abdominal force (AF) and abdominal pressure (AP) are 75 N and 3 N/m^2, respectively.

For Job 4, the biomechanical result shows that the moment about L4/L5 (M) is -28 Nm, the compression on L4/L5 (C) is 1032 N, and joint shear about L4/L5 (JS) is 50 N (A). Abdominal force (AF) and abdominal pressure (AP) are 0 N and 0 N/m^2, respectively.

For Job 5, the biomechanical result shows that the moment about L4/L5 (M) is 260 Nm, the compression on L4/L5 is 5719 N, and joint shear about L4/L5 is 202 N (A). Abdominal force (AF) and abdominal pressure (AP) are 183 N and 6 N/m^2, respectively.

For Job 6, the biomechanical result shows that the moment about L4/L5 (M) is 116 Nm, the compression on L4/L5 (C) is 3530 N, and joint shear about L4/L5 (JS) is 109 N (A). Abdominal force (AF) and abdominal pressure (AP) are 0 N and 0 N/m^2, respectively.

Table 3.5: Biomechanical analysis results of all six jobs for Traditional Working postures of Excavation

	Job 1-P1	Job 1 –P2	Job 2	Job 3	Job 4	Job 5	Job 6
M (Nm)	258	132	75	156	-28	260	116
C (N)	**5044**	**2213**	**1063**	**2587**	**1032**	**5719**	**3530**
BLC (N)	263	-308	-351	-49	604	179	606
ATC (N)	25	135	46	25	3	572	30
F/EC (N)	4306	2208	1249	2605	335	4336	1938
JS (N)	**164 (A)**	**550 (A)**	**385 (A)**	**379 (A)**	**50 (A)**	**202 (A)**	**109(A)**
AF (N)	92	84	48	75	0	183	0
AP (N/m^2)	3	3	2	3	0	6	0

Overall, Table 3.5 shows the biomechanical analysis results for all six tasks. The maximum lumbar torque at L4/L5 is found to be 258 Nm, 132 Nm, 75 Nm, 156 Nm, -28 Nm, 116 Nm, and 260 Nm, and compression at L4/L5 is found to be 5044 N, 2213 N, 1063 N, 2587 N, 1032 N, 3530 N, and 5719 N for Job 1 (P-1), Job 1 (P-2), Job 2, Job 3, Job 4, Job 5, and Job 6. The compression of L4/L5 for Job 1 (P-2), Job 2, Job 3, and Job 4 is below the maximum allowable compression force, i.e., 3400 N, recommended by NIOSH. [217][218][219] However, it is higher in Job 1 (P-1), Job 5, and Job 6.

Joint shear load at L4/L5 is found to be 164 N (Anterior), 550 N (Anterior), 385 N (Anterior), 379 N (Anterior), 50 N (Anterior), 109 N (Anterior), and 202 N (Anterior) in Job 1 (P-1), Job 1 (P-2), Job 2, Job 3, Job 4, Job 5, and Job 6. The joint shear load is higher for Job 1 (P-2), which exceeds the maximum action limit of 500 N/m² recommended by NIOSH. [217][218][219]

All other jobs have a lower joint shear load than the recommended limit, but it is higher for Job 1 (P-1), Job 2, Job 3, and Job 6, as these jobs require high force while performing in a bending forward (flexion) position for a prolonged period. The detailed biomechanical analysis is shown in Table 3.5. The tasks where workers need to work in the flexion position (more than 90°) for a maximum period are not acceptable and should be minimized, as the application of shear force is higher. Job 4 and Job 5 have no abdominal force and abdominal pressure, while others have abdominal force and pressure greater than zero.

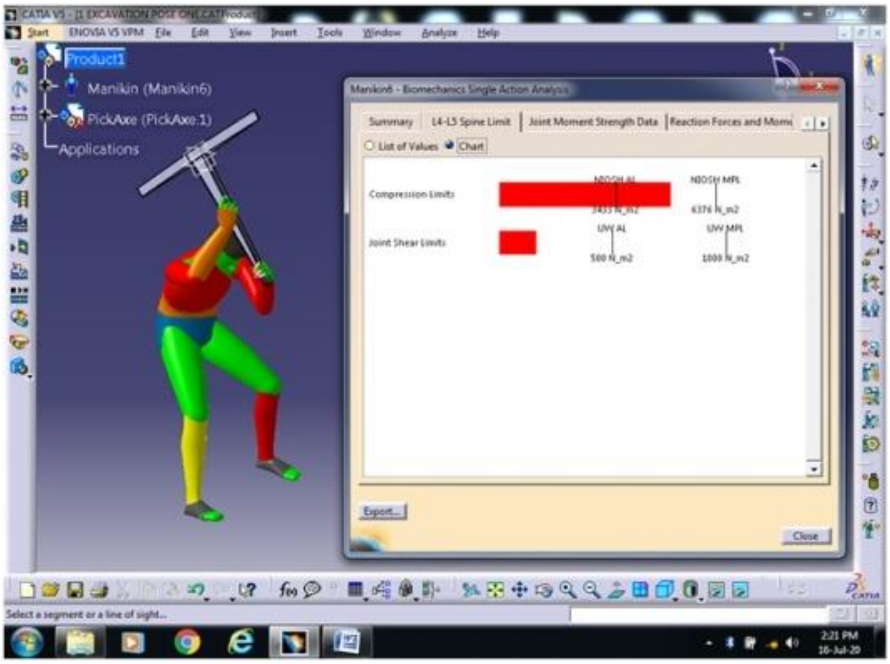


Figure (i)(a): Biomechanical analysis of first position with worker holding pick-axe above shoulder height (Job-1) (P-1)

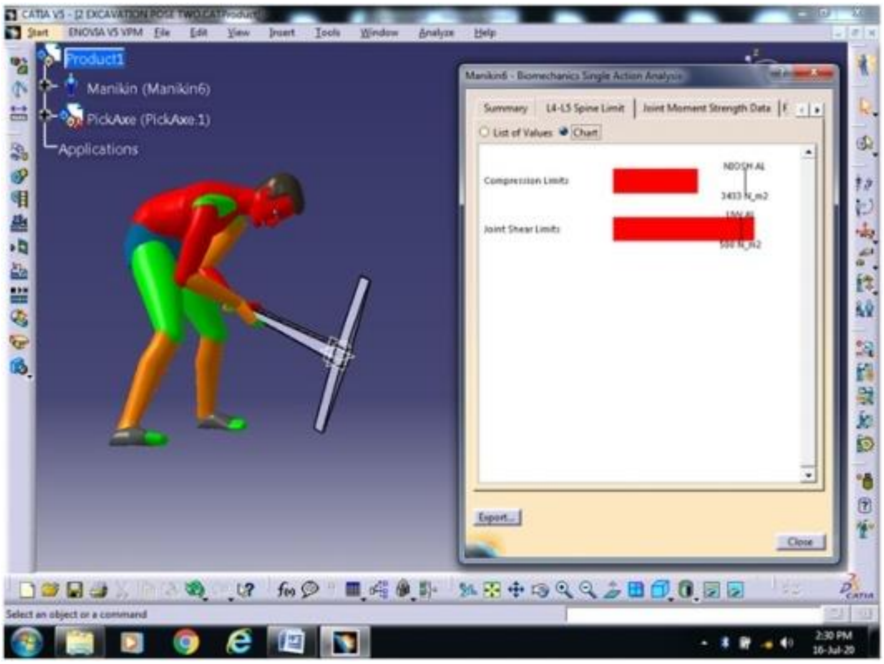


Figure (i)(b): Biomechanical analysis of second position with worker holding pick-axe below shoulder height (Job-1) (P-2)

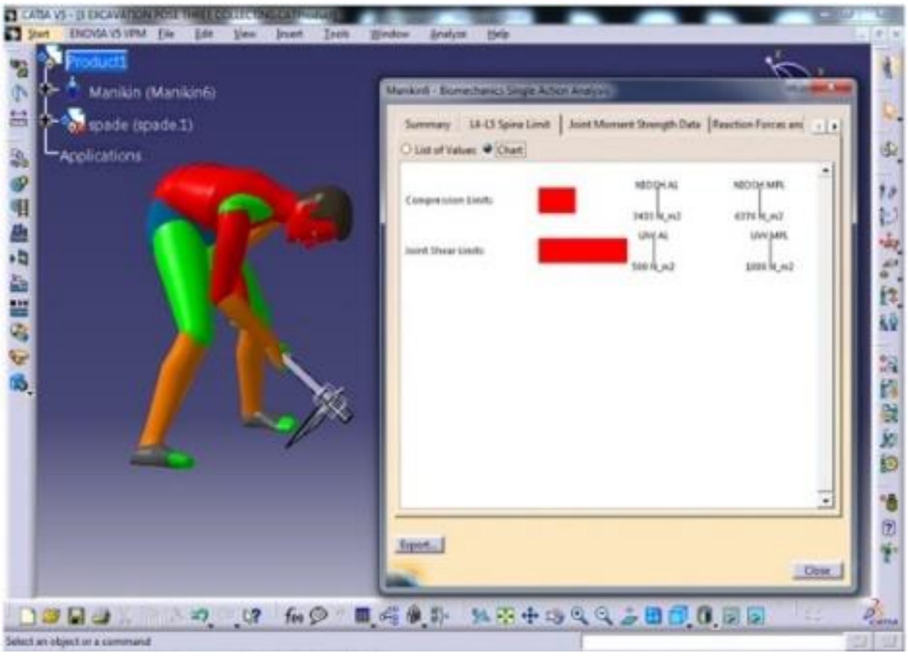


Figure (ii) Soil collection in the Iron-pan (Job-2)

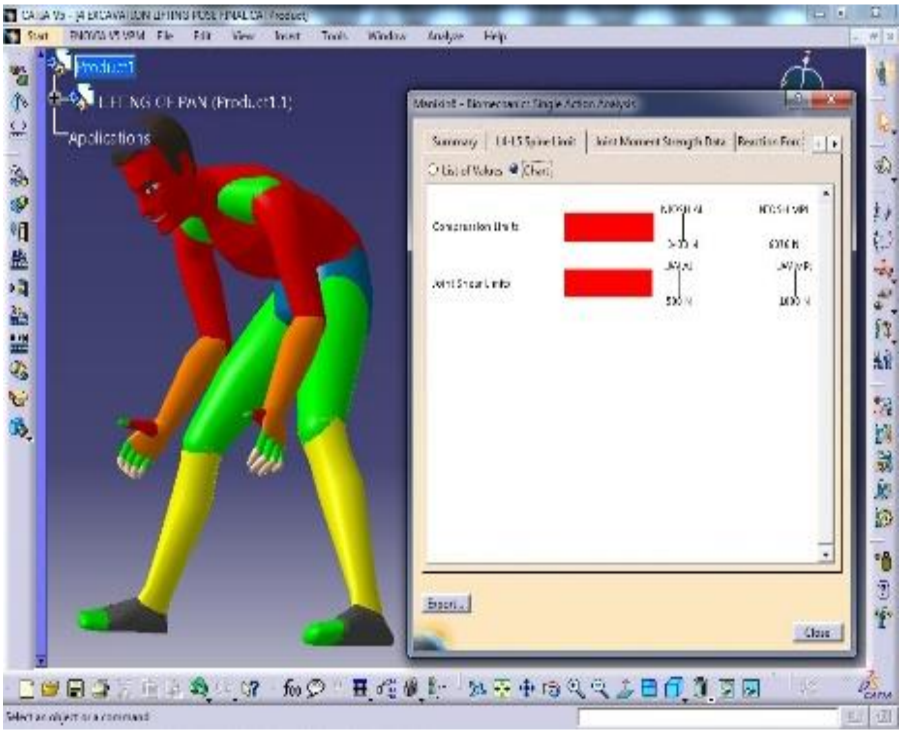


Figure (iii) Lifting of pan (Job-3)

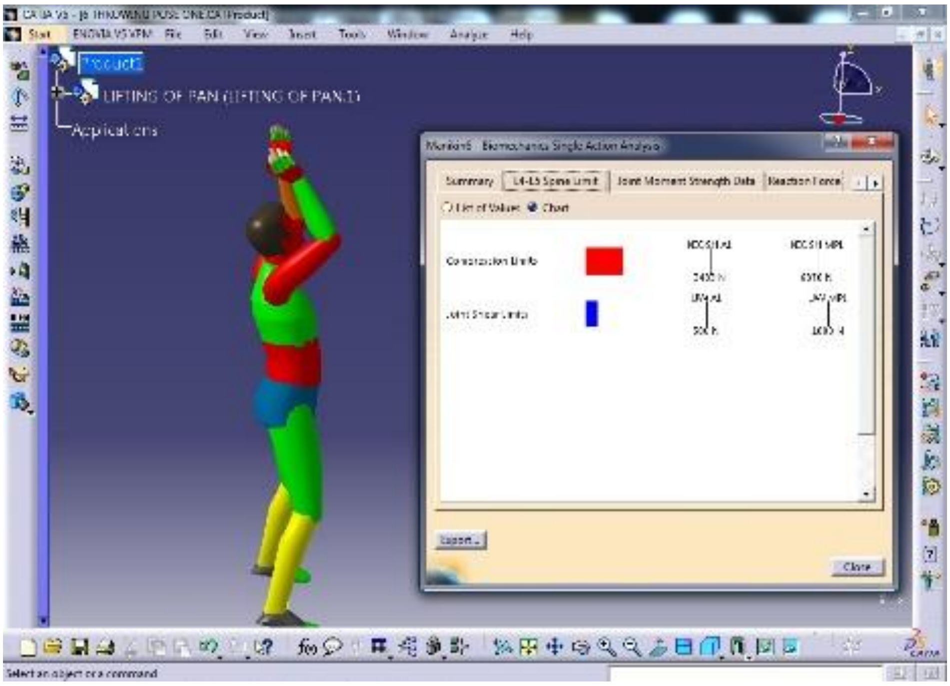


Figure (iv): Throwing of soil outside the pit / pass the iron-pan to outside labourer (Job-4)

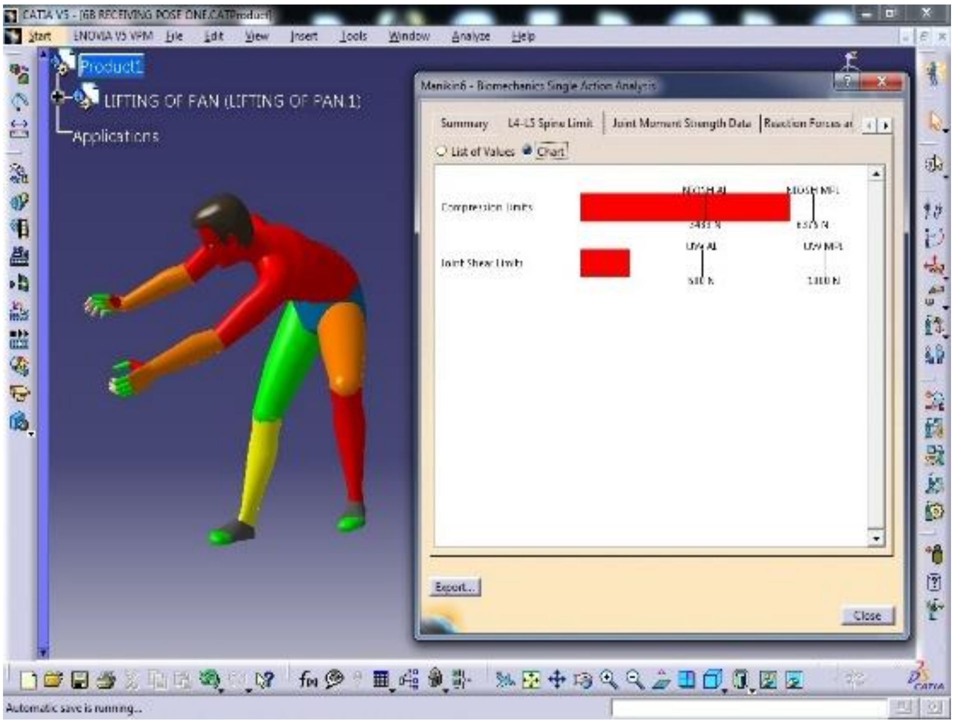


Figure (v): Receiving of iron-pan by the outside labourer (Job-5)

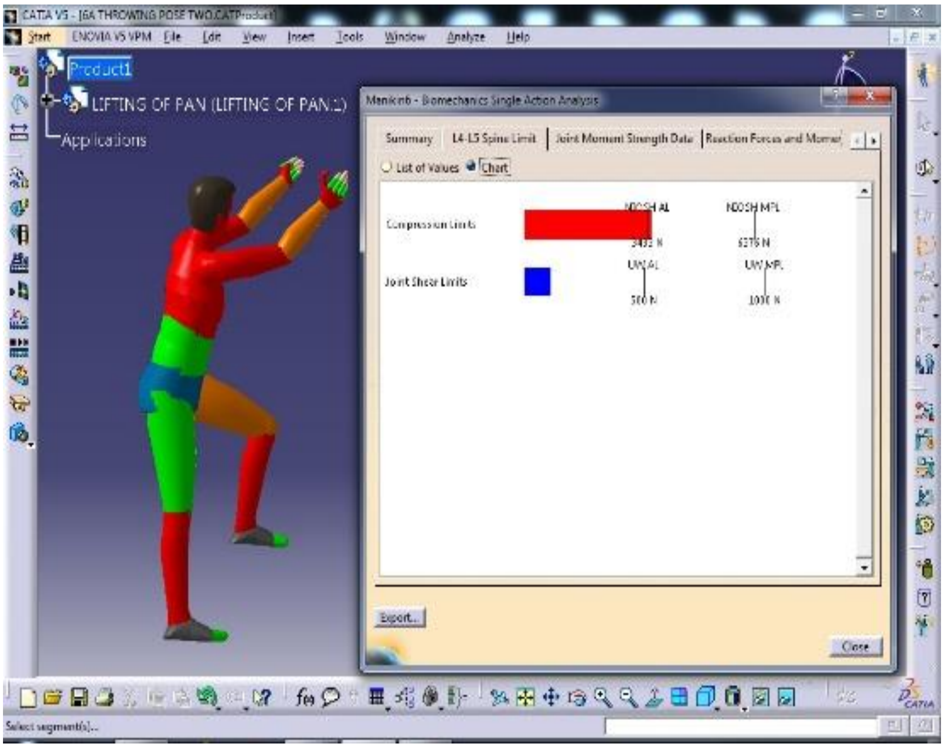
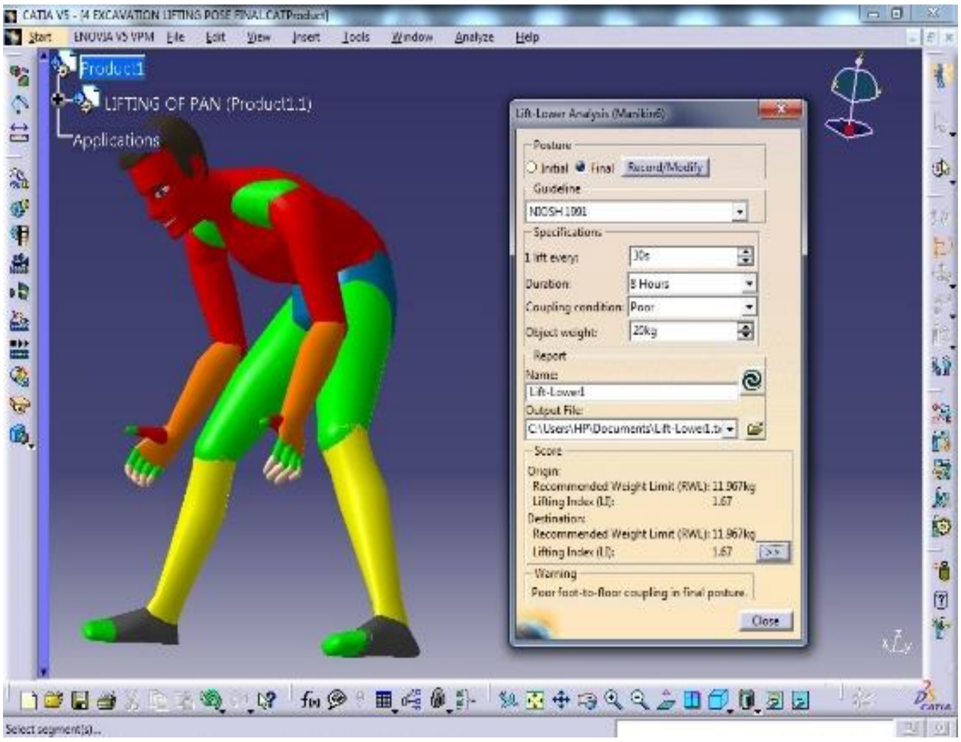


Figure (vi): Throwing of soil by the outside labourer (Job-6)

Figure 3.3 Biomechanical analysis for all Six Jobs designed in CATIA

3.4.3 Lifting Analysis for Traditional Methods adopted:

Lifting analysis was performed to identify the risk of physical stress associated with manual lifting. The National Institute for Occupational Safety and Health has developed and recommended some standard lifting equations with recommended weight limits and a lifting index [217][218][219].



Posture
○ Initial ● Final
Guideline: NIOSH 1991
Specifications
1 lift every: 30s
Duration: 8 Hours
Coupling condition: Poor
Object weight: 20kg
Report
Name: Lift-Lower1
Output File: C:\Users\HP\Documents\Lift-Lower1.t
Score
Origin:
Recommended Weight Limit (RWL): 11.967kg
Lifting Index (LI): 1.67
Destination:
Recommended Weight Limit (RWL): 11.967kg
Lifting Index (LI): 1.67
Warning
Poor foot-to-floor coupling in final posture.

Figure 3.4: Result of lifting of pan as per NIOSH 1991 guidelines designed in CATIA

The manikin developed in CATIA V5 was studied for the lifting of the filled iron pan from the ground level to overhead to pour soil outside the column pit or to hand over the iron pan to a laborer standing outside the column pit at the surface level (Figure 3.4). Laborers fill and lift 15 to 20 kg of weight every 60 seconds throughout the day, except during rest periods. The iron pan is hemispherical in shape and has no handle, so the laborers have to hold the iron pan from the bottom. The laborers lift a pan weighing an average of 20 kg, which includes the weight of the iron pan and the soil. The posture was analyzed according to NIOSH 1991 guidelines (Table 3.6). The results indicate that the recommended weight limit (RWL) (11.967 kg) and the lifting index (1.67) are higher than the recommended level (<1), and that the foot-to-foot coupling is also not in the proper position.

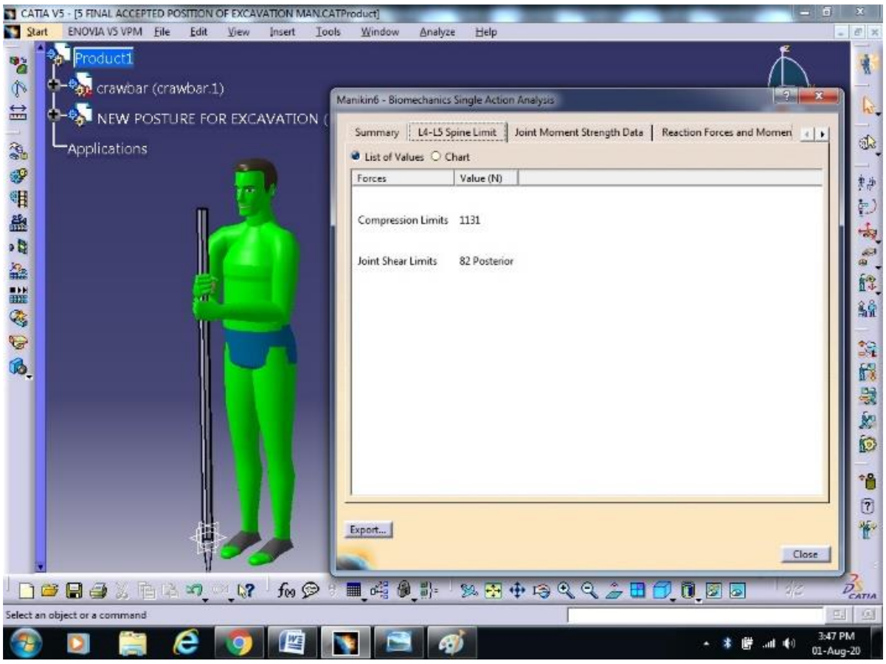
Table 3.6: Lifting pan from ground for Traditional Working Postures of Excavation

Parameters	Values
Recommended weight limit (RWL) (1991)	11.967 kg
Lifting Index (LI) (1991)	1.67
Poor foot to foot coupling in final posture	

3.5 Design Concept and Working Techniques for Excavation Workers:

3.5.1 Proposed Design Concept Of Crowbar and Working Techniques For Excavation Task (Job-1):

In this conceptual design, the pick-axe is replaced by a traditional crowbar (already available in the market and traditionally used) for the excavation task. The weight of the crowbar ranges from 3 kg to 8 kg, which is used for excavation. By using a crowbar, the workers can work in the posture shown in Figure 3.5.



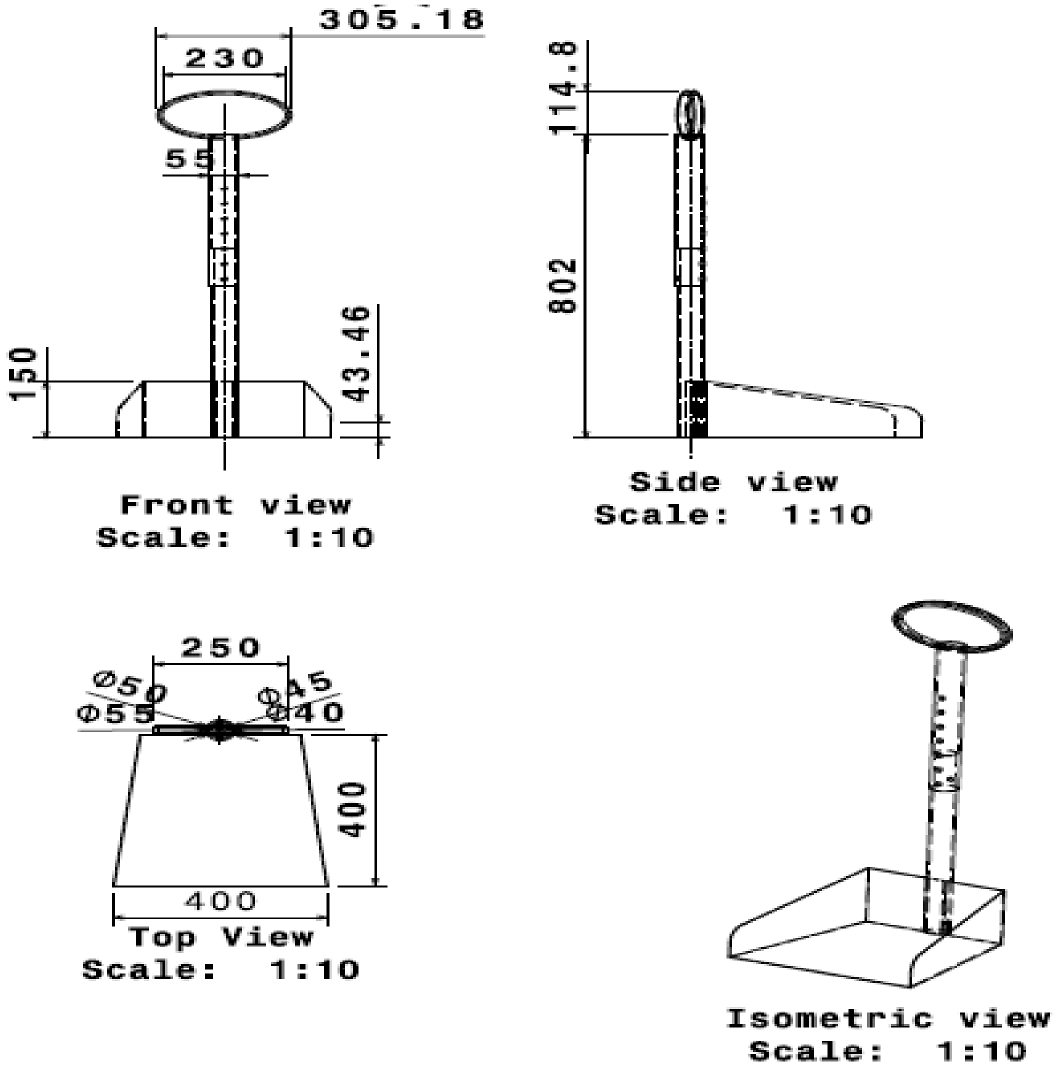
Forces	Value (N)
Compression Limits	1131
Joint Shear Limits	82 Posterior

Figure 3.5 Proposed working posture using crow bar

3.5.2 Novel Design of Iron-Pan for Material Handling and Working Postures Techniques for Job-2 to Job-4:

The new prototype iron pan was designed and modeled in CATIA. Figure 3.6 (i) and (ii) show detailed prototype iron pan drawings. Laborers have to work harder to lift the iron pan filled with the excavated soil, weighing about 15-20 kg, and finally, the biomechanical force works on the vertebrae of the laborers. To reduce this, the prototype design of the iron pan has been designed and modeled. The round pan is replaced with a trapezium-shaped iron pan by providing an adjustable vertical handle, as shown in Figure 3.6 (i) & (ii).

A detailed drawing of the iron pan is shown in Figure 3.6 (i) & (ii), where the length of the pan is 400 mm, the width of the front pan is 400 mm, and the rear is 300 mm. The height of the front side of the pan is 75 mm, and that of the rear side is 150 mm. On the back of the pan, a handle 850 mm high and 80 mm wide is fixed from the bottom, which can be easily handled/gripped using a round rubber handle. Also, the handle length of the spade has been increased from 600 mm to 800 mm to avoid further bending. At the top of the handle, an elliptical handle is provided for proper grip. The length of the handle can vary between 400 mm to 850 mm as per requirement.



All measurement are in mm

Figure (i) Novel Design of Iron-Pan for Material Handling (2D)

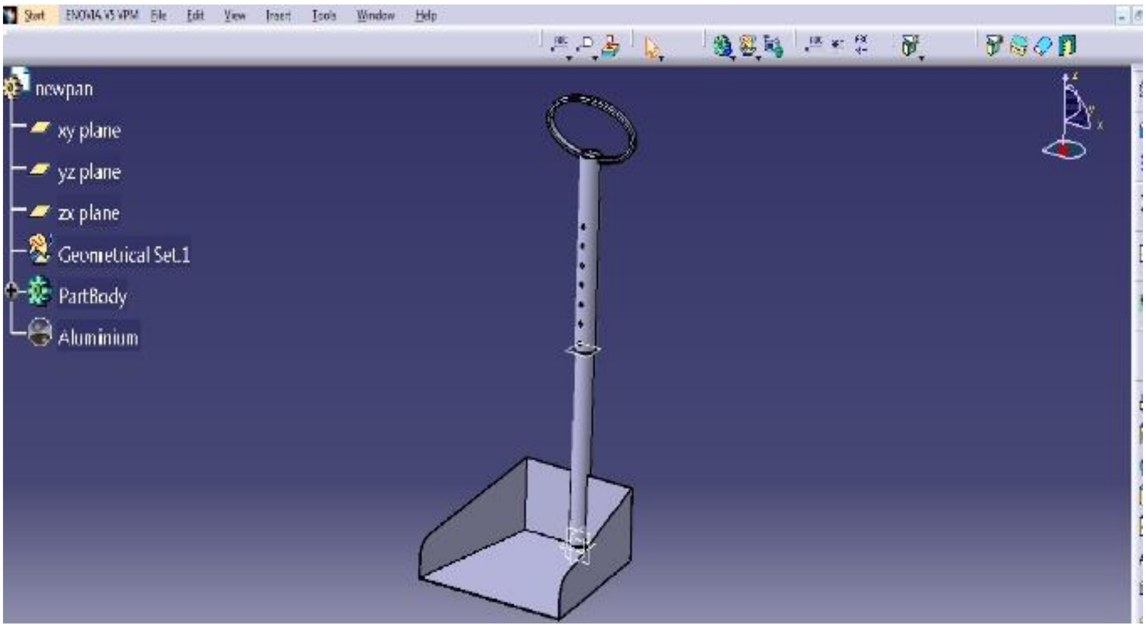
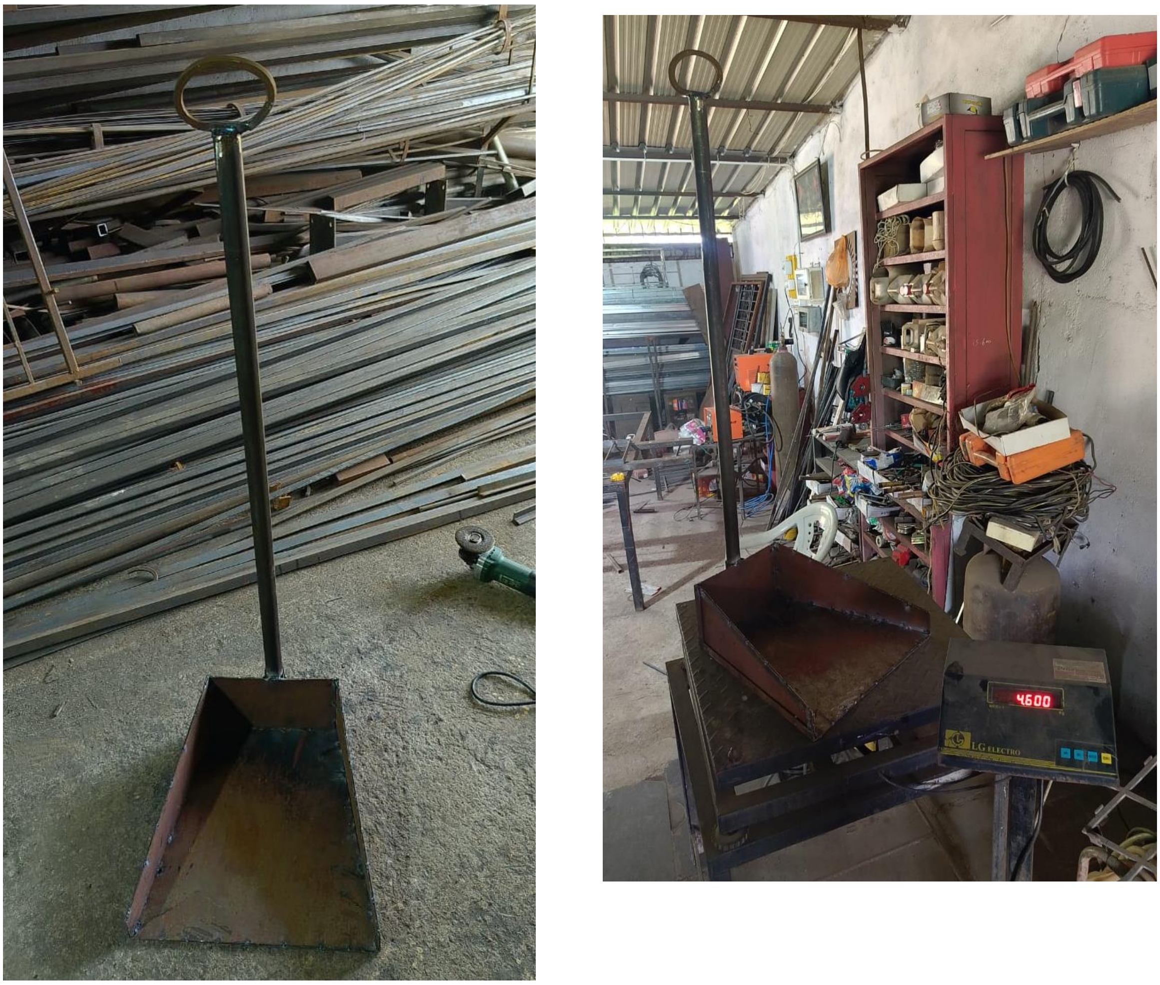


Figure (ii) Novel Design of Iron-Pan for Material Handling (3D)

(a) (b) (c)

Figure (iii) Parts of Nevel Designed Iron-pan



(a) (b)

Figure (iv) Fabricated Iron-pan

(a) (b)

Figure (v) Labour working with Novel Design of Iron-Pan

Figure 3.6 Novel Design of Iron-Pan for Material Handling

3.5.3 Fabrication of Novel Design of Iron-Pan for Material Handling:

3.5.3.1 Model of Novel Design of Iron-pan:

The designed model of novel Iron-pan has been designed in CATIA as shown in figure 3.6 (i) & (ii).

3.5.3.2 Requirment of Materials with specification:

1.	MS Angles L-Shaped	(Size - 20 mm x 20 mm x 2 mm)
2.	MS Plate	(Size – 20 mm x 2 mm)
3.	MS Sheet	(Size- 2 mm thick with required size at bottom, side and back)
4.	MS Cylindrical Pipe	(Size- dia. 30 mm x 2 mm) with length of 1200 mm
5.	MS square Bar	(Size- 10 mm x 10 mm) with oval shap 120 mm x 80 mm for Gripper

3.5.3.3 Different Parts of the Novel Design of Iron-Pan for Material Handling and their functions

1. **Iron Pan Frame:** The main frame is made of MS angle with a size of 20 mm x 20 mm x 2 mm. The frame is in the shape of a trapezium, with dimensions of 400 mm x 400 mm x 250 mm (Figure 3.6(iii)(a)). At the front bottom and side up, MS flats are used with a size of 20 mm x 2 mm. The bottom, back, and both sides of the frame are fitted with MS sheet of thickness 2 mm, as shown in Figure 3.6(iii)(b).
2. **Handle of the Iron pan (Round):** The round handle of the iron pan is fixed at the back side of the frame at the center, with a size of dia. 30 mm x 2 mm. The length of the handle is 1200 mm, which is to be taken by considering the maximum height of the user (Figure 3.6(iii)(c)).
3. **Gripper**: At the top of the handle, an oval-shaped gripper is provided, with a size of 120 mm x 80 mm. The MS square bar of size 10 mm x 10 mm is used for making the gripper. The actual iron pan for material handling is shown in Figure 3.6(iv)(a).

3.5.3.4 Fabrication of Novel Design of Iron-Pan for Material Handling:

The iron pan is made of MS angles, MS plates, MS sheets, MS round bar, and MS square bar. The fabricated iron pan is shown in Figure 3.6(iv)(a). The length of the pan is 400 mm, the width of the front pan is 400 mm, and the rear is 250 mm. The height of the front side of the pan is 60 mm, and that of the rear side is 150 mm. On the back of the pan, a round handle with a height of 1200 mm and a diameter of 30 mm is fixed at the bottom, which can be easily handled/gripped using an oval-shaped gripper. At the top of the handle, an oval-shaped gripper/handle is provided for a proper grip. The length of the handle can vary as per requirement. The working with the novel design of the iron pan is shown in Figure 3.6(v)(a)(b). The labour does not need to work in a flexion position and also does not need to support the traditional round iron pan with the legs, as shown in Figure 3.1(ii), because the bottom of the novel-designed iron pan is flat. The labour does not need to use a spade for collecting the material. By pushing the pan with the help of the leg, the material can be collected in the novel iron pan, as shown in Figure 3.6(v)(a), and it can also be easily lifted without bending forward (flexion) due to the long handle, as shown in Figure 3.6(v)(b). From the study, it is found that the novel-designed iron pan is capable of minimizing the problem of working in flexion positions, and lifting the pan has become easier than with the earlier design.

3.5.3.5 Total cost of manufacturing/Fabrication:

The total weight of the iron pan is 4.600 kg, which can be easily lifted with or without materials (Figure 3.6(iv)(b)). As the rate of the MS is Rs. 115/- including labour charges, the total cost of the iron pan, when calculated, comes out to be Rs. 529/- (rounded off to Rs. 530/-), a very negligible cost.

3.6 Postural Analysis And Biomechanical Analysis Using Novel Design Of Iron-Pan For Material Handling And Proposed Methods

3.6.1 Postural Analysis for Excavation Task (JOB-1) after Modification:

3.6.1.1 RULA Analysis for Proposed Design Concept of Crowbar and Working Technique for Excavation Task (Job-1):

From Table 3.7 and Figure 3.7 (a) & (b), it is found that the RULA score for this working posture is obtained as 5 for both the right and left sides. At the same time, all the body parts are not exposed to any hazardous working posture. Also, the effort required for doing excavation work in this posture seems low.

Table 3.7: RULA scores for first, second and new proposed conceptual body position (Excavation)

	Left			Right		
Task	Wrist/ Arms	Neck/ Trunk/ Legs	Total Score	Wrist/ Arms	Neck/ Trunk/ Legs	**Total Score**
First body position	12	11	> 7	13	11	**> 7**
Second body position	9	12	> 7	8	12	**> 7**
New Body position	5	4	5	5	4	**5**

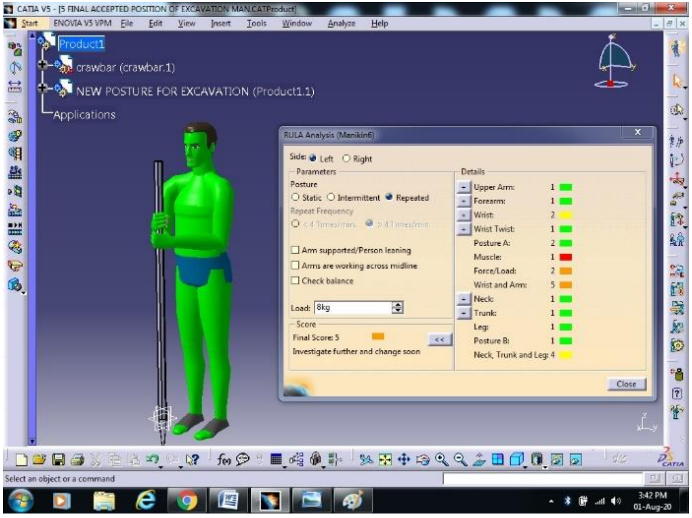
3.6.1.2 Biomechnical Analysis for Proposed Design Concept of Crowbar and Working Technique for Excavation Task (Job-1):

From Table 3.8 and Figure 3.7 (c), the maximum lumbar torque at L4/L5 is found to be 38 Nm, with L4/L5 compression of 1131 N, which is less than the maximum action limit of 3400 N. Also, the joint shear at L4/L5 is 82 N/m², which is also below the maximum permissible action limit. The force and pressure on the abdomen are also found to be zero.

Table 3.8 Biomechanical analysis on the spinal segment of L4/L5 of first, second and proposed conceptual body position (Excavation)

Parameters	Action Limit		
	First body position	Second body position	Proposed conceptual body position
M (Nm)	258	132	38
C (N)	**5044**	**2213**	**1131**
BLC (N)	263	-308	490
ATC (N)	25	135	0
F/EC (N)	4306	2208	631
JS (N)	**164 (Anterior)**	**550 (Anterior)**	**82 (Posterior)**
AF (N)	92	84	0
AP (N/m^2)	3	3	0

Table 3.7 and 3.8 show the comparison of old and new results of the postures for RULA and Biomechanical Analysis. The comparative results show that the RULA score dropped to 5 and the biomechanical score also dropped to the permissible limit and was found to be very low compared to the older one. The use of crowbars was found to be more feasible than the use of pick-axes for excavation work, allowing workers to work in an erect position.



RULA Analysis (Manikin6)

Side: ● Left ○ Right

Parameters

Posture

○ Static ○ Intermittent ● Repeated

Repeat Frequency

○ < 4 Times/min. ● > 4 Times/min.

☐ Arm supported/Person leaning
☐ Arms are working across midline
☐ Check balance

Load: 8kg

Score

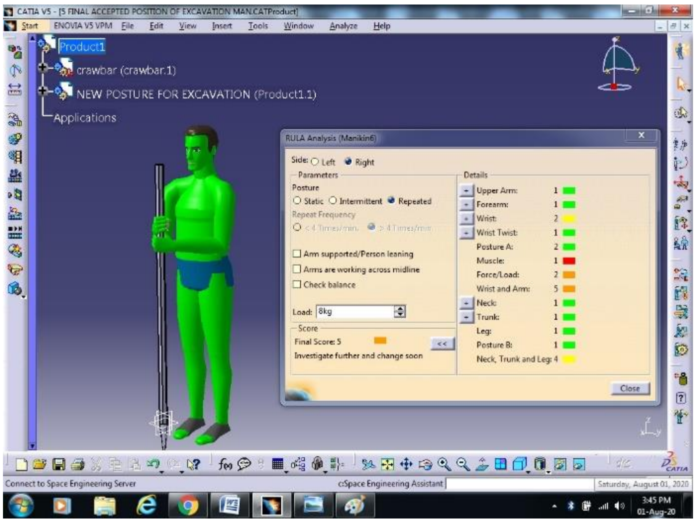
Final Score: 5 🟧

Investigate further and change soon

Details

Upper Arm:	1	🟩
Forearm:	1	🟩
Wrist:	2	🟨
Wrist Twist:	1	🟩
Posture A:	2	🟩
Muscle:	1	🟥
Force/Load:	2	🟧
Wrist and Arm:	5	🟧
Neck:	1	🟩
Trunk:	1	🟩
Leg:	1	🟩
Posture B:	1	🟩
Neck, Trunk and Leg:	4	🟨

Figure (a): RULA score of left side of the proposed working posture using crow bar



RULA Analysis (Manikin6)

Side: ○ Left ● Right

Parameters

Posture

○ Static ○ Intermittent ● Repeated

Repeat Frequency

○ < 4 Times/min. ● > 4 Times/min.

☐ Arm supported/Person leaning
☐ Arms are working across midline
☐ Check balance

Load: 8kg

Score

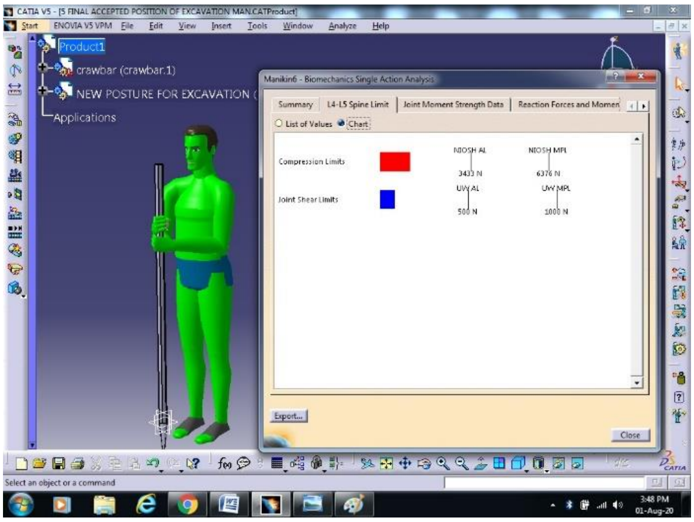
Final Score: 5 🟧

Investigate further and change soon

Details

Upper Arm:	1	🟩
Forearm:	1	🟩
Wrist:	2	🟨
Wrist Twist:	1	🟩
Posture A:	2	🟩
Muscle:	1	🟥
Force/Load:	2	🟧
Wrist and Arm:	5	🟧
Neck:	1	🟩
Trunk:	1	🟩
Leg:	1	🟩
Posture B:	1	🟩
Neck, Trunk and Leg:	4	🟨

Figure (b): RULA score of left side of the proposed working posture using crow bar



Manikin6 - Biomechanics Single Action Analysis

○ List of Values ● Chart

Figure (c): Biomechanical analysis of proposed working posture using crow bar

Figure 3.7 Proposed working posture using crow bar, RULA and Biomechanical Scores

3.6.2 Postural Analysis, Biomechanical Analysis and Lifting Analysis for Other Task (JOB-2 to JOB-5) using Novel Design of Iron-Pan after Modification:

The RULA, REBA, biomechanical, and lifting analysis are done by modeling a manikin for various jobs using this prototype iron pan, as shown in Figures 3.8, 3.9, 3.10, 3.11, 3.12, and 3.13. All the analysis is done using the novel design of the iron pan for material handling on a manikin for various tasks.

1) 1) Collection of soil in the iron-pan (Job-2)
2) 2a) Lifting of Iron-pan from the ground level when weight is 20 kg (Job-3(a)),
3) 2b) Lifting of Iron-pan from the ground level when weight is 15 kg (Job-3(b)),
4) 2c) Lifting of Iron-pan from the ground level when weight is 10 kg, (Job-3(c))
5) 3a) Throwing of the soil outside the column pit or hand over the Iron-pan to the outside labourer when Iron-pan is at shoulder level and weight is 20 kg (Job-4(a)),
6) 3b) Throwing of the soil outside the column pit or hand over the Iron-pan to the outside labourer when Iron-pan is at shoulder level and weight is 15 kg (Job-4(b)),
7) 3c) Throwing of the soil outside the column pit or hand over the Iron-pan to the outside labourer when Iron-pan is at shoulder level and weight is 10 kg (Job-4(c)),
8) 4a) Receive Iron-pan by the outside labourer when weight of the Iron-pan is 20 kg (Job-5(a)),
9) 4b) Receive Iron-pan by the outside labourer when weight of the Iron-pan is 15 kg (Job-5(b))
10) 4c) Receive Iron-pan by the outside labourer when weight of the Iron-pan is 10 kg was done (Job-5(c)).
11) Lifting Analysis as per NIOSH 1991 using Novel design of Iron-Pan for material handling (Job-3, Job-4 and Job-5).

3.6.2.1 Postural and Biomechnical Analysis of Collection of Soil in the Novel Designed Iron-Pan for Material Handling (Job-2):

The 850 mm long handle on the novel design of the iron pan for material handling and the spade handle length of 800 mm mean that there is no need to bend forward from the lumbar position. Also, the flat base of the novel design of the iron pan for material handling allows the iron pan to rest comfortably on the ground, so the novel design of the iron pan for material handling does not require the extra support that is needed in the conventional round-shaped iron pan (Figure 3.8).

Table 3.9 and Table 3.10 show the RULA and REBA scores obtained from the worksheet. The results of both methods show medium and low risk, respectively, while working with this posture using the novel design of the iron pan for material handling.

Table 3.11 shows the biomechanical analysis score. The biomechanical score indicates 1258 N compression and 76 N (A) joint shear load on L4/L5. These two values are found within the maximum permissible limits and in the acceptable range. Although the compression force on L4/L5 appears to have increased slightly (from 1063 N to 1258 N), the joint shear load has decreased significantly (from 385 N to 76 N). The abdominal force and pressure become zero while using this iron pan.

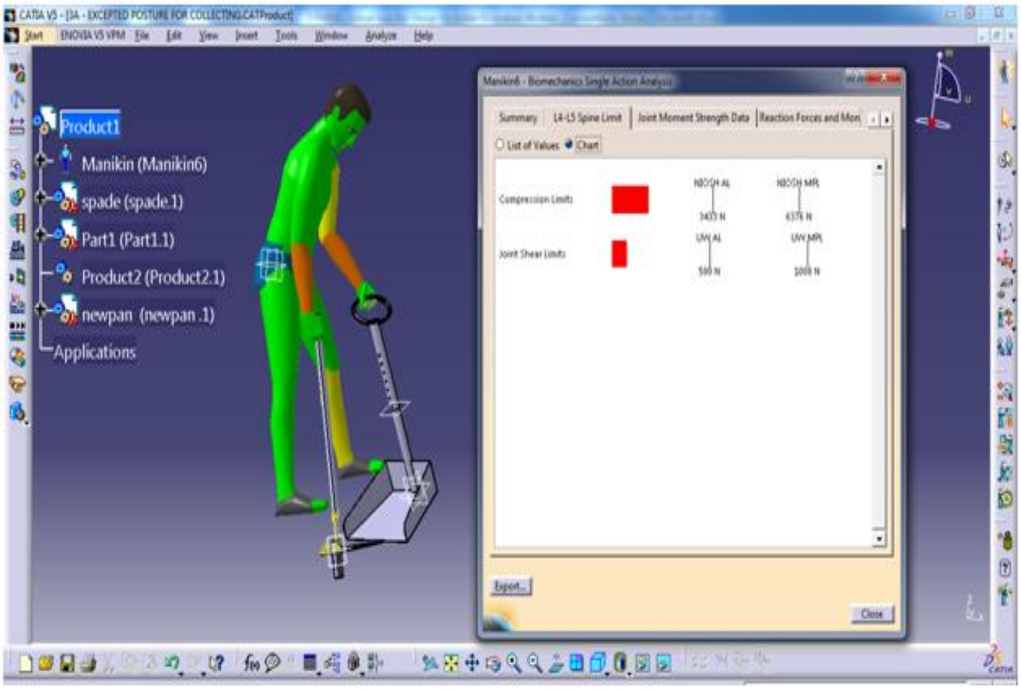


Figure 3.8 Collection of soil in the Novel Design of Iron-Pan for Material Handling (Job-2)

3.6.2.2. Postural and Biomechanical analysis for Lifting of Novel Designed Iron-Pan for Material Handling from ground level (Job-3):

The novel design of the iron pan lifting was analyzed in three ways: 1) Lifting of the iron pan from the ground level when the weight is 20 kg (Job-3(a)), 2) Lifting of the iron pan from the ground level when the weight is 15 kg (Job-3(b)), and 3) Lifting of the iron pan from the ground level when the weight is 10 kg (Job-3(c)) (Figure 3.9(i)-(iii)).

From Table 3.9, the RULA score obtained from the worksheet shows that the job is at high to medium risk. The RULA score indicates that when the laborer lifts a weight of 20 kg from the ground level, the posture adopted is at high risk. However, as the weight decreases to 15 kg and 10 kg, the risk is reduced to medium. From Table 3.10, the REBA score obtained from the worksheet shows that the job has medium risk for lifting 20 kg, 15 kg, and 10 kg.

The results of the biomechanical analysis show that the compression force at L4/L5 is 2398 N, 2189 N, and 1981 N for lifting weights of 20 kg, 15 kg, and 10 kg from the ground level, respectively. Joint shear loads at L4/L5 are 308 N, 284 N, and 260 N for lifting the same weights. Both results show that the compression and shear forces decrease while using the novel design of the iron pan for material handling. Compared with the old results, the compression force decreases for all weights, and the shear force also decreases. The novel design of the iron pan for material handling is extremely effective for lifting from the ground, as all the forces acting are below permissible limits.

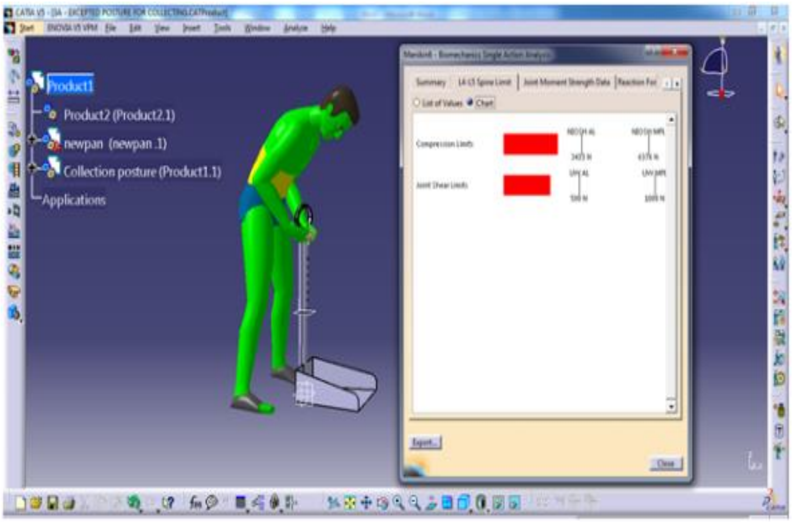


Figure (i): Lifting of Iron-pan from ground level (for 20 kg) (Job-3(a))

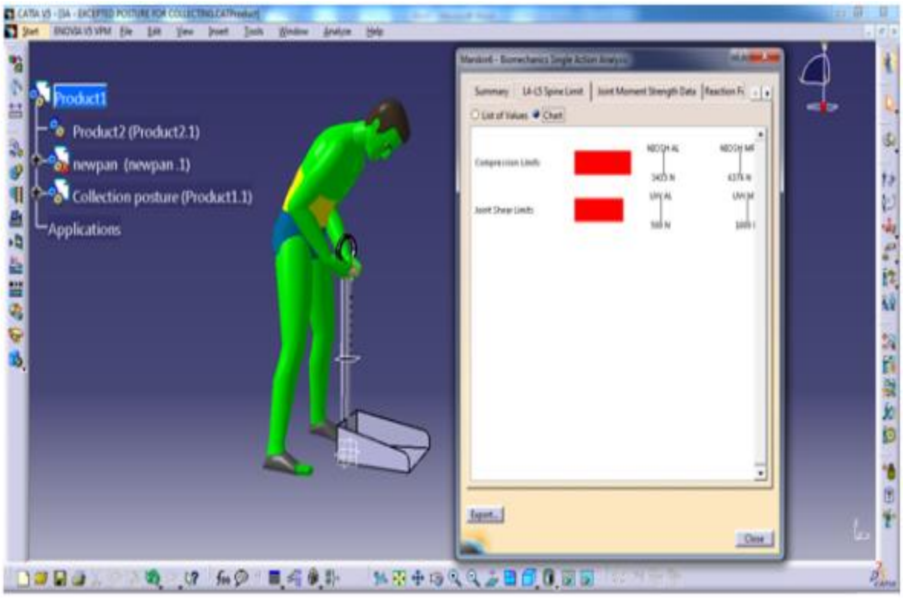


Figure (ii): Lifting of Iron-pan from ground level (for 15 kg) (Job-3(b))

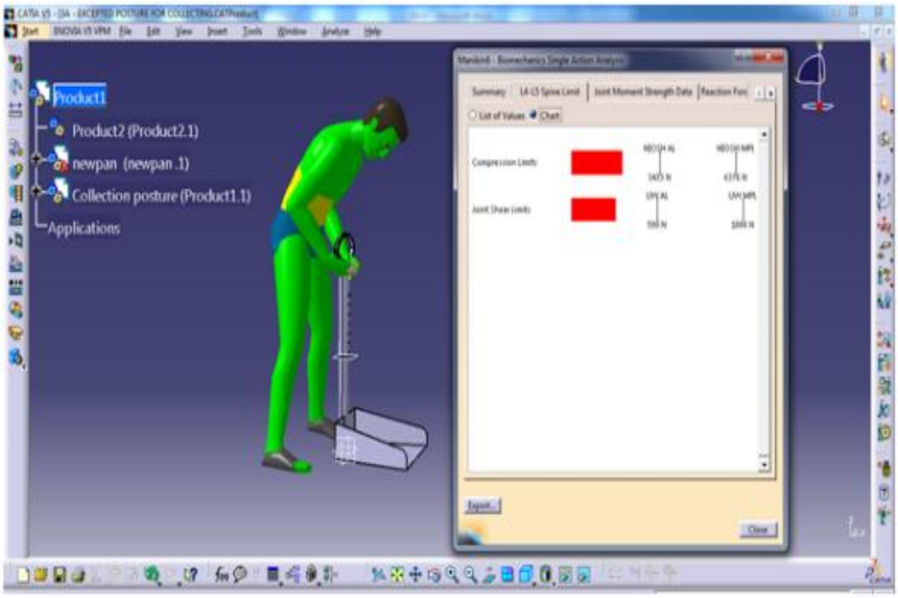


Figure (iii) Lifting of Iron-pan from ground level (for 10 kg) (Job-3(c))

Figure 3.9 Lifting of Novel design of Iron-pan from ground level (Job-3)

3.6.2.3 Postural and Biomechanical Analysis for throwing of soil or passing of Novel Designed Iron-Pan for Material Handling to outside labour (Job-4):

The throwing of soil outside the pit or passing the novel design of the iron pan for material handling to the outside laborer was again analyzed in three ways: 3a) Throwing the soil outside the column pit or handing over the iron pan to the outside laborer when the iron pan is at shoulder level and the weight is 20 kg (Job-4(a)), 3b) Throwing the soil outside the column pit or handing over the iron pan to the outside laborer when the iron pan is at shoulder level and the weight is 15 kg (Job-4(b)), and 3c) Throwing the soil outside the column pit or handing over the iron pan to the outside laborer when the iron pan is at shoulder level and the weight is 10 kg (Job-4(c)) (Figure 3.10(i)-(iii)).

The analysis was performed when the iron pan was at chest level for three different weights. From Table 3.9, the RULA score obtained from the worksheet shows that the job is at medium to high risk. The RULA score indicates that when the laborer holds the weight of 20 kg and 15 kg at chest level, the posture adopted by the laborer is at high risk. However, as the weight decreases to 10 kg, the risk is reduced to medium. From Table 3.10, the REBA score obtained from the worksheet shows that the job has medium risk for 20 kg and 15 kg, while low risk for the 10 kg weight to be lifted.

The outcome of the biomechanical analysis shows that when the iron pan is at chest level, the compression force at L4/L5 is 2922 N, 2501 N, and 2080 N for weights of 20 kg, 15 kg, and 10 kg for throwing the soil outside the pit or passing the iron pan to the outside laborer, respectively. Joint shear loads at L4/L5 were 52 N, 32 N, and 13 N for holding the same weight at chest level. Both results show that the compression force increases while the joint shear load decreases using the novel design of the iron pan for material handling for the 15 kg and 10 kg weights when the iron pan is at chest level. Though the compression forces appear to increase, all are within the permissible limit, and therefore can be recommended. It is advisable not to hold the novel design of the iron pan at chest level for more than 10 seconds, as this will help the worker minimize the compression force when throwing the materials outside or passing the iron pan to the outside worker.

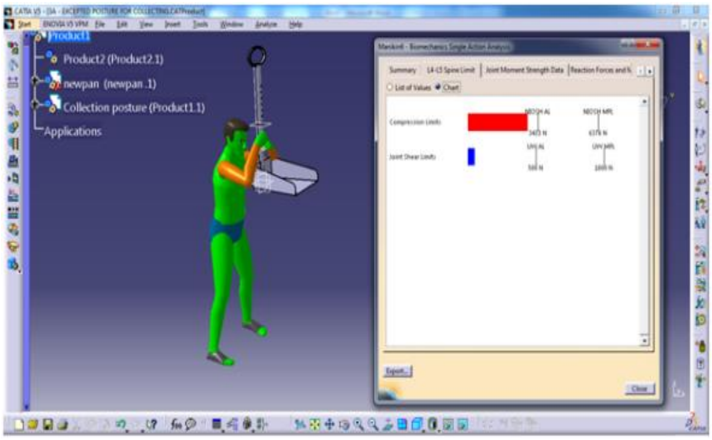


Figure (i): Throwing of soil labour/ passing Iron-pan to outside labour (Iron-pan at shoulder level - 20kg) (Job-4(a))

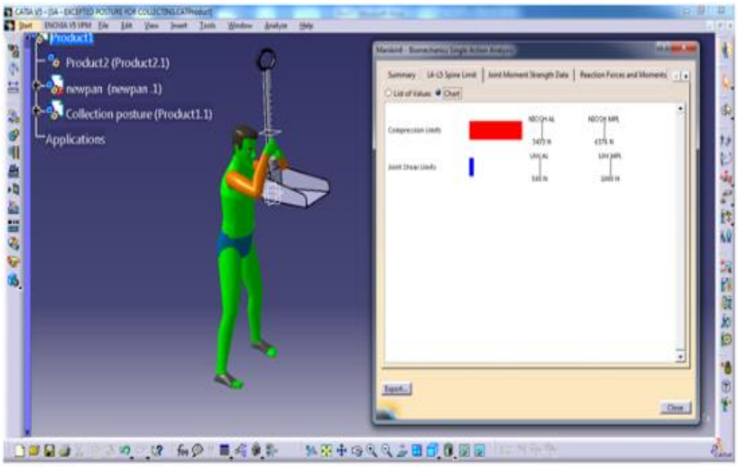


Figure (ii): Throwing of soil labour/ passing Iron-pan to outside labour (Iron-pan at shoulder level - 15kg) (Job-4(b))

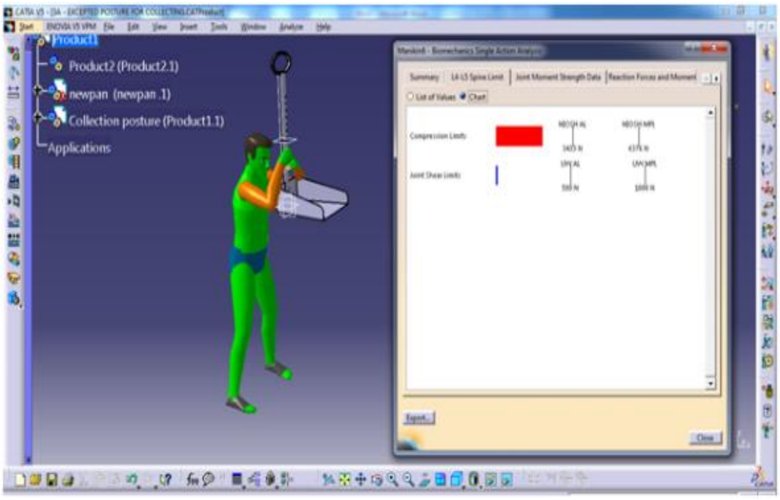


Figure (iii): Throwing of soil labour/ passing Iron-pan to outside labour (Iron-pan at shoulder level - 10kg) (Job-4(c))

Figure 3.10 Throwing of soil or passing of Novel Design Iron-pan to outside labourer (Job-4)

3.6.2.4 Postural and Biomechanical Analysis for Receiving of Novel Designed Iron-Pan for Material Handling by the outside labourer (Job-5):

The receiving of the iron pan by the outside laborer was also analyzed in three ways: 4a) Receiving the iron pan by the outside laborer when the weight of the pan is 20 kg (Job-5(a)), 4b) Receiving the iron pan by the outside laborer when the weight of the pan is 15 kg (Job-5(b)), and 4c) Receiving the iron pan by the outside laborer when the weight of the pan is 10 kg (Job-5(c)) (Figure 3.11(i)-(iii)).

When receiving or lifting 20 kg, 15 kg, and 10 kg of weight, the scores obtained from the RULA worksheet show that the laborers are at very high, high, and medium risk, respectively. However, the REBA worksheet scores obtained show that the laborers are at medium risk. In this case, as the weight reduces, the score declines.

The compression force at L4/L5 decreases to 3133 N from 5719 N when collecting or lifting the iron pan of weight 20 kg, which is under the maximum allowable limit. The compression force at L4/L5 is 2783 N and 2433 N when the laborer receives or lifts the iron pan of weight 15 kg and 10 kg from the inside laborer, which is also found to decrease for the outside worker. Both of these loads are under the maximum allowable limits. For receiving or lifting 20 kg of weight, the joint shear load is 205 N; for 15 kg, it is 196 N; and for 10 kg, it is 187 N. It seems to decrease for 15 kg and 10 kg, while for 20 kg, it is nearly the same. In this job, compression at L4/L5 reduces as the weight reduces. Hence, from the results, it is found that the lifting weight is the main cause of the development of work-related musculoskeletal disorders (WRMSD) among the construction workers.

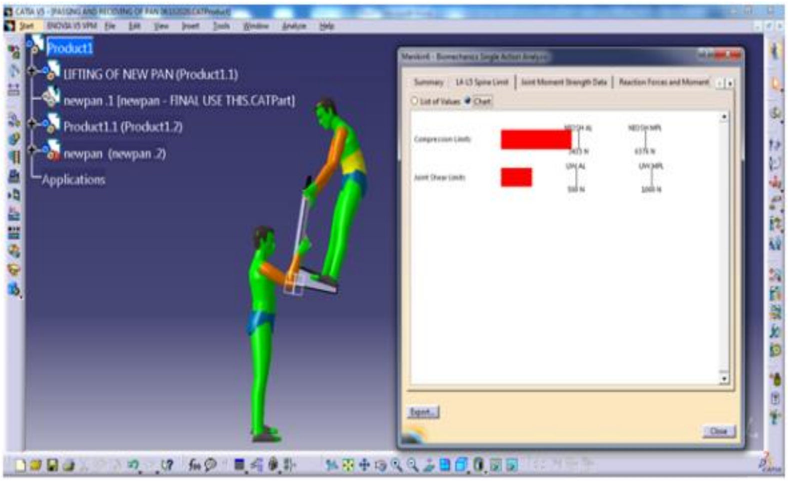


Figure (i): Receiving of pan by the outside labourer (20 kg) (Job-5(a))

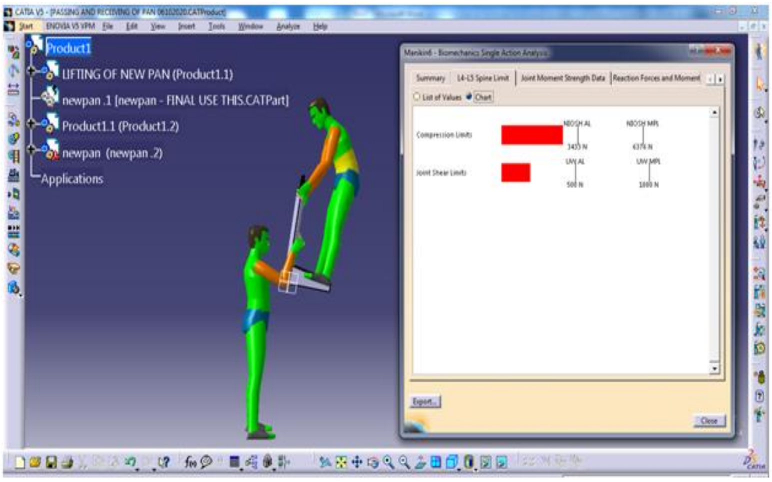


Figure (ii): Receiving of pan by the outside labourer 15 kg) (Job-5(b))

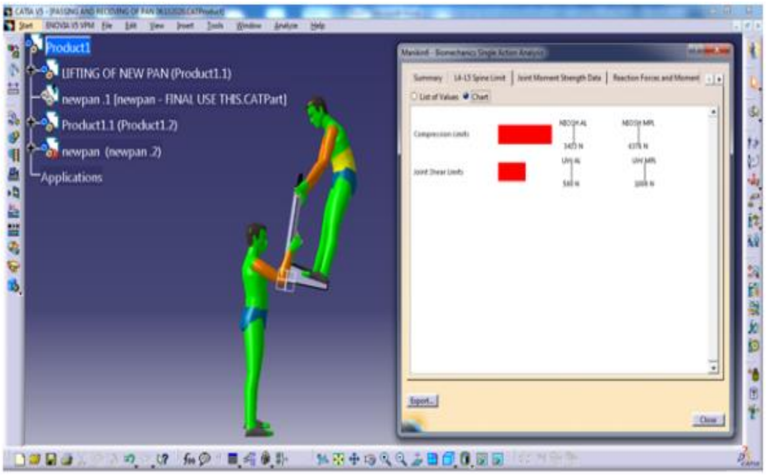


Figure (iii): Receiving of pan by the outside labourer (10 kg) (Job-5(b))

Figure 3.11 Receiving of Iron-Pan by outside labour

Table 3.9: RULA score after modification (Job-2, Job-3, Job-4, Job-5)

		UA	LA	W	WT	SC (A)	M	F	SC (C)	N	BK /T	L	SC (B)	M	F	SC (D)	**RLS**
Job 2		1	2	1	1	2	0	1	**5**	1	2	2	3	0	0	**3**	**4@**
Job 3	a)	1	1	2	1	2	0	3	**5**	1	2	1	2	0	3	**5**	**6#**
	b)	1	1	2	1	2	0	2	**4**	1	2	1	2	0	2	**4**	**4@**
	c)	1	1	2	1	2	0	1	**3**	1	2	1	2	1	1	**3**	**3@**
Job 4	a)	4	2	2	1	4	0	3	**7**	1	1	1	1	0	3	**4**	**6#**
	b)	4	2	2	1	4	0	2	**6**	1	1	1	1	0	2	**3**	**5#**
	c)	4	2	2	1	4	0	1	**5**	1	1	1	1	0	1	**2**	**4@**
Job 5	a)	2	2	2	1	3	1	3	**7**	1	2	1	2	0	3	**5**	**7***
	b)	2	2	2	1	3	1	2	**6**	1	2	1	2	0	2	**4**	**6#**
	c)	2	2	2	1	3	1	1	**5**	1	2	1	2	0	1	**3**	**4@**

Table 3.10 REBA Scores after modification (Job-2, Job-3, Job-4, Job-5)

		N	BK /T	L	PS-A	F	TS-A	UA	LA	W	PS-B	CP	TS-B	TS-C	A	**RBS**
Job 2		1	2	1	3	0	3	1	2	1	1	0	1	2	1	**3$**
Job 3	a)	2	3	1	4	2	6	1	1	1	1	0	1	1	1	**7@**
	b)	2	3	1	4	1	5	1	1	1	1	0	1	1	1	**6@**
	c)	2	3	1	4	0	4	1	1	1	1	0	1	1	1	**5@**
Job 4	a)	1	1	1	1	2	3	3	2	1	4	0	4	3	1	**4@**
	b)	1	1	1	1	1	2	3	2	1	4	0	4	3	1	**4@**
	c)	1	1	1	1	0	1	3	2	1	4	0	4	2	1	**3$**
Job 5	a)	1	3	1	2	2	4	2	2	1	2	0	2	4	1	**5@**
	b)	1	3	1	2	1	3	2	2	1	2	0	2	3	1	**4@**
	c)	1	3	1	2	0	2	2	2	1	2	0	2	2	1	**3@**

Table 3.11 Biomechanical analysis results after modification (Job-2, Job-3, Job-4, Job-5)

	Job 2	**Job 3**			**Job 4**			**Job 5**		
		(a)	**(b)**	**(c)**	**(a)**	**(b)**	**(c)**	**(a)**	**(b)**	**(c)**
Parameters		20 kg	15 kg	10 kg	20 kg	15 kg	10 kg	20 kg	15 kg	10 kg
M (Nm)	49	120	109	99	132	111	90	-157	-139	-121
C (N)	**1258**	**2398**	**2189**	**1981**	**2922**	**2501**	**2080**	**3133**	**2783**	**2433**
BLC (N)	385	371	341	312	592	545	497	427	393	358
ATC (N)	2	10	7	5	11	9	7	26	20	15
F/EC (N)	824	1997	1826	1655	2199	1849	1499	2615	2320	2024
JS (N)	**76 A)**	**308 (A)**	**284 (A)**	**260 (A)**	**52 (P)**	**32 (P)**	**13 (P)**	**205 (A)**	**196 (A)**	**187 (A)**
AF (N)	0	0	0	0	0	0	0	0	0	0
AP (N/m^2)	0	0	0	0	0	0	0	0	0	0

3.6.2.5 Lifting Analysis as per NIOSH 1991 using new prototype Iron-pan (Job-3, Job-4 and Job-5):

Table 3.12 shows the results of the NIOSH lifting analysis for Job-3, Job-4, and Job-5 for 20 kg, 15 kg, and 10 kg weights. This lifting analysis was performed using the NIOSH 1991 guidelines for lifting 20 kg, 15 kg, and 10 kg with a 120-second time for each lift, working hours of 8 hours or more (excluding rest periods), and better coupling conditions. An analysis was also performed on Job-2 for a 5 kg weight to check for differences in the results.

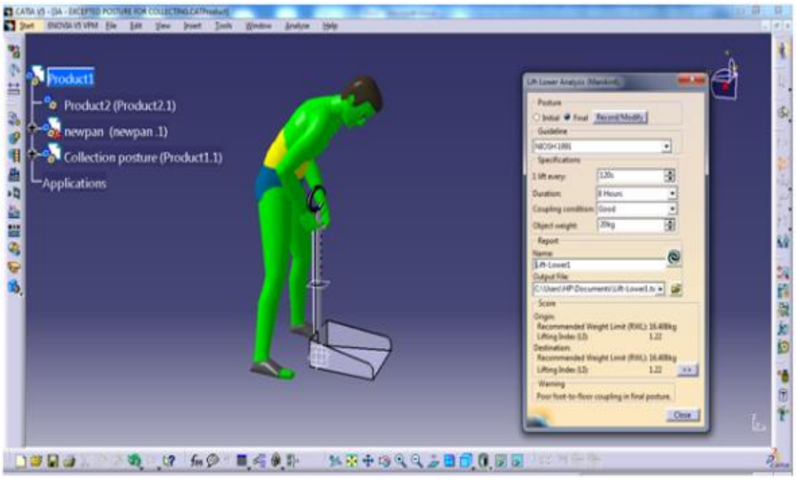
For Job-3, the recommended weight limit (RWL) for lifting 20 kg, 15 kg, and 10 kg was found to be 16.408 kg, while the lifting index (LI) for 20 kg, 15 kg, and 10 kg was found to be 1.22, 0.91, and 0.61, respectively. This result concludes that lifting a maximum weight of 15 kg and below is permissible for Job-3 (Figure 3.12(i)-(iii)).

Whereas, for Job-4, the recommended weight limit (RWL) for lifting 20 kg, 15 kg, and 10 kg was found to be 5.969 kg, while the lifting index (LI) for 20 kg, 15 kg, and 10 kg was found to be 3.35, 2.51, and 1.68, respectively. This result shows that lifting 20 kg, 15 kg, and 10 kg is not permissible for Job-4. The experiment was performed to lift 5 kg of weight, and for this weight, the RWL came to 5.969 with the LI coming to 0.84, which is below the permissible limit. So, it can be concluded that lifting a 6 kg weight for Job-4 will be permissible (Figure 3.13(i)-(iv)).

For Job-5, the recommended weight limit (RWL) for lifting 20 kg, 15 kg, and 10 kg was found to be 11.945 kg, while the lifting index (LI) for 20 kg, 15 kg, and 10 kg was 1.67, 1.26, and 0.84, respectively. This result shows that lifting a maximum weight of 12 kg is permissible for Job-5, while 15 kg and 20 kg weights are not permissible, as the LI for both is found to be greater than 1.

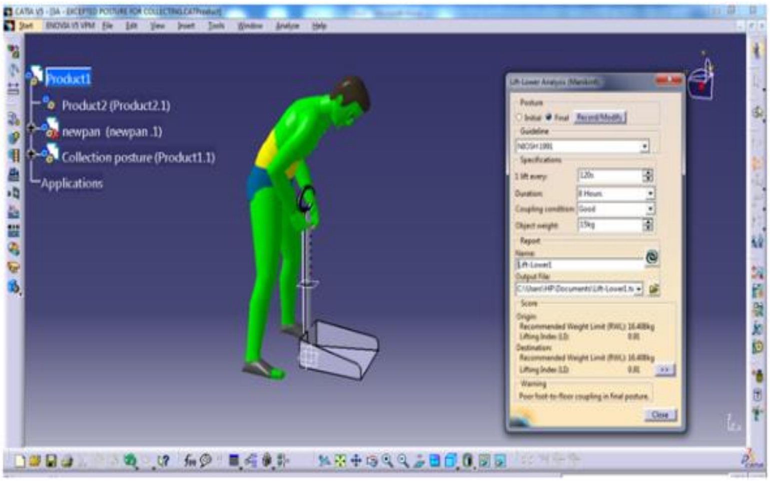
Table 3.12: Lifting analysis results after modification (Job-3, Job-4, Job-5)

	Job 3			Job 4			Job 5		
	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
Parameters (Wt. Lifted/hold)	20 kg	15 kg	10 kg	20 kg	15 kg	10 kg	20 kg	15 kg	10 kg
Recommended weight limit (RWL) (1991)	16.408 kg	16.408 kg	16.408 kg	5.969 kg	5.969 kg	5.969 kg	11.945 kg	11.945 kg	11.945 kg
Lifting Index (LI) (1991)	1.22	0.91	0.61	3.35	2.51	**1.68 (0.84 for 5kg)**	1.67	1.26	0.84



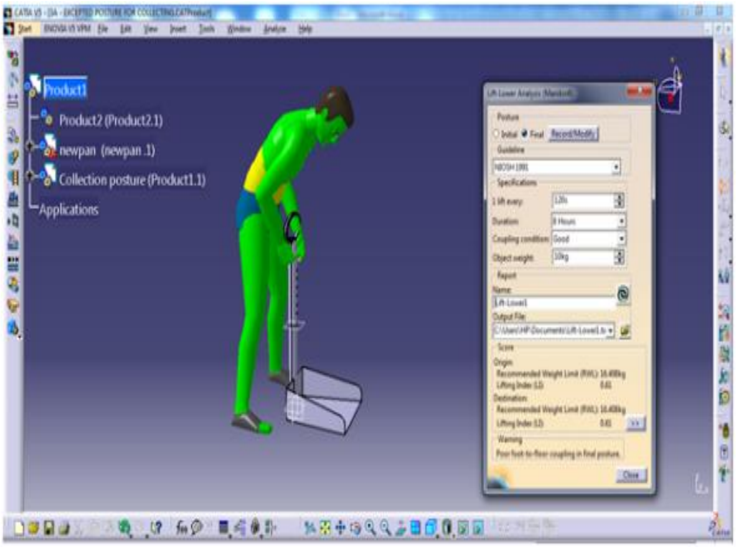
Posture: ○ Initial ● Final
Guideline: NIOSH 1991
Specifications
1 lift every: 120s
Duration: 8 Hours
Coupling condition: Good
Object weight: 20kg
Report
Name: Lift-Lower1
Output File: C:\Users\HP\Documents\Lift-Lower1.t
Score
Origin:
Recommended Weight Limit (RWL): 16.408kg
Lifting Index (LI): 1.22
Destination:
Recommended Weight Limit (RWL): 16.408kg
Lifting Index (LI): 1.22
Warning
Poor foot-to-floor coupling in final posture.

Figure(i): Lifting result when time per lift is 120 second for lifting 20 kg weight



Posture: ○ Initial ● Final
Guideline: NIOSH 1991
Specifications
1 lift every: 120s
Duration: 8 Hours
Coupling condition: Good
Object weight: 15kg
Report
Name: Lift-Lower1
Output File: C:\Users\HP\Documents\Lift-Lower1.t
Score
Origin:
Recommended Weight Limit (RWL): 16.408kg
Lifting Index (LI): 0.91
Destination:
Recommended Weight Limit (RWL): 16.408kg
Lifting Index (LI): 0.91
Warning
Poor foot-to-floor coupling in final posture.

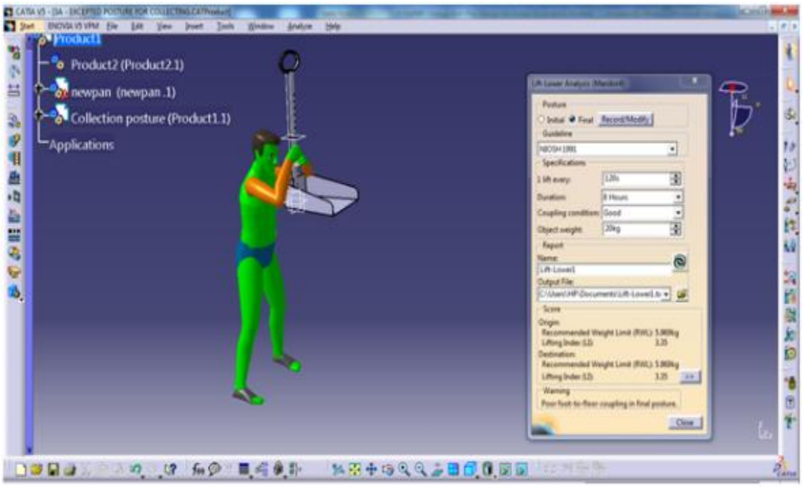
Figure (ii): Lifting result when time per lift is 120 second for lifting 15 kg weight



Posture: ○ Initial ● Final
Guideline: NIOSH 1991
Specifications
1 lift every: 120s
Duration: 8 Hours
Coupling condition: Good
Object weight: 10kg
Report
Name: Lift-Lower1
Output File: C:\Users\HP\Documents\Lift-Lower1.t
Score
Origin:
Recommended Weight Limit (RWL): 16.408kg
Lifting Index (LI): 0.61
Destination:
Recommended Weight Limit (RWL): 16.408kg
Lifting Index (LI): 0.61
Warning
Poor foot-to-floor coupling in final posture.

Figure (iii): Lifting result when time per lift is 120 second for lifting 10 kg weight

Figure 3.12 NIOSH 1991 Lifting result lifted from ground level (Job-3)



Posture
○ Initial ● Final

Guideline
NIOSH 1991

Specifications
1 lift every: 120s
Duration: 8 Hours
Coupling condition: Good
Object weight: 20kg

Report
Name: Lift-Lower1
Output File: C:\Users\HP\Documents\Lift-Lower1.tx

Score
Origin:
Recommended Weight Limit (RWL): 5.980kg
Lifting Index (LI): 3.35
Destination:
Recommended Weight Limit (RWL): 5.980kg
Lifting Index (LI): 3.35

Warning
Poor foot-to-floor coupling in final posture.

Figure (i): Lifting result when time per lift is 120 second for lifting 20 kg weight when pan at shoulder level

Posture
○ Initial ● Final

Guideline
NIOSH 1991

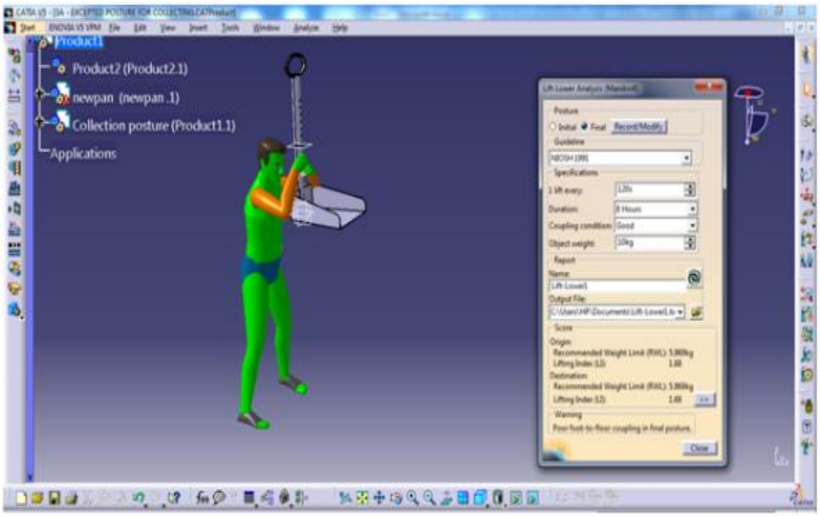
Specifications
1 lift every: 120s
Duration: 8 Hours
Coupling condition: Good
Object weight: 15kg

Report
Name: Lift-Lower1
Output File: C:\Users\HP\Documents\Lift-Lower1.tx

Score
Origin:
Recommended Weight Limit (RWL): 5.980kg
Lifting Index (LI): 2.51
Destination:
Recommended Weight Limit (RWL): 5.980kg
Lifting Index (LI): 2.51

Warning
Poor foot-to-floor coupling in final posture.

Figure (ii): Lifting result when time per lift is 120 second for lifting 15 kg weight when pan at shoulder level



Posture: ○ Initial ● Final

Guideline: NIOSH 1991

Specifications

1 lift every: 120s

Duration: 8 Hours

Coupling condition: Good

Object weight: 10kg

Report

Name: Lift-Lower1

Output File: C:\Users\HP\Documents\Lift-Lower1.tx

Score

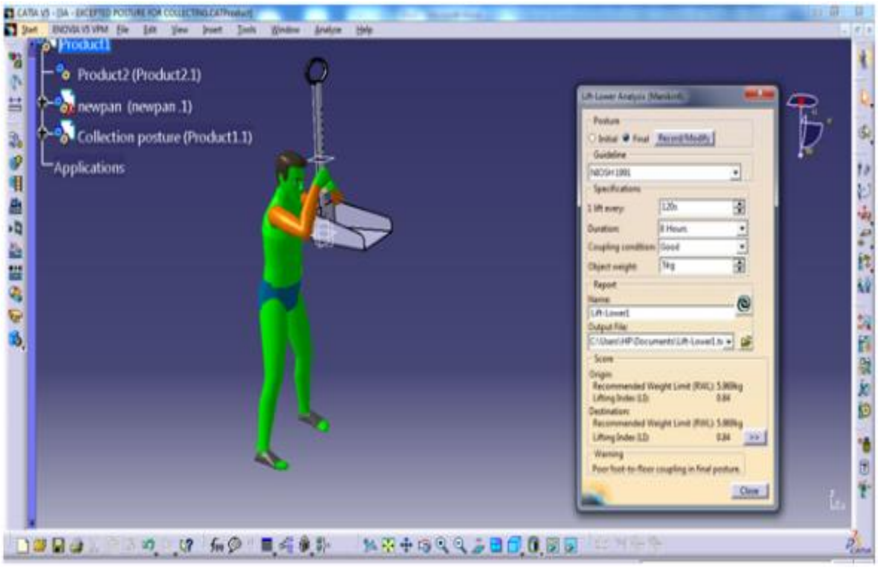
Origin:
Recommended Weight Limit (RWL): 5.960kg
Lifting Index (LI) 1.68

Destination:
Recommended Weight Limit (RWL): 5.960kg
Lifting Index (LI) 1.68

Warning

Poor foot-to-floor coupling in final posture.

Figure(iii): Lifting result when time per lift is 120 second for lifting 10 kg weight when pan at shoulder level



Posture: ○ Initial ● Final

Guideline: NIOSH 1991

Specifications

1 lift every: 120s

Duration: 8 Hours

Coupling condition: Good

Object weight: 5kg

Report

Name: Lift-Lower1

Output File: C:\Users\HP\Documents\Lift-Lower1.tx

Score

Origin:
Recommended Weight Limit (RWL): 5.960kg
Lifting Index (LI) 0.84

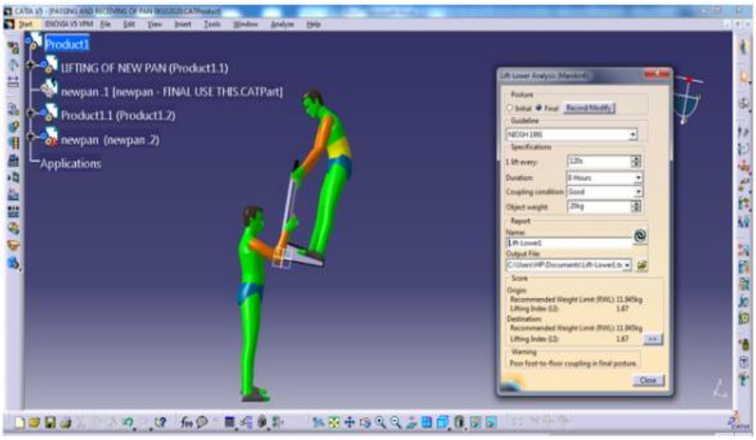
Destination:
Recommended Weight Limit (RWL): 5.960kg
Lifting Index (LI) 0.84

Warning

Poor foot-to-floor coupling in final posture.

Figure(iv): Lifting result when time per lift is 120 second for lifting 5 kg weight when pan at shoulder level

Figure 3.13 NIOSH 1991 Lifting result when iron-pan at chest level of the inside labourer (Job-4)



Posture: ○ Initial ● Final

Guideline: NIOSH 1991

Specifications

1 lift every: 120s

Duration: 8 Hours

Coupling condition: Good

Object weight: 20kg

Report

Name: Lift-Lower1

Output File: C:\Users\HP\Documents\Lift-Lower1.tx

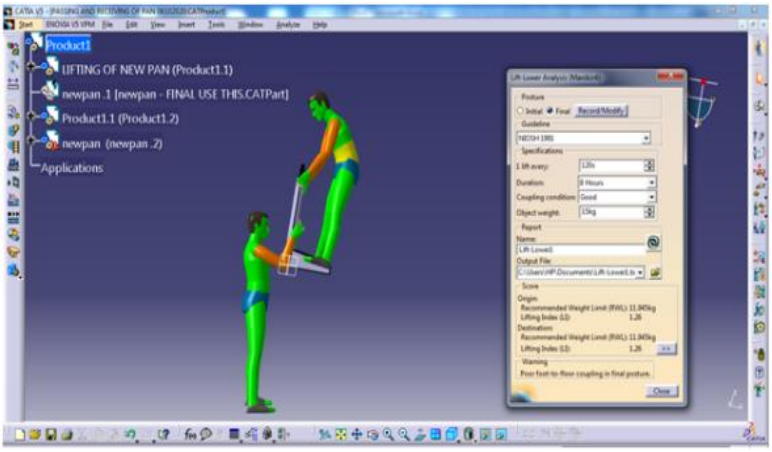
Score

Origin:
Recommended Weight Limit (RWL): 11.845kg
Lifting Index (LI): 1.67

Destination:
Recommended Weight Limit (RWL): 11.845kg
Lifting Index (LI): 1.67

Warning: Poor foot-to-floor coupling in final posture.

Figure (i): Lifting result of external laborer when time per lift is 120 second for lifting 20 kg weight



Posture: ○ Initial ● Final

Guideline: NIOSH 1991

Specifications

1 lift every: 120s

Duration: 8 Hours

Coupling condition: Good

Object weight: 15kg

Report

Name: Lift-Lower1

Output File: C:\Users\HP\Documents\Lift-Lower1.tx

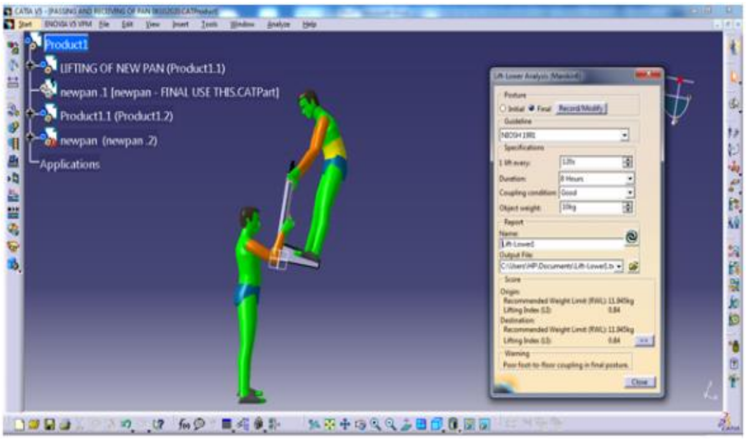
Score

Origin:
Recommended Weight Limit (RWL): 11.845kg
Lifting Index (LI): 1.26

Destination:
Recommended Weight Limit (RWL): 11.845kg
Lifting Index (LI): 1.26

Warning: Poor foot-to-floor coupling in final posture.

Figure (ii): Lifting result of external laborer when time per lift is 120 second for lifting 15 kg weight



Posture: ○ Initial ● Final

Guideline: NIOSH 1991

Specifications

1 lift every: 120s

Duration: 8 Hours

Coupling condition: Good

Object weight: 10kg

Report

Name: Lift-Lower1

Output File: C:\Users\HP\Documents\Lift-Lower1.tx

Score

Origin:
Recommended Weight Limit (RWL): 11.845kg
Lifting Index (LI): 0.84

Destination:
Recommended Weight Limit (RWL): 11.845kg
Lifting Index (LI): 0.84

Warning: Poor foot-to-floor coupling in final posture.

Figure (iii): Lifting result of external laborer when time per lift is 120 second for lifting 10 kg weight

Figure 3.14 NIOSH 1991 lifting result for outside labourer (Job-5)

3.7 SUMMARY

As mentioned above, excavation work involves various tasks that are dynamic, forceful, and injurious in nature. Factors such as working in awkward postures, wear and tear, repetitive tasks, traumatic incidents, and age are responsible for the development of WRMSD. While performing various excavation tasks, there is tremendous stress and intense pressure on the body postures of the laborers, as they are working in awkward postures. Therefore, in this study, CATIA is used to evaluate the postures of five excavation tasks. RULA and REBA worksheet scores show that all the six jobs are at very high risk. Initially, RULA and REBA scores indicate that the lumbar spine, shoulders, and arms/hands were exposed to high ergonomic risks while working with conventional tools.

CATIA's biomechanical analysis has shown that for Job-1 (excavation), the position-1 of the laborer and that of the outside laborer (Job-5) have higher compression on L4/L5, which is higher than the maximum allowable compression of 3400 N. Although there is less compression on the L4/L5 vertebrae in the lifting task, the joint shear load is closer to the maximum allowable limit of 500 N, and as the weight increases, this shear load increases as well. Laborers are working in a twisting posture while throwing soil and taking the iron pan from the laborer working inside the column pit. When collecting soil in an iron pan and lifting the iron pan, laborers bend forward more than 90°, which is not acceptable. This forward bending angle must be reduced by improving the design of the iron pan or the method of collection. According to the NIOSH 1991 guidelines, if the lifting score is greater than 1, the lifting technique is considered poor. The recommended weight limit (RWL) given by CATIA software is 11.987 kg, and the lifting index (LI) for 20 kg weight is 1.67, which appears to be higher.

Based on the analytical results of RULA, REBA, biomechanical analysis, and the lifting index extracted from the worksheet and CATIA V5 software, excavation workers are working on physically demanding tasks with high loads on the vertebral segment L4/L5. The same result has been obtained by Suman Das et al., 2018. Therefore, it is necessary to reduce this load on the spine.

On the basis of the results from traditional working methods, the use of a crowbar is suggested and validated through CATIA, and a Novel Design of Iron-Pan for Material Handling is designed and modeled in CATIA for collecting, lifting, throwing, or passing materials outside the pit to achieve better working posture. The RULA, REBA, biomechanical, and lifting analysis were performed on the manikin postures to validate the variation in the manikin posture while working with the Novel Design of Iron-Pan for Material Handling. The results show that the RULA and REBA scores decreased while performing all the tasks using the Novel Designed Iron-Pan. The RULA and REBA worksheet scores, which were previously very high risk, have now become medium to low risk when using the Novel Designed Iron-Pan. Initially, RULA and REBA scores indicated that the lumbar, shoulders, and arms/hands were exposed to high ergonomic risks, but they are now at lower risk when using the Novel Designed Iron-Pan for Material Handling.

Biomechanical analysis results for Job-2 show that although the compression force is slightly increased, the joint shear load on L4/L5 is significantly reduced. For Job-3, the compression force and shear force for all weights have been reduced. In Job-4, the compression force increases for all weight lifting, but it is below the maximum allowable limit. However, the joint shear load is decreased. For Job-5, the compression force for all weights lifted decreases, and the joint shear load is also decreased. In Job-5, initially, the laborers had to bend forward more than 30 degrees from the lumbar spine and also worked in a twisting position. After using the Novel Designed Iron-Pan, they no longer had to bend and twist, thus reducing the compression force and joint shear load.

The lifting result showed that for Job-3, the LI is higher than 1 when lifting 20 kg of weight, which is higher than the recommended index. However, for Job-4 and Job-5, the LI is more than 1 for lifting weights greater than 15 kg. A weight of up to 15 kg is recommended for lifting from ground level, while 6 kg is recommended for chest level, and 10 kg for receiving at surface level. The study concluded that 6-10 kg weight is the optimal weight for all jobs in excavation work. In all proposed lifting techniques, laborers did not need to bend more than 30° when using the Novel Designed Iron-Pan. For all jobs, the lifting capacity of the soil must be limited to 10 kg to reduce the adverse effects of weight and to work in awkward positions.

Studies have shown that lifting weights are directly proportional to the load on the spine. The weight on the vertebrae increases as the weight increases and decreases as the weight decreases. The study has also revealed that the compression force is higher when laborers work with straight vertebrae, and the shear load increases when laborers work in a flexed position.

The results of RULA, REBA, biomechanical, and lifting analysis show that the Novel Design of Iron-Pan for Material Handling, with its long handle and flat bottom pan, reduces ergonomic risks while working in awkward positions—collecting soil in the iron pan, lifting the iron pan, throwing soil outside the pit, passing the iron pan to the outside laborer, and receiving the iron pan by the outside laborers. The same experience was found when laborers used the actual fabricated novel iron pan for material collection and dumping.

CHAPTER – 4

POSTURAL ANALYSIS OF UNSKILLED WORKERS (LABOUR) AND PROTOTYPE DESIGN PROPOSAL OF MATERIAL COLLECTION AND EVICTION TABLE FOR SLAB CONCRETING WORK

4.1 Introduction

Work-related musculoskeletal disorders are the major component of job-related illness in the workplace which occur due to different ergonomic risk factors. These are caused by working in awkward positions, working repetitively, heavy lifting/lowering, prolonged working in static and dynamic postures, undue pressure on the lower back, gravity force on body parts, etc. Unskilled workers in construction, the so-called laborers or coolies, work very hard at construction sites. They are involved in physically demanding work where they perform lifting, lowering, carrying construction materials, and moving materials from one place to another for the smooth running of various construction activities. At the same time, they also perform different construction-related activities like excavation, surface or area cleaning, mixing mortar and concrete, and supplying construction materials, etc.

Slab concreting is one of the major tasks to be carried out in the construction work. This slab concreting is carried out at the floor as well as for the roof. This is the general structural element of the house or any building that is used to develop a flat horizontal surface at the floor, roof decks, and ceilings. The floor concrete provides a plain horizontal surface at the base, and the roof or ceiling concrete serves as a protection and covering for the house or building and also insulates the house from sound, heat, fire, cold, etc. Slab concreting is a layer of molded plain or reinforced concrete, flat, horizontal, and uniformly distributed, which is supported by beams, columns, walls, and other frameworks, and on the ground as well. This is generally several millimeters thick and supported by beams, walls, floor surfaces, and columns. The concrete mixture composition uses four major elements: gravel, sand, cement, and water mixed in a required ratio.

In India, slab concreting is done manually. Concrete mixes are traditionally made and transported by hand, but currently, concrete mixer machines are used to mix the concrete, as well as elevators used for concrete mixer transportation at the required elevated height. Though the mixing of the concrete is performed using a concrete mixing machine and lifted to the desired height using a lift, some work is still performed manually. This work involves transferring the concrete mixture to the desired location for the centering (formwork) from the depository location. The concrete mixture is collected at one of the spaces on the centering or roof with the help of the lift. The hopper unloads the concrete mix onto the centering floor (temporary place), and then it is transported to the desired location for laying with the help of laborers. Laborers collect the mixture in the iron pan, lift the iron pan, and transport the mixture. For this work, the laborer has to bend forward (flexion) to collect and lift the iron pan. The average weight of the iron pan with the mixture is 20kg. This transporting of concrete mix is found to be hazardous, as it is overwhelming, forceful, repetitive, and diligent in nature, as well as laborers working in awkward postures. At the same time, before mixing the materials, like gravel, sand, and cement sacks, are also transported by the laborers working on the ground. Working in such awkward postures, frequent bending, and forceful and heavy lifting weights is hazardous work, which leads to the development of work-related musculoskeletal disorders. The type of work causes back and shoulder injuries and is associated with vertebral disorders. It has a depressing effect on individual labor and society and impairs the health of workers [157]. Many researchers have performed risk assessments of working posture on various construction works and other areas [87][88][7][107][108][118]. Investigating such risk factors and their intensity is the crucial step that can minimize the problem of work-related musculoskeletal disorders. Sensor-based risk assessments have also been performed to evaluate ergonomic risk for different tasks and conditions [11][17][176][138][139][162].

Despite such studies, there has been a limited focus and effort in India on unskilled workers such as laborers, helpers, or coolies. According to Hoonemans et al. (2008), height and weight lifting play a significant role in contributing to low back disorder. Therefore, the vertical position of the object to be lifted should be in the range of 320 mm to 1550 mm for manual material handling. At the same time, the weight of the object to be lifted should be in the range of 7.5–15 kg [220].

Therefore, the objective of this study was to 1) identify the hazard factors of slabs, body parts, lifting height, weight lifting, and other related parameters with the laborers involved in the work of slab concreting, and 2) to propose some designs to collect and lift concrete mixture from a permissible height and of permissible weight.

4.2 Task Performed by the Un-skilled worker (Labour) for concreting work:

4.2.1 Transportation of concrete materials to concrete mixture machine from dump yard:

The mixing machine is placed on the surface ground, and the concrete mixture is transported using an elevator equipped with a hopper attached to the mixing machine. To prepare the concrete mixture, materials like gravel, sand, cement, and water are required, which are transported from the dump yard nearby. These materials are transported by the unskilled workers (laborers/coolies) from the dumping yard to the mixing machine, as shown in Figure 4.1(i)-(iv).

Figure (i) Collecting, Lifting and Transportation of Gravels

Figure (ii) Collecting, Lifting and Transportation of Sand

Figure (iii) Lifting, Transportation and unloading of cement sack

Figure (iv) Mixture Operator collecting water from barrel

Figure 4.1 Transportation of materials to concrete mixture machine

4.2.2 Mixing of concrete by operator using Concrete Mixture machine:

The mixer operator adds water to the hopper of the mixer and starts the mixer machine, for which the operator has to bend forward to collect water from the barrel (Figure 4.1 (iv)). After mixing, the operator has to rotate the mixer hopper and unload the mixture into the hopper of the elevator opposite to the mixer hopper. For this, the operator has to put in some high effort to rotate the mixer hopper.

4.2.3 Elevate the mixture to Slab Level:

The mixer operator pulls the lever to lift the elevator hopper to the desired height.

4.2.4 Unloading the mixture from Elevator:

Another worker on the centering stands beside the elevator, unlocks the elevator hopper, and unloads the mixture, then locks it back onto the elevator. This locking and unlocking are done manually and require effort, as shown in Figure 4.2(a)(b)(c). For this, a temporary foundation made up of form plates is used to drop and collect the concrete mixture, as shown in Figure 4.3(i). The size of the temporary foundation is approximately 2400 mm x 2400 mm, which is placed on the centering of the slab, as shown in Figure 4.3(i) and (ii). The hopper stops at a height of 900 mm from the base of the centering and drops the material onto the temporary floor, from where the laborers collect it (Figure 4.4(i)(ii)). The total height of the elevator is maintained at about 3000–3300 mm from the base of the centering/formwork (Figure 4.3(i)). Figure 4.4(i) shows how the concrete mixture is being dropped and collected on the temporary floor. From Figure 4.4(ii), it can be seen how laborers are collecting the concrete mixture in an iron pan from the ground.

Also, in Figure 4.2(a)(b) and (c), the laborer is performing the task of unlocking the hopper from the elevator to drop the concrete mixture onto the temporary floor. The laborer appears to be working in an awkward posture and an unsafe condition while performing this task.

(a) (b) (c)

POSTURE-4

Figure 4.2 Unlocking and locking of Hopper

Figure (i) Real time elevator with vertical distance (at first floor)

Figure (ii) Real time Elevator (view from ground)

Figure 4.3 Figure of Elevator

Figure (i) Figure of real time elevator with hopper releasing concrete on floor (unloading of concrete mixture)

Figure (ii) Laborers collecting concrete in the iron-pan

Figure 4.4 Figure of elevator with hopper at first floor and collection of concrete

4.2.5 Collection and Transfer the Mixture by the Labour

The laborers collect the concrete mixture from the unloading station, as shown in Figure 4.5(a), 4.5(b), and 4.5(c). From the figures, it can be seen that all the laborers are working in a forward bending (flexion) posture to collect the concrete mixture.

Figure (a): Collection of Concrete in the Iron-pan

POSTURE-1

Figure (b): Lifting of Iron-Pan

POSTURE-2

Figure (c): Lifting and holding Iron-Pan on head

POSTURE-3

Figure 4.5 Real time images of collectiong, lifting and holding of iron-pan on head

4.2.6 Uniform distribution of the concrete mixture on the Slab Centering

The concrete mixture is then spread uniformly by the mason with the help of a vibrator, trowel, and wooden trowel.

4.3 RESULTS:

A four-week study was conducted to study the work of slab concreting at various construction sites. Eight different construction sites were visited, and a total of 68 laborers were observed, video recorded, and interviewed. Only male laborers were employed for this work. The table 4.1 shows the background characteristics of the laborers. The standard weighing machine and measuring steel tape were used to measure the height and weight of the laborers, as well as the height of the elevator and the weight of the filled head-pan. The individual data, like age, working experience, daily working hours, pain in the body parts, history of traumatic incidents, feeling discomfort, addiction to alcohol/smoking/tobacco, were asked using a simple questionnaire.

Laborers between the ages of 26 to 59 were found to have 3 to 36 years of experience. Statistics show that 44 laborers migrated from other states. Out of 68 laborers, 6 were illiterate, 38 laborers had completed primary education, 19 laborers had completed secondary education, and 5 laborers had completed intermediate education.

When laying slab concrete casting work, the laborers have to perform four tasks: i) Collecting slab-concrete mixture in the iron pan, ii) lifting the iron pan, and iii) laying the slab-concrete mixture in the desired place on the formwork/centring. While performing these tasks, the laborers have to bend forward (flexion posture at lumbar), work in the extended posture, and use awkward postures. While lifting the iron pan, the laborers have to work hard to lift the head-pan. Though all laborers are forced to perform the above-mentioned tasks.

Working in awkward posture is dangerous and injurious to health, as it applies compression load on the L4/L5 vertebrae of the spinal cord, which exceeds the recommended limit of NIOSH. The ERIN, RULA, and REBA methods were used to evaluate the ergonomic risk of selected postures of laborers. Also, the new collection and eviction table, as well as the manikin, were designed and modeled in CATIA software for postural, biomechanical, and lowering/lifting analysis. An analysis was performed by considering lifting weights of 10 kg, 12 kg, 15 kg, and 20 kg in CATIA. While evaluating the posture, repetition, static muscle load, force, working postures, and break time were not considered. The standard rule of anthropometry is set according to rules. The colors green, yellow, orange, and red are designated for "No risk posture", "Medium Risk Posture", "High Risk Posture", and "Very high risk postures" respectively [216].

Table 4.1 Somatic Characteristics of workers (N=68)

Characters	**Mean (±SD)**
Age (years)	42.49 (± 9.03)
Height (cm)	163.47 (± 4.70)
Weight (kg)	61.82 (± 5.64)
Work Experience (years)	18.15 (± 8.15)
BMI (kg/m^2)	23.14 (± 1.90)
Working hours/day (hours)	6 (±1)
Rest hours/day (hours)	0 (± 30min)

The studied laborers are engaged in collecting and discharging concrete on the slab formwork. The duration of working hours depends on the need of the work, but usually, these laborers are engaged in slab concreting work for 6 to 7 hours, depending on the height of the slab from the ground and the total area of the slab.

The response to the pain in the body parts and its percentage is shown in Table 4.2, Figure 4.6, and Figure 4.7. From Table 4.2, it is noticed that laborers suffer from lower back pain (85.29%), shoulders (66.18%), arms/hands (48.53%), chest (20.59%), knees (16.18%), ankle/feet/toes (11.76%), neck (10.29%), head (7.35%), fingers/thumbs (7.35%), legs (7.35%), and wrist (5.88%). According to the survey, it is revealed that 86.76% of laborers are working in awkward postures. From Table 4.3, it is found that 36.76% of laborers have pain after working, 30.88% laborers have pain in the morning, 13.24% laborers experience pain during work, while 10.29% of the laborers experience pain during sleeping. Figure 4.2 shows that 30%, 23%, 17%, and 6% of laborers have pain in the lower back, shoulders, arms/hands, and fingers/thumbs, respectively, from the total number of laborers. Average BMI was found to be well under control; however, 9 laborers' BMI were found to be above the BMI control limit. The average weight of the head-pan with concrete is 21.55 kg, and the average lifting time was 180 seconds per lift.

Table 4.2 Laborers' reaction about pain/discomfort in body (N=68)

Body Parts	No. of workers having pain in different body parts	Percentage of workers
Head	5	7.35
Neck	7	10.29
Shoulder	45	66.18
Chest	14	20.59
Arms/Hands	33	48.53
Wrist	4	5.88
Finger/Thumbs	5	7.35
Lower Back	58	85.29
Legs	5	7.35
knee	11	16.18
Ankle/feet/toe	8	11.76
Working in Awkward Posture	59	86.76

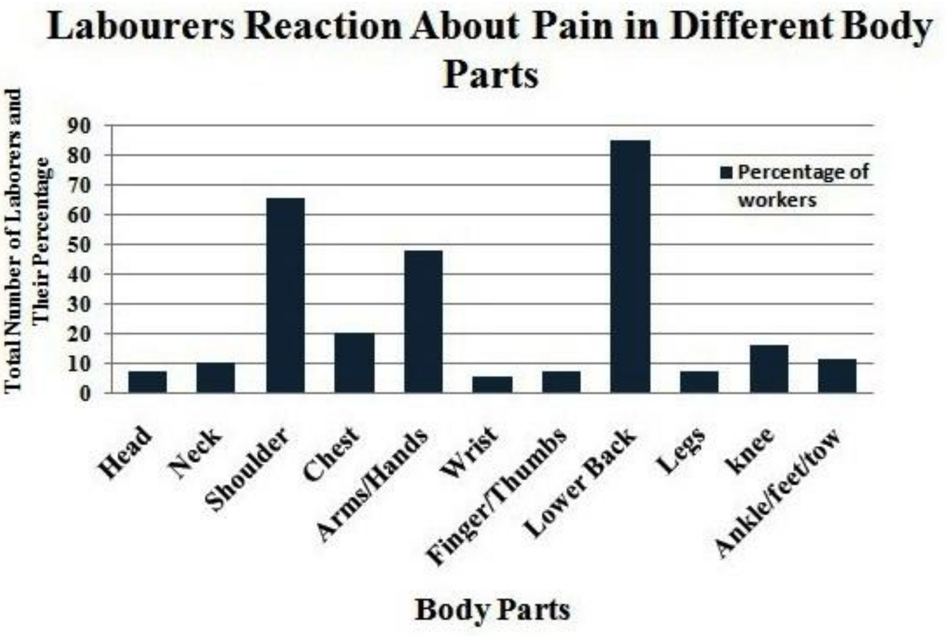


Figure 4.6 Labourers Reaction About Pain in Different Body Parts

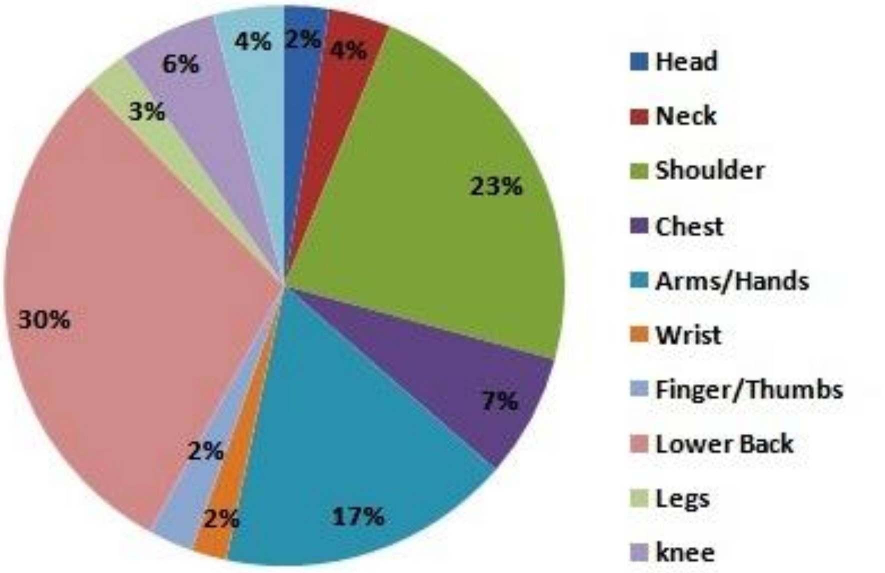


Figure 4.7 Percentage of Laborers having Pain in Different Body Parts

Table 4.3: Laborers' reaction about pain/discomfort in different time zone

Parameters	No. of workers having pain in different body parts	Percentage of workers
During Working	9	13.24
After Working	25	36.76
during sleeping	7	10.29
In the morning	21	30.88

4.4 Results obtained by using ERIN, RULA and REBA methods:

The ERIN, RULA, and REBA methods have shown that all postures performed while collecting concrete in an iron pan and lifting a concrete mixture iron pan are at very high risk, and immediate action is required to minimize further destruction (Table 4.4, 4.5, and 4.6).

From the ERIN method, it is also revealed that all postures are at very high risk as the score obtained for postures is more than 35. The RULA method score for all postures was found to be more than 7, which indicates that they need immediate action. REBA's final score indicates that the score obtained for all the postures is above 11, which indicates that all the assessed postures are at very high risk.

The results of all the methods applied for the assessment of all the working postures of the laborers engaged in the work of slab concreting show that they are at very high ergonomic risk, and immediate action is required. The analysis also found that lower back and shoulders were at very high ergonomic risk, and workers reported the same in their interviews.

Table 4.4 ERIN Score for Traditional Working Postures

B P	**P1**	**P2**	**P3**	**P4**		
				(A)	(B)	(C)
BK/T	8	8	8	8	8	8
S/UA/ LA	5	6	9	9	9	9
H/W	5	5	5	5	5	5
N	7	6	6	3	3	3
R	6	6	6	6	6	6
IOE	8	8	8	7	7	7
SA	3	4	3	2	2	2
GR	**42***	**43***	**45***	**40***	**40***	**40***

Table 4.5 RULA Score for Traditional Working Postures

B P	**P1**	**P2**	**P3**	**P4**		
				(A)	(B)	(C)
UA	3	4	4	4	4	4
LA	2	3	3	3	3	3
W	3	4	3	3	3	3
WT	1	1	1	1	1	1
SC(A)	4	6	5	5	5	5
M	1	1	1	1	1	1
F	2	3	3	3	3	3
SC(C)	7	10	9	9	9	9
N	5	5	4	5	5	5
BK/T	5	5	2	2	2	2
L	2	2	2	2	2	2
SC(B)	8	8	6	7	7	7
M	1	1	1	1	1	1
F	3	3	3	3	3	3
SC(C)	12	12	10	11	11	11
RLS	> **7***	> **7***	> **7***	> **7***	> **7***	> **7***

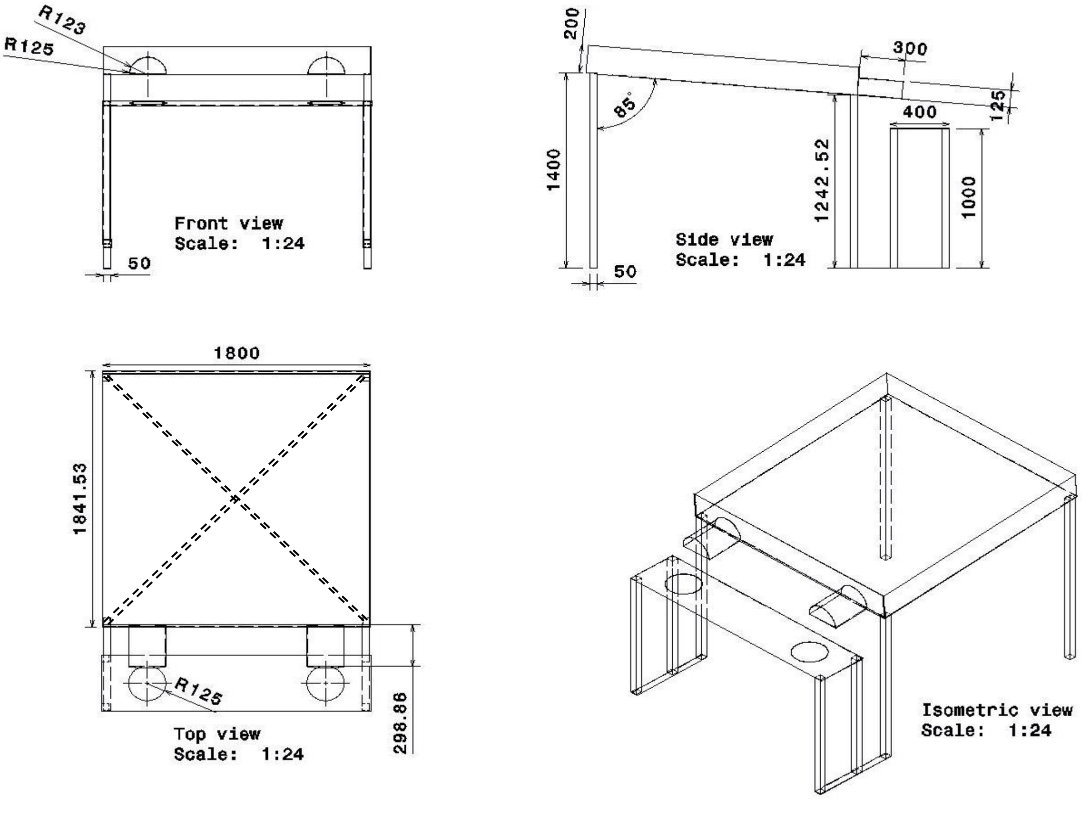
Table 4.6 REBA Score for Traditional Working Postures

B P	**P1**	**P2**	**P3**	**P4**		
				(A)	(B)	(C)
N	3	3	3	3	3	3
BK/T	4	4	4	3	3	4
L	3	2	3	3	3	3
PS-A	8	7	8	7	7	8
F	1	2	2	2	2	2
TS-A	9	9	10	9	9	10
UA	3	4	5	5	5	5
LA	1	2	2	2	2	2
W	2	2	2	2	2	2
PS-B	4	6	8	8	8	8
CP	1	1	1	1	1	1
TS-B	5	7	9	9	9	9
TS-C	10	11	12	11	11	12
A	1	1	1	1	1	1
RBS	11*	12*	13*	12*	12*	13*

4.5 Design of Concrete Collection and Eviction Table:

4.5.1 Design of Model of Concrete Collection and Eviction Table

The new collection and evacuation table was designed and modeled in CATIA software. Figure 4.8 shows a detailed drawing of the proposed design of the concrete collection and evacuation table. After the table was designed, a manikin was modeled and analyzed for the table design using various parameters for collection and lifting of the iron pan. The ERIN, REBA worksheet, and CATIA's RULA method were used to evaluate manikin postures. The biomechanical and lifting analysis for different weights such as 10 kg, 12 kg, 15 kg, and 20 kg was performed in CATIA.



All measurement are in mm

Figure 4.8 Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work

4.5.2 Description of Prototype Design Proposal of Material Collection and Eviction Table for Slab Concreting Work:

The materials proposed for the table are M. S. Sheet of MS 5 mm, M.S. Angle of size (25 mm x 25 mm x 5 mm), and Square Pipe (50 mm x 50 mm x 2 mm). The height of the table is 1400 mm on the elevator side and 1250 mm on the discharge side. The inclination of 15° is placed towards the discharge area. The size of the collection bin is 1800 x 1800 x 200 mm, and there are two openings on the discharge side. The MS angles were used on all four sides and in the center diagonally to support the storage bin on the base. The MS angle is used to support the storage bin of the table at the four sides and diagonally at the base of the bin. The top border of the bin table is fenced by the MS sheet of height 200 mm; hence, the total height of the table increases to 1600 mm. The height of the table used for holding the iron pan is 1000 mm, and the width is 400 mm, which is at the discharge side of the table (attachable and detachable) as shown in Figure 4.8. The upper side of this attached table is equipped with two round holes for proper base to position the iron pan just below the discharge opening. The height of the table used to hold the iron pan is such that the iron pan can be comfortably placed and lifted. From this study, it has been shown that the comfortable height/space for lifting any material is between 900-1100 mm.

For this, an experiment has been performed to find the comfortable height of the head pan to be lifted. Stands of 1000 mm and 500 mm height were constructed, and experiments were performed for height validation (Figure 4.9(a) and (b)). Experimental results showed that when the iron pan was lifted from the ground level and from 500 mm above the ground level, the laborers had to bend (flexion) more to lift the iron pan, and at the same time, they had to put more effort into lifting the iron pan. But when the iron pan was lifted from a height of 1000 mm above the ground, it became more convenient to lift and required less effort. This has been reported by other researchers with some variation [220][221][175][215][219].

Therefore, the height of the table for collecting concrete mix is kept at a height of 1000 mm. When deploying the new table, the height of the elevator will have to be increased by 1600-1800 mm, as required. It is necessary to increase the height of the elevator by 1600-1800 mm as required. In such cases, the total height of the elevator will have to be increased from 3000 mm to 4800 mm as per the requirement. The scaffolding must be arranged at the desired height on the left side of the elevator for the laborer to stand, involved in unlocking and locking the hopper from the elevator.

Figure (a) Person lifting Iron-Pan from Height of stand 1000 mm

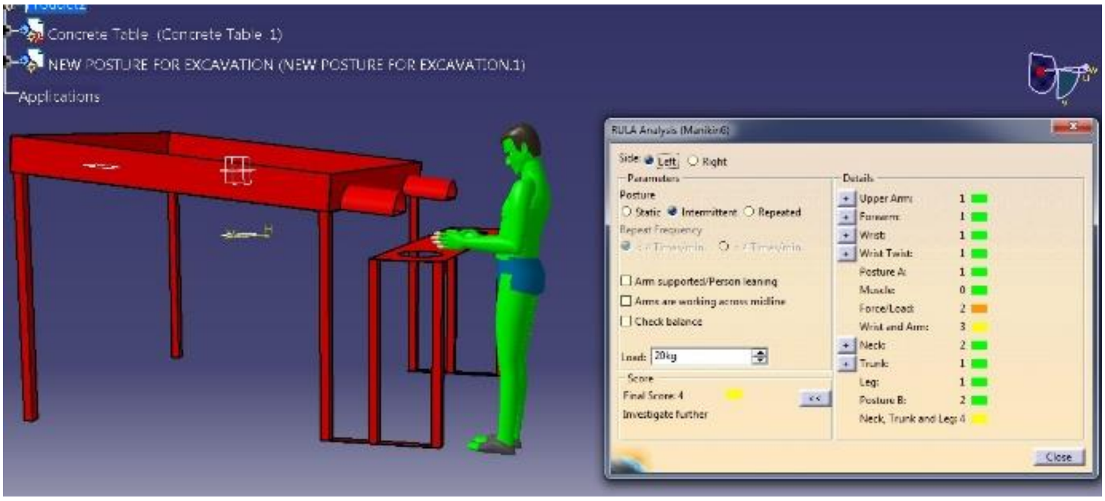
Figure (b): Person lifting Iron-Pan from Height of stand 500 mm

Figure 4.9 Lifting of Iron-pan from the height of 1000 mm and 500 mm

4.6 Postural Analysis Using Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work:

4.6.1 ERIN, RULA and REBA Score using Prototype Design Proposal of Material Collection and Eviction Table for Slab Concreting Work:

The score obtained from the ERIN, RULA, and REBA methods shows (Table 4.7, 4.8, and 4.9) that the proposed table is proficient in collecting and discharging the concrete mixture as the laborers do not need to bend forward for collecting the concrete in the iron pan as well as lifting the iron pan. The results of all methods show low to medium risk to the body parts. At the same time, the load on the muscles has decreased because of the increase in the height of the collecting and lifting table. The postures adopted while working with the new table show that the laborers are working in appropriate and proper postures, but the weight of the pan needs to be decreased to an acceptable weight limit. The RULA score (Figure 4.10(a) and (b)) for 20 kg in CATIA software also got the same result, i.e., 4 (Medium Risk).



Side: ● Left ○ Right

Parameters

Posture

○ Static ● Intermittent ○ Repeated

Repeat Frequency

● < 4 Times/min. ○ > 4 Times/min.

☐ Arm supported/Person leaning

☐ Arms are working across midline

☐ Check balance

Load: 20kg

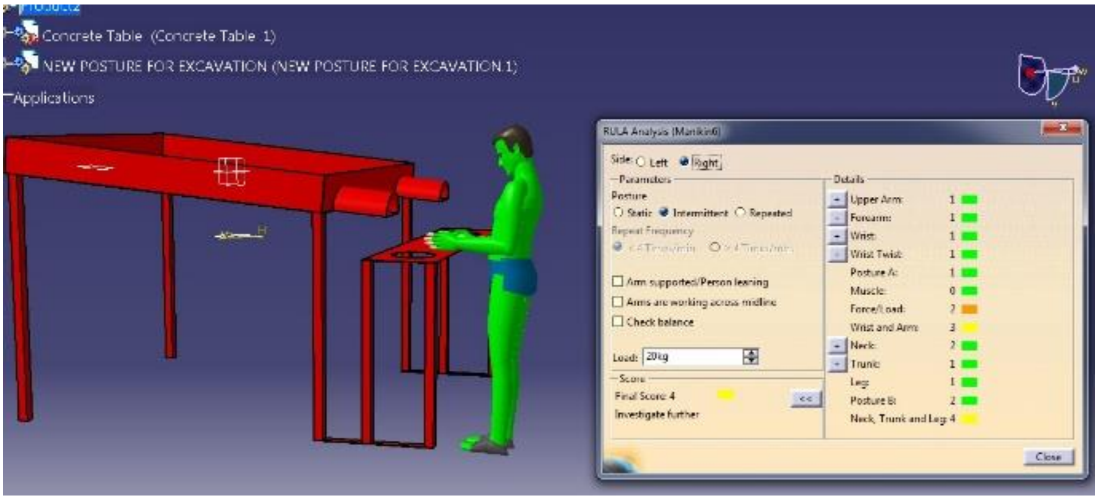
Score

Final Score: 4

Investigate further

Details		
Upper Arm:	1	🟩
Forearm:	1	🟩
Wrist:	1	🟩
Wrist Twist:	1	🟩
Posture A:	1	🟩
Muscle:	0	🟩
Force/Load:	2	🟧
Wrist and Arm:	3	🟨
Neck:	2	🟩
Trunk:	1	🟩
Leg:	1	🟩
Posture B:	2	🟩
Neck, Trunk and Leg:	4	🟨

Figure (a): RULA Scores for left side of the manikin after Modification



Side: ○ Left ● Right

Parameters

Posture: ○ Static ● Intermittent ○ Repeated

Repeat Frequency

☐ Arm supported/Person leaning

☐ Arms are working across midline

☐ Check balance

Load: 20kg

Score

Final Score: 4

Investigate further

Details

Upper Arm:	1	🟩
Forearm:	1	🟩
Wrist:	1	🟩
Wrist Twist:	1	🟩
Posture A:	1	🟩
Muscle:	0	🟩
Force/Load:	2	🟧
Wrist and Arm:	3	🟨
Neck:	2	🟩
Trunk:	1	🟩
Leg:	1	🟩
Posture B:	2	🟩
Neck, Trunk and Leg:	4	🟨

Figure (b): RULA Scores for right side of the manikin after Modification

Figure 4.10 RULA Score (Obtained in CATIA) from Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work

Table 4.7 ERIN Score using Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work

B P	**P1**	**P2**	**P3**	**P4**		
				(A)	(B)	(C)
BK/T	2	2	2	2	2	2
S/UA/ LA	2	2	2	2	2	2
H/W	2	2	2	2	2	2
N	1	1	1	1	1	1
R	3	3	3	3	3	3
IOE	2	2	2	2	2	2
SA	1	1	1	1	1	1
GR	**13$**	**13$**	**13$**	**13$**	**13$**	**13$**

Table 4.8 RULA Score using Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work

B P	**P1**	**P2**	**P3**	**P4**		
				(A)	(B)	(C)
UA	1	1	1	1	1	1
LA	1	1	1	1	1	1
W	1	1	1	1	1	1
WT	1	1	1	1	1	1
SC (A)	1	1	1	1	1	1
M	1	1	1	1	1	1
F	1	1	1	1	1	1
ROW (C)	3	3	3	3	3	3
N	1	1	1	1	1	1
BK/T	1	1	1	1	1	1
L	1	1	1	1	1	1
SC (B)	1	1	1	1	1	1
M	1	1	1	1	1	1
F	1	1	1	1	1	1
COL (C)	3	3	3	3	3	3
FS	**3@**	**3@**	**3@**	**3@**	**3@**	**3@**

Table 4.9 REBA Score using Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work

B P	**P1**	**P2**	**P3**	**P4**		
				(A)	(B)	(C)
N	1	1	1	1	1	1
BK/T	1	1	1	1	1	1
L	1	1	1	1	1	1
PS-A	1	1	1	1	1	1
F	0	1	0	0	0	0
TS-A	1	2	2	2	2	2
UA	1	1	1	1	1	1
LA	1	1	1	1	1	1
W	1	1	1	1	1	1
PS-B	1	1	1	1	1	1
CP	0	0	0	0	0	0
TS-B	1	1	1	1	1	1
TS-C	1	1	1	1	1	1
A	1	1	1	1	1	1
RS	2$	2$	2$	2$	2$	2$

4.6.2 Biomechanical Analysis Using Prototype Design Proposal of Material Collection and Eviction Table for Slab Concreting Work for different weight:

Biomechanical analysis for lifting 10 kg, 12 kg, 15 kg, and 20 kg was performed in the CATIA software using the proposed design concrete Collection and Evacuation Table and manikins shown in Figure 4.11 (a), (b), (c), and (d). The Table 4.10 shows detailed results of biomechanical analysis. From the analysis, it is found that when laborers lifted a weight of 10 kg, the compression at L4/L5 reduced to very low, i.e., 1190 N, and that for 12 kg, it is found to be 1319 N. However, as the weight increases, the compression at L4/L5 increases, i.e., for 15 kg, 1513 N, and for 20 kg, 1837 N. The joint shear is also observed to increase as the weight increases. The other factors are also found to be reduced, while force and pressure on the abdomen became zero.

Table 4.10 : Biomechanical analysis score using Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work

	10 KG	**12 KG**	**15 KG**	**20 KG**
M (Nm)	-31	-37	-47	-63
C (N)	1190	1319	1513	1837
BLC (N)	507	526	555	604
ATC (N)	25	29	35	45
F/EC (N)	520	625	784	1047
JS (N)	96(P)	107 (P)	124 (P)	152 (P)
AF (N)	0	0	0	0
AP (N/m^2)	0	0	0	0

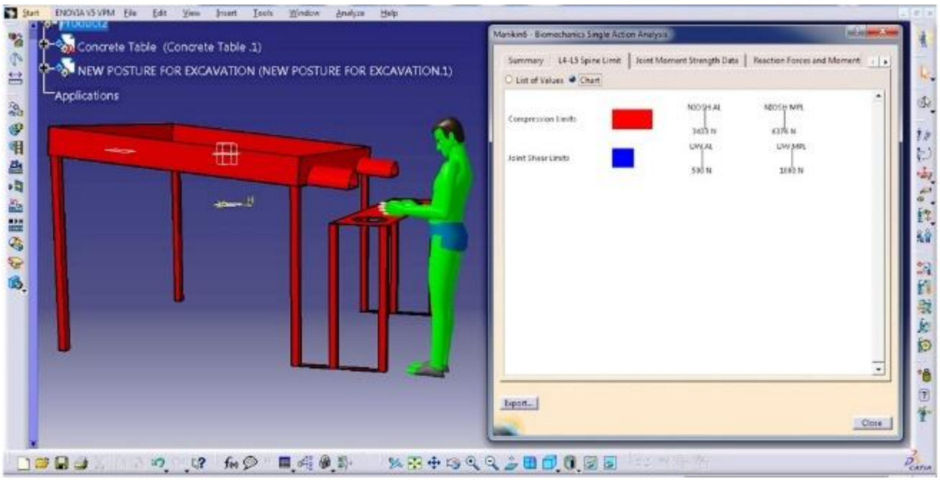


Figure (a): Biomechanical analysis score for 10 kg

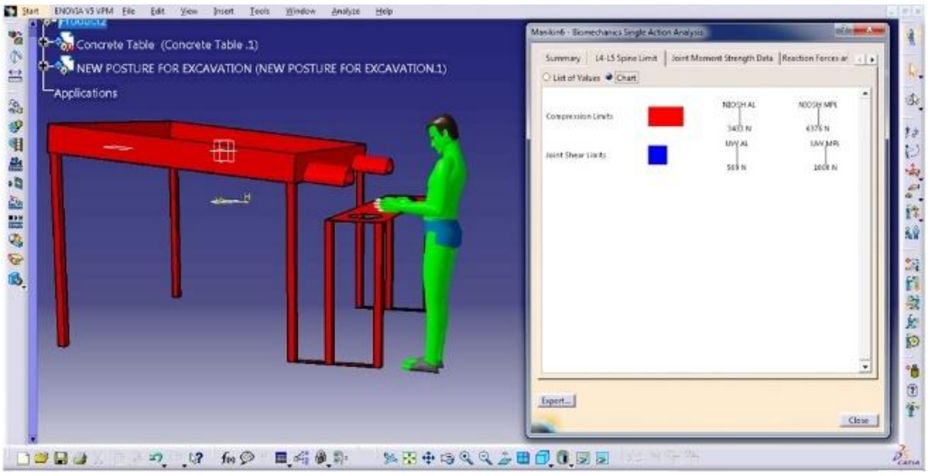


Figure (b): Biomechanical analysis score for 12 kg

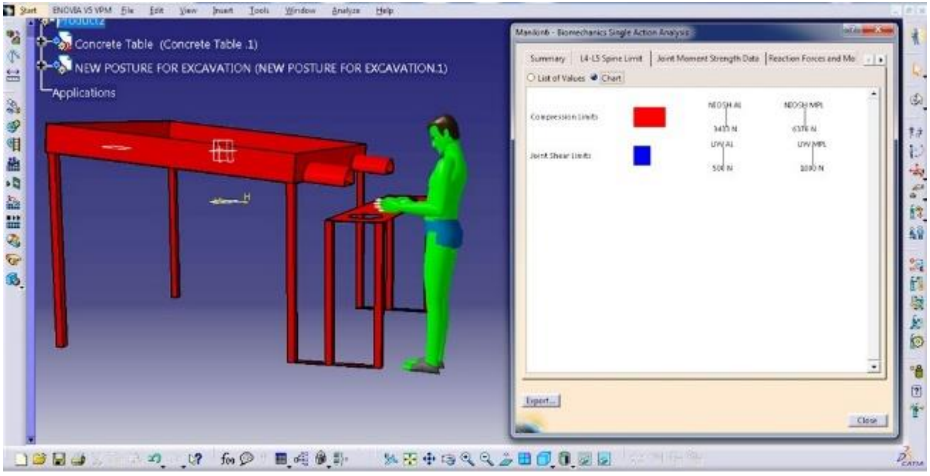


Figure (c): Biomechanical analysis score for 15 kg

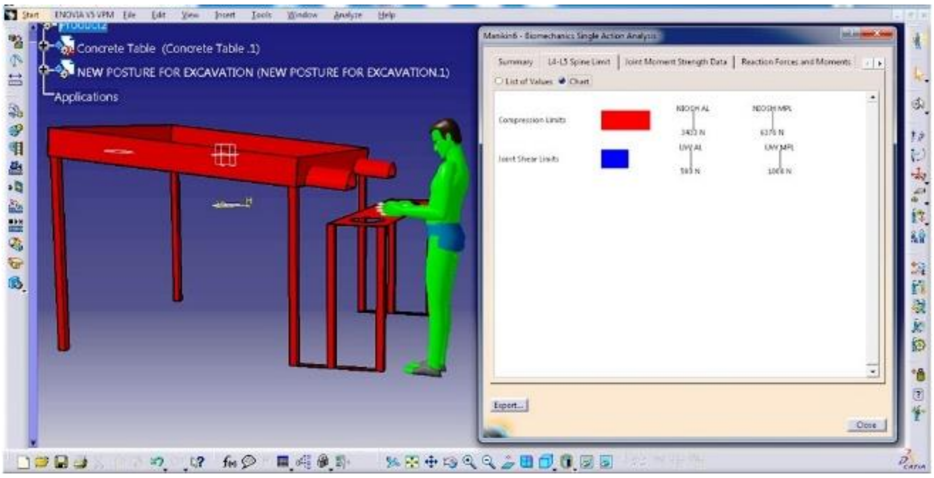


Figure (d): Biomechanical analysis score for 20 kg

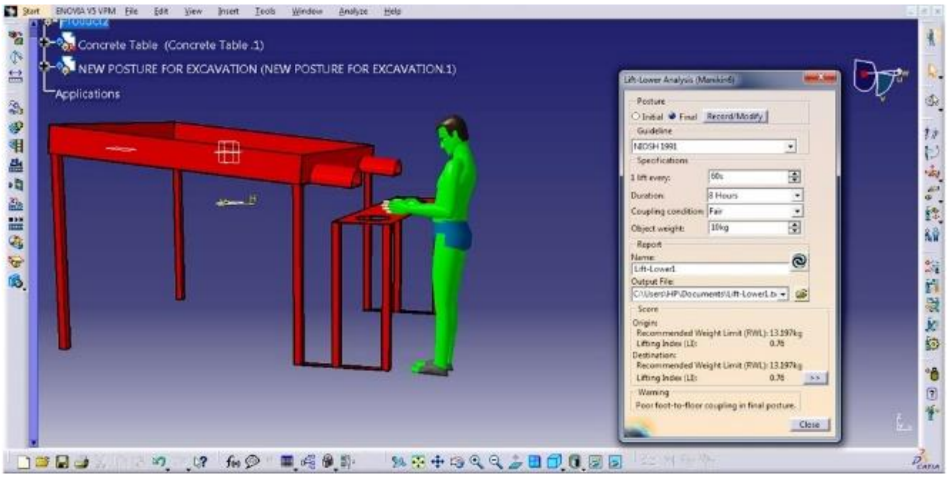
Figure 4.11 Biomechanical Analysis for different weight using Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work

4.6.3 Lifting Analysis Using Newly Proposed Design Concrete Collection and Eviction Table For Different Weight as Per NIOSH 1991:

Table 4.11 shows the NIOSH lifting analysis scores obtained from CATIA software. The analysis was performed by considering 60 seconds time for per lift, duration of work 8 hours, excluding break, better coupling conditions, and weight lifted 10 kg, 12 kg, 15 kg, and 20 kg. After analysis, the result found that the recommended weight limit (RWL) for all positions is 13.197 kg. However, variable values of the lifting index (LI) were obtained. For 10 kg and 12 kg, LI obtained 0.76 and 0.91, while for 15 kg and 20 kg, it is obtained more than 1, i.e., 1.14 and 1.52 respectively. Therefore, from the NIOSH lifting analysis result, it is revealed that the lifting weight should not be more than 13.197 kg, approximately 14 kg. Lifting 14 kg or less weight will bring about positive changes in the body of the laborers (Figure 4.12 (a), (b), (c), and (d)).

Table 4.11: Result of lifting-lowering analysis by CATIA after Modification

Parameters	**10 KG**	**12 KG**	**15 KG**	**20 KG**
Recommended weight limit (RWL) (1991)	13.197	13.197	13.197	13.197
Lifting Index (LI) (1991)	**0.76**	**0.91**	1.14	1.52



Posture: ○ Initial ● Final

Guideline: NIOSH 1991

Specifications

1 lift every: 60s

Duration: 8 Hours

Coupling condition: Fair

Object weight: 10kg

Report

Name: Lift-Lower1

Output File: C:\Users\HP\Documents\Lift-Lower1.tx

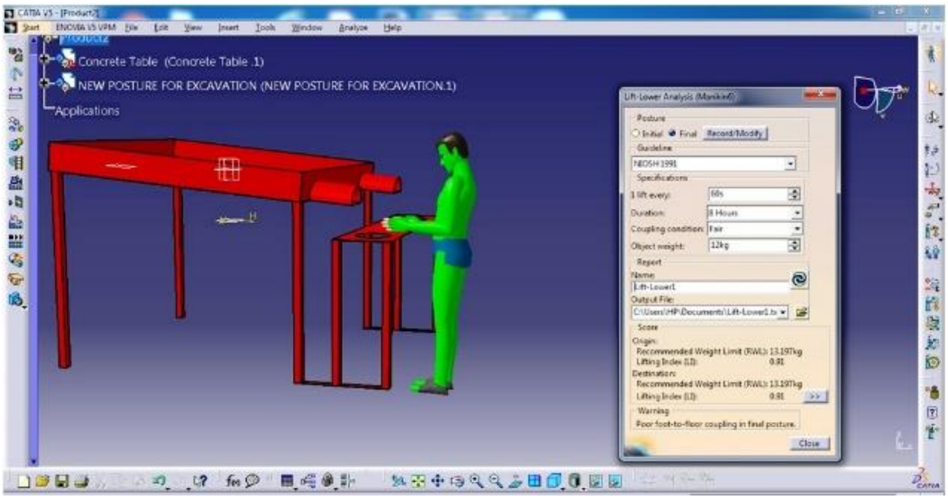
Score

Origin:
Recommended Weight Limit (RWL): 13.197kg
Lifting Index (LI): 0.76
Destination:
Recommended Weight Limit (RWL): 13.197kg
Lifting Index (LI): 0.76

Warning

Poor foot-to-floor coupling in final posture.

Figure (a) NIOSH Lifting analysis score for 10 kg



Posture: ○ Initial ● Final

Guideline: NIOSH 1991

Specifications

1 lift every: 60s

Duration: 8 Hours

Coupling condition: Fair

Object weight: 12kg

Report

Name: Lift-Lower1

Output File: C:\Users\HP\Documents\Lift-Lower1.tx

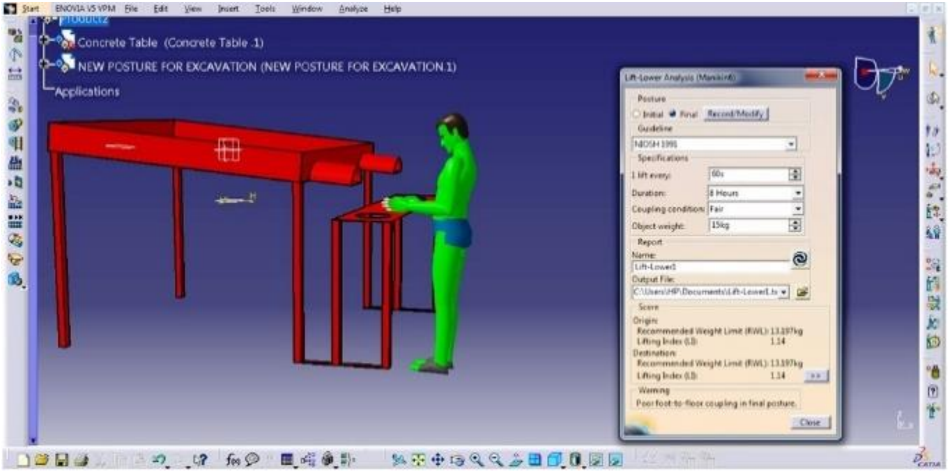
Score

Origin:
Recommended Weight Limit (RWL): 13.197kg
Lifting Index (LI): 0.91
Destination:
Recommended Weight Limit (RWL): 13.197kg
Lifting Index (LI): 0.91

Warning

Poor foot-to-floor coupling in final posture.

Figure (b) NIOSH Lifting analysis score for 12 kg



Lift-Lower Analysis (Manikin6)

Posture

○ Initial ● Final

Guideline: NIOSH 1991

Specifications

1 lift every: 60s

Duration: 8 Hours

Coupling condition: Fair

Object weight: 15kg

Report

Name: Lift-Lower1

Output File: C:\Users\HP\Documents\Lift-Lower1.tx

Score

Origin:

Recommended Weight Limit (RWL): 13.197kg

Lifting Index (LI): 1.14

Destination:

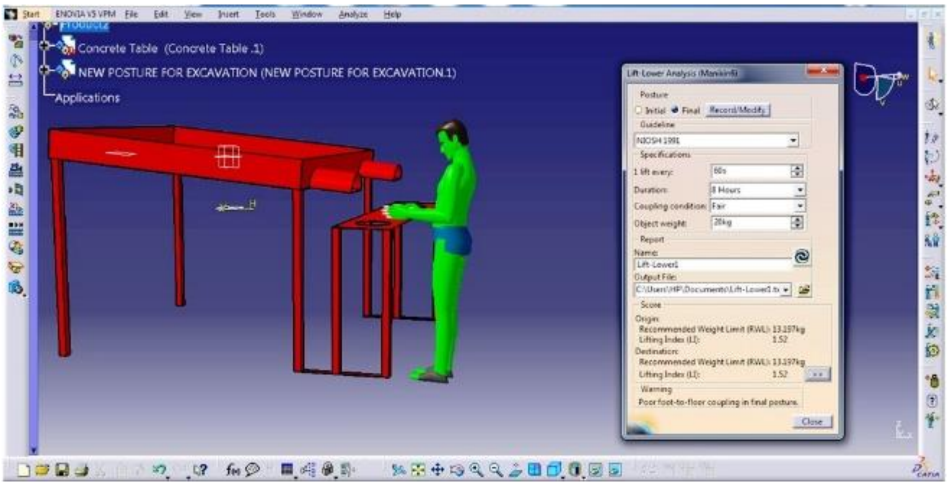
Recommended Weight Limit (RWL): 13.197kg

Lifting Index (LI): 1.14

Warning

Poor foot-to-floor coupling in final posture.

Figure (c) NIOSH Lifting analysis score for 15 kg



Lift-Lower Analysis (Manikin6)

Posture

○ Initial ● Final

Guideline: NIOSH 1991

Specifications

1 lift every: 60s

Duration: 8 Hours

Coupling condition: Fair

Object weight: 20kg

Report

Name: Lift-Lower1

Output File: C:\Users\HP\Documents\Lift-Lower1.tx

Score

Origin:

Recommended Weight Limit (RWL): 13.197kg

Lifting Index (LI): 1.52

Destination:

Recommended Weight Limit (RWL): 13.197kg

Lifting Index (LI): 1.52

Warning

Poor foot-to-floor coupling in final posture.

Figure (d) NIOSH Lifting analysis score for 20 kg

Figure 4.12 Lifting analysis scores for different weight using Prototype Design Proposal Of Material Collection And Eviction Table For Slab Concreting Work

4.7 SUMMARY

The aim of this study was to measure the effect of collecting and lifting concrete mixtures on the body parts of the laborers. To find the effect of working in a forward-bent posture while collecting concrete in the iron pan, the effect of lifting up the iron pan from the ground, and the effect of lifting concrete mass having weight ranges between 18 to 21 kg on the different body parts. Also, to find the most exposed body parts with remedial actions. In this study, ERIN, RULA, and REBA methods and worksheets were used to find the effect of ergonomic risk. From the result of ERIN, RULA, and REBA, it was found that the laborers were working in an extremely vulnerable condition, and their lower back, shoulders, and arms/hands are highly affected. From the different studies of postural analysis, biomechanical analysis, and frequent lifting, it was also revealed that not only heavy lifting but also low and moderate levels of loadings are also responsible for considerable injuries, morbidity, and WRMSD risk [220][222][118][7][107][114].

Moreover, more prevalence of WRMSD occurs due to repetitive activities, heavy exertion, prolonged working in static and dynamic postures, high muscular activities, undue pressure on lower back, no intermittent rest, working in awkward postures, inadequate nutrition, gravity force on L4/L5 and L5/S1 of the spinal cord, wrong tools design and use, environmental effect [118].

Jones et al., 2011 [222] also infer that peak load is also hazardous and cumulative load also has significant effect on the tissue. As per Hoozemans et al., 2008 [220], the vertical location of the load to be lifted must be kept between 320mm to 1550mm and lifting mass should be between 7.5kg to 15kg.

The problem with the study was also revealed that workers often had to work in a forward-bending posture and lift heavy material off the ground, which eventually led to the development of work-related musculoskeletal disorders.

The newly designed Collection and Eviction table is solving the problem of forward bending for collecting the concrete in the iron-pan and lifting the pan from ground level. The newly designed collection and eviction table showed the potential to reduce the risk on lumbar and shoulder problems, as well as the increased height of the table also reduced the risk of shoulder, arm, hands, and neck injury. To find the comfortable lifting height, an experiment was also done using stands of height 500mm and 1000mm. Laborers had to bend over 90 degrees to lift the pan from the bottom, laborers had to bend 90 degrees to lift from a height of 500mm, but workers did not have to bend to lift from a height of 1000mm, and the iron-pan could be lifted easily. The proposed table was designed in CATIA software and analysis was performed on the manikin developed in the same software. ERIN, RULA and REBA analysis as well as biomechanical and lifting analysis were performed on the manikin in the CATIA software. RULA score also obtained from the CATIA and ERIN and REBA score obtained from the worksheets. RULA score obtained from the CATIA showed that when the force of 20, 15, and 12 kg was applied on the body, the score obtained was 4, and when the force of 10 kg was applied on the body, the score obtained was 3, which explained medium risk with further investigation. However, the result obtained from the ERIN and REBA showed low risk.

The biomechanical analysis revealed that lifting weight ranged between 10-20 kg applied low compression forces and joint shear on the lumbar when working in the posture using the proposed table, but it is very much low for the weight of 10 kg and 12 kg. However, the lifting and lowering analysis result showed that the recommended lifting weight should be 13.197 kg because lifting index obtained was more than one for the weight lifted more than 15 kg and less than one when lifting weight is 10 kg and 12 kg. The force and pressure on the abdomen were also obtained as zero when work was done using the proposed table. There were no twisting moments for trunk and neck.

From the different result obtained from ERIN, REBA worksheet and from RULA, biomechanical and lifting/lowering analysis after the proposed collection and eviction table and technique, it concluded that working by using the proposed collection and eviction table minimizes the ergonomic risk on the body parts as well as on the vertebrae that leads to work-related musculoskeletal disorders.

The newly designed collection and discharge table shows that the use of this table for laying concrete mix on the centering for slab concreting work reduces the risk associated with collecting and lifting the iron pan from the ground level and reduces the exposure of vertebral L4/L5 and L5/S1 while performing concrete mix laying on the floor for slab concreting work.

CHAPTER – 5

POSTURAL ANALYSIS OF REBAR AND DESIGN OF FOLDABLE MUTLITASKING WORKABLE PLATFORM FOR REBAR WORK

5.1 BACKGROUND

The construction work remains hazardous despite safety augmentations [223]. In the construction industry, workers are exposed to various ergonomic hazards due to its physical demands and dynamic working environment [224]. Inappropriate workplace conditions give physical sickness and mental discomfort to the workers at construction sites, whereas it is necessary to maintain both physical and mental well-being of the workers to improve productivity [225]. One of the major health challenges facing construction workers is work-related musculoskeletal disorders (WRMSD). This problem is increasing in the construction area worldwide. The construction workers face this problem at an early age [1] [2].

The construction work is physically demanding compared to other jobs, and WRMSDs are influenced by awkward work postures, repetitive motions, heavy lifting from ground level, pace of work, prevalent jobs, traumatic incidents, and addiction. Construction workers, especially Rebarers, play an important role in construction work. However, their occupation itself presents health problems due to the physically demanding work and ergonomic risks inherent in rebar work.

Rebar work involves high physical exertion, force, and repetitive motions of the hand/arm, wrist, shoulder, and lower back. The Rebarers are forced to work for numerous hours without breaks, which causes fatigue and tiredness among them. They tend to adopt awkward postures while working, which may lead to problems with the spine or vertebrae or discs in the future. Due to the unavailability of proper tools and equipment, Rebarers use traditional tools and methods through which they unknowingly cause pain or discomfort in the hand, wrist, palm, shoulders, and lower back. Rebarers are forced to perform heavy and laborious work at construction sites. Construction work is extremely dangerous, where workers are badly affected by work-related musculoskeletal disorders due [17]. Assessment of WRMSD among the workers engaged in construction work is complicated to continuous, dynamic, and complex work tasks. [15] Rebarers are considered the strength of construction work and are responsible for binding iron bars for column and slab reinforcement. Physical fatigue influences hazards to the construction worker and threatens workers' safety at construction workplaces. [226] Prolonged working in awkward postures, repetitions, and forceful exertions affect the workers' health and efficiency [227]. The construction workers experience ergonomic risk factors every day during the task and hence are sensitized to work-related musculoskeletal disorders [228].

The construction workers' work-related musculoskeletal disorders remarkably influence occupational stress and health-related quality of life and have a consequential moderate effect on the association between occupational stress and health-related quality of life, which emphasizes developing techniques to reduce occupational stress and avoid work-related musculoskeletal disorders [229]. The most significant risk factors are not wearing a belt on scaffolding, falling from stairs or ladders, exposure to hazardous materials, improper tools and machinery, repetitive tasks, improper layout at the construction site, and lack of safety precautions [230]. The research findings revealed that work-related musculoskeletal disorders, hazards, injuries, and fatalities can be prevented by recognizing the risks and taking preventive measures [231]. Therefore, this study aims to explore the level of risk among Rebarers during rebar work and identify body parts highly affected, and propose some remedial solutions by designing a Foldable Multitasking Workable Platform.

5.2 VARIOUS TASK PERFORMED BY THE REBAR:

5.2.1 Task 1: Rebar Straightening (using Benders / Hickey Bar) (R1):

In this task, the Rebarer uses to straighten the rebar received using a bar bender (local make), as shown in figure 5.1(i)(c). In this task, the Rebarer has to: a) Bend 90° flexion, b) Legs flexion at the knee (bent): < 90°, c) Both arms up to shoulder level, d) Trunk flexion position, e) Trunk lateral right-side position, and f) Forearm pronation (Figure 5.1(i)(c). In another position, as shown in figure 5.1(i)(a), the trunk of the Rebarer is working in extension posture while the legs are bent and arms are straight. In Figure 5.1(i)(b), the Rebarer is working in flexed position with twisting postures. The Rebarer's left leg is slightly bent while the right leg is bent more than 60°. In both Figures 5.1(i)(a) and 5.1(i)(b), the Rebarer has to apply a high level of force to straighten the bar, as the diameter of the rebar increases, the requirement for force increases.

5.2.2 Task 2: Rebar Cutting to required length (R2):

In this task, the Rebarer uses to cut the rebar into the required length, as shown in figure 5.1(ii)(a)(b). In this task, the Rebarer has to: a) Sit in a squatting position, b) Legs flexion at the knee (bent): > 90°, c) Ankle extension, d) Both arms below the shoulder, e) Left shoulder abduction, f) Trunk in a bent position, g) Neck in rightward turn position, and h) Wrist in ulnar deviation. The rebar used to be cut with the help of a chisel, but currently the Rebarer uses a hand-held electric cutting machine. Due to the high speed of this cutter, the Rebarer has to face vibration and contact stress.

5.2.3 Task 3: Making of Stirrups / Ties (R3):

In this task, the Rebarer uses to make the stirrups of the required size using rebar with a diameter of 4 mm to 6 mm, as shown in figure 5.1(iii)(b). Basically, the Rebarer uses a temporary arrangement for making stirrups, called a “Thiyya” in Maharashtra, as shown in figure 5.1(iii)(a)(b). In this task, the Rebarer has to: a) Stand with slight flexion, b) Arms below the shoulder, c) Neck in a flexed position, d) Right arm wrist twisted with ulnar deviation, e) Right arm fingers twisted, and f) Left arm holding the stirrups with force. They use a rebar hand bender to bend the rebar to convert it into stirrups. On the temporary arrangement, they fix the studs of the Rebarer on the wooden block at the required length so that it can hold the rebar and bend it. They mark a scale on the wooden block to measure and make stirrups.

5.2.4 Task 4: Making of reinforcement / rebar steel cage for column (R4):

In this process, the rebarer makes a steel cage for the column using stirrups and long rebar bars as shown in figure 5.1(iv). In this task, the rebarer has to: a) work in flexion and squatting position, b) leg flexion at the knee (bent): > 90°, c) ankle extension, d) arms above/below shoulder, e) right wrist twisting, f) neck in extension position, g) right arm fingers in holding position, h) left arm fingers in holding position. The rebar cage of various sizes, as per requirement, is made for reinforcement to the column.

5.2.5 Task 5: Tying stirrups in plinth and beam (R5):

In task work, the rebarer is engaged in tying stirrups for plinth/beam as shown in figure 5.1(v). In this task, the rebarer has to: a) sit in a squatting position, b) leg flexion at the knee (bent): > 90°, c) arms above shoulder, d) neck in extension with right bend position, and e) trunk flexion/bend. It is a very tedious job for the rebarer.

5.2.6 Task 6: Tying of Slab reinforcement / Rebar using wires (R6):

In task work, the rebars are being tied with the help of steel wire for slab concreting as shown in figure 5.1(vi). In this task, the rebarer has to: a) sit in a squatting position, b) leg flexion at the knee (bent): > 90°, c) arms below shoulder, d) neck in extension position, e) trunk flexion, f) arms in abduction position, g) right arm's wrist and fingers in flexion position, h) left arm's fingers in extension position. In this method, the rebars are tied to horizontal rebars placed across the roof using steel wire.

5.2.7 Task 7: Bending column bar to attach new rebar for extension (R7):

In this process, the rebarer bends the bar attached to a new rebar for vertical extension or straightens the rebar already present, as shown in figure 5.1(vii). In this task, the rebarer works in: a) trunk flexion posture, b) leg flexion at the knee (bent): < 90°, c) arms up to shoulder, d) neck in extension position with twist, e) trunk extension, f) arms in abduction position, g) right arm's extension in straight position, h) left arm in holding position, i) right arm applying force. This is not a regular process, but it has to be performed frequently.

(a) (b) (c)

Figure (i) Rebar Straightening (R1)

[redacted]

(a) (b)

Figure (ii) Rebar Cutting (to required length) (R2)

(a) (b)

Figure (iii) Making of Stirrups / Ties (R3)

Figure (iv) Making of reinforcement / rebar steel cage for column (R4)

Figure (v) Tying stirrups in plinth and beam (R5)

Figure (vi) Tying of Slab reinforcement / Rebar using iron wires (R6)

Figure (vii) Straightening of column rebar for extension of column (R7)

Figure 5.1 Various Task performed by the Rebarers

5.3 RESULTS

A total of 48 Rebarers were observed, interviewed, and video recorded for fifteen weeks, performing various rebar tasks, including 1) straightening of rebar, 2) cutting of rebar, 3) making of stirrups, 4) making of rebar cages, 5) laying of rebar cage at plinth level with stirrups, 6) tying of slab reinforcement using wires, and 7) various rebar tasks at construction sites in Nagpur (Maharashtra) and Kolkata (West Bengal) areas. The somatic characteristics of Rebarers are shown in Table 5.1.

Rebarers' personal data such as age, experience, working hours, pain/discomfort, working technique, and other related data were recorded through interviews. The height and weight of the Rebarers were recorded using a standard anthropometric scale and weighing machine. The age group of Rebarers was 26 to 59 with 2 to 36 years of experience. The average working hours were 8, from 9 am to 6 pm including lunch, depending upon the need and priority of the work. Forty-two out of 48 Rebarers had completed primary education, and the rest had completed secondary education. It shows that Rebarers are not highly educated, and most of them have migrated from nearby areas (57%). Also, there is no proper education or courses available for this work. However, Rebarers learn from their years of experience. Various methods are available for assessment of postures that can be implemented to assess working postures. In this study, the Novel Ergonomic Postural Assessment Method (NERPA) [71], Assessment of Repetitive Tasks of the Upper Limbs (ART) [202][203][204], and The Job Strain Index (JSI) [207] method were used to assess the ergonomic risk among the Rebarers.

The postures of rebarers have been evaluated using NERPA, ART, and JSI methods. Various postures were selected for analysis while performing rebar work, as shown in figures 5.1(i) to (vii). These assessments were conducted at various construction sites, and data were collected for pain/discomfort in body parts.

Results show that (Table 5.2 and Figure 5.2), the rebarers have complaints about pain/discomfort in the lower back (82%), knees (63%), legs (57%), arms/hands (53%), elbows (38%), wrists (36%), fingers/thumbs (25%), chest (23%), and neck (21%). It is also revealed that 36% of rebarers have pain after working, but not on a regular basis, which seems to be normal. It is noticed that the rebarers' body parts which are under the highest prevalence of risk are the lower back (82%), knees (63%), legs (57%), and arms/hands (53%).

Table 5.1 Somatic Characteristics of Rebar workers (N=48)

Characters	**Mean (±SD)**
Age (years)	43.46 (± 8.63)
Height (cm)	163.75 (± 5.81)
Weight (kg)	61.73 (± 6.51)
Work Experience (years)	19.35 (± 8.08)
BMI (kg/m2)	23.02 (± 2.10)
Working hours/day (hours)	9 (±1)
Rest hours/day (hours)	1 (± 30min)

Table 5.2 Rebarer reply to pain/discomfort (N=48)

Body Parts	Number of workers	% of workers
Head	0	0
Neck	10	21
Shoulder	0	0
Chest	11	23
Elbow	18	38
Arms/Hands	25	53
Wrist	17	36
Fingers/Thumbs	12	25
Upper Back	0	0
Lower Back	39	82
Thigh/Hip/Buttock	0	0
Legs	27	57
Knees	30	63
Ankle/Feet/Toe	0	0

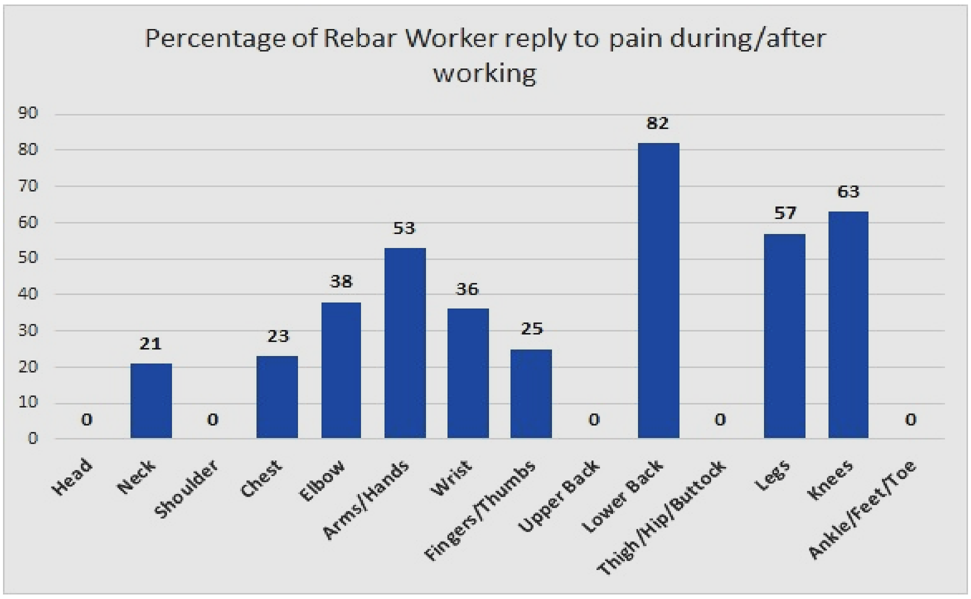


Figure 5.2 Number and percentage of worker reply to pain/discomfort

5.4 RESULTS OF NERPA, ART AND JSI METHODS FOR TRADITIONAL WORKING POSTURES:

The ergonomic risk scores were calculated using the NERPA method, ART method, and JSI method, as shown in Table 5.3, Table 5.4, and Table 5.5, respectively, for all selected working postures.

5.4.1 Result of NERPA Method for Traditional Working Technique:

The result obtained by NERPA method is shown in Table 5.3. From the result of the NERPA worksheet, it is found that the tasks R1, R4, R6, and R7 are at very high risk, while other tasks are at high risk.

Table 5.3 Ergonomics Risk Scores Of NERPA Method For Traditional Working Postures

BP	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**
UA	2	1	1	3	3	3	3
LA	2	1	1	3	2	2	3
W	2	2	2	2	2	2	2
WT	1	1	2	2	1	1	1
PS-A	3	2	2	4	4	4	4
M	1	1	1	1	1	1	1
F	1	1	1	1	1	1	2
TS-C	5	4	4	6	6	6	7
N	4	4	4	4	4	4	4
LB	5	2	2	4	2	4	5
L	1	1	1	1	1	1	2
PS-B	7	5	5	7	5	7	7
M	1	1	1	1	1	1	1
F	1	1	1	1	0	0	1
TS-C	9	7	7	9	6	8	9
FS	+7	6	6	+7	7	+7	+7
RL	*	#	#	*	#	*	*

5.4.2 Result of ART Method For Traditional Working Technique:

The result obtained by ART method is shown in Table 5.4. As per the result obtained from the ART score sheet, the tasks R1, R3, R4, R6, and R7 are at high risk. The right-hand side of the rebarers is shown to be at high risk level, while the left hand is at medium risk level. As per the ART method, the tasks R2 and R4 are at medium risk for both hands.

Table 5.4 Ergonomics Risk Scores of Assessments of repetitive tasks of the upper limbs (ART) Method for Traditional Working Postures

BP	**R1**		**R2**		**R3**		**R4**		**R5**		**R6**		**R7**	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R
A1	0	3	0	3	0	3	0	3	0	3	0	3	0	3
A2	0	0	0	0	0	3	0	3	0	3	0	3	0	0
B	0	8	0	2	0	9	0	4	0	0	0	4	0	8
C1	2	2	1	1	1	1	2	2	1	1	2	2	2	2
C2	2	2	1	1	1	1	2	2	1	1	2	2	2	2
C3	2	2	2	2	0	2	2	2	0	2	2	2	2	2
C4	2	2	2	2	2	2	2	2	2	2	2	2	2	2
C5	2	2	1	2	2	2	2	2	1	1	2	2	2	2
D1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
D2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
D3	2	2	2	2	2	2	2	2	2	2	2	2	2	2
TS	16	27	13	19	12	29	16	26	11	19	16	26	16	27
D4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ES	16	27	13	19	12	29	16	26	11	19	16	26	16	27
RL	@	#	@	@	@	#	@	#	$	@	@	#	@	#

5.4.3 Result of JSI Method for Traditional Working Technique:

The result of the Job Strain Index shows that all the tasks of rebar work are at high risk for both hands. The result obtained by JSI method is shown in Table 5.5. The result of the Job Strain Index was calculated using the Revised Strain Index worksheet. [207] All risk factors were micro-observed with time and noted down. The SI result shows that all the values obtained are more than 10, which shows that all the tasks of rebar work are at high risk for both hands. While calculating JSI, the total observation time was taken as 60 seconds and kept constant for all tasks, as the total number of exertions was observed for 60 seconds for all tasks done. Also, the duration of the task per day was taken as 8 hours. All other parameters, like intensity of exertion, duration per exertion, hand/wrist posture, were recorded as per the postures, approximate force required.

Table 5.5: Ergonomics Risk Scores Of Revised Job Strain Index (JSI) Method For Traditional Working Postures

BP	**R1**		**R2**		**R3**		**R4**		**R5**		**R6**		**R7**	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R
JS	45.6	45.6	21.6	21.6	48.3	36.2	29.8	17.9	17.1	17.1	14.6	10.3	68.7	72.6
	#	#	#	#	#	#	#	#	#	#	#	#	#	#

5.5 Design Of Foldable Mutli-tasking Workable Platform for Rebar Work:

5.5.1 Design Model of Foldable Mutli-tasking Workable Platform for Rebar Work:

The new working platform for rebarers was designed, modeled, and assembled using Siemens NX 12.1 Module. Figure 5.3 shows the detailed 2D drawing of the foldable working platform. The size of each part of the working platform has been taken from real-time requirements. The size of the table is L 1510 mm x W 550 mm x H 940 mm. Both sides of the platform are provided with MS bars on which studs are fixed, each at a 2-inch distance, to measure the length of the stirrups while making them for various sizes. These studs are provided on both sides and arranged in such a manner that left- and right-handed persons can use it. The vertical columns are supported by a cross link for folding and opening the platform. The folded size of the platform is 250 mm, and that of the unfolded platform is 1510 mm. It is provided with an MS plain lock link of size 120 mm x 10 mm at the top to lock the platform when opened. The cross-support studs are also provided to each frame to provide proper support to the frame and platform. To fix the platform to the ground, a plate with a hole is attached to the bottom of the platform.

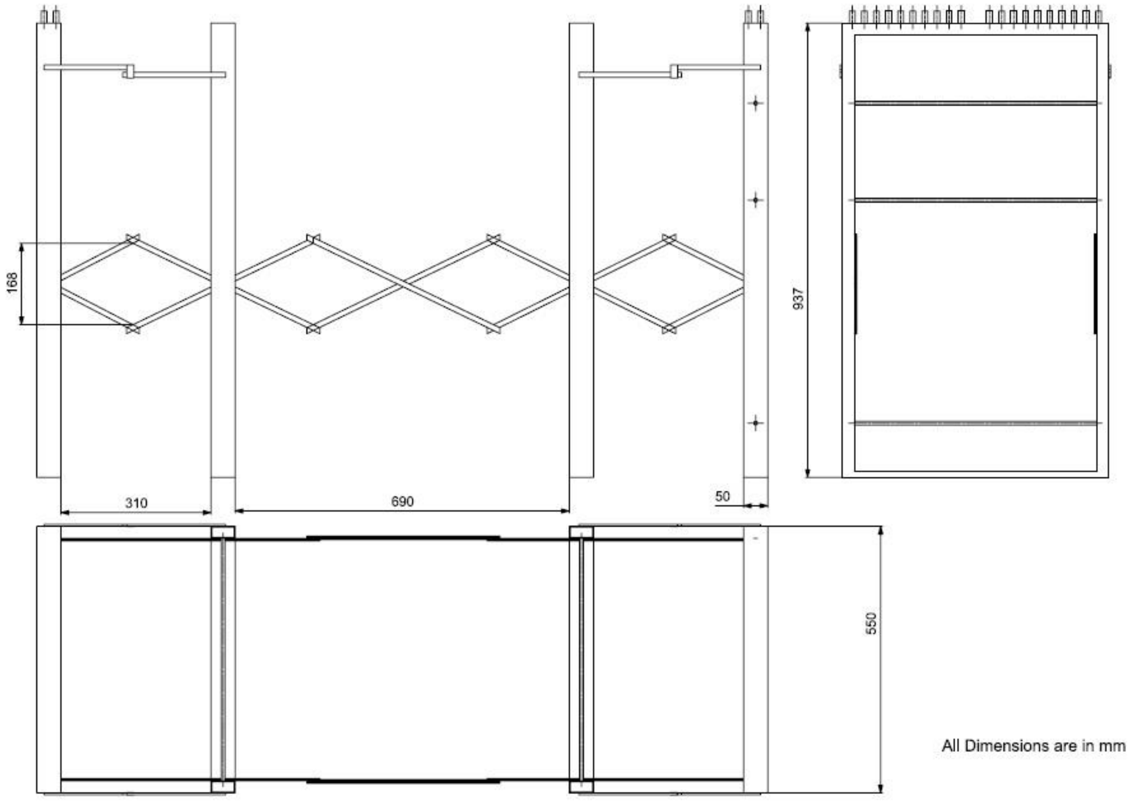
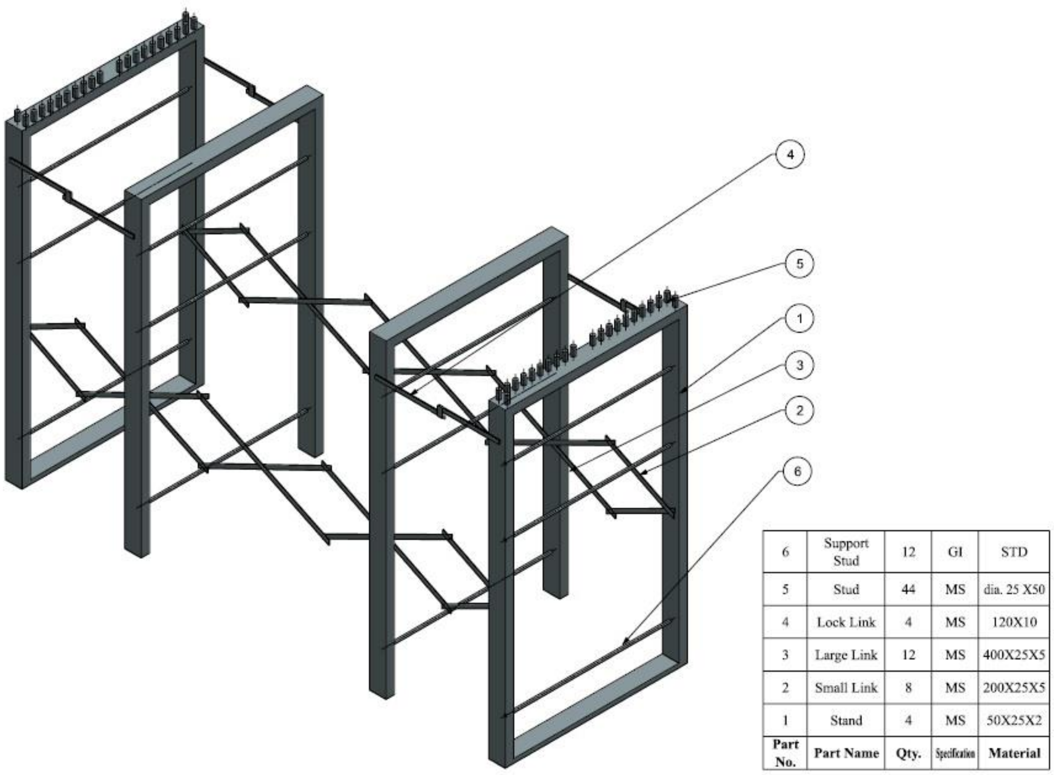


Figure 5.3 Detailed 2D Drawing of Foldable Mutlitasking Workable Platform for Rebar work



6	Support Stud	12	GI	STD
5	Stud	44	MS	dia. 25 X50
4	Lock Link	4	MS	120X10
3	Large Link	12	MS	400X25X5
2	Small Link	8	MS	200X25X5
1	Stand	4	MS	50X25X2
Part No.	**Part Name**	**Qty.**	**Specification**	**Material**

Figure 5.4 Detailed 3D Drawing of Foldable Mutlitasking Workable Platform for Rebar work (Isometric view)

5.5.2 Fabrication of Foldable Mutlitasking Workable Platform for Rebar Work:

5.5.2.1 Requirment oF Materials with Specification:

1.	MS Rectangular Pipe	(Size- 50x25x2),	Quantity-8
2.	MS flat (small)	(Size-200x25x5),	Quantity-8
3.	MS flat (large)	(Size-400x25x5),	Quantity-12
4.	MS flat (locklink)	(Size-120x10),	Quantity-8
5.	MS Studs	(Size- dia. 25x50),	Quantity-44
6.	GI Support Studs	(Size- std size),	Quantity-12

5.5.2.2 Different Parts of the Foldable Mutlitasking Workable Platform for Rebar and Their Functions:

1. **Frame (Stand)**:

   The main frame is made up of an MS rectangular pipe of size 50 mm x 25 mm x 2 mm. For the fabrication of the platform, four frames of the given sizes are cut and welded. The top side of the frame (on both sides) is free to fix the stud bars (horizontal), which are attachable and detachable. They can be removed and fixed whenever required. This helps in the transportation of the platform, and the horizontal stud bars can be used anywhere without the frame if required.

2. **Crosslink**:

   The cross links are made up of MS flat of size 200 mm x 25 mm x 5 mm for the small link and 400 mm x 25 mm x 5 mm for the long link. These links help to fold and open the platform.

3. **Locklink**:

   The lock link is made up of MS flat of size 120 mm x 10 mm. This lock link helps in holding the frame tightly when opened. It is provided on both sides of the frame.

4. **Support Studs**:

   The GI support studs are provided across the frame. On each frame, there are three support studs. The diameter is 25 mm, and the length is 560 mm. The studs used are screwed to the frame. These support studs are provided for extra support to the frames and platform.

5. **Studs**:

   On each side, the frame is provided with another cross frame, which can be attached and detached. On this attachable and detachable frame, the studs are provided. These studs are used to make stirrups. These studs are fixed in such a way that any size of the rebar stirrups can be made on the platform, ranging from 4 mm to 10 mm. It has been mounted on the frame as needed for the making of stirrups, as shown in Figure. These are provided on both sides of the platform and manufactured in such a way that both left- and right-handed persons can use it.

6. **Base Plate**:

   The base plate is provided at the base of the frame to fix the platform on the ground with a hole of diameter 10 mm.

7. **Fixing Screw**:

   The fixing screws are used to fix this frame onto the surface. The size of the fixing screw is diameter 10 mm x 100 mm.

The actual fabricated foldable working platform for rebar work is shown in
Figures 5.5(a), (b), (c), and (d).

5.5.2.3 Fabrication of Foldable Mutlitasking Workable Platform for Rebar Work:

The actual fabricated foldable working platform for rebar work is shown in Figures 5.5(a), (b), (c), and (d). The detailed drawing, parts, and fabrication are explained in the above section. The size of the platform is 250 mm when folded and 1100 mm when opened, as shown in Figures 5.5(b) and (c). The platform is provided with a top plate having studs fixed on it at a distance of 50 mm, which can be used for making stirrups, as shown in Figure 5.5(d).

(a) Fabricated Foldable multitasking workable plateform

(b) Fabricated Foldable multitasking workable plateform (Folded)

(c) Fabricated Foldable multitasking workable plateform (Opened)

(d) Fabricated Foldable multitasking workable plateform (Arrangement for making stirrups)

5.5 Fabricated Foldable Mutlitasking Workable Platform for Rebar work

5.5.2.4 Total cost of manufacturing/Fabrication:

The total weight of the foldable multitasking workable platform is 21.360 kg with all materials (Figure 5.10). As the rate of MS is Rs. 115/- with labor charges, the total cost of the foldable multitasking workable platform, when calculated, comes out to be Rs. 2456/- (rounded off to Rs. 2500/-), which is also a very negligible cost.

5.6 Postural Analysis Using Newly Designed Foldable Mutlitasking Workable Platform:

The newly designed foldable multitasking workable platform for rebar work is capable of solving the problem of tasks R1, R2, R3, and R4, i.e., rebar straightening, rebar cutting, stirrup making, and rebar cage making. The rebar cutting and straightening work can be performed on this foldable multitasking workable platform, as shown in Figures 5.6 and 5.7, where the rebarer is tying (fastening) stirrups to the cage. The rebarer can cut and straighten the rebar using the same posture; hence, the postures in Figures 5.6, 5.7, and 5.8 are considered for three tasks, i.e., R1, R2, and R4. The posture adopted by the rebarer in Figure 5.9 is considered for task R3.

Figure 5.6 Rebar Cage tying with newly designed Foldable Mutlitasking Workable Platform

Figure 5.7 Rebar Cage tying with newly designed Foldable Mutlitasking Workable Platform

Figure 5.8 Cutting of Rebar using newly design foldable multitasking workable platform

Figure 5.9 Stirrups making with newly designed newly design Foldable Mutlitasking Workable Platform

Figure 5.10 Newly design foldable multitasking workable platform with weight

5.6.1 Result of NERPA Method for Newly Designed Foldable Mutlitasking Workable Platform after Modification:

The result obtained by the NERPA method is shown in Table 5.6 (a). From the result of the NERPA worksheet for tasks R1/R2/R4, it is found that tasks R1, R2, and R4 are at lower risk, while task R3 is found to be of medium risk. The NERPA score obtained after using the newly designed foldable multitasking workable platform is found to be much lower than the old one and is acceptable.

5.6 NERPA and ART Score after using Newly Designed Foldable Multitasking Workable Platform

Table (a) Scores Of NERPA after Improvement			Table (b) Scores of ART after Improvement				
BP	**R1/R2/R4**	**R3**	**BP**	**R1/R2/R4**		**R3**	
UA	2	2		L	R	L	R
LA	1	2	**A1**	3	3	3	3
W	1	1	**A2**	0	0	0	0
WT	1	1	**B**	0	0	0	1
PS-A	2	3	**C1**	1	1	0	0
M	0	1	**C2**	0	0	1	1
F	0	1	**C3**	0	0	0	0
TS-C	2	5	**C4**	1	1	1	1
N	2	1	**C5**	0	0	0	0
LB	1	1	**D1**	2	2	2	2
L	1	1	**D2**	2	2	2	2
PS-B	2	1	**D3**	2	2	2	2
M	0	0	**TS**	11	11	11	12
F	0	0	**D4**	1	1	1	1
TS-C	2	2	**ES**	11	11	11	12
FS	2	4					
RL	**$**	**@**	**RL**	**$**	**$**	**$**	**@**

5.6.2 Result of ART Method for Newly Designed Foldable Mutlitasking Workable Platform:

The result obtained by the ART method is shown in Table 5.6(b). As per the result obtained from the ART score sheet, tasks R1, R2, and R4 are found to be low risk for both hands, while the score for R3 is found to be low risk for the left hand and medium risk for the right hand, as for this task, the right hand needs to put more effort than the left hand, and it is quite acceptable.

5.6.3 Result of JSI Method for Newly Designed Foldable Mutlitasking Workable Platform:

The result of the Job Strain Index shows that all the tasks of rebar work have dropped below 10, as shown in Table 5.7. All risk factor micro-observations were performed with time and noted down. While calculating JSI, the total observation time was taken as 60 seconds and kept constant for all tasks, as the total number of exertions was observed for 60 seconds for all tasks done. Also, the duration of the task per day was taken as 8 hours. All other parameters, like intensity of exertion, duration per exertion, hand/wrist posture, were recorded as per the postures and approximate force required, as taken in the previous study.

Table 5.7 Revised Job Strain Index Score after using Newly Designed Foldable Multitasking Workable Platform

BP	**R1/R2/R4**		**R3**	
	L	R	L	R
JS	8.6	9.1	3.1	5.4

5.7 SUMMARY

The main cause of discomfort in these body parts is because of working in prolonged repetitive activities, working in flexion position, standing position, squatting position, and twisting position, excessive pressure on the hand/arms, fingers, and wrist. A requirement of precision in work, heavy material handling, and working time add some burden on the rebarers. For rebar work, the right hand seems to be highly involved and engaged while performing all the tasks mentioned above. It is also observed that while performing various rebar tasks, the wrist and fingers of the rebarers are working in a flexion position with ulnar deviation and a proper grip. Many manual and automatic bar benders (for bending and straightening), rebar wire twisters (locking the iron bar in the frame or cage), and stirrup ring makers (ring making) are available, but only manual bar benders, locally made wire twisters, and local arrangements for stirrup (ring) making built by the rebarers are mostly used in the studied area due to the higher cost of automatic bar benders, rebar wire twisters, and stirrup (ring) makers.

All three methods show that the rebarers are suffering from work-related musculoskeletal disorders while performing all tasks as discussed, and require comprehensive investigation and modifications for working posture and tools used. The real-time images show that the rebarers are working at a very high to high level of risk while performing this tedious job.

For this study, extremely risky working postures were selected. All these postures were evaluated using NERPA, ART, and JSI methods. The result of these methods showed that rebarers were at the utmost level of ergonomic risk and need immediate action for remedies. The most exposed body parts to ergonomic risk are the lower back, knees, legs (calf), arms/hands, elbows, wrists, and fingers.

The newly designed foldable multitasking workable platform has shown the potential of solving the problems of rebar work, such as cutting, straightening, cage making, and stirrup making, which can be performed on the platform easily without working in flexion posture, squatting posture, kneeling postures, etc., as seen earlier. The total fabrication cost of the platform is 2500/-, hence, without investing much more money, the problem of work-related musculoskeletal disorders may be reduced.

The result of this study shows that there is a close correlation between working in awkward postures and work-related musculoskeletal disorders amongst the rebarers, as the rebarers have to work in prolonged kneeling, squatting, standing, trunk flexion, and trunk twisting postures. Also, rebarers have a high risk of WRMSD since they work in seized posture at the lower body, repetitive work, trunk flexion, wrist flexion and extension, and lumbar flexion for more than the average angle and prolonged periods of time to complete their work. In rebar work, all real-time images show that the rebarers are working at a very high level of ergonomic risk.

This foldable working platform helps the rebarers reduce the risk to the lower back, knees, legs, arms/hands, and wrists as they do not need to work in awkward, kneeling, and squatting postures. Also, the platform can move easily as it is foldable, and the folded size of the platform is 250 mm, which can be easily transported. The proposed foldable working platform will improve the health of the rebarers at a low cost.

CHAPTER – 6

POSTURAL ANALYSIS OF MASONS AND PROTOTYPE DESIGN PROPOSAL OF MULTI-TASKING PORTABLE WORKBENCH

6.1 INTRODUCTION

The construction workers are forced to carry out high physical, laborious, and exhausting work at construction sites. The tasks to be carried out are excavation, material transportation and material preparation, formwork, rebar work, masonry work which includes brick laying and plastering, electrical, plumbing, tiling, painting, and furniture work, etc. These works are painstaking in nature and need heavy physical strength. Construction work is considered to be one of the most hazardous jobs in which workers are adversely affected by work-related musculoskeletal disorders due to working in awkward postures [17] and stress [12] [189]. Chakraborty et al., 2017 revealed the relation between stress, WRMSDs, and QoL amongst construction workers, who experience a high level of stress due to overwork with low quality of life [189]. Assessment of WRMSDs in workers engaged in construction work is complicated due to continuous, dynamic, and complex work tasks [15].

Details of work performed by Indian masons, tools used, body postures, exposed body parts, and related risks are presented in Chapter 1. A study reveals that masons are working under high stress [189], working in awkward postures [32] [109] [111], and suffering from work-related musculoskeletal disorders [121] [122].

Hence, the aim of this study was to 1) find the level of ergonomic risk amongst the masons while performing bricklaying and plastering work, and 2) propose a prototype design of a multi-tasking portable workbench to reduce the risk level.

6.2 VARIOUS TASK PERFORMED BY THE MASONS:

6.2.1 Masons' / Masons' nature of job and ergonomic risks:

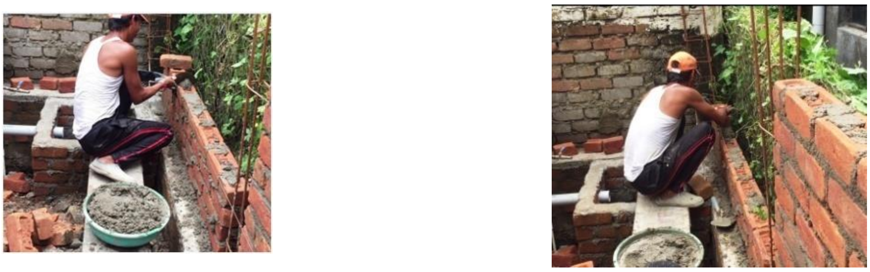
Masons are the backbone of the construction industry. They are skilled and, most importantly, the person who performs major construction work. In India, masons perform bricklaying, plastering, and concreting work. In addition, these people also perform some auxiliary work on the construction site. These tasks include lifting bricks from the ground, for which they bend more than 90 degrees at the lumbar, handling iron pans filled with mortar, erection of scaffolds, making of props, etc. But the main work of the mason is to lay bricks, plaster the wall, and roof. The second job is to spread and smooth the concrete mix while concreting the roof and columns.

6.2.2 Task 1: Bricklaying Work:

The bricklaying work includes tasks like 1) collection of mortar from iron pan (from ground) (Task-BL-1), 2) laying/spreading of mortar on bed (Task-BL-2), 3) filling of brick gaps (Task-BL-3), 4) string lining (Task-BL-4), 5) picking brick (from ground) (Task-BL-5), 6) laying brick (Task-BL-6-(i)(ii)), 7) breaking brick (Task-BL-7). The real-time images of the above tasks are shown in figure 6.1 (a) to (g). In these figures, it can easily be seen how masons are performing different work tasks as mentioned above and at different working conditions. The masons are working in standing postures, flexion posture, neck extension, squatting posture, twisting posture, flexion with twisting posture, and sometimes kneeling posture. The masons' whole body parts are exposed to somewhat ergonomic risk during the initial stages while performing bricklaying tasks.

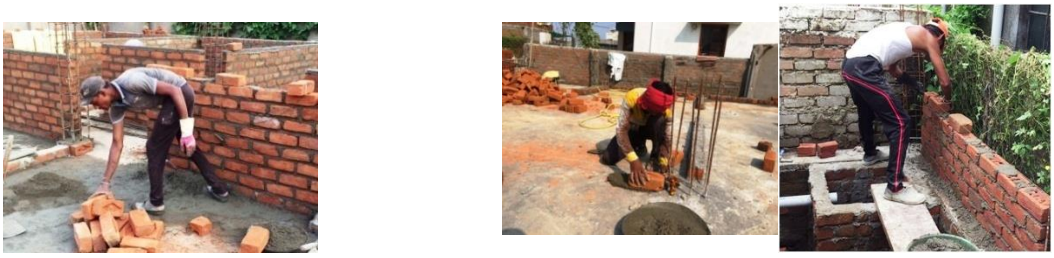
(a) Collect mortar from iron pan (BL-1)

(b) laying of mortar bed (BL-2)



c) Filling bricks gap(BL-3)

d) Adjust level (BL-4) String Line (Adjust Level and line)



(i)

(ii)

(e) Picking of Brick (from ground) (BL-5)

(f) Laying of Brick (BL-6)

[redacted]

(g) Breaking of Brick (BL-7)

Figure 6.1 Real time images of Masons' performing bricklaying work

6.2.3 Task 2: Plastering Work:

Plastering is one of the main processes of construction work. It is performed for smoothing of the wall surface. It covers the rough walls and uneven surfaces of the wall of houses and other construction work. Plastering materials are a mixture of fine sand, cement along with water. The plastering work includes tasks like 1) applying mortar to the ceiling (Task-PL-1), 2) leveling/planing the mortar applied on the ceiling (Task-PL-2), 3) applying mortar on the inside wall (Task-PL-3), 4) leveling/planing the mortar applied on the inside wall (Task-PL-4), 5) picking mortar for plastering the outside wall (from ground) (Task-PL-5), 6) applying mortar on the outside wall (Task-PL-6), and 7) leveling/planing the mortar (Task-PL-7). In plastering, the mason applies a base coat of mortar to the wall with the help of a trowel, spreads the plaster mortar on the wall, and then flattens and smooths the mortar with the help of a metal float or aluminum channel. For roof plastering, the mason uses wooden floats to spread and smooth the plaster, and then uses a metal float for finishing instead of aluminum channels. For vertical wall plastering, an aluminum channel is used which involves finishing interior and exterior walls to cover uneven or rough surfaces of walls. Figures 6.2 (a) to (g) show the real-time images of the plastering work. From these figures, it can easily be understood how masons are performing different work tasks as mentioned above and at different working conditions for plastering the walls and ceiling. The masons are working in standing postures with neck extension and bending, flexion posture, neck extension with twisting, squatting posture, twisting posture, flexion with twisting posture, sometimes kneeling posture, and working overhead for ceiling plastering. While plastering, the masons are also exposed to environmental effects like cold as the plastering mortar is moist. The masons also face the problem of light inside the house/room. The masons’ whole-body parts are exposed to somewhat ergonomic risk while performing plastering tasks.

(i) (ii) (i) (ii)

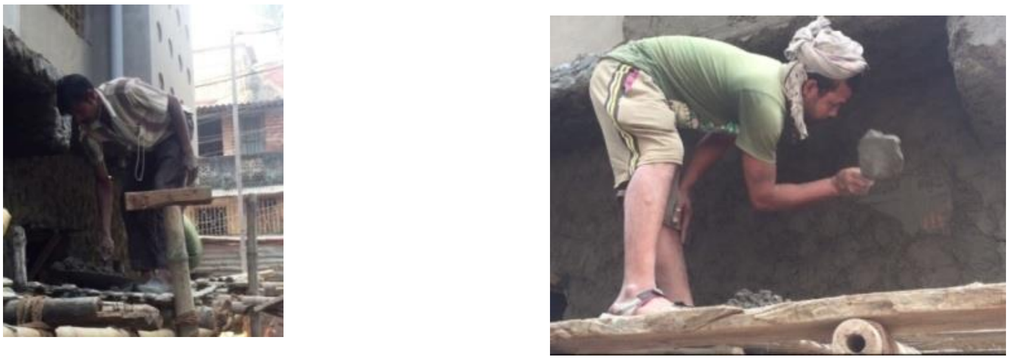
(a) Applying mortar to ceiling (PL-1)

(b) Level /Plan the mortar (PL-2)

(i) (ii) (i) (ii)

(c) Applying mortar on wall (for inside plastering) (PL-3)

(d) Level/plain the mortar (for inside plastering) (PL-4)



(e) Picking mortar for plastering (to apply on wall) (for outside plastering) (PL-5)

(f) Applying mortar on wall (for outside plastering) (PL-6)

(g) Level / plain the mortar (for outside plastering) (PL-7)

Figure 6.2 Real time images of Masons' performing plastering work

6.3 RESULTS

Twelve-week study was performed at various construction sites, where bricklaying and plastering work was underway. A total of 64 masons performing bricklaying work and plastering work were interviewed and video recorded. Table 6.1 shows the population characteristics of all masons performing bricklaying work and plastering work. Height and weight of the masons were measured using a standard anthropometric scale and weighing machine. Personal Information such as age, years of experience, daily working hours, procedures, pain/discomfort in the body parts, and other related problems were reported. The masons were between the age group of 28 to 52 years, with 1-36 years of working experience. The masons have to perform three types of work: bricklaying, plastering, and concreting.

Table 6.2 shows that most bricklayers are between the ages of 31-40 and 41-50, with 11 to 30 years of work experience. Table 6.2 also shows that about 83% of the masons have completed primary education, 11% of masons have completed secondary education, 1.56% of masons have completed intermediate education, and 4.69% masons are illiterate. It has also been revealed that 56.25% of masons are migrants.

Different procedures have been applied for the analysis of masons' working postures. These methods can be used to measure various functions, in any sitting position where the position of the body is static, dynamic, or changing quickly. These are quick survey methods used in ergonomic interventions of workplaces where WRMSDs are reported. This assessment method can apply biomechanical as well as postural loading on the mason's body. Several methods have been developed to assess ergonomic risk. RULA [189], NIOSH [217], REBA [194], QEC [188], WERA [57], ERIN [51], [71], NERPA [71], and NMQ [28] are some of them. In this study, REBA, ERIN, WERA, and QEC methods were used to evaluate the risk exposure.

Table 6.1 Demographic characteristics of Masons'

Characters	Mean ± SD
Age (years)	42.59±0.09
Weight (kg)	62.39±6.20
Height (cm)	163.75±4.47
Experience (years)	18.53±9.19
BMI (Kg/m^2)	23.23±1.69

Table 6.2 Number of Masons' feeling pain (n=64)

	Parameter	No. of workers feel pain	Percentage of workers feel pain
Age	21-30	8	12.50
	31-40	19	29.69
	41-50	23	35.94
	≥ 51	14	21.88
Experience	00 - 10	16	25.00
	11-20	24	37.50
	20 - 30	15	23.44
	≥ 30	9	14.06
Education	Illiterate	3	4.69
	Primary	53	82.81
	Secondary	7	10.94
	Intermediate	1	1.56
Migrant		36	56.25

The study was performed on the masons that perform bricklaying and plastering work. The postures were evaluated using REBA, ERIN, WERA, and QEC methods for different tasks of bricklaying and plastering work. The eight postures for bricklaying and 11 postures for plastering were selected for evaluation purposes. Figure 6.1 (a)-(g) and Figure 6.2(a)-(g) show the real images of bricklaying and plastering postures selected for this study. The survey was conducted at different construction sites, and information was collected for pain or discomfort in different body parts, at various time zones, and other psychosocial parameters. From table 6.3 and figure 6.3, it is revealed that the masons complained about pain in the lower back (84.38%), shoulders (79.69%), wrists (43.75%), elbow, finger, and thumb (29.69%). From table 6.4 and figure 6.5, it is found that a higher number of masons have pain after working time (57.81%) and in the morning (23.44%). Table 6.5 and figure 6.6 show that 87.50% of masons are working in awkward postures, 76.56% of masons are addicted to some bad habits, 57.81% of masons have pain due to physical exhaustion, 34.38% due to the pace of work, and 25% due to pervasive jobs. Figure 6.4 shows that 24% of masons have pain in the lower back, 23% have pain in the shoulder, 12% have pain in the wrists, and 8% have pain in the fingers/thumbs and elbows from the total population. The risk score for selected postures for the bricklaying and plastering using REBA, ERIN, WERA, and QEC methods are shown in Table 6.6, 6.7, 6.8, 6.9, while Table 6.10, 6.11, 6.12, 6.13 show the corresponding results.

Table 6.3 Feeling Pain in different body parts by the Masons (n=64)

Body Parts	Total	Percentage
Head	4	6.25
Neck	13	20.31
Shoulders	51	79.69
Chest	2	3.13
Elbow	19	29.69
Arms/Hands	14	21.88
Wrists	28	43.75
Fingers/Thumbs	19	29.69
Upper back	12	18.75
Lower back	54	84.38
Thigh/ hip/ buttocks	0	0.00
Legs	8	12.50
Knees	0	0.00
Ankle/ feet/toe	2	3.13

Table 6.4 Pain at different time zone by all Masons

Time zones	Total	%
During working	6	9.36
After working	37	57.81
During Sleeping	5	7.81
In the morning	15	23.44

Table 6.5 Details of pain due to other parameter are mentioned below

Parameters	Total	Percentage
Working in Awkward Posture	56	87.50
Pace of work	22	34.38
Pervasive jobs	16	25.00
Traumatic Incidents	2	3.13
Addiction to Alcohol/ chewing	49	76.56
Social support	12	18.75
Physically Exhausted	37	57.81

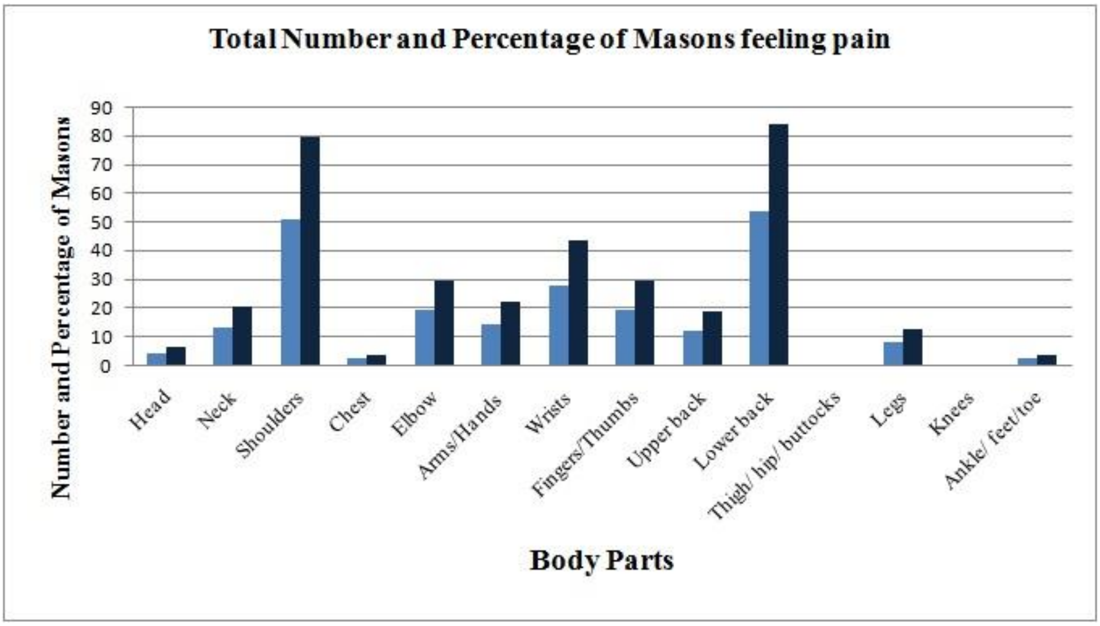


Figure 6.3 Feeling Pain in different body parts by Mason

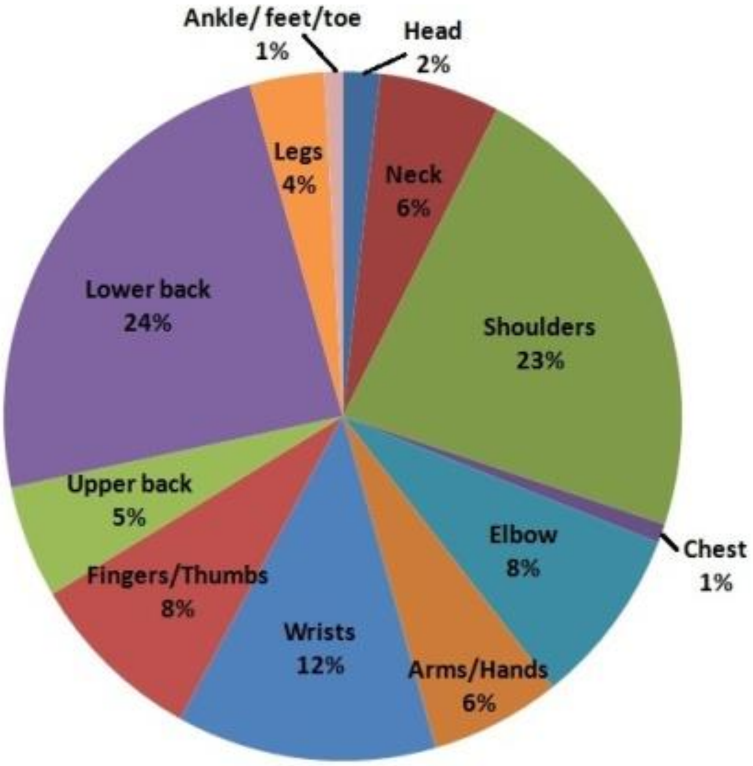


Figure 6.4 Percentage of body part feeling pain by Mason

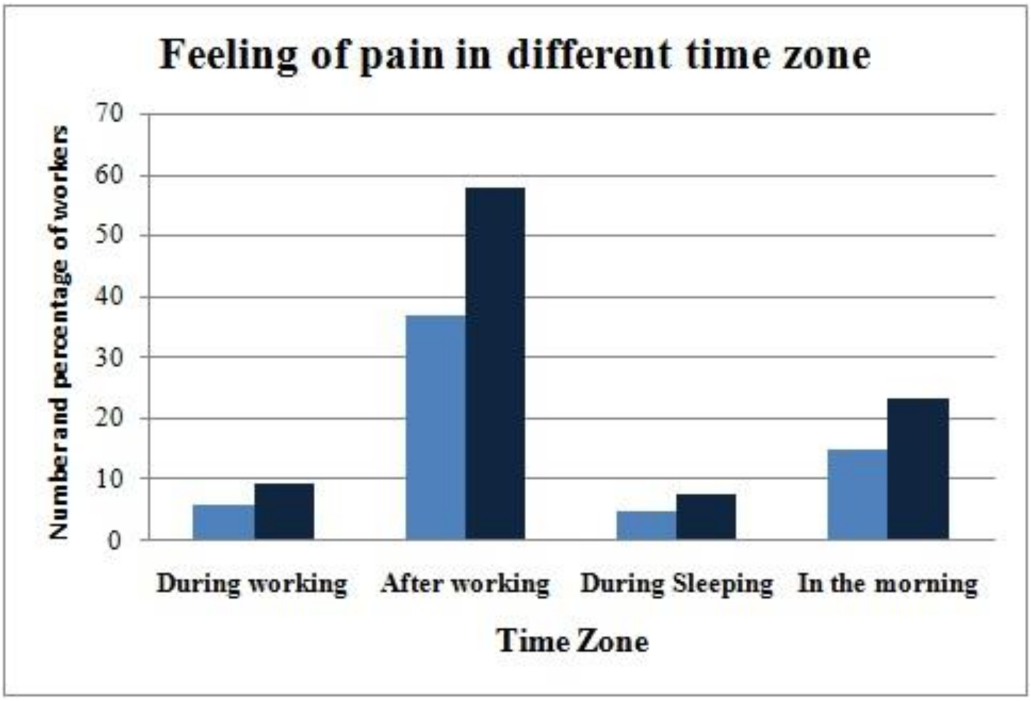


Figure 6.5 Pain at different time zone by all Masons

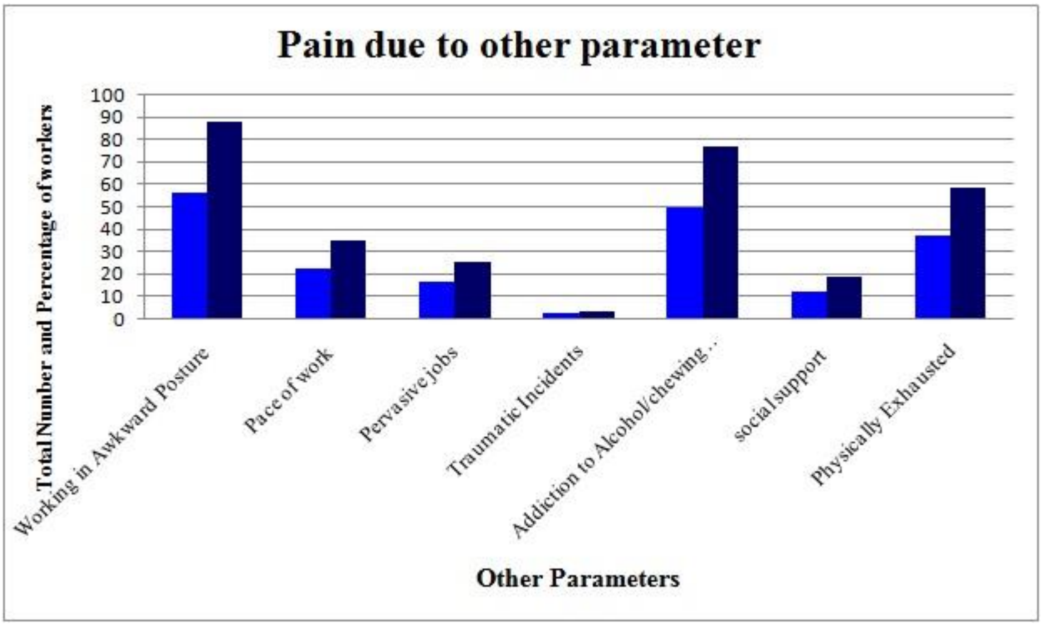


Figure 6.6 Details of pain due to other parameter complaint by Masons

6.4 RESULTS OF REBA, ERIN, WERA AND QEC METHODS FOR TRADITIONAL WORKING POSTURES:

Various masonry works on bricklaying (BL) and plastering (PL) have been evaluated. The bricklaying work includes tasks like 1) collection of mortar from the iron pan (from ground) (Task-BL-1), 2) laying/spreading of mortar on bed (Task-BL-2), 3) filling of brick gaps (Task-BL-3), 4) string lining (Task-BL-4), 5) picking bricks (from ground) (Task-BL-5), 6) laying bricks (Task-BL-6-(i)(ii)), 7) breaking bricks (Task-BL-7).

The plastering work includes tasks like 1) applying mortar to the ceiling (Task-PL-1), 2) leveling/planning the mortar applied on ceiling (Task-PL-2), 3) applying mortar on the inside wall (Task-PL-3), 4) leveling/planning the mortar applied on the inside wall (Task-PL-5), 5) picking mortar for plastering the outside wall (from ground) (Task-PL-5), 6) applying mortar on the outside wall (Task-PL-6), and 7) leveling/planning the mortar (Task-PL-7).

During all these tasks, masons worked in different postures as per the requirements of the work. Each task has different postures. In this study, extreme awkward postures were considered for evaluation, and the results of the REBA, ERIN, WERA, and QEC methods are presented.

6.4.1 Result Of REBA, ERIN, WERA and QEC methods for Traditional Bricklaying Work Posture:

Brick work involves 1) collection of mortar from the iron pan (from ground) (Task-BL-1), 2) laying/spreading of mortar on the bed (Task-BL-2), 3) filling of brick gaps (Task-BL-3), 4) string lining (Task-BL-4), 5) picking bricks (from ground) (Task-BL-5), 6) laying bricks (Task-BL-6-(i)(ii)), 7) breaking bricks (Task-BL-7). The mason breaks the bricks to the required size with the help of a trowel when needed. Tables 6.6, 6.7, 6.8, 6.9 show the results of REBA, ERIN, WERA, and QEC methods, respectively.

From the results of these REBA, ERIN, WERA, and QEC methods used for assessment of the bricklaying tasks, it was shown that all the tasks and all the postures are associated with high to very high ergonomic risk. REBA score revealed that Task BL-4 (both sides of the body) and BL-6(ii) (both sides of the body) are at very high risk, while in Task BL-5, the right side is at very high risk. Approximately similar results were obtained from the ERIN method. The results obtained from the WERA method also show that all the tasks are at high risk, while task (BL-1) is at very high risk for the right side. The QEC method revealed that total stress exposure for all tasks and postures is at medium risk; however, exposure to the neck was found to be very high, exposure to the wrist/hand was found to be high, and exposure to the shoulder/arm was found to be medium. If masons work in a static posture for a prolonged period, it will be at high risk.

Table 6.6 Ergonomics Risk Scores of REBA (Bricklaying Work)

		1		**2**		**3**		**4**		**5**		**6**				7	
STEPS	**BP**	**BL-1**		**BL-2**		**BL-3**		**BL-4**		**BL-5**		**BL-6(i)**		**BL-6(ii)**		**BL-7**	
A:NECK,TRUNK AND LEG																	
1	**N**	2		2		3		3		2		3		3		3	
2	**BK/T**	4		3		3		4		5		3		4		4	
3	**L**	3		3		4		4		3		4		3		4	
4	**PS-A**	7		6		8		9		8		8		8		9	
5	**LD/F**	0		0		0		0		0		0		0		0	
6	**TS-A**	**7**		**6**		**8**		**9**		**8**		**8**		**8**		**9**	
B: ARMS AND WRIST																	
		L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
7	**UA**	2	3	3	2	3	3	3	3	1	3	1	2	4	4	2	2
8	**LA**	1	2	1	1	1	1	1	1	2	2	2	2	1	1	1	1
9	**W**	1	2	2	3	2	2	2	2	1	2	2	2	2	2	2	2
10	**PS-B**	1	5	4	3	4	4	4	4	1	5	2	3	5	5	2	2
11	**CS**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	**TS-B**	**1**	**5**	**4**	**3**	**4**	**4**	**4**	**4**	**1**	**5**	**2**	**3**	**5**	**5**	**2**	**2**
	TS-C	7	9	7	6	9	9	10	10	8	10	8	8	10	10	9	9
13	**AS**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	FS	**8 #**	**10 #**	**8 #**	**7 @**	**10 #**	**10 #**	**11***	**11 ***	**9 #**	**11***	**9 #**	**9 #**	**11 ***	**11 ***	**10 #**	**10 #**

Table 6.7 Ergonomics Risk Scores of ERIN (Bricklaying Work)

	1		**2**		**3**		**4**		**5**		**6**				7	
BP	**BL-1**		**BL-2**		**BL-3**		**BL-4**		**BL-5**		**BL-6(i)**		**BL-6(ii)**		**BL-7**	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
BK/T	7	7	4	4	4	4	4	4	8	8	6	6	6	6	4	4
S/LA/LA	2	5	2	5	2	2	5	5	2	5	2	2	5	5	2	2
H/W	5	5	2	5	4	4	2	5	2	5	2	4	4	4	4	4
N	2	2	6	6	6	6	7	7	6	6	6	6	6	6	7	7
R	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
IOE	6	6	6	6	6	6	6	6	8	8	6	6	6	6	6	6
SA	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
GR	**27 #**	**30 #**	**25 #**	**31 #**	**27 #**	**27 #**	**29 #**	**32 #**	**31 #**	**37 ***	**27 #**	**29 #**	**32 #**	**32 #**	**28 #**	**28 #**

Table 6.8 Ergonomics Risk Scores of WERA (Bricklaying Work)

	1		**2**		**3**		**4**		**5**		6				7	
BP	**BL-1**		**BL-2**		**BL-3**		**BL-4**		**BL-5**		**BL-6(i)**		**BL-6(ii)**		**BL-7**	
PART A																
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
S	4	4	4	4	4	3	4	4	3	4	4	4	4	4	2	4
W	4	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5
BK/T	5	5	5	5	4	4	4	4	5	5	5	4	5	5	4	4
N	6	5	4	5	3	4	5	5	6	5	4	4	5	5	3	5
L	5	5	5	5	5	6	6	6	5	5	5	6	4	5	5	6
PART B																
LD/F	4	5	4	4	3	3	3	3	4	4	3	3	4	4	3	3
V	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
CST	5	6	6	6	4	6	6	6	6	6	6	6	2	6	6	6
TD	4	5	4	4	2	4	4	4	4	4	3	4	3	4	3	4
FS	**40 #**	**45 ***	**41 #**	**42 #**	**34 #**	**39 #**	**41 #**	**41 #**	**42 #**	**42 #**	**39 #**	**40 #**	**36 #**	**42 #**	**35 #**	**41 #**

Table 6.9 Ergonomics Risk Scores of QEC (Bricklaying Work)

	1	2	3	4	5	5		7
Body Parts / Score	**BL-1**	**BL-2**	**BL-3**	**BL-4**	**BL-5**	**BL-6(i)**	**BL-6(ii)**	**BL-7**
Observer's Assessment								
BK/T								
A	A3	A2	A2	A2	A3	A2	A3	A2
B	B1	B1	B1	B1	B1	B1	B1	B1
S/LA/UL								
C	C2	C2	C2	C2	C2	C2	C2	C2
D	D2	D2	D2	D2	D2	D2	D2	D2
W/H								
E	E2	E2	E2	E2	E2	E2	E2	E2
F	F2	F2	F2	F2	F2	F2	F2	F2
N								
G	G3	G3	G2	G3	G2	G3	G2	G2
Workers Assessment								
H	H1	H1	H1	H1	H1	H1	H1	H1
J	J3	J3	J3	J3	J3	J3	J3	J3
K	K2	K2	K2	K2	K2	K2	K2	K2
L	L2	L2	L2	L2	L2	L2	L2	L2
M	M1	M1	M1	M1	M1	M1	M1	M1
N	N1	N1	N1	N1	N1	N1	N1	N1
P	P2	P2	P2	P2	P2	P2	P2	P2
Q	Q2	Q2	Q2	Q2	Q2	Q2	Q2	Q2
EB(S)	28#	24#	24#	24#	28#	24#	28#	24#
EB(M)	-	-	-	-	-	-	-	-
ESA	30@	30@	30@	30@	30@	30@	30@	30@
EWH	36#	36#	36#	36#	36#	36#	36#	36#
EN	18*	18*	16*	18*	16*	18*	16*	16*
EDR	1$	1$	1$	1$	1$	1$	1$	1$
EVT	1$	1$	1$	1$	1$	1$	1$	1$
EWP	4@	4@	4@	4@	4@	4@	4@	4@
TSE	4@	4@	4@	4@	4@	4@	4@	4@

6.4.2 Result of REBA, ERIN, WERA and QEC methods for Plastering Posture:

Table 6.10, 6.11, 6.12, and 6.13 show the results of REBA, ERIN, WERA, and QEC methods, respectively, for plastering work. The results obtained from REBA, ERIN, WERA, and QEC for plastering tasks assessment revealed that all the tasks and postures are at high risk. REBA and ERIN methods' scores revealed that all the postures employed for performing all seven tasks are at high to very high risk. REBA method results revealed that the right side of the workers is at very high risk for task PL-3(ii) (right side), PL-5 (right side), PL-6 (right side), and PL-7 (both sides), while ERIN method's results revealed that all tasks, particularly the right side, are at very high risk except PL-4. The results obtained from the WERA method again show that all the tasks performed in plastering work are at high risk and require immediate correction. The QEC method's results revealed that all the tasks are at medium risk for exposure, but exposure to the neck is high.

Table 6.10 Ergonomics Risk Scores of REBA (Plastering Work)

		1		**2**		**3**				4				5		6		7	
STEPS	**BP**	**PL-1(i)(ii)**		**PL-2(i)(ii)**		**PL-3(i)**		**PL-3(ii)**		**PL-4(i)**		**PL-4(ii)**		**PL-5**		**PL-6**		**PL-7**	
A:NECK,TRUNK AND LEG																			
1	**N**	3		3		2		2		2		2		2		3		3	
2	**BK/T**	3		3		2		2		2		2		5		5		3	
3	**L**	2		2		2		4		2		4		3		3		4	
4	**PS-A**	6		6		4		6		4		6		8		9		8	
5	**LD/F**	0		0		0		0		0		0		0		0		0	
6	**TS-A**	**6**		**6**		**4**		**6**		**4**		**6**		**8**		**9**		**8**	
B: ARMS AND WRIST																			
		L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
7	**UA**	1	4	1	5	1	4	1	5	4	1	4	3	1	4	2	4	5	5
8	**LA**	1	2	2	2	1	2	1	2	2	2	2	2	1	2	1	2	2	2
9	**W**	2	3	1	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2
10	**PS-B**	2	7	1	8	2	6	2	8	6	2	6	5	2	6	2	6	8	8
11	**CS**	2	0	0	0	2	1	1	1	2	2	1	1	0	1	0	1	1	1
12	**TS-B**	**4**	**7**	**1**	**8**	**4**	**7**	**3**	**9**	**8**	**4**	**7**	**6**	**2**	**7**	**2**	**7**	**9**	**9**
	TS-C	7	9	6	9	4	7	6	10	8	4	9	8	8	10	9	11	10	10
13	**AS**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	FS	**8** **#**	**10** **#**	**7** **@**	**10** **#**	**5** **@**	**8** **#**	**7** **@**	**11** *****	**9** **#**	**5** **@**	**10** **#**	**9** **#**	**9** **#**	**11** *****	**10** **#**	**12** *****	**11** *****	**11** *****

Table 6.11 Ergonomics Risk Scores of ERIN (Plastering Work)

	1		**2**		**3**				4				5		6		7	
B P	**PL-1(i)(ii)**		**PL-2(i)(ii)**		**PL-3(i)**		**PL-3(ii)**		**PL-4(i)**		**PL-4(ii)**		**PL-5**		**PL-6**		**PL-7**	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
BK/T	4	4	6	6	6	6	2	2	6	6	2	2	8	8	8	8	6	6
S/LA/LA	2	6	5	9	2	9	2	9	6	2	6	6	2	5	2	9	9	9
H/W	2	5	2	5	4	5	4	6	5	4	5	5	5	6	4	6	4	4
N	7	7	7	7	7	7	6	6	7	7	7	7	7	7	7	7	7	7
R	3	3	3	3	3	6	3	6	3	3	3	3	3	6	3	6	3	3
IOE	8	8	8	8	8	8	6	6	8	8	6	6	6	8	6	8	8	8
SA	3	3	3	3	3	3	2	2	3	3	2	2	3	3	3	3	3	3
GR	**29** **#**	**36** *****	**34** **#**	**41** *****	**33** **#**	**44** *****	**25** **#**	**37** *****	**38** *****	**33** **#**	**31** **#**	**31** **#**	**34** **#**	**43** *****	**33** **#**	**47** *****	**40** *****	**40** *****

Table 6.12 Ergonomics Risk Scores of WERA (Plastering Work)

	1		**2**		**3**				**4**				**5**		**6**		**7**	
BP	**PL-1(i)(ii)**		**PL-2(i)(ii)**		**PL-3(i)**		**PL-3(ii)**		**PL-4(i)**		**PL-4(ii)**		**PL-5**		**PL-6**		**PL-7**	
PART A																		
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
S	2	5	2	5	2	5	2	5	5	4	5	4	3	5	4	5	5	5
W	3	5	2	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
BK/T	4	4	4	4	3	3	4	4	2	2	4	4	5	5	5	5	4	4
N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
L	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6	6
PART B																		
LD/F	4	3	3	3	2	3	3	3	2	2	3	3	4	4	4	4	3	3
V	3	4	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
CST	6	6	4	6	4	4	6	6	6	6	6	6	6	6	6	6	6	6
TD	5	6	4	4	5	4	3	3	4	4	3	3	4	4	4	4	4	4
FS	**38** **#**	**44** **#**	**32** **#**	**42** **#**	**36** **#**	**39** **#**	**38** **#**	**41** **#**	**39** **#**	**38** **#**	**41** **#**	**40** **#**	**42** **#**	**44** **#**	**43** **#**	**44** **#**	**43** **#**	**43** **#**

Table 6.13 Ergonomics Risk Scores of QEC (Plastering Work)

	1	2	3		4		5	6	7
Body Parts / Score	**PL-1(i)(ii)**	**PL-2(i)(ii)**	**PL-3(i)**	**PL-3(ii)**	**PL-4(i)**	**PL-4(ii)**	**PL-5**	**PL-6**	**PL-7**
BK/T									
A	A2	A2	A2	A1	A2	A2	A3	A3	A2
B	B1	B1	B1	B1	B1	B1	B1	B1	B1
S/LA/UL									
C	C3	C3	C3	C3	C3	C3	C3	C3	C3
D	D2	D2	D2	D2	D2	D2	D2	D2	D2
W/H									
E	E2	E2	E2	E2	E2	E2	E2	E2	E2
F	F2	F2	F2	F2	F2	F2	F2	F2	F2
N									
G	G3	G3	G3	G3	G3	G3	G3	G3	G3
H	H2	H1	H2	H1	H1	H1	H1	H1	H1
J	J2	J2	J2	J2	J2	J2	J2	J2	J2
K	K2	K2	K2	K2	K2	K2	K2	K2	K2
L	L2	L2	L2	L2	L2	L2	L2	L2	L2
M	M1	M1	M1	M1	M1	M1	M1	M1	M1
N	N1	N1	N1	N1	N1	N1	N1	N1	N1
P	P2	P2	P2	P2	P2	P2	P2	P2	P2
Q	Q3	Q3	Q3	Q3	Q3	Q3	Q3	Q3	Q3
EB(S)	18@	18@	18@	14$	18@	18@	22@	22@	18@
EB(M)									
ESA	28@	28@	28@	28@	28@	28@	28@	24@	32@
EWH	30@	30@	30@	30@	30@	30@	30@	30@	30@
EN	14#	14#	14#	14#	14#	14#	14#	14#	14#
EDR	1$	1$	1$	1$	1$	1$	1$	1$	1$
EVT	1$ LR	1$ LR	1$ LR	1$ LR	1$ LR	1$ LR	1$	1$	1$
EWP	4@	4@	4@	4@	4@	4@	4@	4@	4@
TSE	4@	4@	4@	4@	4@	4@	4@	4@	4@

6.5 PROTOTYPE DESIGN PROPOSAL OF MULTI-TASKING PORTABLE WORKBENCH

6.5.1 Design Model of Multi-Tasking Portable Workbench for Masonry Work:

The Prototype Design Proposal of Multi-Tasking Portable Workbench for masons was designed, modeled, and assembled using Siemens NX 12.1 module. Figure 6.7, Figure 6.8, Figure 6.9, and Figure 6.10 show the detailed drawing of the portable workbench. The size of each part of the workbench has been taken from real-time requirements. The top and base plate size of the table is 1700 mm x 700 mm. The hydraulic cylinder is provided for the up and down movement of the table. The footrest is provided at the center of the table with a size of 800 mm x 300 mm x 350 mm. On both sides of the top plate, a support plate of size 300 mm x 310 mm has been provided to keep materials and tools used in construction work. While designing the workbench, the body balance technology has been used for proper balance of the workbench when the mason stands on the footrest and top plate. The minimum and maximum vertical height of the table are 400 mm, and it can be extended vertically up to 1200 mm. This minimum height and maximum height were decided by taking the average length of the inner side of the leg (called as “calf”) as shown in figure 6.11. The Multi-Tasking Portable Workbench is provided with a hydraulic cylinder which can be easily operated to move the workbench up and down.

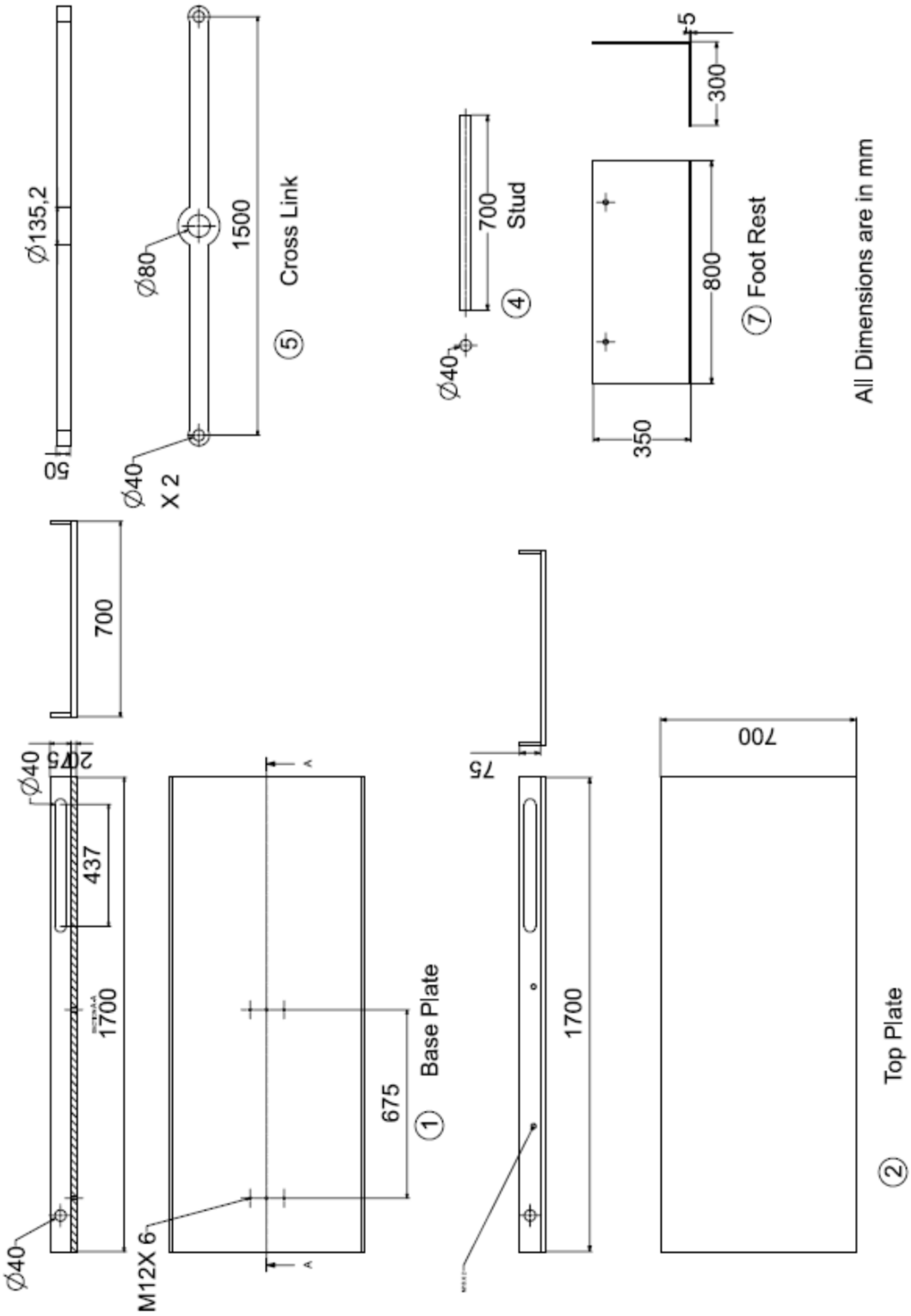


Figure 6.7 Detailed 2D Drawing of Proposed Multi-Tasking Portable Workbench (Parts)

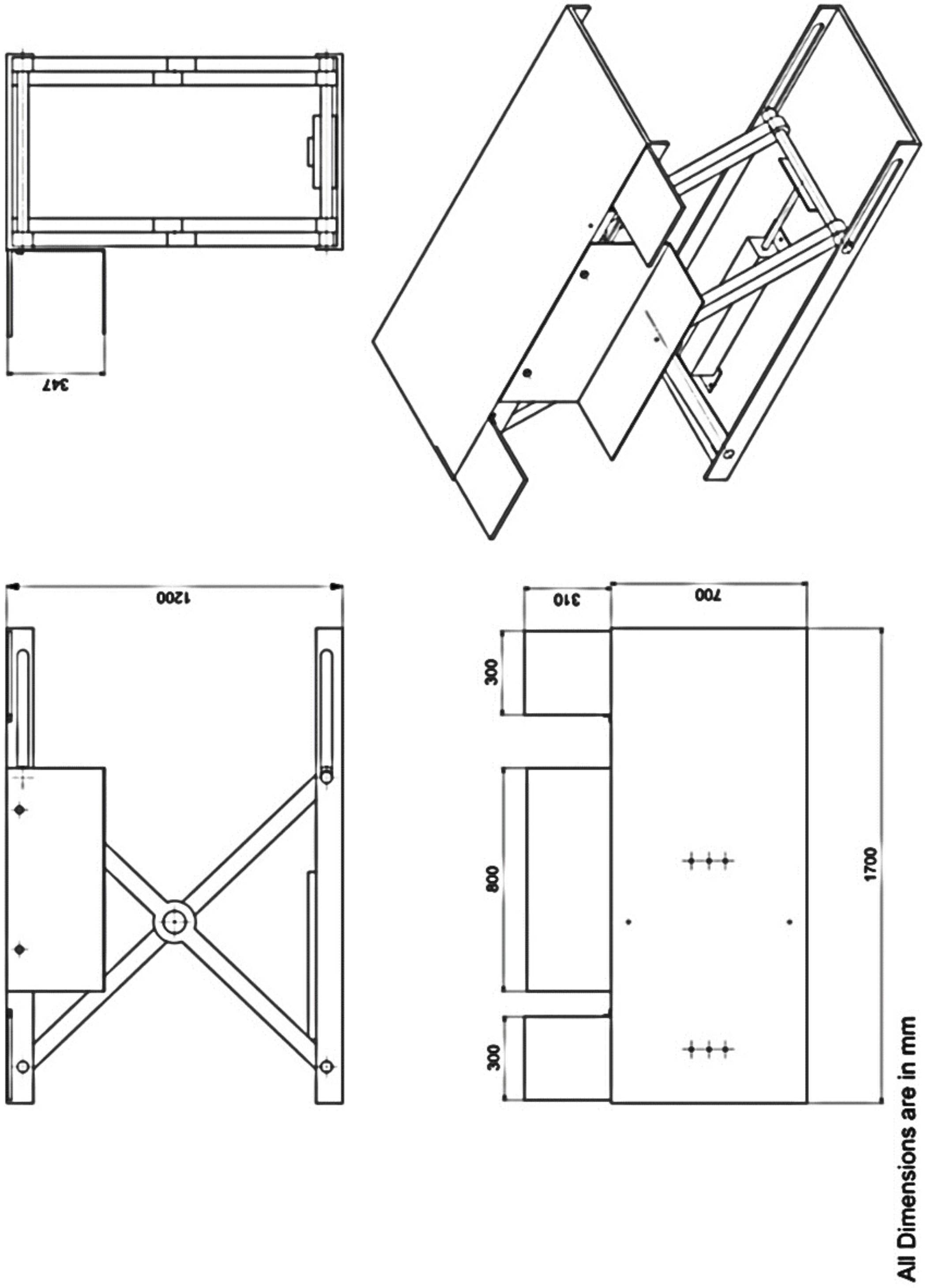


Figure 6.8 Drawing of Multi-Tasking Portable Workbench
(with Top view, Front view, Side view and Isometric view)

9	HYDRULIC CYLINDER_1200	1	STD
8	BOLT	2	STD
7	FOOT REST	1	MS
6	PIN	1	SS
5	CROSS LINK	4	MS
4	STUD	4	SS
3	BUSH	4	MS
2	TOP PLATE	1	MS
1	BASE PLATE	1	MS
PC NO	PART NAME	QTY	Material

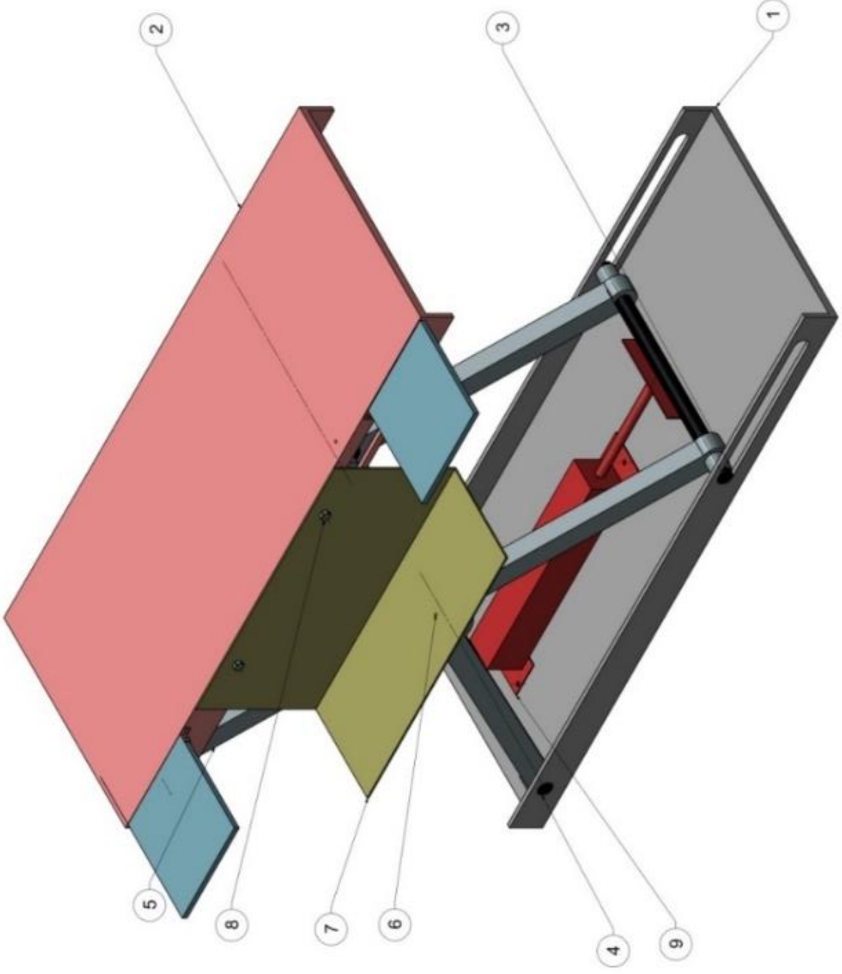


Figure 6.9 Drawing of Multi-Tasking Portable Workbench with BOM and Maximum height (1200 mm)

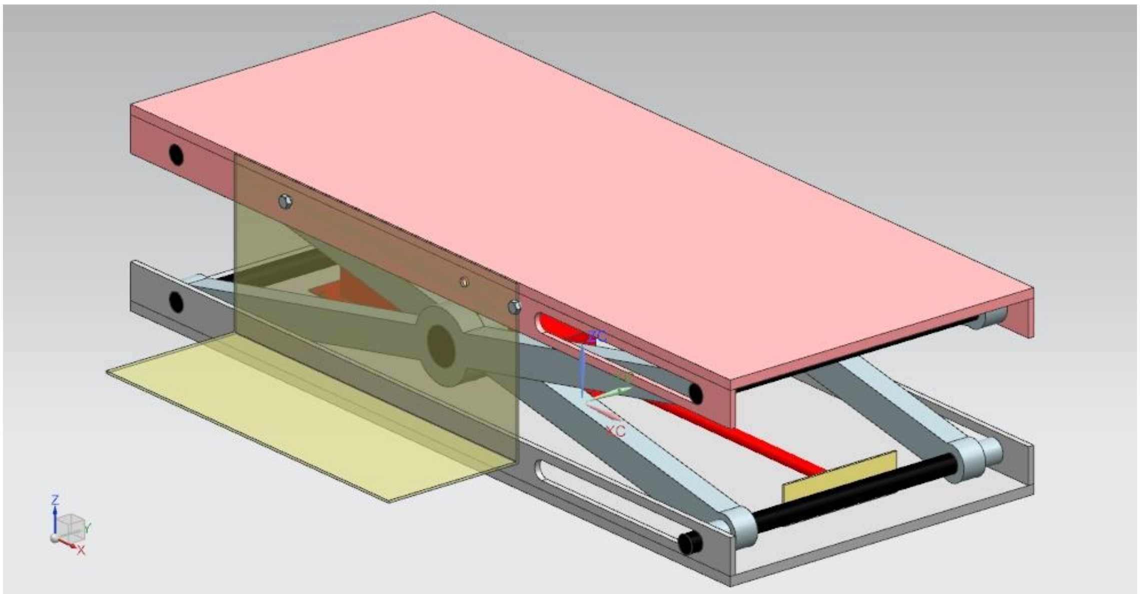


Figure 6.10 Multi-Tasking Portable Workbench with minimum height (400 mm)

6.6 Postural Analysis Using Newly designed Multi-Tasking Portable Workbench for Masonry Work

Figure 6.11, 6.12, and 6.13 show the working postures of masons while performing bricklaying and plastering work. As the newly designed multi-tasking portable workbench can move vertically from a minimum height of 400 mm to 1200 mm, the person working on it can adjust the height as per requirement and does not need to bend their neck and trunk, as shown in figure 6.2.

The base of the workbench is 1700 mm x 700 mm, thus this can be placed at any location on the construction site. On both sides of the top plate, a support plate of size 300 mm x 310 mm has been provided on both sides of the workbench to keep materials and tools used in construction work; hence, the mason does not need to work in flexion when working in a sitting position. The footrest is also provided with a vertical height of 350 mm, which provides strong support to the legs while working in a sitting position. (Figure 6.11)

The maximum height of the workbench is 1200 mm, and the person working on it is considered to be of a height of 5’6” (i.e., approximately 1707 mm); hence, the total height becomes approximately 2907 mm. Also, when the person raises their hand, the height will again increase by 500 mm, with a total working height of 3407 mm. The average height of the working wall is 3000-3200 mm; hence, by using this table, the mason can work on bricklaying work and plastering work on the ceiling and wall inside the house/room. The same height can be achieved for outdoor plastering work. (Figure 6.13) If the mason works by standing on the footrest, the working height can be achieved to 3000 mm. (Figure 6.12) Hence, in any circumstances, the portable workbench will be able to serve for bricklaying and plastering work. Ergonomic risk scores of REBA and WERA Methods (for Bricklaying and Plastering Work) after modifications are shown in Table 6.14.

Figure 6.11 Manikin working in sitting position with resting its foot on foot rest.

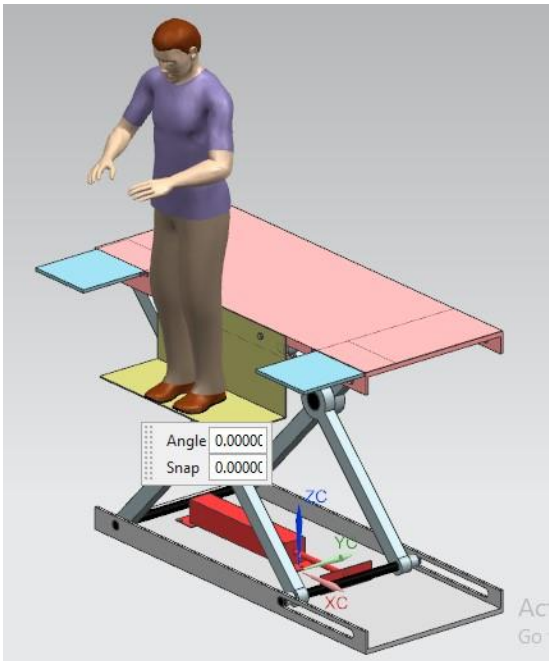

Angle 0.00000
Snap 0.00000

Figure 6.12 Manikin working on standing position with resting its foot on foot rest.

Figure 6.13 Manikin working on standing position on top

6.6.1 REBA Score after Modification for both working postures:

REBA score obtained from the REBA worksheet by considering applied force of up to 0-5kg, with good coupling and the activity assumed to be repetitive in nature at a moderate rate. The working hours are considered as 8 hours. The same parameters were set at the time of scoring the posture of traditional working postures. The score obtained by the REBA score worksheet was shocking. The score obtained for both the cases was 2, which is considered to be low risk or negligible risk.

6.6.2 WERA socre after Modification for both working postures:

For WERA Analysis, repetition of movement is considered moderate (Medium) with pause, the duration of work is 8 hours (>4hrs), lifting weight is 0-5kg, no vibration from tools used, the tools used with good shape were considered while scoring for traditional working postures. The score obtained for WERA after modification is 27 for all postures and is of low risk level and acceptable.

Table 6.14 Ergonomic risk score of REBA and WERA Methods (for Bricklaying and Plastering Work) after modifications

REBA SCORE			WERA SCORE		
BP	Posture of Fig.6.11,	Postures of Fig. 6.12 & 6.13		Posture of Fig.6.11,	Postures of Fig. 6.12 & 6.13
A:NECK, TRUNK AND LEG			**PART A**		
N	1	1	S	3	3
BK/T	1	1	W	4	4
L	1	1	BK/T	3	3
PS-A	1	1	N	3	3
LD/F	0	0	L	4	4
TS-A	1	1			
B: ARMS AND WRIST			**PART B**		
UA	2	2	LD/F	2	2
LA	1	1	V	2	2
W	2	2	CST	2	2
PS-B	2	2	TD	4	4
CS	0	0			
TS-B	2	2			
TS-C	1	1			
AS	1	1			
FS	**2**	**2**	**FS**	**27**	**27**
RISK LEVEL	**$**	**$**		**$**	**$**

6.7 SUMMARY

This result of this study shows that there is a close correlation between working in awkward posture and work-related musculoskeletal disorders amongst the masons as the masons have to work in prolonged standing, sitting, trunk flexion, squatting, and trunk twisting postures. Also, masons have a high risk of WRMSD since they work in abducted posture at lower body, repetitive work, trunk flexion, wrist flexion and extension, lumbar flexion for more than the average angle, and a prolonged period of time to complete their work. In both bricklaying and plastering work, all real-time figures show that masons are working at a very high level of ergonomic risk.

For hazardous levels of posture, it has been perceived that the masons are working in bending position at lumbar (trunk flexion). Wrist and fingers are engaged for long periods of time to pick and hold the tools and materials like brick, pan with mortar and are not working in the recommended standards. Working in such postures leads to development of low back pain [232][233][234].

The study of Behesthti et al., 2014 shows that plasterers suffer from upper body, upper arm and failed to assess neck, elbow, wrist, repetition and duration of the work [235]. The prolonged working in standing position will increase the physiological and ergonomic risk of work-related musculoskeletal disorder [232]. Also, lack of knowledge, proper training and guidance, properly designed ergonomic tools and equipment as well as poor habits. The factors like working in awkward posture, age, pervasive jobs, traumatic incidences and age are also responsible for the development of WRMSD. In bricklaying work,

Table 6.15 shows the comparison of results obtained from different methods used to evaluate the ergonomic risk for brick laying work. The results of REBA, ERIN and WERA show that all the postures studied are at high ergonomic risk while task BL-4 and BL-6(ii) are at very high ergonomic risk. The results of QEC method show that all the tasks are at medium risk. The results of QEC also show there is a medium risk to the mason due to work pace. If masons work in static posture, they will be at high risk to the back and high exposure to neck if they work in twisting, bending and a prolonged period in static posture.

Table 6.15 Comparative result of REBA, ERIN, WERA and QEC for Bricklaying work for Traditional working Postures

TASK	SIDE	REBA	ERIN	WERA	QEC
BL-1	LEFT	HR	HR	HR	MR
	RIGHT	HR	HR	VHR	MR
BL-2	LEFT	HR	HR	HR	MR
	RIGHT	MR	HR	HR	MR
BL-3	LEFT	HR	HR	HR	MR
	RIGHT	HR	HR	HR	MR
BL-4	LEFT	VHR	HR	HR	MR
	RIGHT	VHR	HR	HR	MR
BL-5	LEFT	HR	HR	HR	MR
	RIGHT	VHR	VHR	HR	MR
BL-6 (i)	LEFT	HR	HR	HR	MR
	RIGHT	HR	HR	HR	MR
BL-6 (ii)	LEFT	VHR	HR	HR	MR
	RIGHT	VHR	HR	HR	MR
BL-7	LEFT	HR	HR	HR	MR
	RIGHT	HR	HR	HR	MR

The plastering work, Table 6.16 shows the comparison of results obtained from different methods used to evaluate the plastering work postures of the Masons. The results of REBA method show that the right side of the masons for the task PL-3 (ii), PL-5 and PL-6 is at very high risk while both sides of the task PL-7 is at very high risk. The ERIN method shows that the right side of the masons for all tasks except PL-4(i) (ii) is at high risk while both sides of the masons while performing task PL-7 are at very high ergonomic risk level. The WERA method shows that all the plastering tasks performed by the masons are at high risk. QEC method shows that, similar to WERA method, all plastering tasks are at medium risk; however, exposure to the neck is high because masons have to twist and bend their neck while plastering the ceiling, inner wall, inner staircase, and sometimes plastering the wall as well. Similar to brick laying work, the QEC shows that there is a medium risk to the mason due to work pace while performing plastering work. If masons work in static posture, they will be at medium risk to their back, while there is very high exposure to the neck if they twist and bend the neck and work for a prolonged period in static position of neck as shown in Figure 6.2.

Table 6.16 Comparative result of REBA, ERIN, WERA and QEC for Plastering work for Traditional working Postures

TASK	**Side**	**REBA**	**ERIN**	**WERA**	**QEC**
PL-1(i)(ii)	Left	HR	HR	HR	MR
	Right	HR	VHR	HR	MR
PL-2 (i)(ii)	Left	MR	HR	HR	MR
	Right	HR	VHR	HR	MR
PL-3 (i)	Left	MR	HR	HR	MR
	Right	HR	VHR	HR	MR
PL-3 (ii)	Left	MR	HR	HR	MR
	Right	VHR	VHR	HR	MR
PL-4 (i)	Left	HR	VHR	HR	MR
	Right	MR	HR	HR	MR
PL-4 (ii)	Left	HR	HR	HR	MR
	Right	HR	HR	HR	MR
PL-5	Left	HR	HR	HR	MR
	Right	VHR	VHR	HR	MR
PL-6	Left	HR	HR	HR	MR
	Right	VHR	VHR	HR	MR
PL-7	Left	VHR	VHR	HR	MR
	Right	VHR	VHR	HR	MR

The study revealed that masonry workers are at high ergonomic risk caused by working in inappropriate posture during work and this should be avoided [236]. The weight, poor lifting posture, and lifting materials as well as tools with one side of the body put strain on the trunk [236]. The other researchers also commented that concrete blocks, mortar, and tools/equipment should be kept within reach to reduce unnecessary motions, whereas periodically working in sitting and standing positions will reduce the ergonomic risk of musculoskeletal disorders [237].

In this context, the suggested newly designed Multi-Tasking Portable Workbench provides some remedies to all these. The prototype of the Multi-Tasking Portable Workbench is designed with body balance technique and provided with proper working space as per the requirement of the workspace at the construction site. The top of the workbench is sufficient to sit and stand, furnished with a footrest while working in a sitting position. On both sides of the top, the workbench is provided with support plates, which will help to keep the materials and tools so that the masons do not need to bend (flexion) or twist while picking the materials and tools from the ground. It will also help the unskilled workers (helpers) to keep the materials without bending down to ground level. The minimum height of the table is 400 mm and it can be extended vertically up to 1200 mm height; hence, the worker can easily perform his work at ground level to higher levels. The Multi-Tasking Portable Workbench is provided with a hydraulic cylinder which can be easily operated to move the workbench top. The Multi-Tasking Portable Workbench was designed using Siemens NX 12.1 Module according to the construction site requirements after thorough discussions with masons. This workbench will help to reduce the risk to the neck, trunk, lower back, shoulders, and improve the health of the masons.

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

7.1 CONCLUSION

From the study, it is found that there is no awareness about Ergonomics among the construction workers of Maharashtra and West Bengal. On the basis of the scope and limitations of the present study and research, the following conclusions may be drawn:

1) It is concluded that males had a higher prevalence of WRMSD than females for labor work. The age group of 31-50 was found to be more active in construction work and experienced less pain or discomfort. However, as age increases, the rate of pain or discomfort also increases.
2) The main causes of work-related musculoskeletal disorderrs are working in an awkward posture, years of experience, and age. Other major factors include awareness of working techniques, the pace of work, repetitive jobs, ignorance of symptoms in the early stage, lack of medication, inadequate diet, lack of exercise, traumatic incidents, duration of the task, environmental effects, poverty, poor work sites, physical risk factors, psychosocial factors.
3) It is concluded from the results of RULA, REBA, biomechanical, and lifting analysis performed for the assessment of postures of excavation workers that excavation workers have a high level of ergonomic risk and high compressive and shear loads acting on L4/L5 of the spinal cord. The comparative results of the methods adopted show that the suggested use of a crowbar and novel design of an iron pan for material handling have the potential to minimize work-related musculoskeletal disorders among excavation workers. From the field study, it is found that the novel-designed iron pan is capable of minimizing the problem of working in flexed positions, and lifting the iron pan has become easier than with the earlier design.
4) Also, from the analysis of postures of workers engaged in slab concreting work using ERIN, NERPA, and WERA methods, it was shown that the laborers had a high level of correlation with traditional methods and the risk of work-related musculoskeletal disorders. The suggested prototype design proposal for material collection and eviction tables is capable of minimizing the problems faced by laborers. The results obtained from CATIA, RULA, biomechanical, and lifting analysis showed that the suggested design can reduce exposure to the spine. The concrete mix can be transferred by connecting a hose pipe to the bin openings to avoid the manual

transmission of concrete mix. Also, the number of eviction openings can be increased as per requirements.

5) Postural evaluation of the rebar workers while performing rebar work was performed by considering extremely risky working postures. The results of the NERPA, ART, and JSI methods showed that rebar workers had the highest level of ergonomic risk and immediate action was needed. The most exposed body parts to ergonomic risk were the lower back, knees, legs, arms/hands, and wrists. The ergonomic risk was found to be due to working in awkward postures, performing repetitive jobs, and being physically exhausted while working in different environmental conditions. The design of a foldable, multitasking, workable platform for rebar work can reduce the risk to the lower back, knees, legs, arms/hands, and wrists. The table can move easily, and the proposed design of the foldable multitasking workable platform for rebar work will improve the health of the rebar workers.
6) The REBA, ERIN, WERA, and QEC methods used for the assessment of postures of masons while performing bricklaying and plastering work showed that the masons faced the highest level of ergonomic risk. The most exposed body parts to ergonomic risk were the shoulders, trunk, lower back, and neck. It is concluded that the suggested design proposal of a multi-tasking portable workbench will help to reduce the risk and may improve the health standards of the masons.

The proposed tools were generally acceptable to the construction workers, as they contributed to improving working postures. The results obtained from various methods and from CATIA confirmed that the suggested design improved working conditions and, subsequently, might overcome the problem of work-related musculoskeletal disorders and their signs and symptoms. Although the comparative results showed improvement, further investigation and optimization are still needed.

7.2 FUTURE SCOPE

The research is ongoing, hence the author feels that further research work is needed for the postural analysis of construction workers. The construction workers, working in awkward postures, improper working sites, forceful exertion, heavy lifting or lowering, repetitive work movements, static and dynamic working conditions, extreme cold and heat, extreme temperatures, frequency of work, lack of recovery time, vibration, contact stress, improper tool design, improper working techniques, duration of stress, and carrying multiple jobs, experience fatigue. The biomechanical exposures, psychosocial stresses, and individual risk factors are the main risk factors that cause WRMSD due to physical exposure.

So, the following are the future scope the research work:

1) The same type of analysis may be conducted using direct measurement methods for further validation purposes.
2) Posture analysis may be performed using computer software and mobile apps nowadays.
3) The investigation of the effect of temperature, various stresses and fatigue can perform.
4) There is always scope for improvement; hence, the suggested design may be modified for improvements, such as:
    a. The iron pan for material handling may be provided with wheels (single/tri-wheel for stair climbing) so that other laborers may be used for material collection, transportation, and handling purposes.
    b. Similarly, the proposed design of the material collection and eviction table may be used for other construction work.
    c. Likewise, the proposed multi-tasking portable workbench for masonry work may be used by electricians, painters, and others as well.

Most of the construction workers are found to be in the unorganized sector and depend on daily wages. The investigation may be conducted for their well-being, safety, and health. Hence, the author believes that the present work will provide productive and methodological information to researchers, scientists, and engineers who work in the area of Human Factors and Ergonomics.

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24/6/25