POSTURAL ANALYSIS OF WELDING WORKERS WORKING IN DIFFERENT SSI OF WEST BENGAL AND SUGGESTING FOR DESIGN IMPROVEMENTS

Thesis submitted by

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PREFACE

The efficiency of the workers and quality of job are directly depended on the appropriate work posture, good health and safety of workers in any manufacturing industry. So, the identification and evaluation of potential risks factors should be the main steps to regulate them. “Ergonomics” is the science and practice of designing jobs and workplaces rather than physically forcing the workers’ body to fit the job. It is defined as the study of work. It may be deduced that all types of physical as well as mental stresses are related to work. Musculoskeletal Disorders (MSDs) are common in the workplaces and small scale industries. Various muscles, nerves, tendons, ligaments, joints and spinal discs are affected due to bad work postures. Due to automation in industry, more and more efforts have been made to achieve efficient as well as human-less manufacturing. But manual work is still significant due to increase of customized products and human’s potential of learning and adapting. Maximum work efficiency with minimum human effort signifies that the workers are in good work postures. Occupational injuries, muscular diseases, imbalance of muscles and tissues can be influenced by body posture. Postural stresses and bodily discomfort in various joints of human body may be increased by poor postural positions of workers. MSD injury and risk in the workplaces may be reduced by systematic observation of posture of workers. The most common spinal disease of workers is low back pain that causes the limitation of the movement.

Keeping all these considerations in view, the present research work has been planned and designed for the analysis of posture of welders working in different small scale industries in West Bengal.

The thesis is prepared in well-organized manner into six chapters. A brief summary of each chapter is provided as below:

An over view of working environment, job activities and job conditions in industries, importance of Ergonomics in industries and factors related to MSDs are discussed in chapter 1. Requirement of postural analysis of welding workers is also described in this chapter. Literature review of previous work is incorporated and studied for finding out the existing knowledge gap to outline the research objectives. Details of different methodologies used in this research work have been discussed in chapter 2. Biomechanical model of welder, anatomy of the human spine have been discussed in chapter 3. Design and development of welding workstation based on postural analysis have been discussed in this chapter 4. The various methods like RULA, REBA and OWAS have been analysed as well as discussed in chapter 5. Bodily discomforts, postural stresses of different postural positions, low back compressive force and it's comparison with different postural positions of welders have been analysed in this chapter. Different MCDM methods have also been used to find out best postural position of welders. Finally a design solution is there in this chapter. Conclusions on the results and discussions of various processes have been included in the chapter 6. Recommendation for the future work is also outlined in this chapter.

It is evident that the existing research work on posture analysis of welding workers in different small scale industries will provide useful information and guidance to the researchers about the most stressed muscles and joints during the welding operation.

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(Suman Das)

VITA

The author, Suman Das, son of late Kanailal Das and Mrs.Urmila Das, was born on 15th January, 1974 at Nabadwip, Nadia in West Bengal. He studied at Nabadwip Bakultala High School and passed the Secondary as well as Higher Secondary (H.S) Examination in 1990 and 1992 respectively. The author graduated in Mechanical Engineering in 1998 from Bengal Engineering and Science University (BESU), West Bengal. Author completed his M. E. in Machine Design in 2000 from Mechanical Engineering Department, Bengal Engineering and Science University (BESU), West Bengal. Then he joined at Asansol Engineering College as a lecturer in Mechanical Engineering Department in August, 2000.After that, he joined at Bengal Institute of Technology, in August 2001. Then he joined Swami Vivekananda Institute of Science & Technology as an Assistant Professor in Mechanical Engineering Department in August, 2009. Presently he is working as an Associate Professor and head at Swami Vivekananda Institute of Science & Technology in the same Department. Author has published 7 research papers in international referred journals as well as presented 4 research papers in reputed international conferences and one research paper in national conference related to Ergonomics.

Dedicated to my parents....

My foundation of strength and source of inspiration

for their trust in education, never-ending support,

love and encouragement

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CHAPTER-1

INTRODUCTION

1.0 INTRODUCTION

Appropriate work posture, good health and proper safety of workers in manufacturing industries should be the key factors for enhancing efficiency and job quality. In order to accomplish these, the identification and assessment of potential risks should be the first step to control them. This may increase the protection level of workers as well as the efficiency of work environment. The word, Ergonomics, has its origin in two Greek words, ergon and nomos, which together mean to “work (by) natural laws” [1]. “Ergonomics” is defined more pointedly as the science and practice of designing jobs and workplaces to match the capabilities as well as limitations of the human body, rather than physically forcing the worker’s body to fit the job. It can be defined simply as the study of work [2]. It can also be used to minimize as well as reduce all types of physical stresses related to job. Musculoskeletal Disorders (MSDs) are the injuries most commonly seen in the workplaces. Various muscles, nerves, tendons, ligaments, joints and spinal discs are affected. These are caused by repetitive motions, high body stresses and bad work posture [3]. Automation in industry has been increased in recent years and more and more efforts have been made to achieve efficient as well as flexible manufacturing. Still, manual work is significant due to increase of customized products and human’s capability of learning and adapting. Posture is the assertiveness of the human body. Good posture signifies the maximum efficiency with minimum human effort. Occupational injuries, muscular diseases, imbalance of muscles and tissues can be influenced by body posture. Poor work posture may also increase postural stresses and muscular fatigue in various joints of human body. In the digital human simulation, the joint torque load can be calculated after geometrical and dynamic modelling of human body [4]. The Various occupational musculoskeletal disorders (MSDs) are controlled as well as prevented by appropriate work posture of workers. So measurable or semi measurable descriptions of posture are inputs to many job analysis tools applied for prevention in MSDs. Studies of the relationship between risk factors such as posture, repetition and force resulting MSD prevalence have used various approaches to characterizing working posture, including observation-based methods. Posture classification by systematic observation of a worker is commonly used in research and safety professionals, to help inform job design decisions and establish safe work limits to reduce MSD injury risk in the workplace. Low back pain is the most common spinal disease causing from movement limitation to temporary disability. It is generally related to the occupational environment with increased risks associated to vibrations of the whole body awkward postures and lifting heavy weights. RULA was developed to evaluate the exposure of individual workers to Ergonomic risk factors associated with upper extremity MSD [5]. It was established by Lynn Mc Atamney and E Nigel Corlett in 1993.This method helps to examine Ergonomics especially upper limbs of the workers body. Musculoskeletal loads of the workers can be calculated due to body postures, motion-repetition and forces. No special equipments and tools are necessary for this valuation. An action is created by using a coding system which indicates the level of intervention necessary to decrease the risk of injury due to physical loading of the workers. This method accomplished these aims by providing a "Grand Score" that can be categorized by Action Levels. Upper score point out immediate changes to be made in the body posture for reducing muscular fatigued and also for enhancement of job quality [6].

REBA (Rapid Entire Body Assessment) and RULA (Rapid Upper Limb Assessment) were techniques to quantify the fatigue experienced by the worker while manually lifting loads. These assessments were carried out by a procedural analysis of body postures involved. The fatigue involved in a particular operation was quantified and accordingly changes in work method for system improvement were suggested. These techniques helped in process refinement by identifying actions causing high fatigue.

The Ovako Working Posture Assessment System (OWAS) was formulated in Finland, specifically in the OVAKOOY Company, a leading European producer of steel bars and profiles. This system was used to evaluate the work load in the repair process of smelting furnaces.

The OWAS was initially created with the identification of 72 postures established by photographing the work postures used in different working areas in OVAKOOY. Its reliability was confirmed by the analysis of several tasks by a group of engineers previously trained in the method. For this, the observations were made by two engineers on two workers during two different work shifts (morning and afternoon). The results found by both groups were roughly similar. Afterwards, they established four risk categories, the first being related to normal postures without recommendations of any type for corrective activity. The second and third categories concerned postures with some risk with recommendations for corrective actions to be taken over the middle term. The fourth category referred to unacceptable postures with recommendations for immediate corrective measures.

The OWAS method was intended to identify the frequency and time spent in the postures adopted in a given task, to study and evaluate the situation, and thus, recommends corrective actions17). The OWAS identified the most habitual back postures in workers (4 postures), arms (3 postures), legs (7 postures) and weight of the load handled (3 categories). All this implies up to 252 possible combinations.

A combination of archival, subjective and observational field data collection methods were used to investigate the relationship between biomechanical and postural stresses and the resulting physical strain experienced by industrial workers of a packaging plant. Assessment of physical strain was based on the number and incidence rate of Occupational Safety and Health Administration (OSHA)-reportable injuries that were recorded based on the self-reported ratings of perceived body discomfort. The results illustrated the usefulness of postural and biomechanical analyses for assessing the risk of injury in industry [7]. The investigation also stated the relationship between posture and force and the resulting physical strain among a selected group of industrial workers. This analysis focused on examining correlations between measures of postural and biomechanical stress and measures of strain. Strain was based on the number and incidence rate of injuries and self-reported ratings of perceived discomfort, whereas stress was estimated from postural and biomechanical analyses. The musculoskeletal history survey clearly demonstrated the prevalence of musculoskeletal problems experienced by employees at the facility. Prevalence rates in excess of 50% were reported for the low back (65%), the wrist (60%), and the ankle (53%). In addition, with the exception of the toes (18%), at least one third of the respondents reported ‘‘trouble’’ in the other body areas: shoulder (48%), elbow (35%), fingers (36%), neck (42%), upper back (43%), hip (33%), and knee (35%). It was expected that the discomfort scores would be distributed across the wide range of values. These results from musculoskeletal discomfort survey have important implications.

Analysis of stress focused on two risk factors associated with musculoskeletal injuries, specifically posture and force. Postural stress and biomechanical stress were both highly correlated with injury rates. This was suggested that either technique was useful for the analysis of work activity for the purpose of preventing musculoskeletal injuries. If the results are confirmed in a more comprehensive study, then the postural analysis is likely to be preferred by industry. Postural analysis utilizes directly observable data, whereas biomechanical models use a number of simplifying assumptions. Moreover, the postural analysis system developed for this study requires fewer data input variables than those required for most biomechanical models [8].

The 3D CAD model of the entire human body was developed in Solid Works software and FEM was used for stress analysis. The maximum Von-Mises stresses were also noticed in this work. It was noticed that the intensity of stresses and the Von-Mises stresses were good injury indicators for the body muscles and joints independent of direction of load. This present research work provides broad information to the researchers for better understanding about the most stressed muscles and joints during welding operation.

Analytic Hierarchy Process (AHP) is one of the multi criteria decision making methods that was developed by Prof. Thomas L. Saaty. This method can be used to derive ratio scales from paired comparisons. The input can be obtained from actual measurement or from subjective opinion such as satisfaction feelings and preference. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution**),** the other multiple criteria method, was used to identify solutions from a finite set of alternatives. The chosen alternative should have the shortest distance from the positive ideal solution and the outermost distance from the negative ideal solution .Using these two MCDM methods the best welding posture of worker was selected.

1.1 Work Activities and Job Conditions in Manufacturing Industries

- Repeating the same motion throughout the workday
- Working in awkward or stationary positions
- Lifting heavy loads
- Using extreme muscle force to perform work
- Being exposed to excessive vibration and noise
- Extreme temperatures in the workstation

1.2 Importance of Ergonomics in Industries

Industries progressively require higher production rates and advances in technologies to remain competitive and stay in market. So job may include

- Frequent lifting, carrying and pushing or pulling loads without help from other workers or devices.
- Performing only one function or movement for a long period of time or day after days.
- Working more than 8 hours a day.
- Working at a quicker pace of work such as faster assembly line speeds.
- Having tighter grips when using tools.

The above factors if coupled with design of poor machines and design of work places can create physical stresses on workers bodies, which may create body injuries.

1.3 Fundamental Definition of Musculoskeletal Disorders (MSDs)

Musculoskeletal disorders are injuries and disorders of the soft tissues of muscles, tendons, ligaments, joints, cartilage and nervous system. Nearly all tissues, including the nerves, tendon, arms and back muscles may be affected. These are also called cumulative trauma disorders, repeated trauma, repetitive stress injuries and occupational overexertion syndrome. These painful injuries generally developed gradually over weeks, months and years. The cause of MSDs can be tingling, stiff joints, difficulty moving, muscle loss and sometimes paralysis. Full health of the workers may not be recovered sometimes.

1.4 Causes of Work related MSDs in Industries

Work-related MSDs may occur when the physical capabilities of the worker do not match the physical requirements of the job. The causes of MSDs problems are as follows:

- ❖ Exerting excessive force.
- ❖ Excessive repetition of movements that can irritate tendons and increase pressure on nerves.
- ❖ Awkward postures or unsupported positions that can compress nerves and irritate tendons.
- ❖ Static postures or positions that a worker must hold for long periods of time may restrict blood flow and may damage muscles.
- ❖ The amount of force exerted on the body at the time of bending and twisting.

1.5 Parts of the Body Affected by MSDs

The following body parts are directly affected by MSDs, these are:

- ✓ Arms
- ✓ Back
- ✓ Hands
- ✓ Wrists
- ✓ Fingers
- ✓ Legs
- ✓ Neck
- ✓ Shoulders

1.6. Factors Directly Related to Musculoskeletal Disorders (MSDs)

The following factors are directly involved to create or enhance musculoskeletal disorders. These are:

- Force
- Repetition
- Awkward postures
- Static postures
- Quick motions
- Compression or contact stress
- Vibration
- Cold temperatures

1.7 Requirement of Postural Analysis of Welding Workers

Manufacturing is the backbone of any industrialized nation. Welding is one of the most essential parts in manufacturing sectors of our country. The production rate as well as job quality are also affected due to awkward working posture and unsuitable management programme. These are highly related with physical ability and skill of the workers. Welders were highly exposed to body fatigue due to work related problems [9]. Occupational safety and health were also main concerns in this unit. It was noticed that physical strength of the welders does not remain immutable in awaking process. Work related musculoskeletal disorders (WRMSD) are very common health problem in this area. Assessment of exposure levels to WRMSD risk factors can be suitable for planning and implementing interventional Ergonomic programs in the work station [10]. WRMSDs are very painful disorders and these happen in different muscles, tendons, nerves and joints. Heavy physical workload may create high frequency muscular disorders of human body. The objective of the present research work was to evaluate the work related musculoskeletal disorders (WRMSD) and discomfort of different body parts of workers engaged in different small scale welding units. That’s why the postural analysis of welding workers was very much needed for higher production rate and getting better job quality.

1.8 Review of Past Research Work

Singh et. al. reported [11] that a hand operated maize dehusker-sheller to be operated by farm women was designed and developed to dehusk and shell the maize cobs using Ergonomics (anthropometric, strength and physiological workload). Axial-flow maize dehuskere-sheller with 540 mm cylinder length and 380 mm diameter required 3.03 N-m torques on cylinder shaft while operating at 5.6 m/s peripheral speed and 100 kg/h feed rate by feeding cob one by one. The heart rate of subject while operating the maize dehuskere-sheller at 54 rpm (5.6 m/s) was 142 beats /min.

Obolewicz et. al. [12] studied that the construction industry was an important sector of the economy in Poland. The number of sufferers of serious injuries in the construction sector amounted to 80 as compared with 187 injured in all other sectors of economy, According to the National Labour Inspectorate (PIP), 2014 in Poland. This article presented the results of surveys on the impact of construction worker behaviour on the occupational safety and health outcomes. For the analysis of results, the method of numerical taxonomy and Pareto charts was employed, which allowed the authors to identify the areas of occupational safety and health at both an operational and a tactical level, in which improvement actions needed to be proposed for workers employed in micro, small, medium and large construction enterprises.

Stuebbe et al. [13] in their research studied that the combination of archival, subjective and observational field data collection methods were used to investigate the relationship between biomechanical and postural stresses. Assessment of physical strain was based on the number and incidence rate of Occupational Safety and Health Administration (OSHA)-reportable injuries that were recorded over a period of 27 months, and based on the self-reported ratings of perceived body discomfort. The results illustrated that the usefulness of postural and biomechanical analyses for assessing the risk of injury in industry.

Kaushik et al. [14] intended to study the effect of standing and sitting workplace in context with wash area in the household. The main objectives of the study were to design a wash area Ergonomically and then test the efficiency. The sample for the study consisted of 30 performers selected on the basis of vision acuity and general wellbeing. The Ergonomic design of the wash area was based on functionality, floor size and placement of work centres, ventilation, storage, safety and others. The findings of the study exposed that the energy consumption was lesser in the performance of the work in standing position than in sitting in context with the job of washing clothes. Also perceived exertion and spine angle deviation was considerably low when the performers accomplished the job in standing as compared to sitting position.

Mukhopadhyay et. al. [15] evaluated the Ergonomic intervention on the occupational stresses of railway workshop’s fitters. Working heart rate (WHR) was measured continuously during their work schedule by portable heart rate monitor. Recovery heart rate and other essential occupational stress indexes were also measured along with total working environmental details. Clear evidences of a direct relationship between occupational hazard and fatigue was found and it can be considered as an environmental stresses which, in conjunction with other environmental and host factors induced a chronic fatigue that lead to non-specific health disorders.

Neville et. al [16] reported in this paper that the data on novice intra-analyst and inter-analyst reliability together with criterion-referenced validity across a range of methods. Considerable variation in the reliability and validity of the methods was found. The data were then used in utility analysis, to determine the cost-effectiveness of the methods for an example of car radio-cassette design. It is shown that the estimates of cost-effectiveness may be helped in the selection of methods.

Rothmore et. al. [17] in their research investigated the implementation of injury prevention advice tailored according to the Stage of Change (SOC) approach. The managers of 25 workgroups, drawn from medium to large companies across a wide range of occupational sectors were allocated to receive either standard Ergonomics advice or Ergonomics advice tailored according to the workgroup SOC. Twelve months after the advice was provided, semi-structured interviews were conducted with each manager. Qualitative analysis identified that the key barriers and facilitators to the implementation of changes were largely related to the workers resistance to change the attitudes of senior managers towards health and safety. The findings from this study recommended that the implementation of Ergonomics recommendations may be improved by the tailoring of advice according to SOC principles.

Garmer et.al.[18] developed a hand-Ergonomics training kit to increase critical thinking concerning choice of hand tools. This study deals with the design, use and evaluation of a hand-Ergonomics training kit for use in Ergonomics training programmes. The effects on awareness of hand Ergonomics among training course participants had been evaluated by means of a questionnaire and interviews at a car production plant in Sweden. The evaluation was carried out about one and a half years after training with the hand-Ergonomics training kit. The evaluation showed that the practical exercises with the hand-Ergonomic training kit had to a remarkable extent, increased individuals' awareness of anthropometric differences and of the importance of Ergonomically well-designed hand tools.

Bentley et. al. [19] reported that highest work-related morbidity and mortality incidence rates were found in the logging sector in New Zealand. It was also highlighted in this paper that the pivotal role of an industry-wide injury surveillance system in an industry-specific strategic research programme, giving examples of the use of ARS data in identification of priority areas for Ergonomics, safety and health research attention, for safety awareness feedback to the industry, and in the evaluation of injury countermeasures. An analysis of injury patterns and trends for one high-risk forestry operation was presented to illustrate both the capabilities and limitations of the ARS in its present stage of development.

Munck-Ulfsfalt et.al., [20] in their research reported that Volvo Cars had a tradition of attention to the work environment and developed a working environment management system, a working environment policy, standards/specifications and methods for efficient practical performance. They also stated that in order to achieve results in Ergonomics one has to work comprehensively, which means working with the product, the process, the workplace and the work organisation. They suggested that key to success was to train all categories concerned in load Ergonomics and to perform methodical Ergonomic work through the whole chain from design to production.

Hendrick et.al [21] described the factors and sources of information that were considered for calculating the costs and benefits of proposed Ergonomic projects. Based upon their experiences and review of numerous Ergonomics projects, they described and illustrated the common characteristics of successful Ergonomics interventions. They drew a conclusion that for industry as well as society, good Ergonomics is good economics.

Shikdara et. al. [22] investigated occupational health and safety problems of a manufacturing industry in Sultanate of Oman. They found some of the common problems which were improper workplace design, ill-structured jobs, mismatch between worker abilities adverse environment, poor human–machine system design and inappropriate management programs. Fifty-six industrial unit managers participated in the study. Forty-eight percent of the managers received worker complaints of back pain, 36% of fatigue, 32% of upper-body pain, 48% of stress and 46% of dissatisfaction. A significant correlation ($p<0.01$) was found among Ergonomics and safety indicators and average injury rates. Lack of skills in Ergonomics, communication and resources were believed to be some of the major factors contributing to the poor Ergonomic conditions and consequent increase in health and safety problems in this industry.

Janowitz et. al. [23] stated that assessing the physical demands of the heterogeneous jobs in hospitals requires appropriate and validated assessment methodologies. This research work focused on the design and implementation of observational techniques to directly assess physical risk factors for musculoskeletal injury among the workers.

Scott et. al [24] explained in their research paper that the musculoskeletal disorders associated with manual labour, the enormity of the problems experienced in industry remains. Recognizing the importance of applying the science of Ergonomics, the focus of this paper was to highlight the substantial difference between conducting rigorous controlled research in the laboratory and the less controlled, but more realistic research within the working environment. This paper was based on research conducted in an industrially developing country. It was suggested that the application of rigorous Ergonomics theory should be improved the poor working conditions as well as work efficiency in developing regions.

Vink et.al.[25] focused on the positive aspects of Ergonomics for the improvement of the working environment in industry as well as higher productivity and greater comfort. This research work investigated that the participation of end-users and management contribution towards success. It was shown that the chance of success increased by empowerment and positive experiences of end-users with the potential improvement.

Lamkull et. al. [26] explained in this study that the appearance of virtual human models influences observers when judging a working posture. A manikin was manually assembling a car battery that was used in this experiment. The 16 different pictures were presented in this work. All pictures had the same background, but included a unique posture and manikin appearance combination. The results showed that the virtual human model appearance influenced subjects when they rated pictures one by one: a more realistic manikin was rated higher than the identical posture visualized with a less natural appearance. This appearance effect was not seen when subjects ranked the pictures while looking at all of them at the same time. This study demonstrated that the human modelling tool used when showing and visually evaluating results makes a difference. A combination of visualizations and objective Ergonomic assessment methods ware recommended in this work.

Robertson et. al. [27] stated that the macro-Ergonomics intervention consisting of flexible workspace design and Ergonomics training which was conducted to examine the effects on psychosocial work environment, musculoskeletal health, and work effectiveness in a computer-based office setting. This research work also stated the work-related musculoskeletal discomfort, job control, environmental satisfaction and Ergonomic climate. This study suggested that a macro-Ergonomics intervention was effective among knowledge workers in office settings.

Neumann et. al. [28] explained the barriers and assists to integrating Ergonomics into production system design remains a research issue. Researchers worked collaboratively with the firm in efforts to improve the company's ability to handle Ergonomics in their daily work of improving and developing production systems. They described a process of organisational change observed under conditions of close collaboration by researchers adopting a holistic or systems perspective, in a company with a long tradition of Ergonomics and a running cooperation with the researchers.

Sagot et. al. [29] investigated that the occupational diseases drops in both productivity and quality as well as increased unit costs. The high numbers of breakdowns were just some of the consequences of the poor design of any product or system that does not take man and his role as a factor of reliability and safety into account. The aim of this paper was to give a number of methodological and theoretical indicators concerning the contribution of Ergonomists to the execution of design projects of new products.

Whysall et. al. [30] explained the importance of reducing work-related musculoskeletal disorders in workplace. It was to be expected that local factors, such as worker safety legislation, insurance and compensation arrangements, will have an influence on the consultant/client interaction, although the primary issues of achieving implementation of recommendations and evaluation of their consequences appear generic. They also explained that the MSDs continuing to be the most common form of work-related ill health in the workplace, this study had revealed important concerns and challenges that should be examined in the attempt to make interventions to reduce the risk of MSDs more effective.

Singh et. al. [31] observed that a hand operated maize dehuskere- sheller to be operated by farm women was designed and developed to dehusk and shell the maize cobs using Ergonomics (anthropometric, strength and physiological workload). An axial-flow maize dehuskere- sheller with 540 mm cylinder length and 380 mm diameter required 3.03 N-m torque on cylinder shaft while operating at 5.6 m s^{-1} peripheral speed and 100 kg h^{-1} feed rate by feeding cob one by one. They also observed the torque which was 30% of isometric torque obtained at front position of handle with lowest crank length. The heart rate of subject while operating the maize dehuskere sheller at 54 rpm (5.6 m s^{-1}) was 142 beats min^{-1}. The output of 60 kg h^{-1} was obtained at the feed rate of 80 kg h^{-1}.

Loisel et. al. [32] described a participatory Ergonomics program aimed at early return to regular work of workers suffering from subacute occupational back pain and assesses the perceptions of the participants on the implementation of Ergonomic solutions in the workplace. The participatory Ergonomics program was used in the rehabilitation of workers suffering from acute back pain for more than 6 weeks, a program that was associated with an increased rate of return to work. The perceptions of the participatory Ergonomics participants were assessed 6 months after completion of the Ergonomic intervention through a questionnaire sent to employer representatives, union representatives and injured workers of participating workplaces. They also suggested in their work that this newly developed model of back pain management was to influence both the physical capacities and work demands of workers absent from regular work due to back pain, in order to allow a quicker and safer return to regular work. This participatory Ergonomics program was intended to generate appropriate Ergonomic solutions that would modify the work demands to better match the worker's reduced capacity.

Wilson [33] stated that Ergonomics/human factors are, above anything else, a systems discipline and profession, applying a systems philosophy and systems approaches. This research work specified just what attributes and notions define Ergonomics/human factors in systems terms. These were obviously systems focused, but also concerned for context, acknowledgement of interactions and complexity, a holistic approach, recognition of emergence and embedding of the professional effort involved within organization system. These six notions were illustrated with examples from a large body of work on rail human factors.

Jahanshahloo et.al [34] stated that the Multi-criteria decision making has been one of the fastest growing areas during the last decades depending on the changings in the business sector. They also explained that the decision maker(s) need a decision aid to decide between the alternatives and mainly excel less preferable alternatives fast. The principal focus of this paper was to extend the TOPSIS method to decision-making problems with fuzzy data. In this paper, the rating of each alternative and the weight of each criterion were expressed in triangular fuzzy numbers. The normalized fuzzy numbers was calculated by using the concept of α-cuts. Finally, a numerical experiment was used to illustrate the procedure of the proposed approach at the end of this work.

Siemieniuch et.al. [35] in their review provided an overview of expected impact of the 'Global Drivers' and the role of sustainability engineering in mitigating the potential effects of these Global Drivers. The message of the paper was that sustainability requires a significant input from Ergonomics/Human Factors, but the profession needs some expansion in its thinking in order to make this contribution. This research work discussed and highlighted the need for some new thinking and knowledge capture by systems Ergonomics professionals. Among these were ethical issues, job content and skills issues.

Majumder et.al. [36] explained the geometry, structure and the biomechanics of the pelvis bone. They also developed a realistic three-dimensional finite element model of the pelvis bone and observing the stress variation of the pelvic bone under normal walking condition. The Finite Element Method (FEM) was used to analyse complex geometries of this bone. They also explained that this type of stress analysis could contribute to the complete understanding of the hip biomechanics before and after different sorts of operation.

Metanl et.al. [37] studied and analysed the stresses induced in different knee joint muscles during flexion leg movement by using FEM model. Accurate and fast 3D knee joint model was generated by reverse modelling technique. ATOS III 3D scanner was used for generating accurate and detailed contours of the knee joint bones. 3D multiple scanning of the bones to obtain a point-cloud model was finalized in this research work. CATIA V5 was used to generate 3D bone from the .stl file imported from the scanned data. Filtering, cloud point alignment, tessellation of the model and referential geometrical entities were done for generating higher order 3D knee bone geometry. According to quadratic dependency, a non-homogeneous bone constitutive law was implemented. During the 3D FEM muscle analysis rectus femoris muscle was the maximum stressed muscle with 1.5579 M Pa compared to the biceps femoris muscle.

Mazzola et.al. [38] discussed the incidence of work-related musculoskeletal disorders (WRMSD) among sonographers' ranges between 82% and 88%. The most frequent causes of musculoskeletal disorders in sonography include the US equipment design. The Digital Human Model (DHM) had been developed in order to increase the level of quality of the Ergonomic design process. Results and Analysis were based on qualitative data produced by the simulations. The new design was well promising to minimize the risk of WRMSD at the wrist and at the hand level.

Björing et.al. [39] studied the Ergonomic conditions of workers of manual spray painting in the wood working industry. Interviews with spray painters showed that they had higher prevalence of musculoskeletal symptoms in their right shoulder compared with other workers with manual work. A majority of the spray painters painted work-pieces lying on a work-table. A majority of these painters abduct the right upper-arm so much when painting the horizontal surface of the work-piece that they risk supraspinatus tendinitis. The upper-arm abduction when painting horizontal surfaces could be decreased without introducing new Ergonomic disadvantages by installing work-tables with powered height control or possibly also by changing the geometry of the spray gun. Gripping the spray gun trigger was for some of the painters identified as causing a high risk for WMSD in the wrist. Lower spray gun trigger force would improve the situation. This could be done by the users in several ways, such as greasing the trigger mechanism and/or decreasing the spring pressure on the fluid needle. The study highlighted some major Ergonomic problems for a fairly large group of workers in the wood working industry.

Bommer.et.al. [40] developed a theoretical framework, which provides a systematic approach for measuring workload using a combination of analytical and empirical techniques. Human performance modelling with a computer simulation and mathematical modelling along with physiological, subjective and performance can also be measured. The independent variable of task complexity was measured, in the modelling of resource demands for a cleaning-inspection process and a final inspection process, using three dependent variables (subjective, physiological and performance measures) with a total of four responses (NASA-TLX, Workload Profile, fixation duration and human error probability). The results indicated that no significant difference among the response variables for each task complexity level, indicating the model accurately represents the operator's workload. Additional analysis had shown the accurate predication from the model in analysing workload peaks. This theoretical framework was designed to evaluate operator mental workload utilization in the manufacturing domain.

Vergara et. al. [41] presented the results of measurements of hand–arm vibration carried out in a field survey. This survey attempted to detect the main usability problems of handheld power tools in industry. Hand–arm vibration was measured in 70 tools used in different industrial sectors. Ninety workers were interviewed about their perception of vibration and the symptoms of diseases related with hand vibration. Compliance with current regulations was checked and the relationships between workers' perception of vibration, measured vibration levels and symptoms of vibration-related disorders were analysed. No preventive action was taken in any of these cases. Furthermore, in most of the cases, workers did not perceive these levels as being too high, which represents an additional risk. The hand–arm vibration generated by the use of power tools affects over 15% of all workers in industry.

Oomen et.al. [42] explained that the rule-based strength scaling was an easy, cheap and relatively accurate technique to personalise musculoskeletal models. This research work presented a new strength scaling approach for musculoskeletal models and validated it by maximal voluntary contractions. A heterogeneous group of 63 healthy subjects performed maximal isometric knee extensions. A multiple linear regression analysis resulted in a best-fit rule-based strength scaling equation, with age, mass, height, gender, segment masses and segment lengths as predictors. A second strength scaling equation was obtained through multiple linear regressions using backwards elimination, resulting in an equation consisting of only the significant predictors: age, body mass and gender. The newly developed strength scaling technique taking all predictors into account resulted in the most accurate predictions of muscle activities compared to alternative strength scaling methods. These techniques personalise musculoskeletal models to a larger extend. However, some applications that require more detailed personalised models, imaging might be necessary to obtain more specific individual muscle characteristics.

Sakka et.al. [43] stated that the repetitive tasks in industrial works may contribute to health problems among operators, such as musculo-skeletal disorders, in part due to insufficient control of muscle fatigue. Assumptions generally accepted in the literature are first explicitly set in this framework. Then, an earlier static fatigue model is recalled and extended to quasi-static situations specifically, the maximal torque that can be generated at a joint is not considered as constant, but instead varies over time accordingly to the operator’s changing posture. The fatigue model is implemented with this new consideration and evaluated in a simulation of push/pull operation.

Rashedi et.al. [44] observed that localised muscle fatigue (LMF) is a complex phenomenon that can differ between individuals, tasks, and muscles. Several muscle fatigue models (MFMs) have been developed in prior research. MFMs have potential practical value in Ergonomics, given that LMF can impair performance, serve as a surrogate measure of injury risk, and may act as a causal factor for work-related musculoskeletal disorders. Existing MFMs are reviewed here, and which are broadly classified as either ‘empirical’ or ‘theoretical’. Two specific MFMs, considered most Ergonomically-relevant, were directly compared and some important differences in predictions were found. Identifying such differences is suggested as a useful approach, both for developing testable hypotheses and in guiding subsequent model development or refinement. Other potential approaches for improving future MFMs are also discussed, including expansion of model structure to account for individual differences (e.g., age, gender, and obesity), task related parameters, and variability in motor unit composition.

Das et.al. [45] noticed that the evaluation of muscle strength is important for human factors engineers, Ergonomists, and healthcare practitioners to formulate successful Ergonomic interventions, prescribe exercise regimens, and model credible rehabilitation programmes. Although previous studies have identified the influence of different head-neck (H-N) positions on joint strength production, none have assessed the influence of H-N position on wrist strength. The objective of this study was to compare wrist flexor strength in different head-neck (H-N) positions, including a neutral neck position and eight non-neutral positions involving single or combined rotations in the sagittal and horizontal planes. Isometric flexor strength of the left wrist was measured from 30 right-handed healthy female volunteers, using an isokinetic dynamometer, in each of the nine H-N positions in a random order. Among the nine H-N positions, significant differences in wrist flexor strength were observed only between neck rotation to the right and the remaining positions. These results suggested that H-N positions should be considered while assessing or predicting wrist strength.

Seo et.al. [46] conducted an experiment of inverse dynamic simulation to enhance the accuracy of the activated muscle power, which was the input value in the FEA of the femur. An inverse dynamical musculoskeletal model was simulated using data from an actual walking experiment to complement the accuracy of the muscular force, the input value of FEA. The results were given as the loading conditions in the FEA, and the difference in the maximum Von-Mises stress and the total deformation was verified according to the method of considering the part where the muscles were attached.

Lu Yuan [47] utilized a participatory Ergonomics approach to examine the Ergonomic hazards and reduce musculoskeletal symptoms for librarians in the East Baton Rouge Parish Main Library. A variety of research activities were conducted, including: Ergonomics training and tests, observations, work environment and health questionnaires, and focus group discussions. A total of 39 employees from 9 different divisions in the Library participated in the study. The results of pre- and post-training Ergonomics knowledge tests indicate significant improvement of librarians' understanding of Ergonomics principles. The questionnaire responses for both 2-month-post- and 8-month-post- Ergonomics training compared against those before the training have shown positive improvements in ratings of the presence and severity of a majority of the musculoskeletal symptoms, the design of computer workstations and manual material handling tasks, as well as perceived control over the work environment. With the identification of Ergonomic hazards through RULA (Rapid Upper Limb Assessment) and REBA (Rapid Entire Body Assessment) observations as well as focus group discussions, the study findings accomplished the project's overall objective of assisting librarians with improvement of Ergonomics in the workplace. The results of this study provide a necessary foundation for future long-term study of participatory Ergonomics to reduce musculoskeletal injuries and disorders for librarians.

Tompa et. al. [48] reported on the Economic evaluation of a participatory Ergonomics process1 undertaken at one plant of a car parts manufacturer in central Ontario, Canada that employs approximately 175 workers including 125 hourly production workers. They undertook both cost-effectiveness and cost-benefit analyses from the perspective of the firm. They considered the implementation costs of the process (e.g., trainer, worker time in training, costs of the changes that were introduced) and the on-going costs of the intervention (e.g., team meeting time). In terms of consequences, they considered measures of health and productivity peroxide by data drawn from the plant's administrative sources.

Albers et. al. [49] studied that the skilled workers in the mechanical and electrical installation (M/EI) building and construction trades experience high rates of disabling work-related musculoskeletal disorders (WMSDs). The M/EI trades involve installing piping; heating, ventilation and air conditioning (HVAC), and electrical systems in residential, commercial, and industrial buildings. In the absence of an Ergonomics standard in the United States, some building and construction contractors, including M/EI sector contractors, have implemented various Ergonomics interventions on their worksites on a voluntary basis. However, no data were available to determine the type of voluntary control measures being implemented, the task-specific hazards for which control measures needed to be developed or refined, and perceived barriers to improving hazard control. As part of a larger effort to obtain this data, the National Institute for Occupational Safety and Health (NIOSH) organized a stakeholder meeting to gather information regarding Ergonomics interventions or ‘best practices’ by M/EI contractors and trades people.

Helander et. al. [50] described the increasing emphasis on Ergonomics in the manufacturing plants of IBM. Since 1978, 250,000 engineering hours had been devoted to Ergonomics training. As a result a systematic approach to Ergonomics improvement of manufacturing facilities had been implemented. This involved an analysis of the production environment including equipment, processes, ambient factors and job procedures. Information was collected through interviews of management, operators, and first-line supervisions, and complemented thorough field measurements of Ergonomic parameters. Individual workstations as well as processes were analysed with the purpose of modifying processes, reallocating tasks between automated devices and human operators and optimizing workstation design. Four case studies of industrial improvements were presented and analysed in terms of improved productivity, quality, and reduction of injuries.

Vignais et. al.[51] presented a system that permits a real-time Ergonomic assessment of manual tasks in an industrial environment. A biomechanical model of the upper body had been developed by using inertial sensors placed at different locations on the upper body. Based on this model, a computerized RULA Ergonomic assessment was implemented to permit a global risk assessment of musculoskeletal disorders in real-time. Furthermore, local scores were calculated per segment, e.g. the neck region, and gave information on the local risks for musculoskeletal disorders. Visual information was fed back to the user by using a see-through head mounted display. Additional visual highlighting and auditory warnings were provided when some predefined thresholds were exceeded. In a user study (N=12 participants) a group with the RULA feedback was compared to a control group. Results demonstrated that the real-time Ergonomic feedback significantly decreased the outcome of both globally as well as locally hazardous RULA values that were associated with increased risk for musculoskeletal disorders. The real-time Ergonomic tool introduced in this study had the potential to considerably reduce the risk of musculoskeletal disorders in industrial settings. Implications for Ergonomics in manufacturing and user feedback modalities were further discussed in this study.

Mirka et. al.[52] informed that the American Furniture Manufacturers Association had taken the initiative of developing such a guideline for its members. The result of this effort was the ‘AFMA Voluntary Ergonomics Guideline for the Furniture Manufacturing Industry’, a document that included basic information about Ergonomics program components as well as a compilation of work-proven, Ergonomics best practices as submitted by members of the furniture manufacturing community. This guideline was developed through an industry-research-government partnership and made strategic use of the unique attributes that each sector brought to this effort. Outlined in this study were some of the characteristics of this partnership including, the roles played by each, the different motivations for pursuing the guideline, the challenges faced during the development of the document, the successes experienced in this process, as well as a proposed outline for measuring the effectiveness of this effort.

1.9 Research Gap Analysis

Review of literature suggests that a number of studies have been carried out to study the analysis of posture and health status of workers in different small scale industries throughout the world. No work on welders particularly in West Bengal has been observed. There is no consciousness of health and safety of welding workers mainly in West Bengal.

No analysis of body stress of welders has been observed in review of past research work. Moreover, most of these studies have been mainly undertaken to understand the impact of bad work posture towards health in developing countries.

Realistic three dimensional model of human body developed by Solid works software has not been observed in earlier research work.

No design solution has been suggested for the welders to reduce the musculoskeletal symptoms.

It has been observed that no welding job table has been suggested to reduce the postural stresses as well as increasing job quality. So, the aim of this analysis is to fill the gap between the past research work and present one. Therefore, the requirement of postural analysis was so impotent for the welders for reducing their musculoskeletal disorders and postural stress.

1.10 Objectives and Scope of Present Research Work

The objectives of the present research work have been outlined as following modules:

1. To study the working postures and various MSD symptoms of welders engaged in different welding industries in West Bengal, India with the help of different postural analysis tools which recommend the changes to be made in the body postures while working in industries.

2. To develop a realistic three dimensional model of the human body and to observe the stress distribution patterns in different joints and muscles in a particular work load and specific body postures of welders.

3. To study the stress distribution patterns in different body regions and joints during the welding operation for better diagnosis of low back pain.

4. To measure and to plot the different areas of pain, dissatisfactions with the help of NIOSH discomfort survey method during the welding operation. This provides broad information to the researchers for better understanding about the most stressed muscles and joints during welding.

5. To calculate the postural stresses and its intensity level in the different joints and muscles during welding operation.

6. To select the effective welding posture and validating it by using AHP & TOPSIS methods.

7. To develop an Ergonomically designed workstation for reducing the muscular stresses, MSD symptoms and increasing the job quality.

CHAPTER-2

METHODOLOGY

2.0 METHODOLOGY

Different techniques were applied for analysis of body postures of welders. The following tools were used to assess a variety of tasks, in any position where body posture was static, dynamic or rapidly changing. These were the quick survey methods for use in Ergonomic interventions of work places where MSDs were reported. This assessment can be accessed biomechanical and postural loading of the workers body.

2.1 Rapid Upper Limb Assessment (RULA) Method

RULA was developed to evaluate the exposure of individual workers to Ergonomic risk factors associated with upper extremity MSD. It was established by Lynn McAtamney and E Nigel Corlett in 1993.This method helped to examine Ergonomics especially upper limbs of the workers body. Musculoskeletal loads of the workers can be calculated due to body postures, motion-repetition and forces. No special equipments and tools were necessary for this valuation. An action was created by using a coding system which indicated the level of intervention necessary to decrease the risk of injury due to physical loading of the workers. This method accomplished these aims by providing a “Grand Score” that can be categorized by Action Levels. Upper score pointed out immediate changes to be made in the body posture for reducing muscular fatigued and also for enhancement of job quality.

The Ergonomic assessment tool RULA considered biomechanical and postural load requirements of job tasks/demands on the neck, trunk and upper extremities. It was designed for easy use without need for an advanced degree in Ergonomics or expensive equipment. A single page worksheet was used to evaluate required body posture, force, and repetition. Based on the evaluations, scores were entered for each body region in section A for the arm and wrist, and section B for the neck and trunk. After the data for each region was collected and scored, tables on the form were then used to compile the risk factor variables, generating a single score that represents the level of MSD risk.

The RULA worksheet is divided into two body segment sections which are labelled as A and B. Section A is covered the arm and wrist and Section B is covered the neck, trunk and legs. This segmenting of the worksheet ensured that any awkward or constrained postures of the neck, trunk or legs which might influenced the postures of the arms and wrist were included in the assessment. The evaluator should score Group A (Arm & Wrist) postures first, then score Group B (Neck, Trunk & Legs) postures for left and right. For each region, there is a posture scoring scale and additional adjustments outlined on the worksheet which need to be considered and accounted for in the score.

2.1.1 The Process of RULA Development

The development of RULA occurred in three stages. The stage I was the development of the method for recording the working posture, the stage II was the development of the scoring system, and the stage III was the development of the scale of action levels which provide a guide to the level of risk and need for action to conduct more detailed assessments.

STAGE I: In this stage the body was divided into segments which formed two groups: A and B. Group A included the upper and lower arm and wrist while Group B included the neck, trunk and legs. This ensured that the whole body posture was recorded so that any awkward or constrained postures of the legs, trunk or neck which might be influenced the postures of the upper limb were included in the assessment. This was used as a suitable basis for RULA.

STAGE II: Development of the system for grouping the body part posture scores A single score was required from the Groups A and B which will be represented the level of postural loading of the musculoskeletal system due to the combined body part postures. The first step in establishing such a system was to rank each posture combination from the least to the greatest loading based on biomechanical and muscle function criteria. This process was conducted over some time by two ergonomists and an occupational physiotherapist.

STAGE III: The third stage of RULA, and thus of its development, was to incorporate both score C and score D into a single grand score whose magnitude provides a guide to the priority for subsequent investigations. Each possible combination of score C and score D was given a rating called a grand score, of l-7 based upon the estimated risk of injury due to musculoskeletal loading. For a grand score of 1 or 2, the working posture would have scored 2 or less for both body segments groups A and B, and the scores for muscle use and force would be 0. Working postures and actions which had a grand score of 1 or 2 were considered acceptable if not maintained or repeated for long periods. A grand score of 3 or 4 will be given to working postures which were outside suitable ranges of motion as defined in the literature and also working postures which were within suitable ranges of motion but where repetitive actions, static loading or the exertion of force were required.

Further investigation was needed for these operations and changes may be required. A grand score of 5 or 6indicated those working postures which were not within suitable ranges of motion: the operator was required to perform repetitive movements and/or static muscle work and there may be a need to exert force. It was suggested that these operations were investigated soon and changes made in the short term while long-term measures to reduce the levels of exposure to risk factors were planned. A grand score of 7 would be given to any working postures at or near the end of range of movement where repetitive or static actions were required. Any postures where the forces or loads may be excessive were also included in this group. Investigation and modification of these operations was required immediately to reduce excessive loading of the musculoskeletal system and the risk of injury to the operator.

Action level 1:
A score of 1 or 2 indicated that posture was acceptable if it was not maintained or repeated for long periods.

Action level 2:
A score of 3 or 4 indicated that further investigation was needed and changes may be required.

Action level 3:
A score of 5 or 6 indicated that investigation and changes were required soon.

Action level 4:
A score of 7 indicated that investigation and changes were required immediately.

The higher action level will not, however, lead to unequivocal actions to eliminate any risks to the operator.

2.2 Rapid Entire Body Assessment (REBA) Method

REBA was also an Ergonomic assessment tool used a systematic process to evaluate whole body postural MSD and risks associated with job tasks. A single page worksheet was used to evaluate required or selected body posture, forceful exertions, type of movement or action, repetition, and coupling. REBA (Rapid Entire Body Assessment) was a technique to quantize the fatigue experienced by the worker while manually lifting loads. These assessments were carried out by a procedural analysis of body postures involved. The fatigue involved in a particular operation was quantified and accordingly changes in work method for system improvement were suggested. These techniques helped in process refinement by identifying actions causing high fatigue.

REBA was developed to fill a perceived need for a practitioner's field tool, specifically designed to be sensitive to the type of unpredictable working postures found in health care and other service industries. Initial reliability for inter-observer coding shown promise but further work was needed to establish the validity of the tool.

It was a quick and easy to use observational postural analysis tool for whole body activities and giving a musculoskeletal risk action level. The method was similar to RULA tool where the assessor assigns scores to postures and body alignment based on body part diagram. Load, Force and coupling scores are added to calculation for the body and then final score for both groups were summated to form the final action score. The REBA method evaluate the Ergonomics risk factor by observation the posture of employees while they working at their workstation directly. Postural and biomechanical loading was assessed on the entire body by valid REBA method.

2.2.1 REBA Clarification

REBA was a simple analytical tool which allows surveying different tasks connecting the whole body of the workers at work places. This method focused on the postural analysis of workers when posture was static, dynamic, rapidly changing or inanimate loads were being handled either frequently or in frequently. The different level of actions and the scores are listed in table.

2.2.2 REBA Action Levels

With the help of table 2.1 the action level of REBA is shown clearly.

Table 2.1 Action level of REBA

REBA Score	Risk Level	Action Level	Action (Including further assessment)
1	negligible	**0**	none necessary
2-3	low	**1**	may be necessary
4-7	medium	**2**	necessary
8-10	high	**3**	necessary soon
11-15	very high	**4**	necessary now

2.3 Ovako Working Posture Assessment System (OWAS)

A steel industry company was developed this Ovako Working Posture Assessment System (OWAS) in 1977 in Finland. It was extensively used to identify and assess the harmful working postures. This method was based on a simple and systematic classification of work postures combined with observations of corresponding tasks. Postures were recorded according to a coding system; such that the code for a posture was are cord of the posture itself, the load or force used and the stage in the cycle or task. The higher the numbers were, at any stage of the analysis, the further away from a desirable posture the posture under consideration. Based on the code numbers of each limb, an action category value was then determined.

2.4 Questionnaires and Interview Technique

The Questionnaires were consisted of questions pertaining to different problems related to this particular operation. Daily activity of the worker, discomfort level of different body parts, working and resting periods were plotted and calculated. NIOSH body discomfort survey was used for mapping and plotting different areas of pain of the body parts with its intensity. Body discomfort level can also be calculated with the help of this method.

2.5 Finite Element Method (FEM)

In the most numerical methods, the unknown state variables were solved at a discrete number of points in the problem domain considered to obtain approximate solutions. Once a problem domain was discretized, solution can be obtained for each of the smaller domains or unit considered. Finally, such domain wise solutions can be combined together to obtain solution for the entire domain. The discrete points considered in the domain were called nodes and the smaller domains or units considered were called elements. Elements and nodes together constituted the mesh. Fineness of the mesh increased the accuracy of the solution but at the cost of computation time. The degree of freedom of unknown parameters at each node was determined finally.

2.5.1 Two-Dimensional Triangular Element

The triangular element was formulated by Turner et al. in 1956. It was commonly used for two- dimensional problems. Triangular elements can be used when the field variables was a function of two independent variables, namely x and y. Variation of field variable Φ over the domain of an element can be written in polynomial form as

$$\Phi=\Phi(x,y)=\alpha_1+\alpha_2 x+\alpha_3 y \quad (1)$$

Where α_1, α_2 and $\alpha_3$werethe coefficients to be evaluated

Let the nodes of the element be designated as 1, 2, 3 as shown in the Fig-1, with known co-ordinates (x_1, y_1), (x_2, y_2) and (x_3, y_3) respectively.

Let

$\Phi=\Phi(x, y) =[1\ x\ y]\{\alpha\}$ or $\{\Phi\}=[P]\{\alpha\}$ (2)

Where $[P] = [1\ x\ y]$ and $\{\alpha\}^T=[\alpha_1\ \alpha_2 \alpha_3]$

If Φ had values Φ_1, Φ_2 and Φ_3 at nodes 1, 2 and 3,

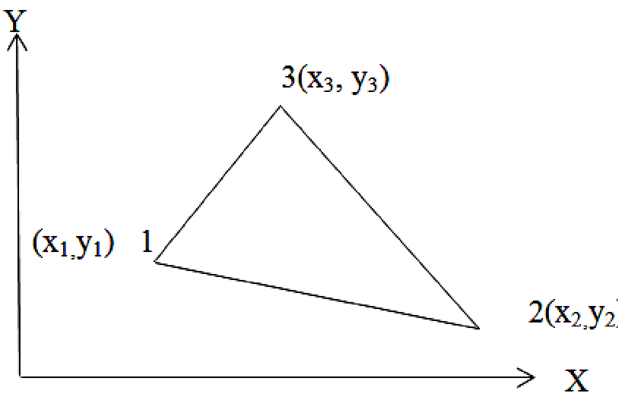


Figure 2.1Triangular element

$$\begin{Bmatrix}\Phi_1\\ \Phi_2\\ \Phi_3\end{Bmatrix}=\begin{bmatrix}1 & x1 & y1\\ 1 & x2 & y2\\ 1 & x3 & y3\end{bmatrix}\begin{Bmatrix}\alpha 1\\ \alpha 2\\ \alpha 3\end{Bmatrix} \quad (3)$$

or $\{\Phi\}=[G]\{\alpha\}$, so, $\{\alpha\}=[G]^{-1}\{\Phi\}$ (4)

Combining equations (2) and (4)

$\Phi = [P][G]^{-1}\{\Phi\}$ was obtained. Field variable Φ can also be written as

$$\Phi = [N]\{\Phi\}$$

Here, $[N] = [P]\,[G]^{-1}$ and

$$[G]=\begin{bmatrix}1 & x_1 & y_1\\ 1 & x_2 & y_2\\ 1 & x_3 & y_3\end{bmatrix} \text{ and } [G]^{-1}=\frac{1}{2A}\begin{bmatrix}a_1 & a_2 & a_3\\ b_1 & b_2 & b_3\\ c_1 & c_2 & c_3\end{bmatrix}$$

$$2A=\begin{vmatrix}1 & x_1 & y_1\\ 1 & x_2 & y_2\\ 1 & x_3 & y_3\end{vmatrix}=2(\text{Area of Element}) =a_1+a_2+a_3$$

Also, $a_1=x_2y_3-x_3y_2$; $a_2=x_3y_1-x_1y_3$; $a_3=x_1y_2-x_2y_1$

$b_1=y_2-y_3$; $b_2=y_3-y_1$; $b_3=y_1-y_2$

$c_1=x_3-x_2$; $c_2=x_1-x_3$; $c_3=x_2-x_1$

$$\text{Thus,}[N] = \frac{1}{2A}[1\quad x\quad y]\begin{bmatrix}a_1 & a_2 & a_3\\ b_1 & b_2 & b_3\\ c_1 & c_2 & c_3\end{bmatrix}$$

Therefore,

$$N_1=N_1(x, y) = (a_1+b_1x+c_1y)/2A$$

$$N_2=N_2(x, y) = (a_2+b_2x+c_2y)/2A$$

$$N_3=N_3(x, y) = (a_3+b_3x+c_3y)/2A$$

2.6 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) was one of Multi Criteria decision making method that was developed by Prof. Thomas L. Saaty. It was a method to derive ratio scales from paired comparisons. The input can be obtained from actual measurement or from subjective opinion such as satisfaction feelings and preference. AHP allowed some small inconsistency in judgment because human was not always consistent. The ratio scales were derived from the principal Eigen vectors and the consistency index was derived from Principal Eigen value.

2.6.1 Theory of AHP

Considering n elements to be compared, $C_1 \ldots C_n$ and denoted the relative weight (or priority or significance) of C_i with respect to C_j by a_{ij} and form a square matrix $A=(a_{ij})$ of order n with the constraints that $a_{ij} = 1/a_{ji}$, for $i \neq j$, and $a_{ii} = 1$, all i. Such a matrix was said to be a reciprocal matrix. The weights were consistent if they were transitive, that was $a_{ik} = a_{ij}a_{jk}$ for all i, j, and k. Such a matrix might exist if the a_{ij} were calculated from exactly measured data. Then find a vector ω of order n such that $A_\omega = \lambda_\omega$. For such a matrix, ω was said to be an eigenvector (of order n) and λ was an eigenvalue. For a consistent matrix, λ = n. For matrices involving human judgment, the condition $a_{ik} = a_{ij}a_{jk}$ does not hold as human judgments were inconsistent to a greater or lesser degree. In such a case the ω vector satisfies the equation $A_\omega = \lambda_{max}\, \omega$ and $\lambda_{max} \geq n$. The difference, if any, between λ_{max} and n was an indication of the inconsistency of the judgments. If $\lambda_{max} = n$ then the judgments had turned out to be consistent. Finally, a Consistency Index can be calculated from $(\lambda_{max}-n)/(n-1)$. A true Consistency Ratio (CR) was calculated by dividing the Consistency Index for the set of judgments by the Index for the corresponding random matrix. It was suggested that if the ratio exceeds 0.1 the set of judgments may be too inconsistent to be reliable. In practice, CRs of more than 0.1 sometimes have to be accepted. If CR equals 0 then that means that the judgments were perfectly consistent. The RI that used when calculating consistency ratio shows Random Index value and is given in Table 2.2

Table 2.2: Random Index Table

n	3	4	5	6	7	8	9
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45

The pair-wise comparison use a scale that ranges from equally preferred to strongly preferred. This comparison scale is described in table 2.3

Table 2.3: Pairwise Comparison Scale

Intensity of Importance	Explanation
1	Equal importance
2	Equally to moderately preferred
3	Moderately preferred
4	Moderately to strongly preferred
5	Strongly preferred
6	Strongly to very strongly preferred
7	Very strongly preferred
8	Very to extremely strongly preferred
9	Extremely strongly preferred

To determine the significance of the criterion after pairwise comparisons, the pairwise comparison matrix (decision matrix) was formed. If there were more than one respondent, the geometric mean of the answers of the decision makers was taken.

2.7 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Analysis

The TOPSIS method was developed by Hwang and Yoon to solve multi-criteria decision making problems. The method was based on the relative closeness to the optimal solution and the relative distance to the worst solution. In this method, the values of the alternatives must be measurable or converted to be measurable in order to be able to perform the calculations. The TOPSIS method took into consideration the distance from both sides. The process of the TOPSIS begins to make original data matrix by using criteria value for each alternatives.

TOPSIS was a multiple criteria method to identify solutions from a finite set of alternatives. The basic principle was that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution.

The procedure of TOPSIS can be expressed in a series of steps:

Step1. Calculation of the normalized decision matrix: The normalized value r_{ij} is calculated as

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$$ Where i =1…,m j=1…,n

Step 2.Calculation of the weighted normalized decision matrix

The weighted normalized value v_{ij} was calculated as

$v_{ij}=w_j\, n_{ij}$, i=1,…m, j=1…n,

Where w_j was the weight of the i^{th} attribute or criterion, and $\sum_{i=1}^{n} w_j=1$.

Step 3.Determination of the positive ideal and negative ideal solution

$A^+= \{v^+_1,\ldots v^+_n\}=\{(\max_j v_{ij}| i\in I),(\min_j v_{ij}| i\in J)\}$,

$A^-= \{v^-_1,\ldots v^-_n\}=\{(\min_j v_{ij}| i\in I),(\max_j v_{ij}| i\in J)\}$,

Where I was associated with benefit criteria, and J was associated with cost criteria.

Step 4.Calculation of the separation measure:

Calculate the separation measures, using the n-dimensional Euclidean distance. The separation of each alternative from the ideal solution is given as

$$S_i^+= \sqrt{\{\sum_{j=1}^{n}(v_{ij} - v_j^+)^2\}}$$ i=1, 2….m

$$S_i^-= \sqrt{\{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2\}}$$ i=1, 2….m

Step 5.Calculation of the relative closeness to the ideal solution (P_i)

$$\mathbf{P_i}=\frac{S_i^-}{S_i^+ + S_i^-}$$ $0<P_i<1$

Step 6.A set of alternatives was arranged in the descending order, according to $\mathbf{P_i}$ value, indicating the most**.**

CHAPTER-3

BIOMECHANICAL MODEL OF WELDER

3.0 BIOMECHANICAL MODEL OF WELDER

An experiment deliberately imposes a treatment on a group of objects or subjects in the interest of observing the response. This differs from an observational study, which involves collecting and analyzing data without changing existing conditions. The attention to biomechanical model is extremely important because the validity of an experiment is directly affected by its construction and execution.

3.1 Kinematic Modelling of Human Body

Human body is the combination of series of revolute joints. As per function, one joint can be modelled by 1-3 revolute joints. Each joint has its own joint coordinate, marked as m_i, with having joint limit. m_i^U and m_i^L are upper and lower limits respectively. So general coordinates will be $m=[m_1.....m_i....m_n]^T$ which is defined as a vector. It is represented as kinematic chain. There are 28 numbers of revolute joints responsible for main movements of human body. Figure 3.1 represents the 2D view of human body with different joints.

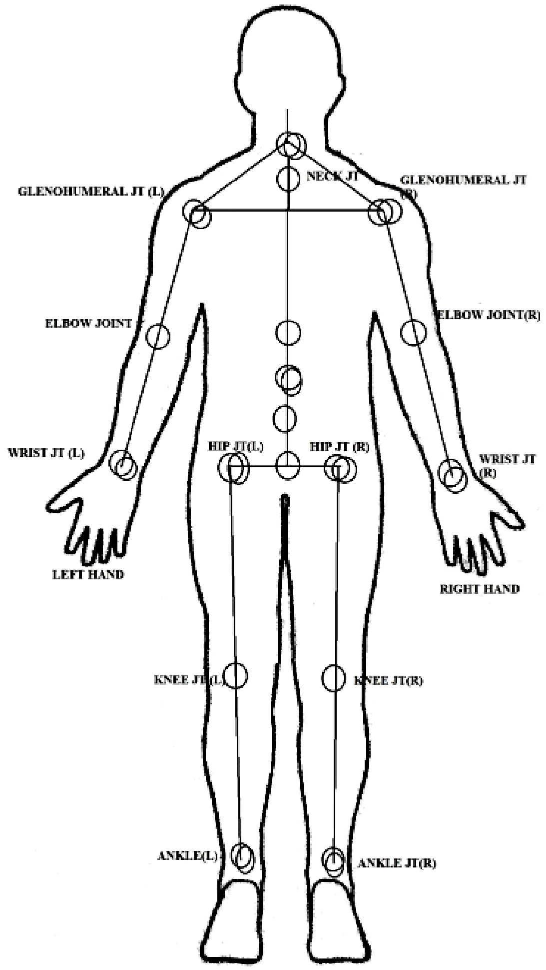


Figure 3.1 2D view of human body with different joints

Worker's upper body is consisted of ten segments. These are trunk, clavicles, upper arms, forearms, hands and head. This provides 20 degree of freedom in the upper part of the body i.e. three for neck, pelvis and shoulder, two for each elbow and wrist. The movement and external effort can produce torque at the joints. The degrees of freedom of different joints of human body are shown in figure 3.2and it is tabulated in table 3.1.

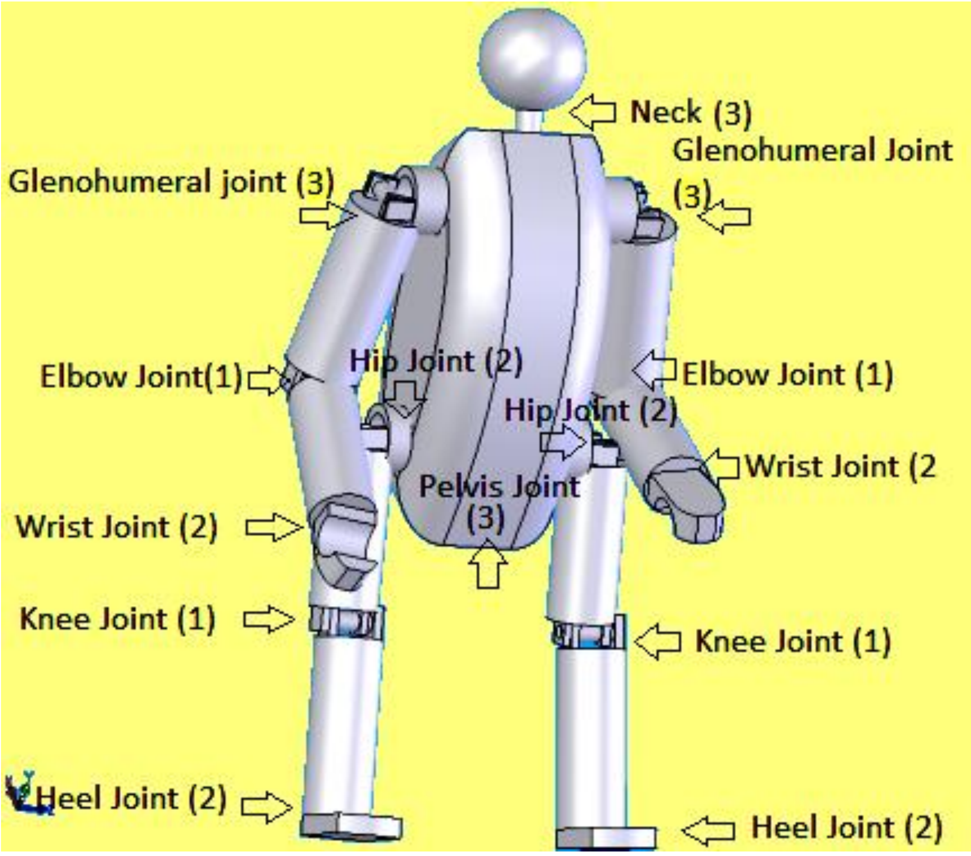


Figure 3.2 3Dimensional modelling of human body with DoF of joints

Table: 3.1 Degree of freedom of different joints

Name of the Joint	Degree of Freedom (DoF)
Neck	3
Each Glenohumeral Joint	3
Pelvis Joint	3
Each Elbow Joint	1
Each Wrist Joint	2
Each Hip Joint	2
Each Knee Joint	1
Each Hill Joint	2

3.2 Anatomy of the Human Spine

The adult human spine or vertebral column is S-shaped assembly of 25 bones called vertebrae which is divided into 4 major regions. These are neck, thoracic region, lumbar area and sacrum. The anatomy of the human spine is shown in the figure 3.3. The neck consists of 7 cervical vertebrae, 12 thoracic vertebrae are in the upper back and 5 lumbar vertebrae are present in the low back region. The sacrum is in the pelvic area. The bones have a roughly cylindrical body, with several bony processes emanating from the rear which served as attachments for the back muscles, the erector spine.

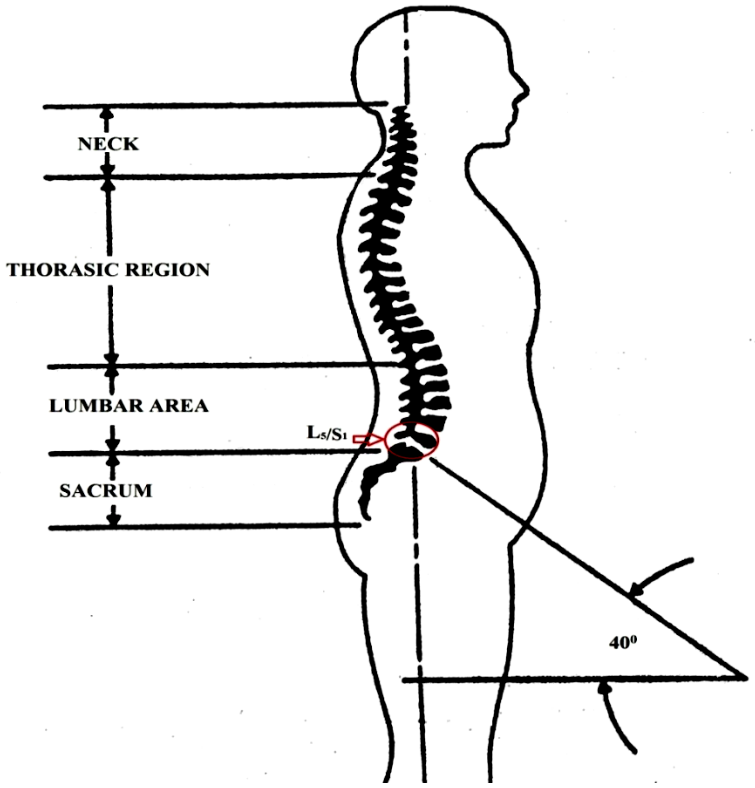


Figure 3.3 Anatomy of the human spine

3.3 Upper Extremity

Three revolute joints are there in the upper arm. These are glenohumeral, elbow and wrist joints. The glenohumeral joint is limited to 2DOF, the elbow joint is 1 DOF and wrist joint is limited to 2 DOF. The rotation of each joint is around its own axis. The actual welding operation and different joints with DOF are shown in figures 3.4(a) and 3.4(b) respectively. The function of each joint is described in the table and these are used to mobilize shoulder, elbow and wrist.

The joint ranges are also shown in the table 3.2.

Figure 3.4(a) Welding operation

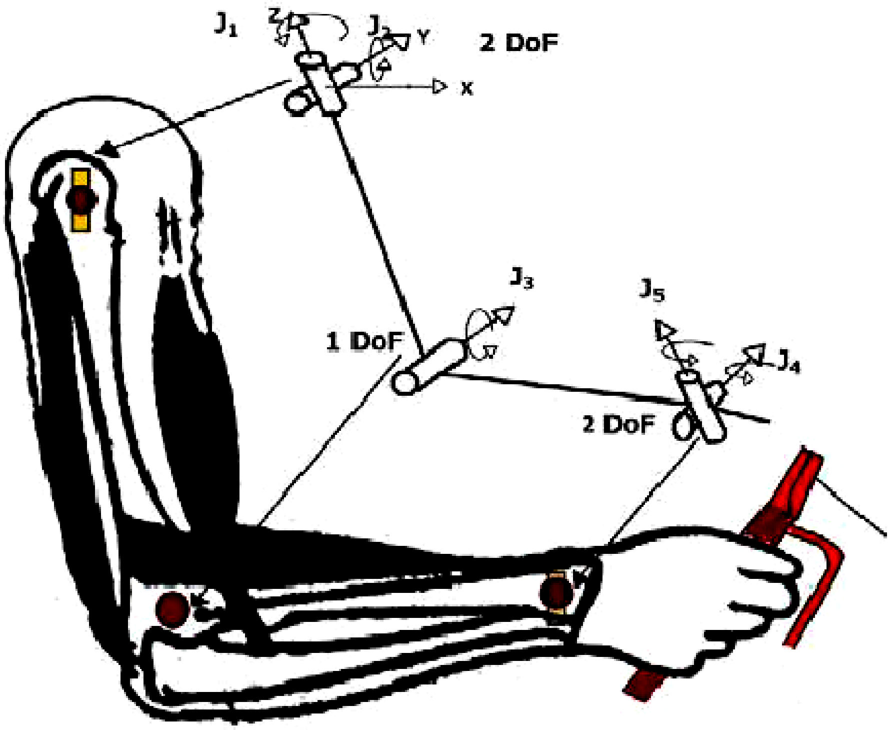


Figure 3.4(b) Joints and DOF of upper arm

Degree of freedom (DOF) of the joints which are involved in this operation shown in table 3.2

Table 3.2 Joint symbol, Joint Function and Joint Range

Joint symbol	Joint Function(s)	Joint ranges
J_1	Flexion and extension of shoulder	$-90^0 \leq J_1 \leq 90^0$
J_2	Adduction and abduction of shoulder	$-110^0 \leq J_2 \leq 120^0$
J_3	Flexion and extension of upper arm	$0^0 \leq J_3 \leq 150^0$
J_4	Flexion and extension of plum & Fingers	$-20^0 \leq J_4 \leq 40^0$
J_5	Adduction and abduction of plum	$-70^0 \leq J_5 \leq 80^0$

3.4 Inverted Pendulum Model

The distribution of body mass is such that the two-thirds of body mass in the head, arms and trunk (HAT) is located two-thirds of body height above the ground. So an inverted pendulum system is formed which is highly unstable when considered the forward movement of HAT. Figure 3.5 shows the actual knee posture and HAT segment of welder.

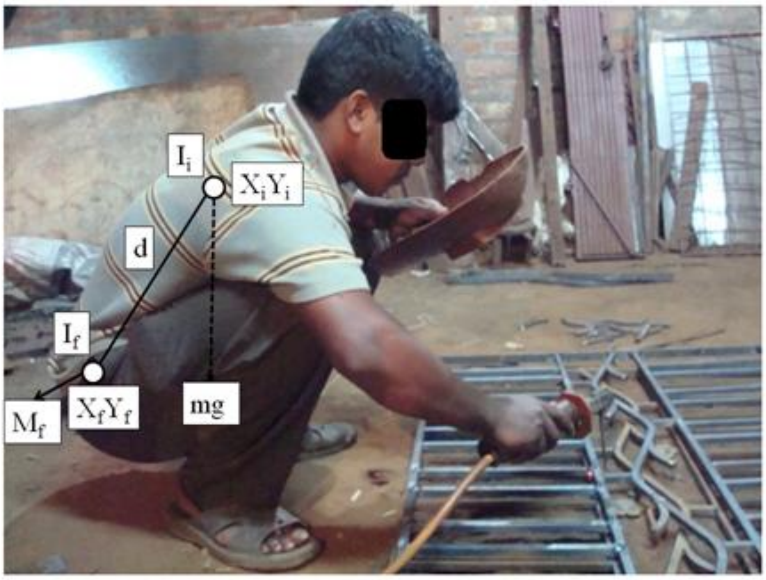


Figure 3.5 Position of welder like inverted pendulum

The biomechanical model of large segments such as head, arms and trunk (HAT) are based on the balance on a joint moving in space. Figure 3.6 shows the model of HAT in the plane of progression as the HAT segment rotates about the hip joint. The dynamic equilibrium equations which described the moments acting on the segment are usually derived as acting about the centre of mass of the segment. The hip joint is acting as a pivot point in this case for moment calculation.

The M_f is the net muscle moment acting at the joint in the plane of interest.

$$M_f = \underbrace{mg(x_i - x_f)}_{\text{gravitational}} + \underbrace{m\ddot{y}_f(x_i - x_f) - m\ddot{x}_f\,(y_i - y_f)}_{\text{Couple due to joint acceleration}} + \underbrace{I_f\alpha}_{\text{inertial}}$$

The gravitational moment is not acted directly over the hip joint centre. The combination of the $\mathbf{m\ddot{y}_f\ (x_i\text{-}x_f)}$ & $\mathbf{m\ddot{x}_f\ (y_i\text{-}y_f)}$ are the couples created by the fact that the joint centre is accelerating. An angular acceleration α is created in this segment due to the associated moment.

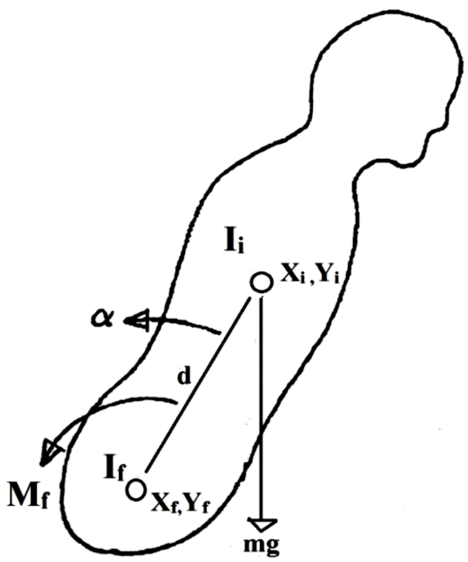


Figure 3.6 Inverted pendulum model of welder of HAT segment

3.5 CAD Modelling of Human Body

In order to know the performance of muscles and joints of human body, realistic and detailed model is required to develop. So a 3D CAD model of entire human body was developed with the help of solid works software. The CAD model was exposed for analysis of stresses in ANSYS. Total human model was divided into 13 active bodies. These consisted of 13810 elements connected through 27007 node points. Figure 3.7 indicates the actual working posture of the welder and figure 3.8 shows the 3D CAD model of entire human body. The upper part of the welder's body i.e. trunk, clavicles, upper arm, fore arm, neck and hands are connected by anatomically motivated restricted articulations which are directly involved with the welding operation. Pelvis, neck, shoulders, elbow, hip and wrists joints provide twenty (28) degree of freedom for the entire movement.

Figure 3.7 Working posture of welder

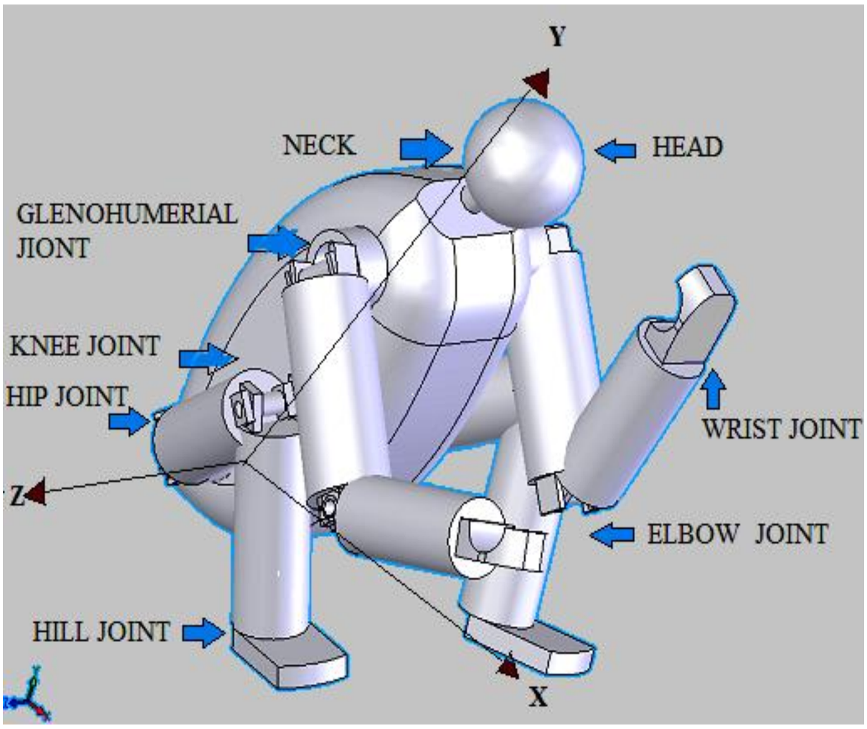


Figure 3.8 3D CAD model of welder's body

CHAPTER -4

DESIGN AND DEVELOPMENT OF WELDING WORKSTATION BASED ON POSTURAL ANALYSIS

4.0 DESIGN AND DEVELOPMENT OF WELDING WORKSTATION

Ergonomically designed workstation (job table) has been developed on empirical data, where by experience and the rules of thumb are used. Design of Ergonomic work station was indeed an optimization problem with many parameters. First of all, a 2D cad model of welder's table was developed and that was converted to 3D model with the help of Solid Works software. Finally, the fabrication of the table was developed as per design.

4.1 2D and 3D CAD Model of Welder's Table

The 2D CAD Model of welder's table which was developed in Auto Cad is shown in the figure 4.1.

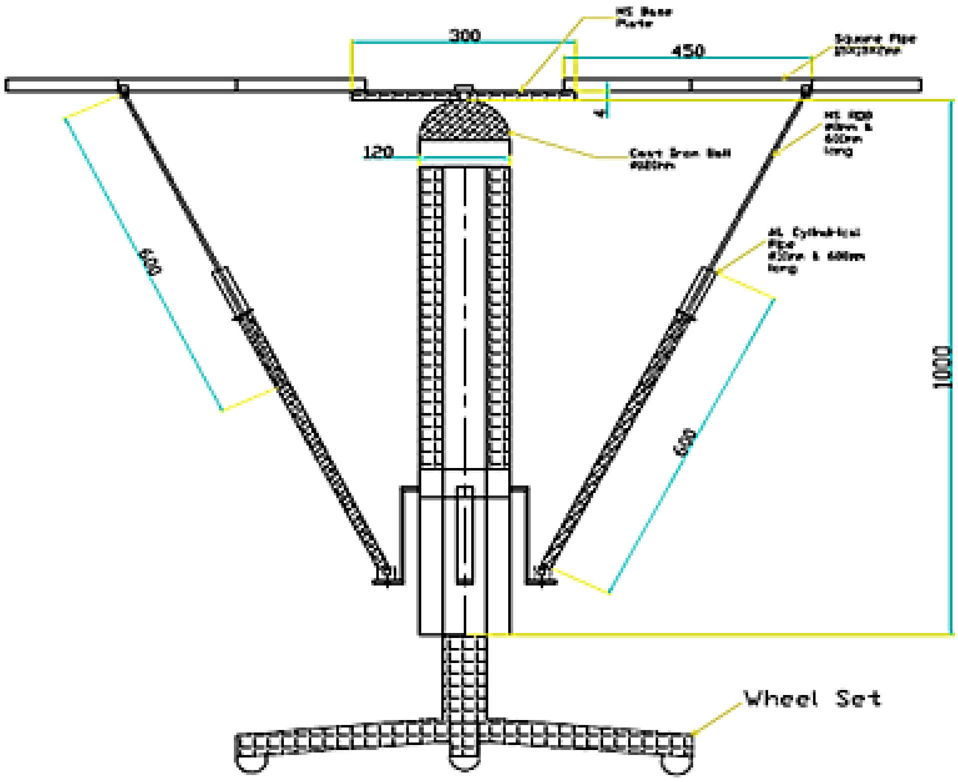


Figure 4.1 2D CAD model of welder's table

Different 3D views of welder's table was developed in Solid works software and shown in figure 4.2 (a, b & c)

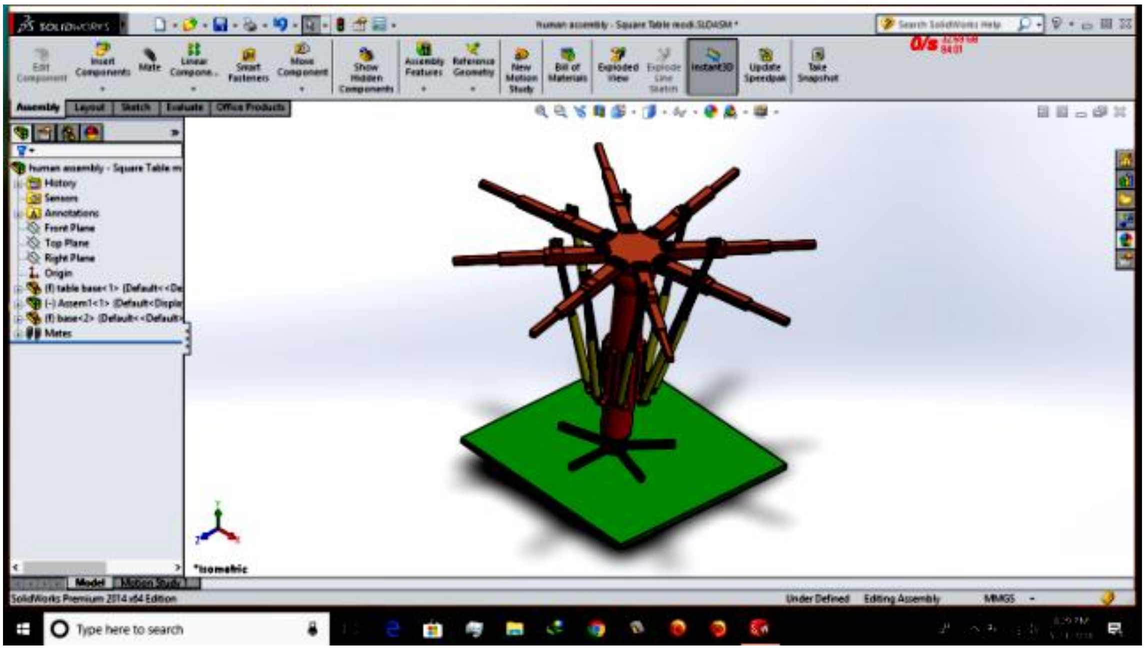


Figure 4.2(a) 3D CAD model of welder’s table

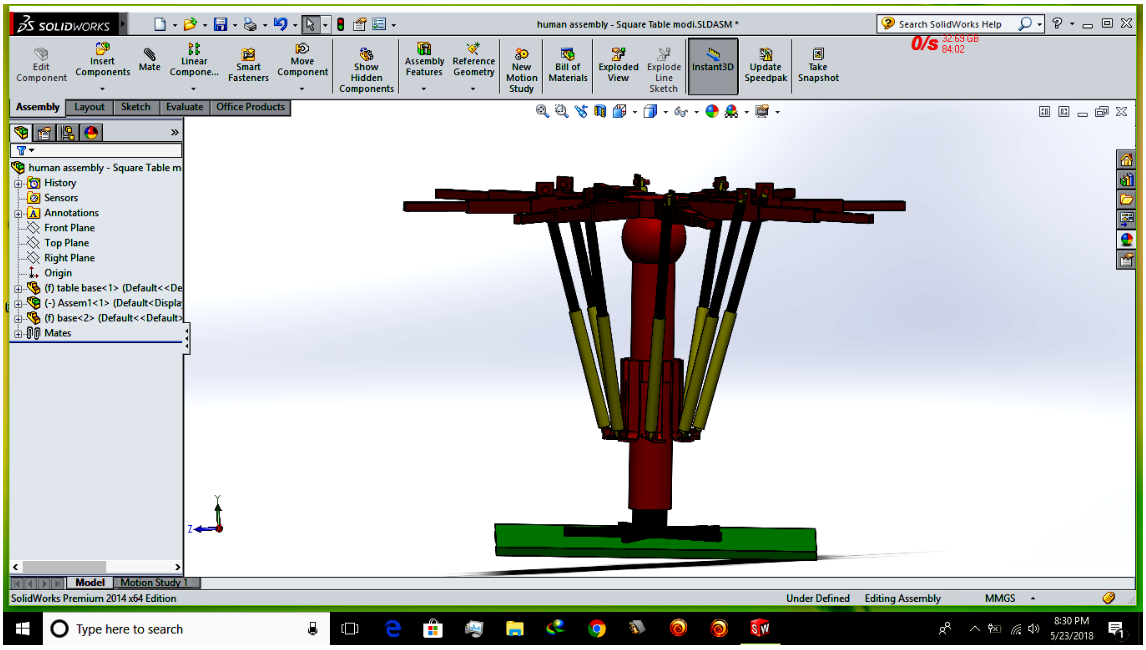


Figure 4.2 (b)

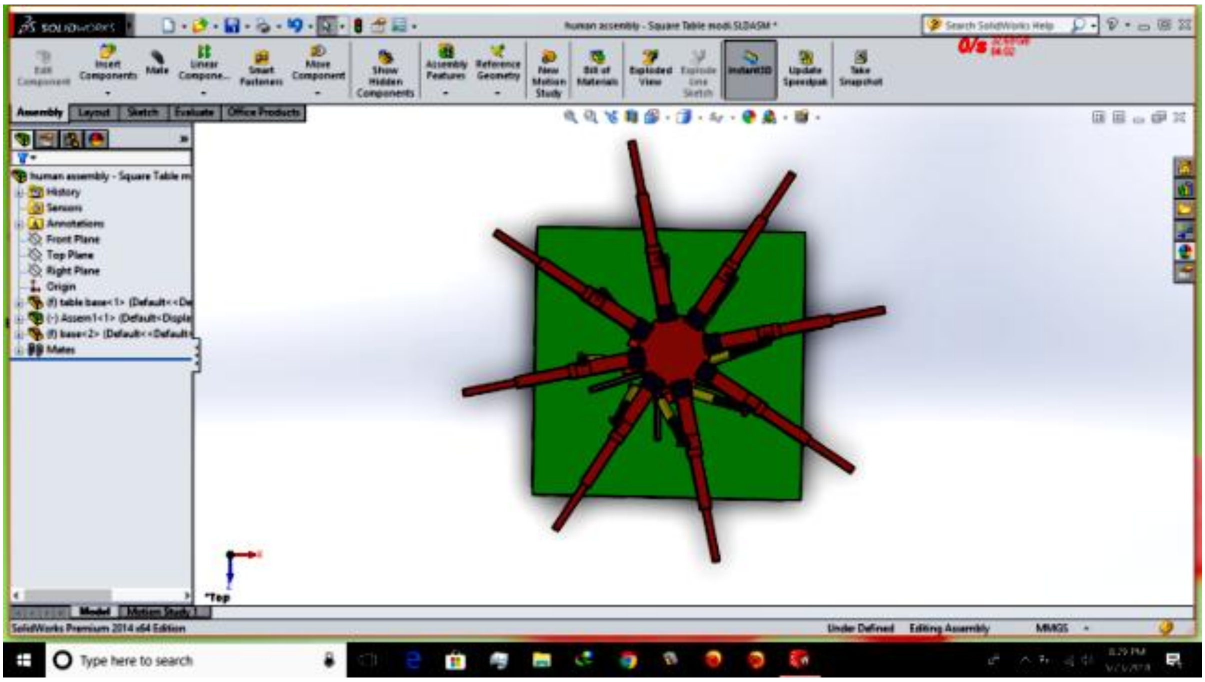


Figure 4.2 (c)

Figure 4.2 (a,b & c) 3D CAD model of welder’s table

Figure 4.3 (a,b& c) also describes the CAD model of welder’s working on the table.

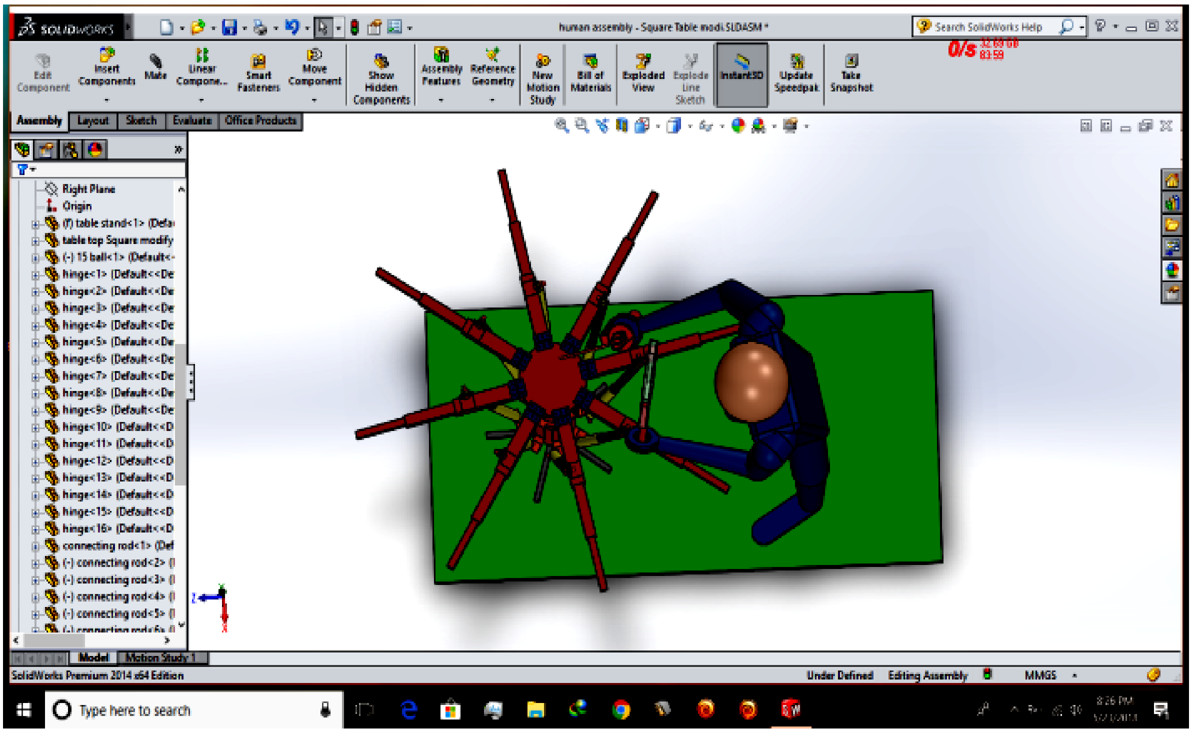


Figure 4.3 a

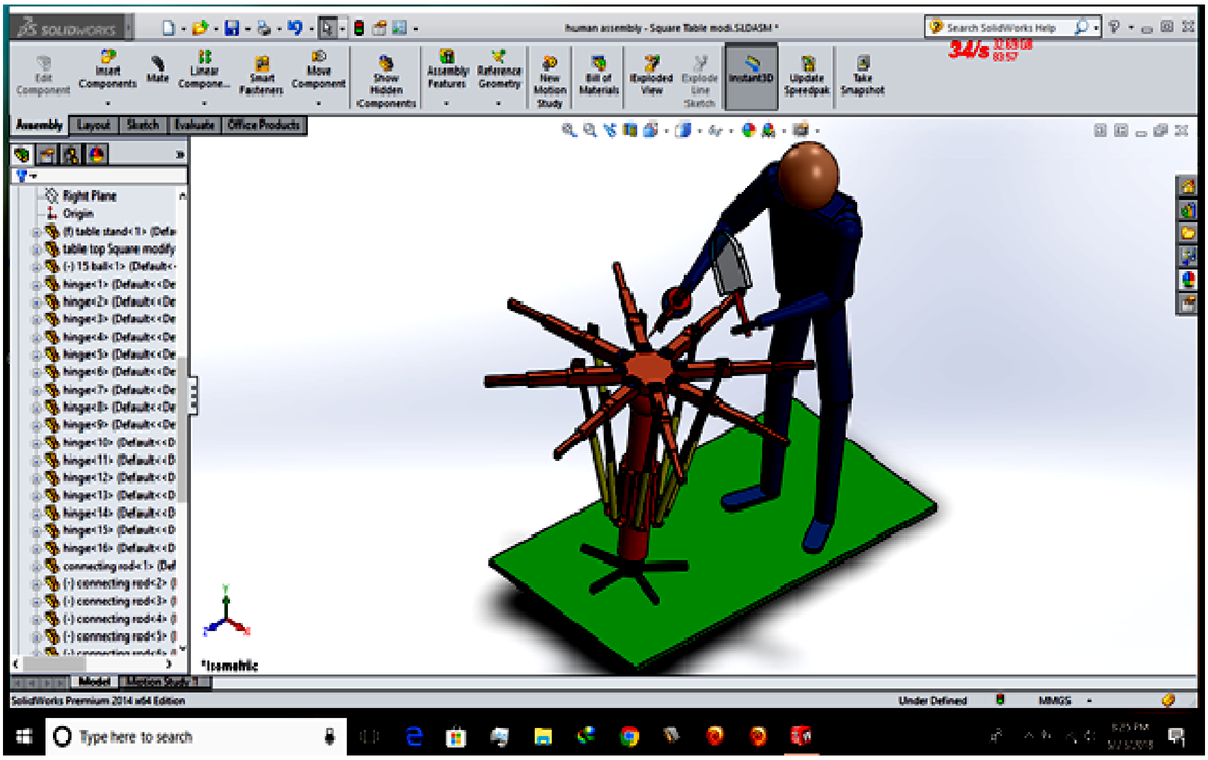


Figure 4.3 b

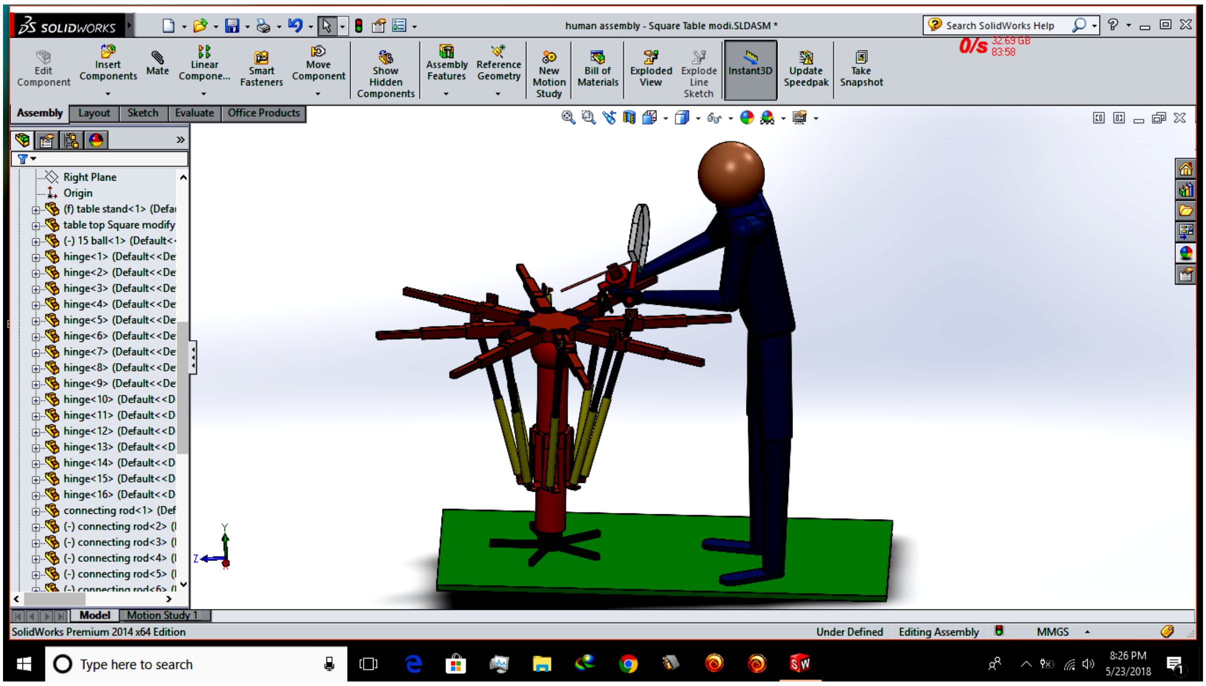


Figure 4.3 c

Figure 4.3 (a,b & c) 3D view of Welder with table

4.2 Requirement of Materials with Specification:

I. MS Base Plate (Dia. 300mm & 4mm thick) (max. tilt angle 20^0)
II. Cast Iron Ball (Dia. 120mm)
III. MS Cylindrical Pipe (Dia. 120mm & 1000mm long)
IV. Cylindrical Pipe (Dia. 10mm & 600mm long)
V. Square Pipe (15mmX15mmX2mm & 450mm long)
VI. Door Hinge (8 pcs.)
VII. Nuts and Bolts (M2-32 pcs,M5-8pcs,M8-8pcs,M10-1pc)
VIII. MS Rod (Dia. 8mm & 600mm long)
IX. L-Shaped MS Angle (25mm X 25mm X 3mm -16pcs)
X. Wheel Set (5 pcs. roller wheel)

4.3 Different Parts of the Table and Its Function

I. Base Plate:

The circular MS plate which is shown in figure 4.4 (a) has thickness 3mm and diameter 30cm acted as the base plate of the table. The base plate was used to hold the arms of the table which is shown in the figure 4.4 (b). The arms were at a distance of 45˚ from each other. There were 8 hinges welded on the surface of the plate and the arms were connected to those hinges.

Figure 4.4 (a) MS base plate (top view)

Figure 4.4 (b) MS base plate with square pipe

II. Cast Iron Ball

A cast iron solid ball which is shown in the figure 4.4 has diameter 150 mm was fitted just below the base plate. It was used as tilting and rotating the table. The job table can be tilted at an angle of 20˚ to 22˚ towards welder and can be rotated 360˚ in horizontal plane. A spring attachment was provided with the ball which kept the ball to remain in that position. The base plate was attached to the ball with a nut bolt system.

Figure 4.4 Cast iron ball

II. Square Pipes:

It was the main component of the table. These square pipes were used as a top surface of the table upon which jobs may rest. The three different sizes of square pipes were used having cross sections 32 mm^2, 25 mm^2 and 19 mm^2 respectively. The length of the first pipe was 45 cm (aprox.1.5 feet), the 2nd one was 30 cm (aprox1feet) and the length of smallest one was15 cm (aprox.0.5 feet). Cast iron square pipes are shown in the figure 4.5.

Figure 4.5 Cast iron square pipes

These pipes can be slid inside each other and can be adjusted according to the need of the welder. The material of the pipe is mild steel. The pipes can be folded in the upward direction.

IV. Cylindrical Pipe:

It was the bottom part of the table. It acted as the leg of the table upon which all the above mentioned set-up was established. Two concentric cylindrical pipes were used, having diameters 9 cm (aprox.3.5 inches) and 6.4 cm (aprox.2.5 inches) respectively. The height of the table can be adjusted according to the height of the welder. Two bushes were provided, one at the top and other at the bottom of the larger pipe to avoid the collision and easy sliding. The length of the larger pipe was 76 cm (aprox.2.5 feet) and the smaller one was 50cm (aprox.1.6 feet).The cylindrical pipe is shown in the figure 4.6.

Figure 4.6 Cylindrical pipe

4.4 Fabrication of Welder's Job Table

The fabrication of welder's job table was one of the main research works. The table was made of mild steel rod and plates. It was circular in shape and the circular dimension was 210 cm (aprox.6.5 feet). The base of the table was made of MS plate. There were 8 adjustable arms which were connected to the base plate to hold the job. The height of the table can be adjusted with the help of two concentric cylindrical pipes. A ball was fitted at the bottom of the base plate for tilting and rotating purpose. 8 adjustable MS rods (dia.10mm) were also used as supporting links to maintain arms in horizontal position. The 3D views of welder's job table open and folded positions are shown in the figures 4.7 (a) and 4.7 (b) respectively.

Figure 4.7 (a) Welder's job table (open)

Figure 4.7 (b) Welder's job table (folded)

CHAPTER-5

RESULT AND DISCUSSION

5.0 RESULT AND DISCUSSION

This research work has resulted in a more detailed knowledge on the occurrence of musculoskeletal complains of welders in different welding units and the features of welding job table. The significant results are discussed in the following paragraphs.

5.1 Flowchart of health outcome

Occupational health and safety are mainly concerned in small scale manufacturing units to increase the productivity as well as job quality. Improper design, mismatch between workers abilities & job demand and adverse environment are the common problems in small scale units.

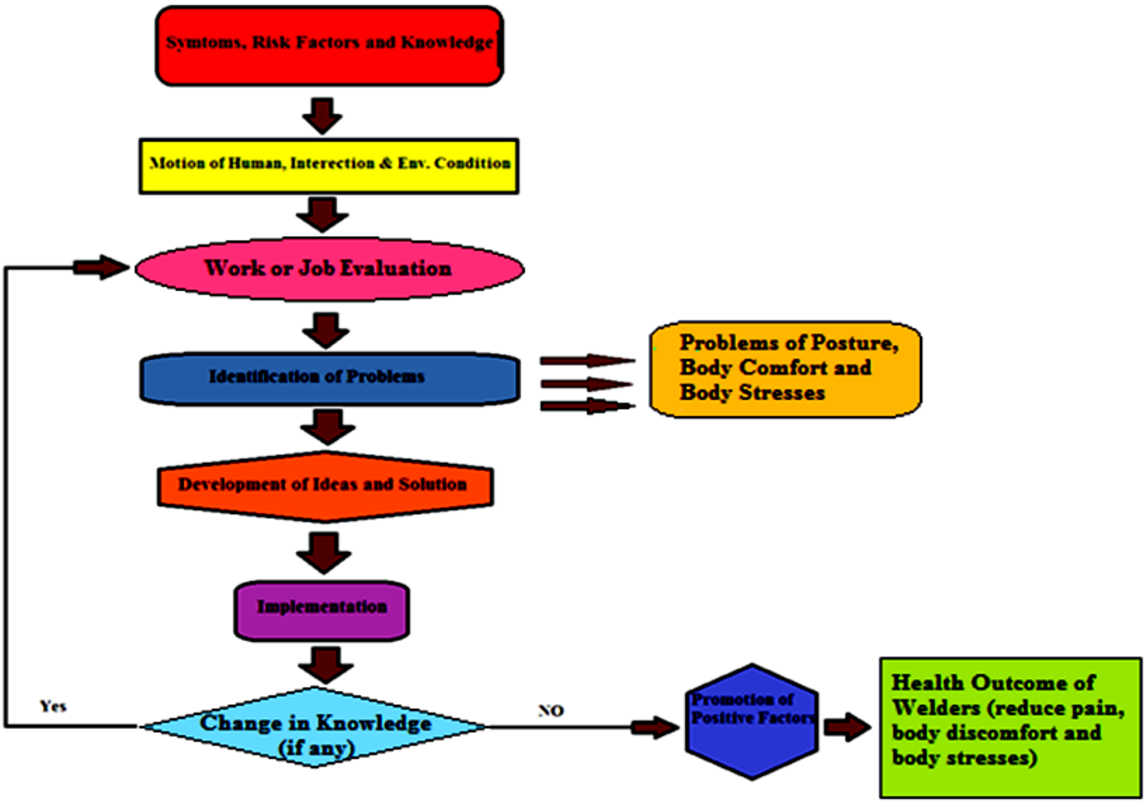


Figure 5.1 Flowchart of health outcome of welders

It has been observed that human factors are directly involved to increase the productivity, workers health, safety and job satisfaction. Muscular problems, physical stresses may be reduced or eliminated and workers health may be recovered just by adopting proper Ergonomically designed machineries and appropriate designed work stations. Figure 5.1 shows the flowchart of health outcome of welders. Physical as well as mental stresses of welders can also be reduced by applying proper Ergonomic knowledge, planning and awareness.

5.2 RULA Analysis and Discussion

It has been observed that the detailed investigations of MSD and occupational health problems of welders were required in welding units in West Bengal. For finding the severity of the problems body postures and muscular fatigues were evaluated with the RULA method. The different angular position of body parts of a welder in the welding unit is shown in the figure 5.2. For investigation of arm, wrist, neck, trunk and limbs the whole body is divided into part-A and part-B respectively. The working postures of the workers and the angles at which they work inside the shop floor were recorded with the help of different snapshots. The posture scores of arms, legs, body and trunk can be measured through RULA method. From figure 5.2 the score has been obtained from RULA work sheet by observing upper & lower arm angle of the welder.

Figure 5.2 Different angular position of body parts of welder

The worksheet of employee assessment with RULA can also be used to assess directly the RULA score and severity of the problem. Figure 5.3 indicated the RULA assessment worksheet and the final RULA score. The final score was 7 which is under the action level "4". Higher RULA score indicated that workers may be suffering painful disorders of muscles tendons, nerves and severed chronic disease in their shoulder & neck in near future.

Target oriented work imposed some pressure on the workers that also increased their muscular and body stresses. Most of the welding industries in West Bengal forced the workers to perform their assigned work in unhealthy, inappropriate and non-Ergonomically designed work places. For these reasons workers also suffered painful disorders of muscles tendons and nerves.

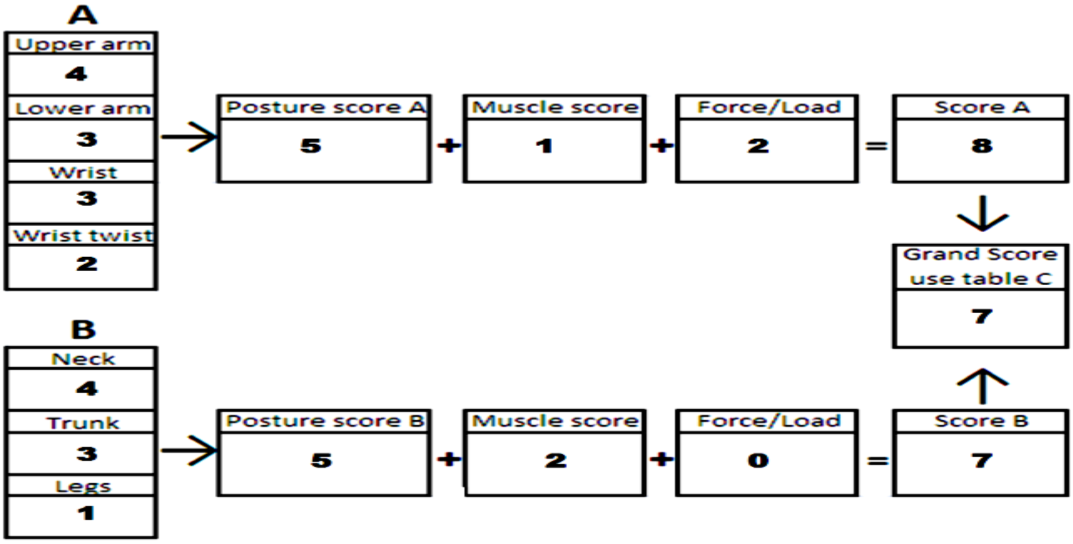


Figure 5.3 RULA assessment sheet

It has also been observed that the space provided in the welding industries was not sufficient for the welders to work. Workers performed their work in the work stations under great difficulties and body stresses. By using RULA method, it was observed that the works taken in to consideration was under high muscular and body stresses. This was justified by the percentage calculated from the RULA Score Sheet which was made by the posture analysis of the worker taken from the photograph. It was also observed from the calculation of the postures that the welders were subjected to different muscular disorders and body stresses that directly affect their health.

5.3 REBA Analysis

REBA is a simple analytical tool which allows surveying different tasks connecting the whole body of the workers at work places. This method focused on the postural analysis of workers when posture is static. It has been observed that detailed investigations of MSD and occupational health of workers were required in small scale welding units in West Bengal. For finding the severity of the problems, body postures were evaluated with the REBA method. The actual work posture is shown in figure 5.4 (a, b) which gives the details of the different angular position of the worker body. The whole worker body was divided into part-

A and part-B for investigation of the different parts of the body. The body postures of the workers and the angles at which they work inside the shop floor were recorded with the help of snapshot. Using the scoring sheet of REBA the score of respective body parts can be obtained.

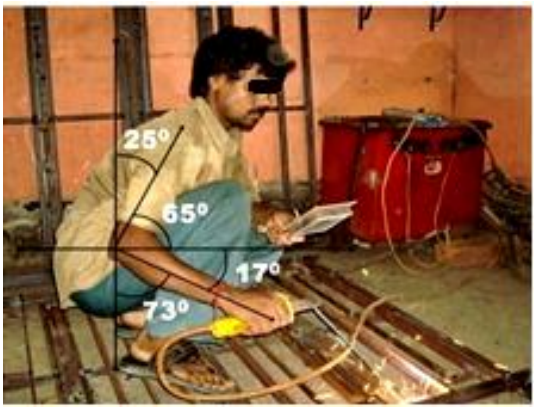


Figure 5.4 (a) Upper and lower arm angle

Figure 5.4(b) Lower arm abduction angle

5.3.1 Results and Discussion

It has been observed by the REBA score that most of the workers were engaged in welding units at very high risk level zone. Welders need an urgent change in their body posture for reducing their WRMSD, stress and body fatigue. From the figure 5.5 it is shown that the final REBA score is 8 which is under the action level "3". It is also shown from the result that the WRMSDs and related risks may be improved by considering workers health and occupational conditions. Proper sitting arrangement and proper arrangement of machineries may also reduce the risk level of welders. All welders must be conscious about the correct work posture while working in welding units.

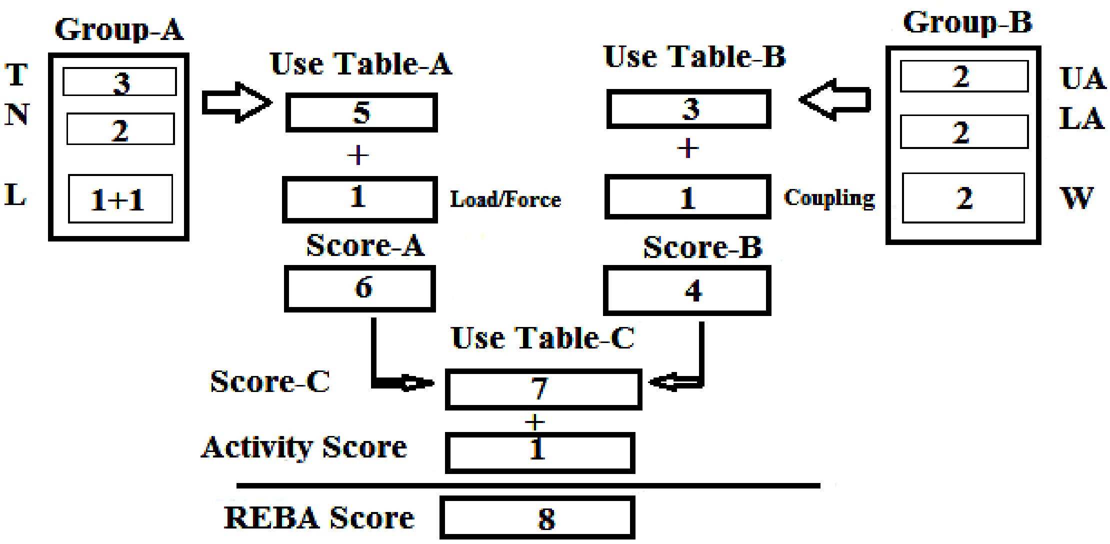


Figure 5.5 REBA score sheet

5.4 OWAS Analysis and Discussion

Ovako Working Posture Analyzing System (OWAS) was used for analyzing and evaluating the working postures adopted by the welders while performing the task. From the figure 4.6 it is clear that the low back pain, wrist and knee problems have the highest frequencies caused by sitting on knee posture of the welders for a long period of time. The demographic data of the welders i.e. age, height, working experience etc. are shown in the table 5.1. The most predominant indications of the welders were in their low back (43%), knee (52%) and wrist (53%) due to incompatible work table and body posture.

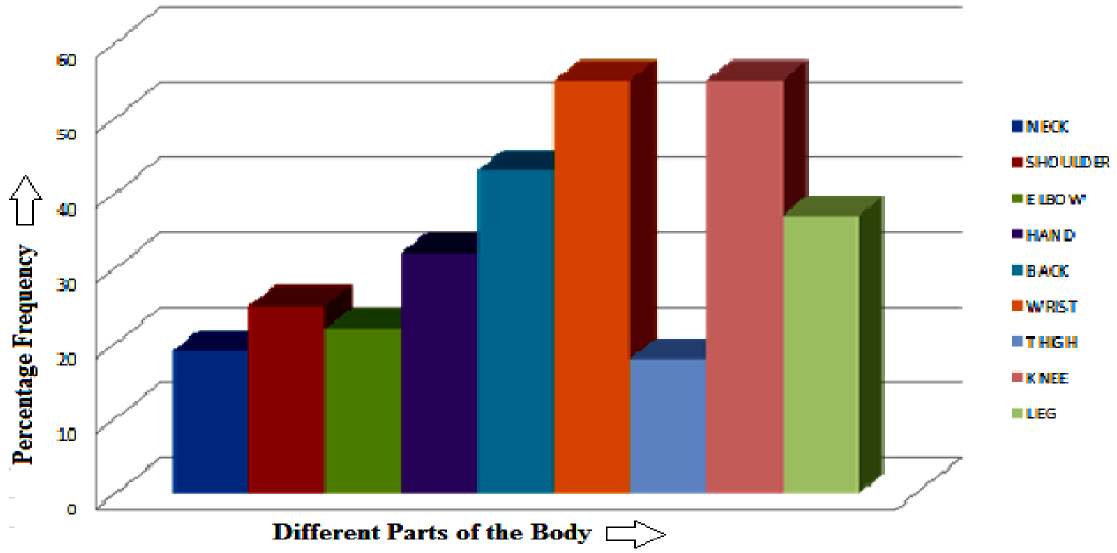


Figure 5.6 Frequency of OWAS Score of different body parts of welders

Table 5.1 Demographic data of the workers (n=12)

Variables	Workers (±SD)
Mean Age (years) Height (cm) Mean working experience (years)	25.4(±4.62) 167.35(± 3.35) 5±2

5.5 NIOSH's Discomfort Analysis and Discussion

NIOSH's discomfort survey method was used for plotting the different areas of pain, dissatisfactions of the welder's body during welding operation. Software Ergo-Fellow was used for the analysis.

The Figure 5.7 indicates the body discomfort level with respect to working hours. In the 8th hour the discomfort level increased markedly for being in awkward working posture for a long time. The level of discomfort in the 1st working hour is within the acceptable range which exceeded beyond the severe level due to in appropriate body posture. It is shown that upper part of the welders' body is highly affected in the last working hour. Red bars are indicating that these body parts are highly affected and could not be recovered in short time.

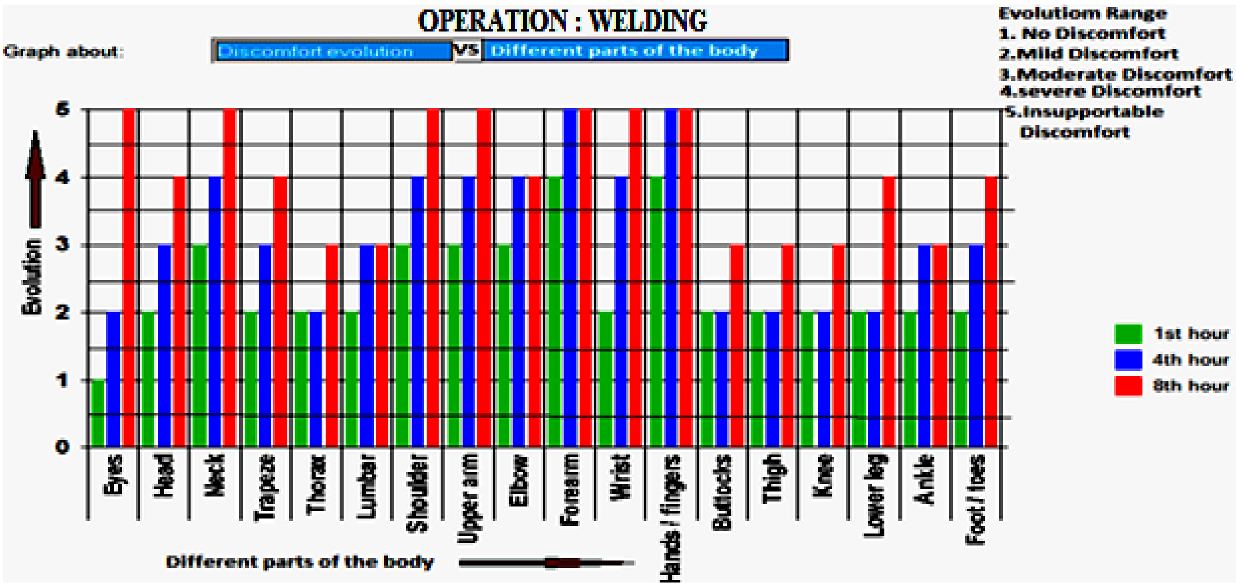


Figure 5.7 Discomfort evolutions in different body parts of welder

It is shown from the figure 5.8 that the neck, wrist, arms and upper part of the body were highly affected in this operation. More than 85% of the welders got affected in their wrist, hand, trapeze and neck due to inappropriate position of electrode holder, body posture and un Ergonomic man machine interface.

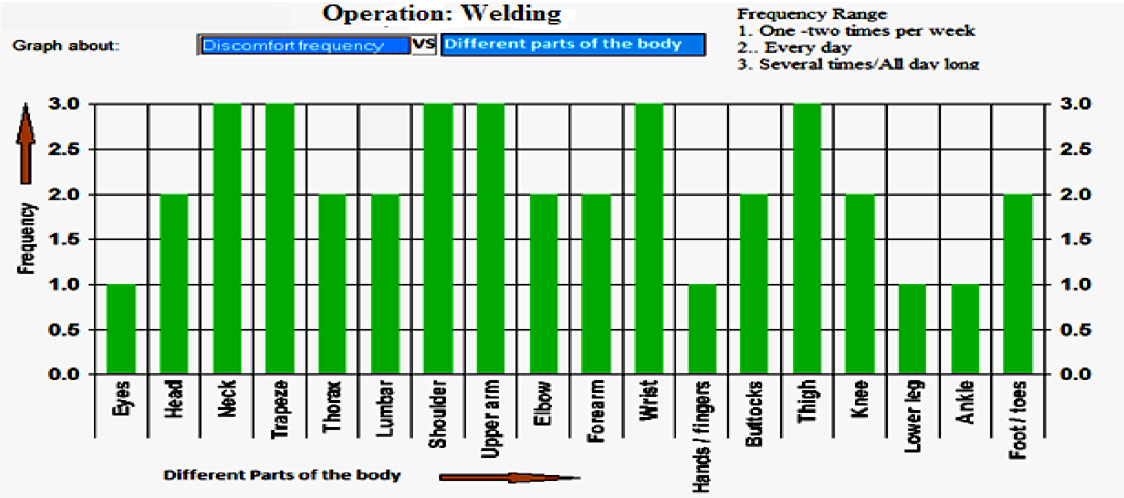


Figure 5.8 Discomfort frequencies in different body parts of welder

5.6 Finite Element Analysis and Discussion

Three dimensional CAD model was exposed to ANSYS for analysis of stresses in different joints and muscles. Figure 5.9 shows the actual working posture of the welders and figure 5.10 shows the 3D CAD model of entire human body. The upper portion of the welder's body i.e. trunk, clavicles, neck, upper as well as lower arms are connected by anatomically motivated restricted articulations. These are directly attached with the welding operation.

Figure 5.9 Actual working posture of welders

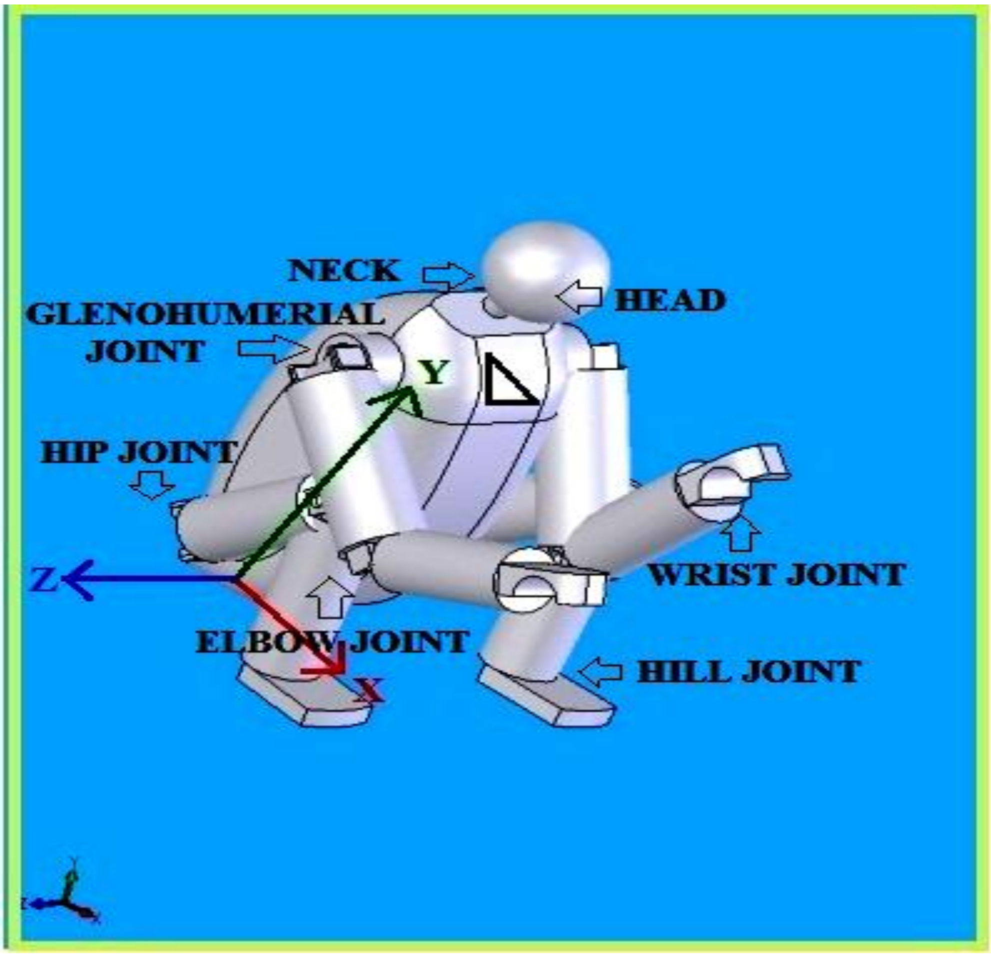


Figure 5.10 3D CAD model of welder's body

5.6.1 Properties of Human Body Materials

Results obtained in any analysis depend upon the properties of the material. The material properties and dimensions used in this analysis are shown in table 5.2

Table 5.2 Material properties used in human model analysis

Material Properties & Dimensions	Values
Volume	$1.4791e^{-4}$ m³
Mass	1.1611 kg
Length X	$2.6e^{-2}$ m
Length Y	$1.4e^{-2}$ m
Length Z	$1.4e^{-2}$ m
Poisson's Ratio	0.44
Young's Modulus	4 M P_a
Density	$1000Kg/m^3$

A finite element technique has been used for human body posture simulation. In that analysis total human body was divided into 13 active parts and 13810 elements. These were connected through 27007 node points. The elements may be either rectangular or triangular. For rectangular element calculation procedure is much simpler than triangular because there is no need of transformation of co-ordinate. But for triangular element, first of all normal Cartesian co-ordinate systems is to be transformed to generalized co-ordinate system. Then the rest of the procedure becomes same. Now, one triangular element has been taken for finite element analysis purpose, which is shown in figure 5.11.

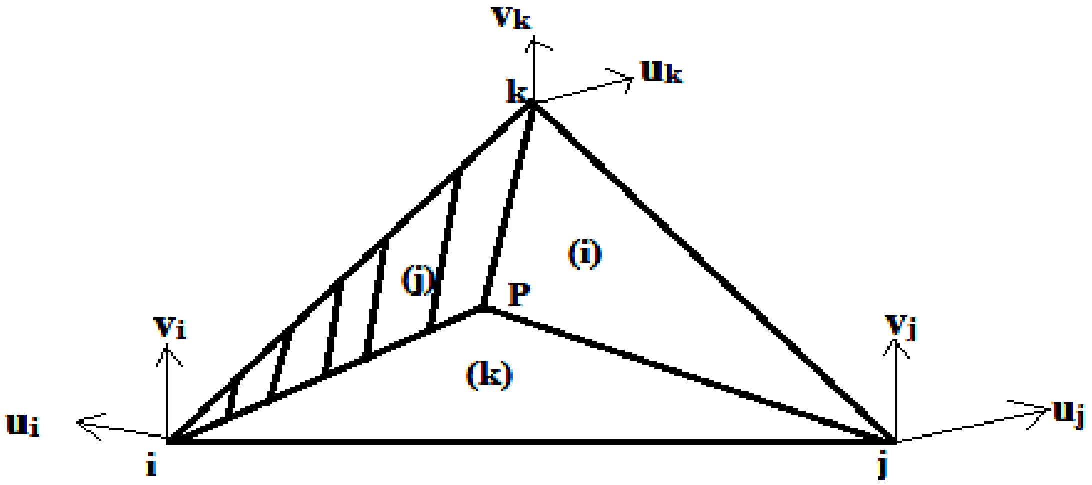


Figure 5.11Triangular element

Area of the triangular element is expressed as,

$$A=\frac{1}{2}\ (\overline{ij}x\overline{ik}).\mathbf{k}$$

$$=\frac{1}{2}\{(x_j\text{-}x_i)\mathbf{i}+(y_j\text{-}y_i)\mathbf{j}\}x\{(x_k\text{-}x_i)\mathbf{i}+(y_k\text{-}y_i)\mathbf{j}\}.\mathbf{k}$$

$$=\frac{1}{2}[(x_j\text{-}x_i)(y_k\text{-}y_i)\,\mathbf{k}\text{-}(y_j\text{-}y_i)(x_k\text{-}x_i)\mathbf{k}].\mathbf{k}$$

$$=\frac{1}{2}[(x_j\text{-}x_i)(y_k\text{-}y_i)\text{-}(y_j\text{-}y_i)(x_k\text{-}x_i)]$$

$$A=\frac{1}{2}\begin{bmatrix}(xj-xi) & (yj-yi) & 0\\ (xk-xi) & (yk-yi) & 0\\ 0 & 0 & 1\end{bmatrix}$$

Now the transformation of co-ordinate becomes

$$\begin{Bmatrix} Li \\ Lj \\ Lk \end{Bmatrix} = \frac{1}{2A} \begin{bmatrix} di & \bar{bi} & \bar{ai} \\ dj & \bar{bj} & \bar{aj} \\ dk & \bar{bk} & \bar{ak} \end{bmatrix} \begin{Bmatrix} 1 \\ x \\ y \end{Bmatrix}$$

$L_j = \frac{Aj}{A}$,

Where $d_j = x_k y_i - x_i y_k$,

$\bar{bj} = y_k - y_i$

$\bar{aj} = x_i - x_k$

Now displacement field is to be considered for the element. So, there are six degrees of freedom.

Displacement field can be written as,

$U(x,y) = \alpha_1 + \alpha_2 x + \alpha_3 y$

$V(x,y) = \alpha_4 + \alpha_5 x + \alpha_6 y$

$$\{\underset{U}{\rightarrow}(x, y)\}^e = c[x, y] \begin{Bmatrix} \alpha 1 \\ \alpha 2 \\ \alpha 3 \\ \alpha 4 \\ \alpha 5 \\ \alpha 6 \end{Bmatrix}$$

Where, c

$$C[x, y] = \begin{bmatrix} 1 & x & y & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & x & y \end{bmatrix}$$

Now, $\{\underset{U}{\rightarrow}\{(x_i, y_i)\} = \begin{Bmatrix} ui \\ vi \end{Bmatrix} = \{ai\}$

$$\begin{Bmatrix} \{ai\}^e \\ \{ai\}^e \\ \{ai\}^e \end{Bmatrix} = \begin{bmatrix} c & (xi, yi) \\ c & (xj, yi) \\ c & (xk, yk) \end{bmatrix} \{\alpha\}^e$$

Finally we have,

$\{a\}^e = [A]^e \{\alpha\}^e$

$$\text{Where } \{a\}^e = \begin{bmatrix} ui \\ vi \\ uj \\ vj \\ uk \\ vk \end{bmatrix}$$

$$[A]^e = \begin{bmatrix} 1 & xi & yi & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & xi & yi \\ 1 & xj & yj & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & xj & yj \\ 1 & xk & yk & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & xk & yk \end{bmatrix}$$

$$\{\alpha\}^e = \begin{bmatrix} \alpha 1 \\ \alpha 2 \\ \alpha 3 \\ \alpha 4 \\ \alpha 5 \\ \alpha 6 \end{bmatrix}$$

$\{\underset{U}{\rightarrow}(x, y)\}^e = c[x, y]\ [A]^{-1e}\{a\}^e$

$= [N]^e\ \{a\}^e$

[N]= Interpolation Matrix

$[N]^e = c[x,y]\ [A]^{-1e}$

Generalized u and v points within the element (valid for any element)

$U(x,y) = \frac{1}{2A}\{u_i(d_i + \bar{b}_i x + \bar{a}_i y) + u_j(d_j + \bar{b}_j x + \bar{a}_j y) + u_k(d_k + \bar{b}_k x + \bar{a}_k y)\}$

$V(x, y) = \frac{1}{2A}\{v_i(d_i + \bar{b}_i x + \bar{a}_i y) + v_j(d_i + \bar{b}_i x + \bar{a}_i y) + v_k(d_k + \bar{b}_k x + \bar{a}_k y)\}$

Now finally strain nodal matrix is to be found out

$\varepsilon_{xx} = \frac{\delta u(x,y)}{\delta x} = \frac{1}{2A}\{\bar{b}_i u_i + \bar{b}_j u_j + \bar{b}_k u_k\}$

$\varepsilon_{yy} = \frac{\delta v(x,y)}{\delta y} = \frac{1}{2A}\{\bar{a}_j v_i + \bar{a}_j v_j + \bar{a}_k v_k\}$

$\tau_{xy} = \frac{\delta u(x,y)}{\delta y} + \frac{\delta v(x,y)}{\delta x}$

$= \frac{1}{2A}\{\bar{a}_i u_i + \bar{a}_j u_j + \bar{a}_k u_k + \bar{b}_i v_i + \bar{b}_j v_j + \bar{b}_k v_k\}$

$$\begin{Bmatrix} \varepsilon\ xx \\ \varepsilon\ yy \\ \tau\ xy \end{Bmatrix} = \frac{1}{2A}\begin{bmatrix} \bar{b}i & \bar{b}j & \bar{b}k & 0 & 0 & 0 \\ 0 & 0 & 0 & \bar{a}i & \bar{a}j & \bar{a}k \\ \bar{a}i & \bar{a}j & \bar{a}k & \bar{b}i & \bar{b}j & \bar{b}k \end{bmatrix}\begin{Bmatrix} ui \\ uj \\ uk \\ vi \\ vj \\ vk \end{Bmatrix}$$

From hooks law,

$\varepsilon_{xx} = \frac{1}{E}(\tau_{xx} - \gamma\ \tau_{yy})$

$\varepsilon_{yy}=\frac{1}{E}\ (\tau_{yy}-\gamma\,\tau_{xx})$

$\tau_{xy}=\frac{1}{G}(\tau_{xy})=\frac{2(1+\gamma)}{E}\tau_{xy}$

So, stress tensor is given by

$$\begin{Bmatrix}\tau xx\\ \tau\ yy\\ \tau\ xy\end{Bmatrix}=\frac{E}{1-\gamma 2}\begin{bmatrix}1 & \gamma & 0\\ \gamma & 1 & 0\\ 0 & 0 & \frac{1-\gamma}{2}\end{bmatrix}\begin{Bmatrix}\varepsilon\ xx\\ \varepsilon\ xy\\ \tau\ xy\end{Bmatrix}$$

5.7 Analysis of Body Stress of Welders

5.7.1 Stress Intensity for Knee posture

A poor posture contributes to stress and stress is caused due to poor posture. Poor work posture increases body stresses and other physical problems as well. Human body is designed to stand strong and erect, effortlessly. Muscles and joints tense up when the human body is stressed. The different joints and muscles of human body are the most affected parts due to poor posture. Sitting in a slouched position in the shop floor for a prolong period of time put a great deal of stresses of upper as well as lower body specially if the welders body is not supported. Poor work posture leads to body stresses, back pain and other physical problems as well.

The three dimensional finite element model consisted of 13810 elements which were connected through 27007 nodes points. The stress contour map revealed that the maximum intensity of stress varied from 8.50668 $x10^8$ P_a to 1.595 $x10^7$ P_a for particular knee posture and load.

Front view and side view of the maximum intensity of stress distribution contour pattern in knee posture is shown in figure 5.12(a) & figure 5.12 (b) respectively.

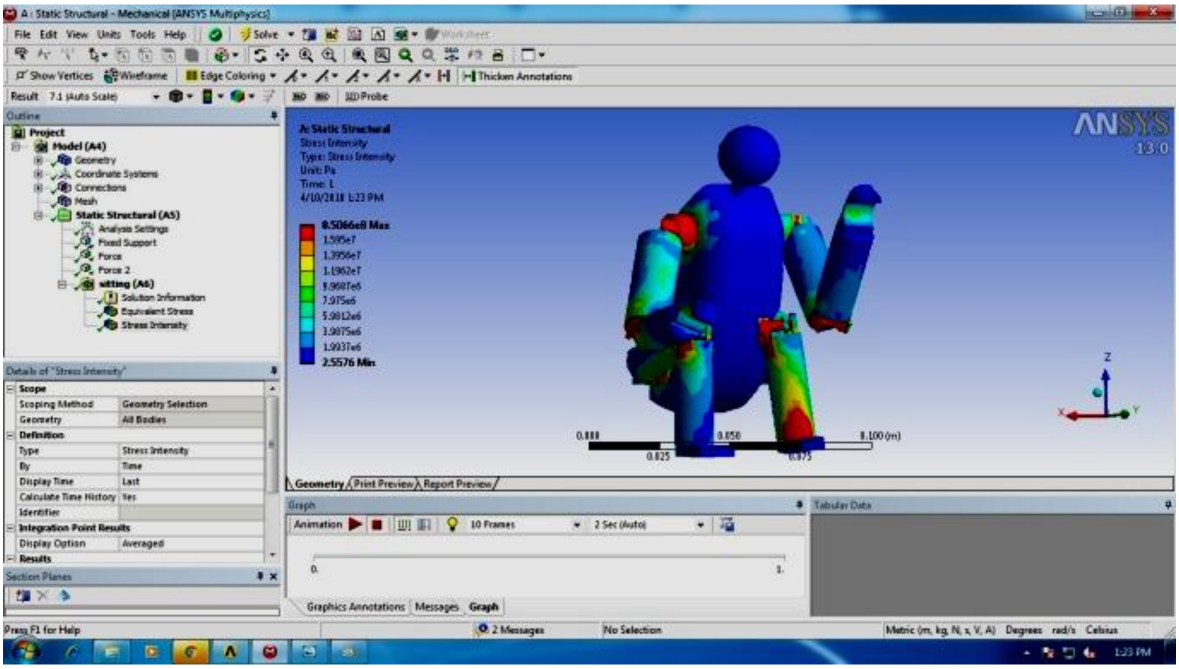


Figure 5.12 (a) Front view of intensity of stress distribution contour pattern in knee posture

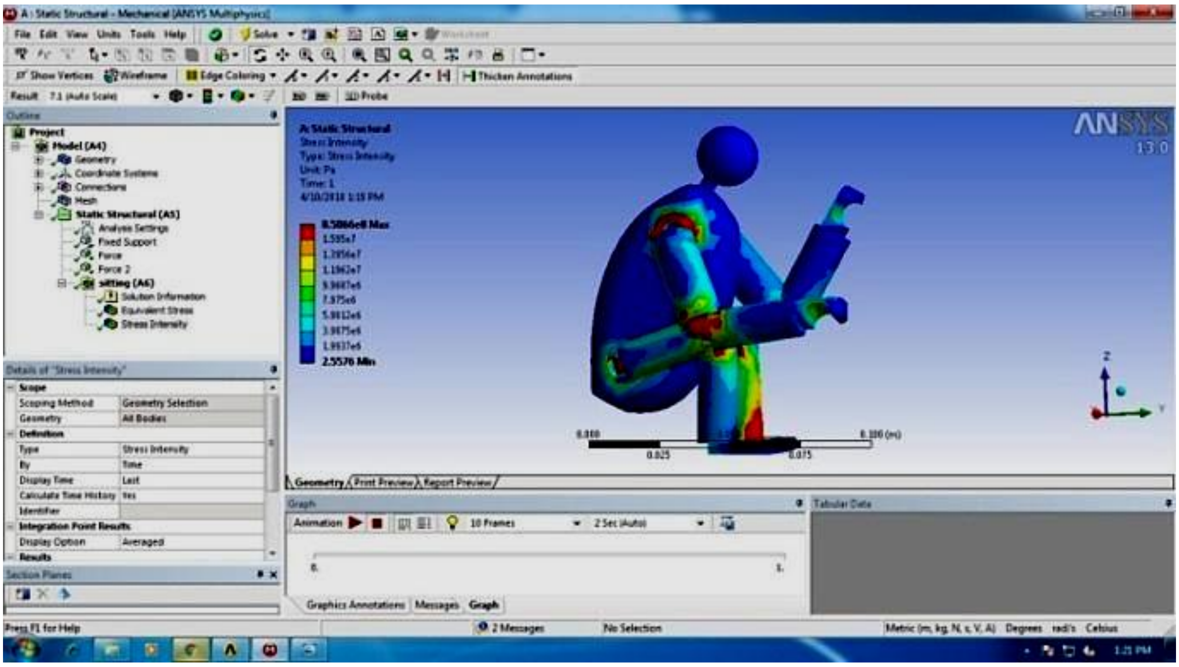


Figure 5.12 (b) Side view of intensity of stress distribution contour pattern in knee posture

Figure 5.13 shows that the node numbers 12160 to 13511, 14862 to 16213, 17371, 24319 mark highly stressed denoted by red colours. The joints like hips and knees do not get the interplay with gravity needed to make enough synovial fluid to keep the joint lubricated.

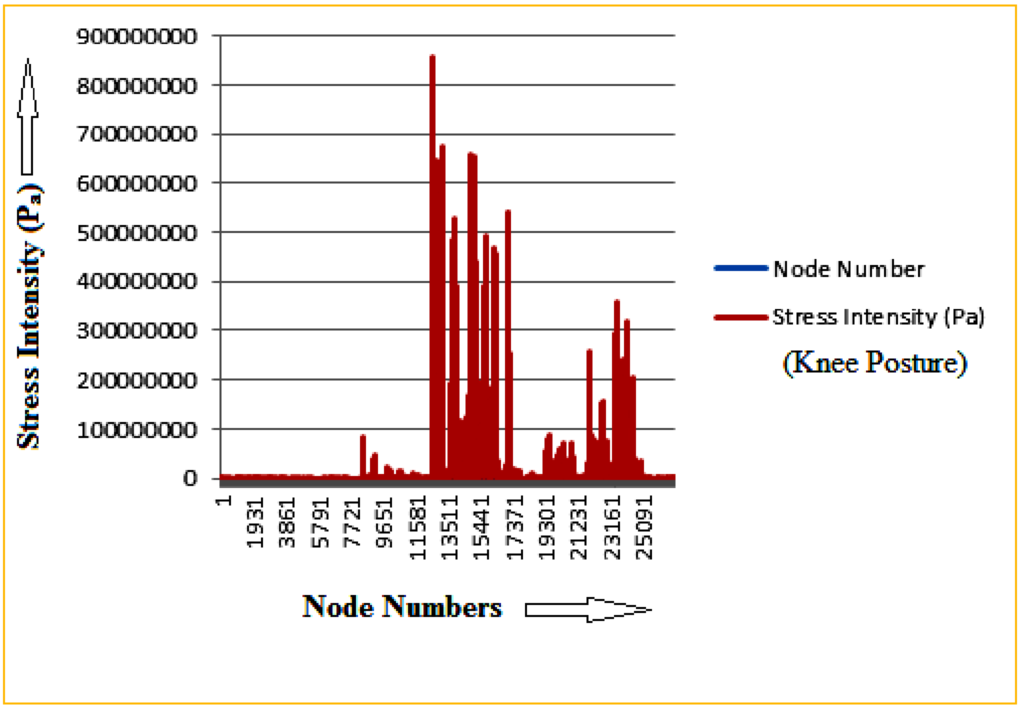


Figure 5.13Stress intensity vs. node number in knee posture

5.7.2 Equivalent (Von-Mises) Stress for Knee Posture

Equivalent Stress or Von Mises failure criterion is most widely used in theories of failure for predicting ductile failure. The square of the Von Mises stress is directly proportional to the distortion strain energy per unit volume. It is excluded from consideration portions of these regions with artificially high stresses due to modelling idealizations, such as point constraints and point loads. In terms of the principal stresses, Von Mises or Equivalent stress is calculated as $\sigma_{vm}=\sqrt{[(\sigma_{11}-\sigma_{22})^2+(\sigma_{22}-\sigma_{33})^2+(\sigma_{33}-\sigma_{11})^2]}$

Von Mises stress is identical to the octahedral shear stress that exists on a plane equally inclined to three principal stress directions. The Software ANSYS R17.0 was used for von Mises stress analysis. This analysis indicated that the maximum Von-Mises stress is a good injury indicator for the muscles with high cortical indices, independent of load directions. The Von Mises stress distribution patterns are shown in figure 5.14. It varied from minimum 2.3372 Pa to maximum 7.428×10^8 Pa in a particular welding posture.

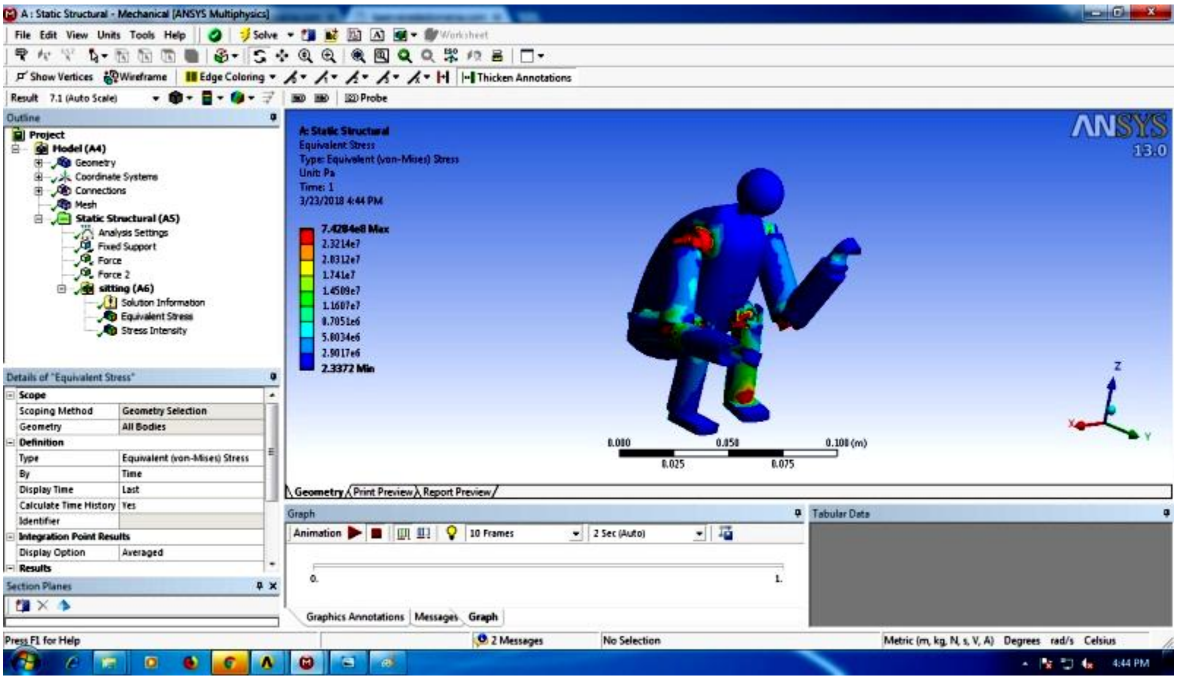


Figure 5.14 Equivalent (Von-Mises) stress distribution contour pattern in knee posture

The graph of maximum, minimum and average Von Mises stresses are plotted in figure 5.15 with respect to node numbers. The node numbers 3861 to 5791, 23161 to 25091 mark highly stressed denoted by red colours.

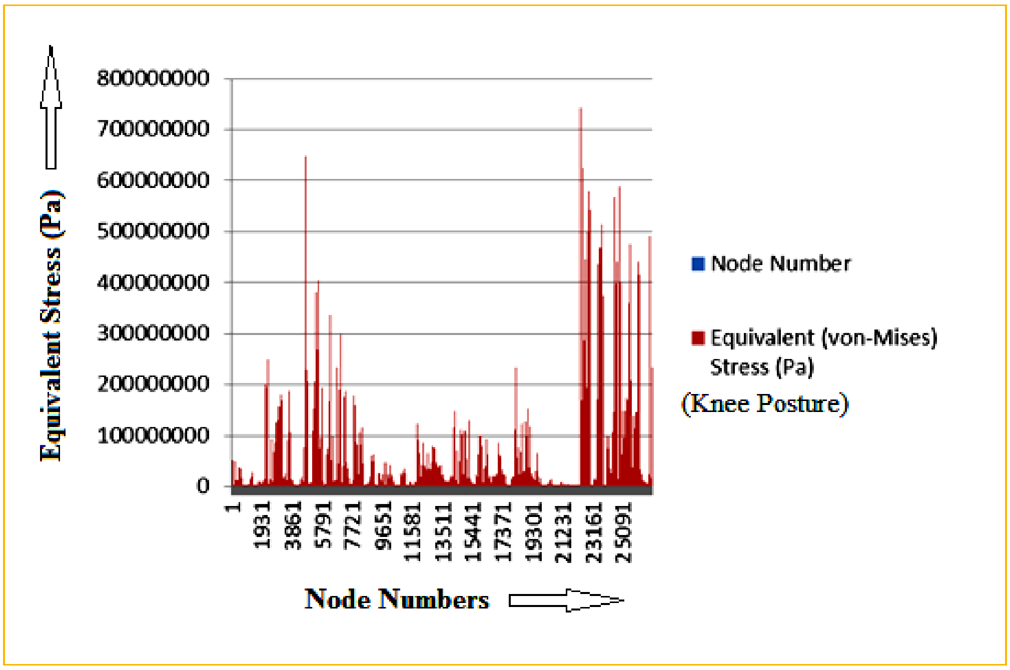


Figure 5.15 Equivalent (Von-Mises) stress vs. node number in knee posture

5.7.3 Stress Intensity for Sitting Posture

The sitting posture (chair) of welder is shown in figure 5.16.

Figure 5.16 Work Posture of Welder (chair)

It is shown from the figure 5.17 that the maximum intensity of stress of different joints varied from 6.0045 $x10^{8}$ Pa to 4.3423 $x10^{7}$ Pa and minimum 4.2066 $x10^{7}$ Pa to 32.886 Pa for sitting posture and specific load. It is also shown from the figure 5.17 that the maximum intensity of stress value in sitting posture was less compared to knee posture.

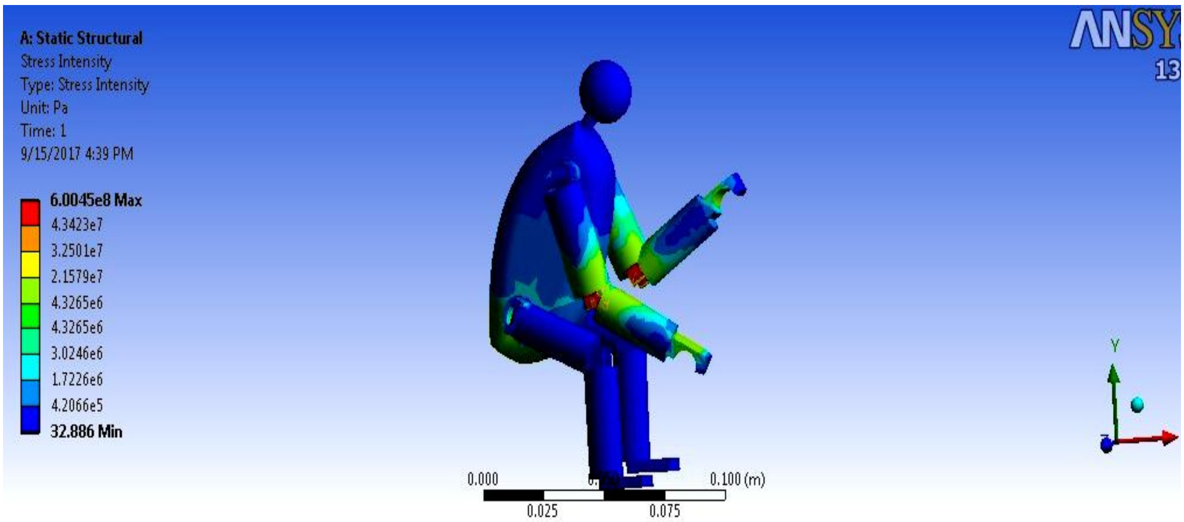


Figure 5.17 Intensity of stress distribution contour pattern in sitting posture

The graph of intensity of stress vs node numbers in sitting posture is shown in figure 5.18.The node numbers 5791 to 7721, 11581 and 17371 mark highly stressed denoted by blue colour.

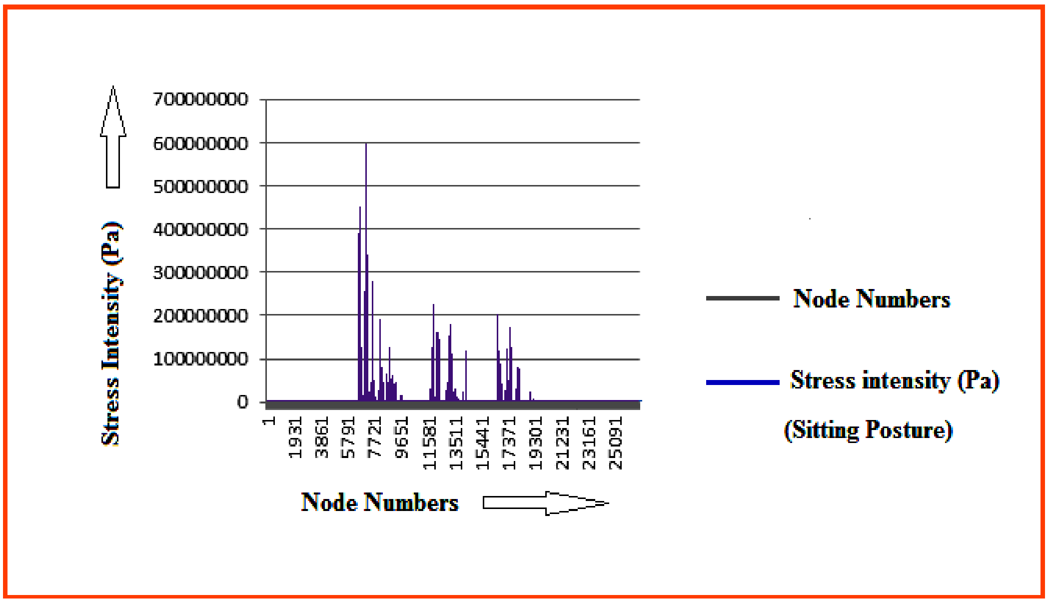


Figure 5.18 Stress intensity vs node number in sitting posture

5.7.4 Equivalent (Von-Mises) Stress for Sitting Posture

Equivalent (Von-Mises) stress distribution contour pattern in sitting posture is shown in the figure 5.19. The figure also shows that the maximum intensity of equivalent (Von-Mises) stress in sitting posture is less compared to knee postural position of the welder.

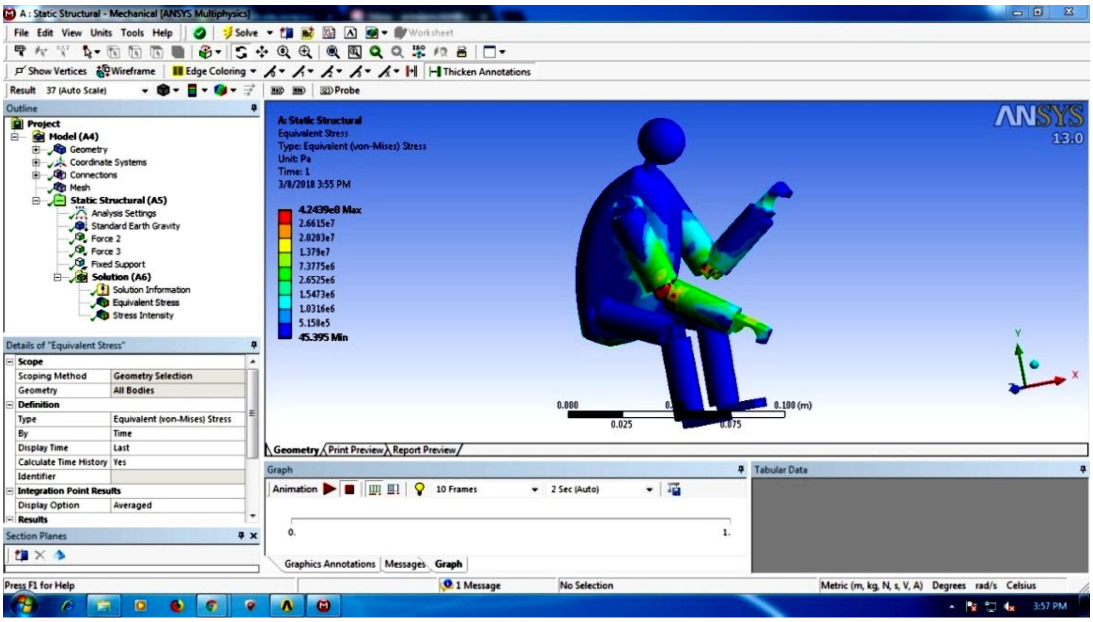


Figure 5.19 Equivalent (Von-Mises) stress distribution contour pattern in sitting posture

5.7.5 Stress Intensity for Standing Posture

Figure 5.20 shows that the maximum intensity of stress of different joints of standing posture varied from 4.3656 x10^8 Pa to 1.6371 x10^7 Pa and minimum 2.0465 x10^6 Pa to 115.61 Pa. It is shown from the figure that the maximum intensity of stress in standing posture is less compared to knee as well as sitting postural position of the welder. The maximum and minimum stresses are denoted by red and blue colours respectively.

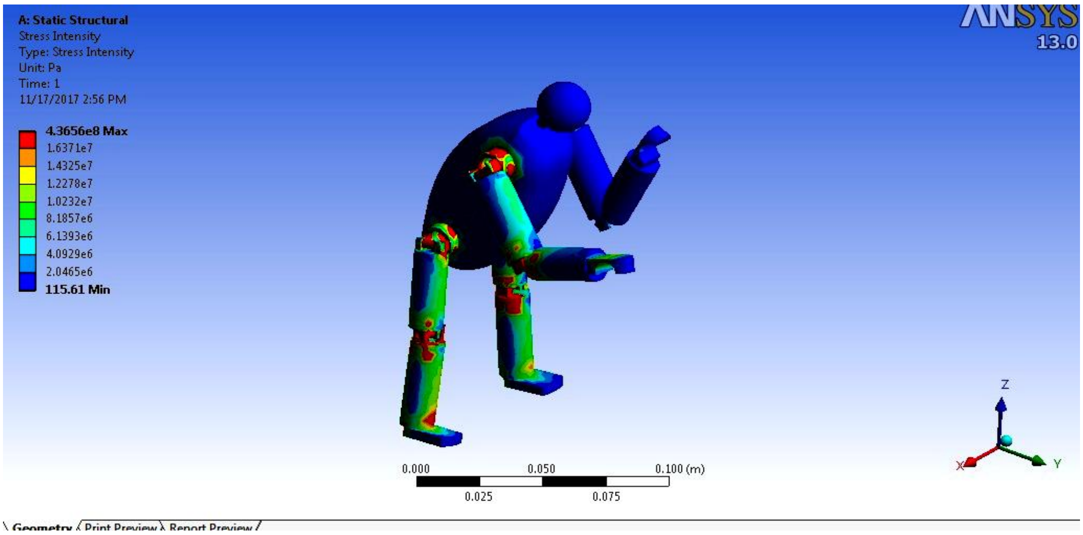


Figure 5.20 Intensity of stress distribution contour pattern in standing posture

5.7.6 Equivalent (Von-Mises) Stress for Standing Posture

Equivalent (Von-Mises) stress distribution contour pattern in standing posture is shown in the figure 5.21. It is shown from the figure that the maximum intensity of equivalent (Von-Mises) stress in standing posture is less compared to knee as well as sitting postural position of the welder. The equivalent (Von-Mises) stress of different joints of standing posture varied from 3.9526 x10^8 Pa to 1.4822 x10^7 Pa and minimum 1.8525 x10^6 Pa to 83.271 Pa. These stresses are denoted by red and blue colours respectively.

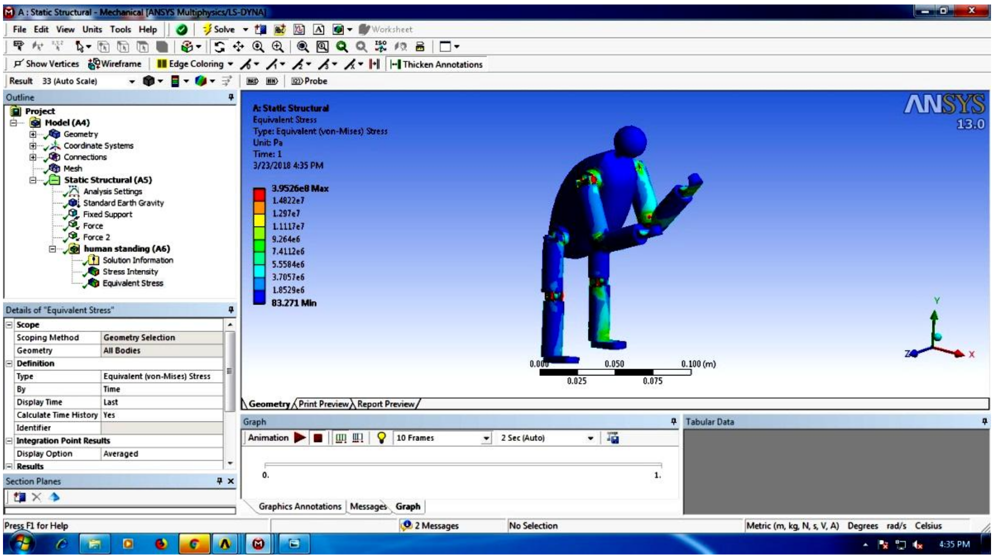


Figure 5.21 Equivalent (Von-Mises) stress distribution contour pattern in standing posture

5.7.7 Analysis of Comparison of Stresses of Three Different Postural Positions (Knee, Sitting and Standing Posture)

(i) Comparison of Intensity of Stresses (Pa):

The comparison of intensity of stresses in three different postural positions is shown in the table 5.3. The band widths are displayed in different colours. From the table 5.3 it is clear that the colour red is showing the maximum intensity of stress and blue is the minimum intensity.

Table 5.3 Comparison of Band Width of Intensity of Stresses (P_a)

Postural Position	Comparison of Band Width of Intensity of Stresses (P_a) [Colour]								
	[Red]	[Orange]	[Yellow]	[Yellow-green]	[Green]	[Aqua]	[Light green]	[Light blue]	[Blue]
Knee Posture	$8.5066x10^8$ to $1.595x10^7$	$1.595x10^7$ to $1.3956x10^7$	$1.3956x10^7$ to $1.1962x10^7$	$1.1962x10^7$ to $9.9687x10^6$	$9.9687x10^6$ to $7.975x10^6$	$7.975x10^6$ to $5.9812x10^6$	$5.9812x10^6$ to $3.9875x10^6$	$3.9875x10^6$ to $1.9937x10^6$	$1.9937x10^6$ to 2.5576
Standing Posture	$4.3656x10^8$ to $1.6371X10^7$	$1.6371X10^7$ to $1.4325x10^7$	$1.4325x10^7$ to $1.2278x10^7$	$1.2278x10^7$ to $1.0232x10^7$	$1.0232x10^7$ to $8.1856.x10^6$	$8.1856.x10^6$ to $6.1393.x10^6$	$6.1393.x10^6$ to $4.0929x10^6$	$4.0929x10^6$ to $2.0465x10^6$	$2.0465x10^6$ to 115.61
Sitting Posture (Chair)	$4.526x10^8$ to $5.0645X10^7$	$5.0645X10^7$ to $2.9208X10^7$	$2.9208X10^7$ to $7.7703X10^6$	$7.7703X10^6$ to $5.8927X10^6$	$5.8927X10^6$ to $4.0151X10^6$	$4.0151X10^6$ to $2.1375X10^6$	$2.1375X10^6$ to $2.1375X10^6$	$1.9131X10^6$ to $2.4713X10^5$	$2.4713X10^5$ to 48.377

Comparison of intensity of stresses vs node numbers in three different postural positions is shown in the figure 5.22. Three different colours represent the stress values in the crucial node points. Comparison also shows that the maximum intensity of stress in knee posture is maximum compared to other postural positions of welder. The figure also shows that the maximum intensity of postural stress in standing posture is less compared to other two postural positions.

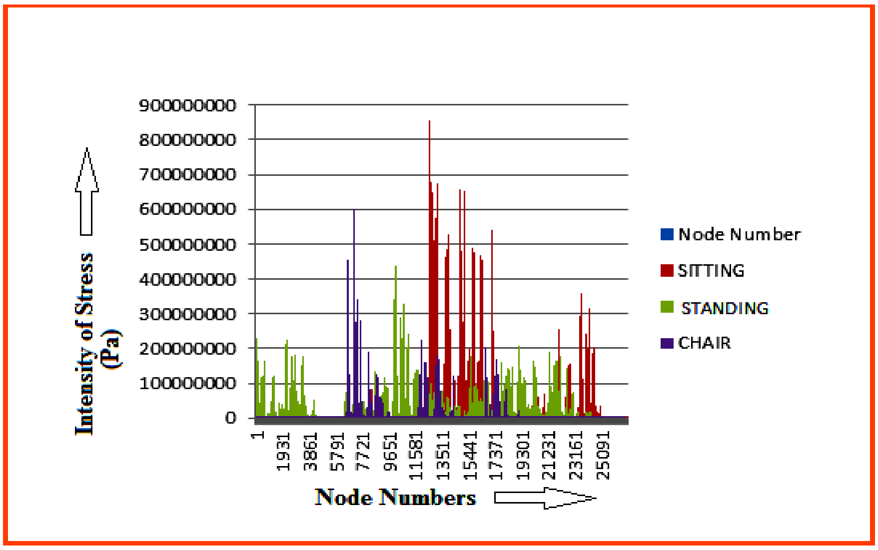


Figure 5.22 Comparison of intensity of stresses vs node number in three different postural positions

(ii) Comparison of Equivalent (Von-Mises) Stresses (P_a):

The comparison of equivalent (Von-Mises) stresses in three different postural positions is shown in the table 5.4. The band widths are displayed in different colours. From the table 5.4 it is also clear that the colour reds are showing the maximum equivalent (Von-Mises) stress and blues the minimum intensity of Von-Mises stress value.

Table 5.4 Comparison of band width of equivalent (Von-Mises) stresses (P_a)

Postural Position	Comparison of Band Width of Equivalent(Von-Mises) Stresses (P_a) [Colour]								
	Red	Orange	Yellow	Yellow-green	Green	Aquamarine	Cyan	Light blue	Blue
Knee Posture	$7.4284x10^{8}$ to $2.3214x10^{7}$	$2.3214x10^{7}$ to $2.0312x10^{7}$	$2.0312x10^{7}$ to $1.741x10^{7}$	$1.741x10^{7}$ to $1.4509x10^{7}$	$1.4509x10^{7}$ to $1.1607x10^{7}$	$1.1607x10^{7}$ to $8.7051x10^{6}$	$8.7051x10^{6}$ to $5.8034x10^{6}$	$5.8034x10^{6}$ to $2.9017x10^{6}$	$2.9017x10^{6}$ to 2.3372
Standing Posture	$3.9526x10^{8}$ to $1.4822x10^{7}$	$1.4822x10^{7}$ to $1.297x10^{7}$	$1.297x10^{7}$ to $1.1117x10^{7}$	$1.1117x10^{7}$ to $9.264x10^{6}$	$9.264x10^{6}$ to $7.4112x10^{6}$	$7.4112x10^{6}$ to $5.5584x10^{6}$	$5.5584x10^{6}$ to $3.7057x10^{6}$	$3.7057x10^{6}$ to $1.8529x10^{6}$	$1.8529x10^{6}$ to 83.271
Sitting Posture (Chair)	$4.2439x10^{8}$ to $2.6615X10^{7}$	$2.6615X10^{7}$ to $2.0203X10^{7}$	$2.0203X10^{7}$ to $1.379X10^{7}$	$1.379X10^{7}$ to $7.3775X10^{6}$	$7.3775X10^{6}$ to $2.6525X10^{6}$	$2.6525X10^{6}$ to $1.5473X10^{6}$	$1.5473X10^{6}$ to $1.0316X10^{6}$	$1.0316X10^{6}$ to $5.158X10^{5}$	$5.158X10^{5}$ to 45.395

The comparison of intensity of stresses vs node numbers in three different postural positions is shown in the figure 5.23. Three different colours are used to represent the stress values of three postural positions of the crucial node points. It is also shown from the graph that the equivalent (Von-Mises) stresses in knee posture is maximum, compared to other postural positions of welder. It is clear from the comparison graph that the maximum Von-Mises stress in standing posture is less compared to other two postures.

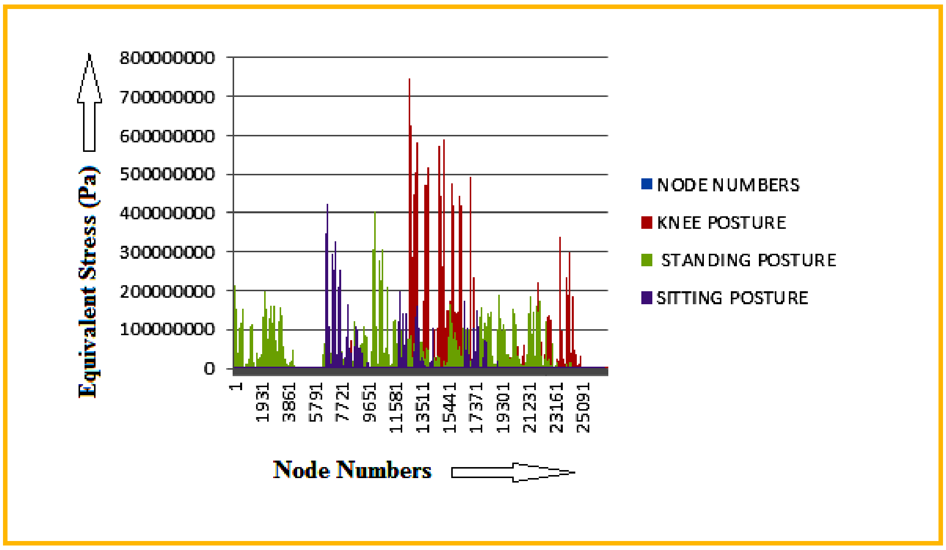


Figure 5.23 Comparison of equivalent stress vs node numbers in three different postural positions

5.8 Low Back Compressive Force Analysis

The most of the trunk flexion and disk herniation occurs in the L_5/S_1disk which is shown in the figure 5.24. The load acting through a moment arm is to be determined by the distance from the centre of the hands to the centre of the disk. The clock wise moment is to be balanced by erector spine muscle. The two moments must be equal to maintain the system in equilibrium.

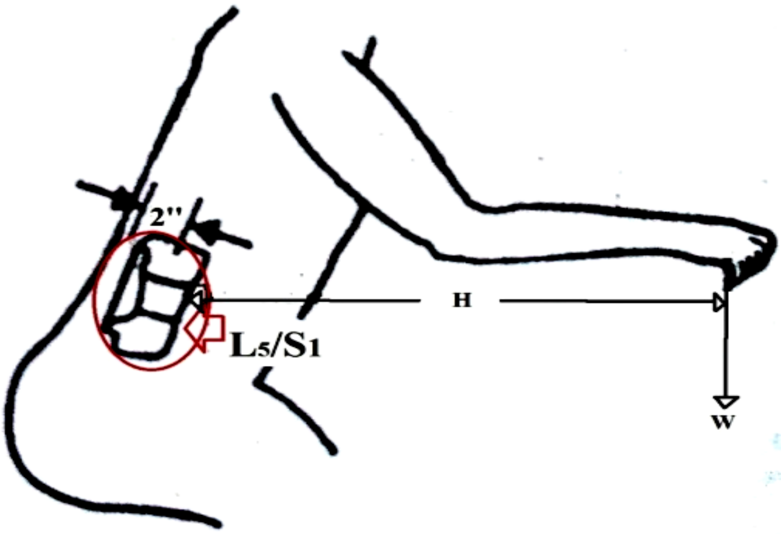


Figure 5.24 Back compressive forces model

The free body model is acting as a first class liver with the centre of the disk (L_5/S_1) acting as the fulcrum. The different loads and distance positions are shown in the figure 5.25.

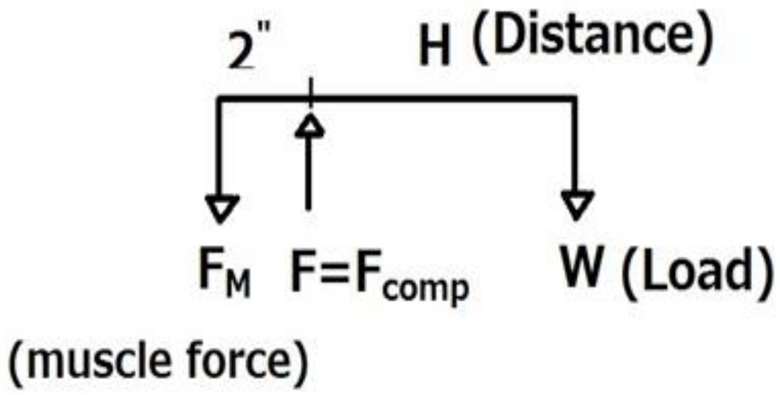


Figure 5.25 First class liver of back compressive force

The disk compressive force (F_M) can also be calculated with the help of following formula. Where F_M is the muscle force and W is the load on the arms.

$$2xF_M = HxW$$
$$F_M = (HxW)/2$$
$$F_{COMP} = F_M + W$$

5.8.1 Back Compressive Force of Knee Posture

The internal forces of the erector spine muscle for knee posture must be:

$$2xF_M=35x4.5$$
$$F_M= 78.75Ib$$

The working length from the disks to hand (H=35”) was considered in this case. The average weight of the electrode holder was W=4.5 Ibs (2Kg) which is shown in the figure 4.26.

The total compressive force (F_{COM}) exerted on the disk was:

$$\mathbf{F_{COM\ (Knee\ Posture)} = F_M + W}$$
$$\mathbf{F_{COM\ (Knee\ Posture)} = 78.75+4.5}$$
$$\mathbf{= 83.25Ib}$$
$$\mathbf{=38\ Kg}$$

The above compressive force on the disk may be increased due to prolonged working hours and static work posture.

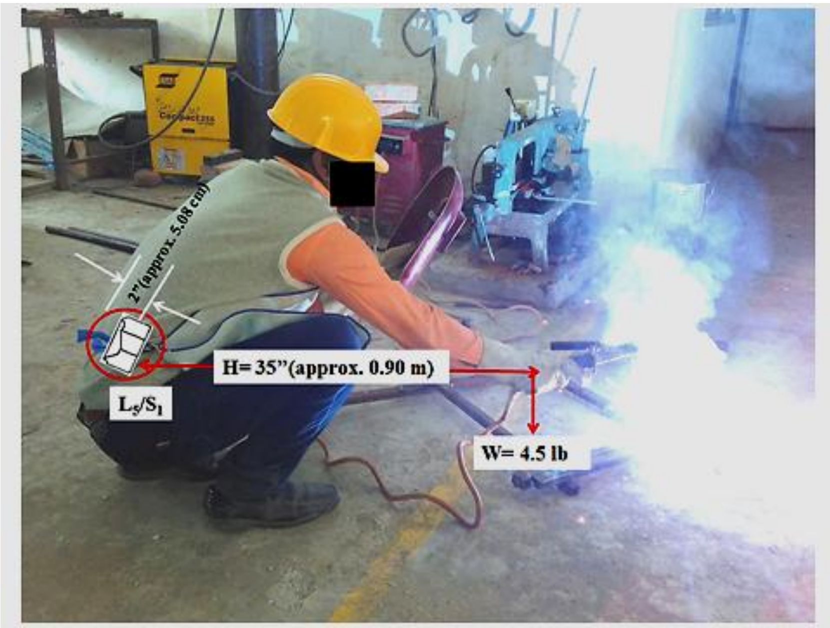


Figure 5.26 Disk compressive force in knee posture

5.8.2 Back Compressive Force of Sitting Posture

The back compressive force in sitting posture in L_5/S_1 disk is shown in the figure 5.27.

For sitting postural position, the internal force of the erector spine muscle may be:

$$F_M = (25x4.5)/2$$

$$=56.25 \text{ Ib}$$

The total compressive force (F_{COM}) applied on the disk was:

$$\mathbf{F_{COM\ (Sitting\ Posture)} = F_M + W}$$

$$\mathbf{F_{COM\ (Sitting\ Posture)} = 56.25 + 4.5}$$

$$\mathbf{= 60.75\ Ib}$$

$$\mathbf{=28\ Kg}$$

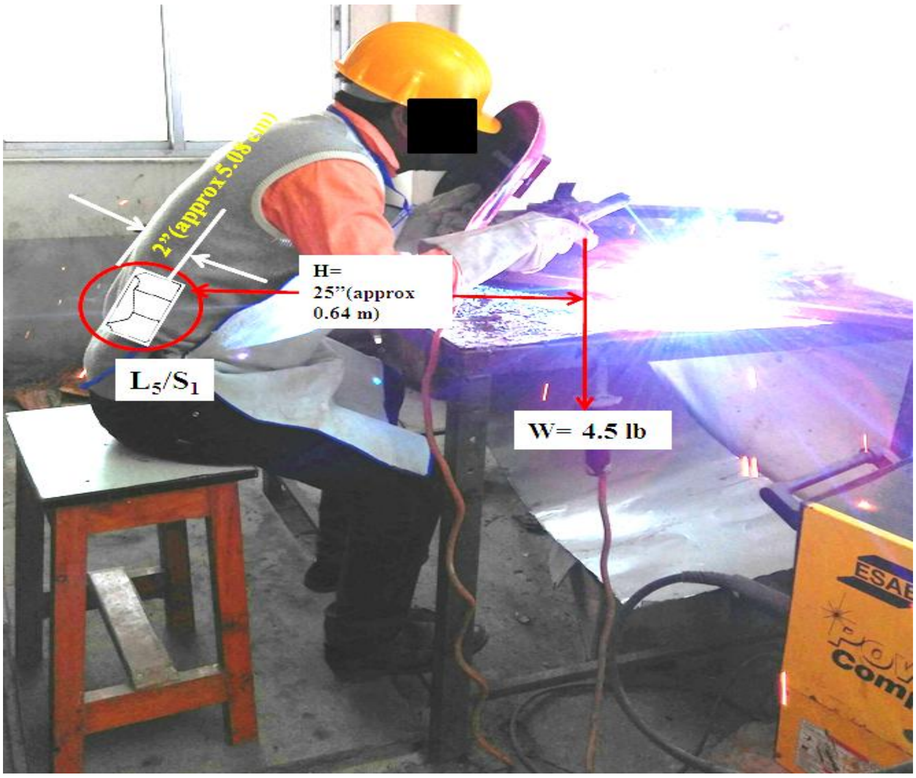


Figure 5.27 Disk compressive force in sitting posture

5.8.3 Back Compressive Force of Standing Posture

The back compressive force in standing posture is shown in the figure 5.28.

For standing postural position, the internal force of the erector spine muscle may be:

$$F_M = (21x4.5)/2$$

$$=47.25 \text{ Ib}$$

The total compressive force (F_{COM}) applied on L_5/S_1 disk was:

$$\mathbf{F_{COM\ (Standing\ Posture)} = F_M + W}$$

$$\mathbf{F_{COM\ (Standing\ Posture)} = 47.25+4.5}$$

$$\mathbf{= 51.75\ Ib}$$

$$\mathbf{=23.5\ Kg}$$

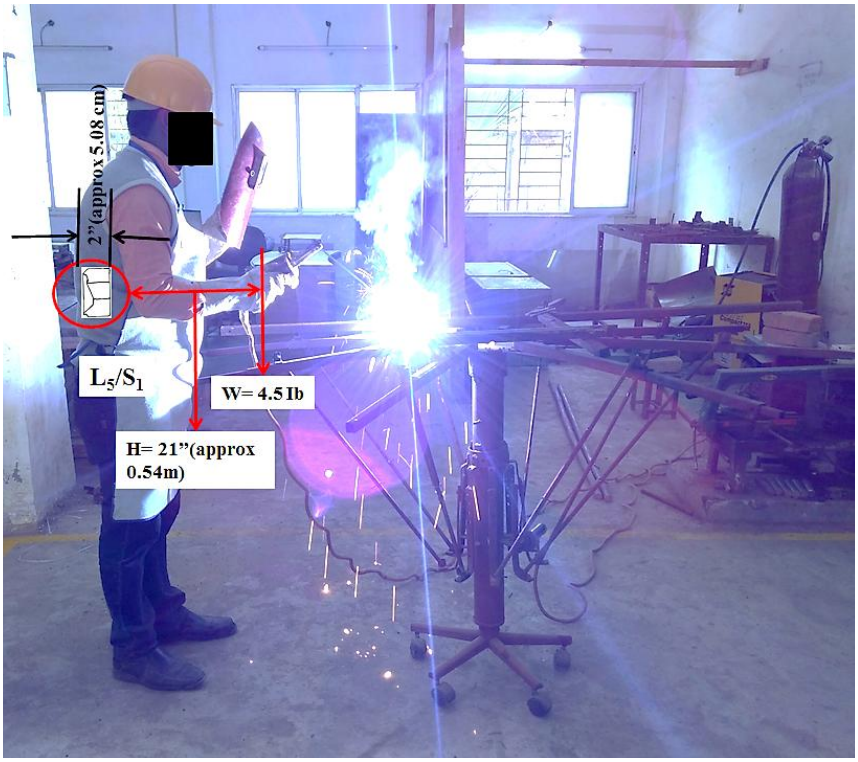


Figure 5.28 Disk compressive force in standing posture

5.8.4 Comparison of Disk Compressive Force in Three Different Postural Positions

The disk herniation may be the main cause of low back injuries of welding workers. Soft tissue injuries, injuries in the ligaments, muscles and tendons are the common health disorders of workers associated with manual work. Figure 5.29 shows the comparison of disk compressive force vs different postural positions of welders. The analysis shows that the disk compressive force was maximum in knee posture compared to other postural positions of welders. The disk compressive force of standing posture of welders was very less due to small bending of trunk.

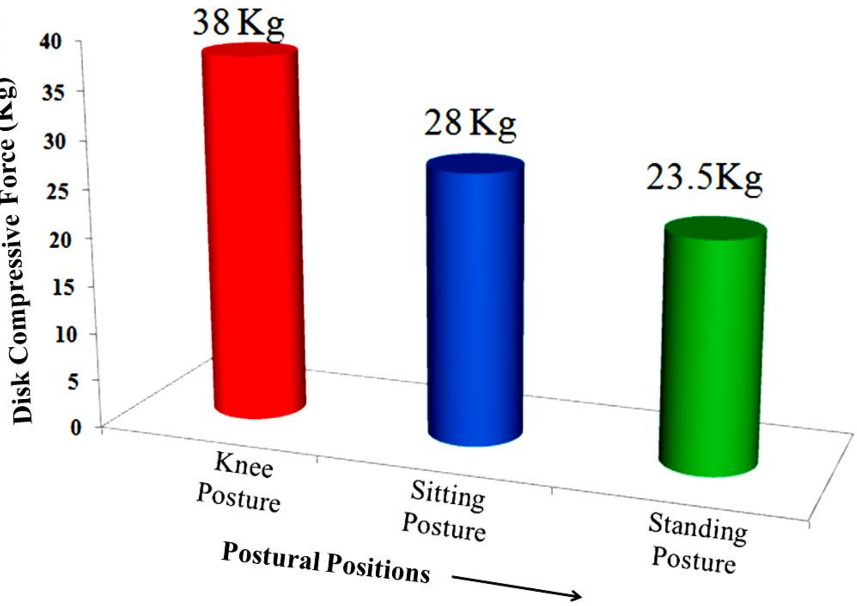


Figure 5.29 Comparison of disk compressive force vs postural positions

5.9 Process of Disk Degeneration

The adult human spine is in S-shaped consisting of 25 separate bones called vertebrae. The bones or vertebrae have a roughly cylindrical body, with several bony processes originating from the back, which serves as attachments for the back muscles, the erector spine. The vertebral bones are parted by softer tissues which are called vertebral disks. These disks serve as joints and also allow a large range of motion in the spine. The most trunk flexion occurs in the two lowest joints. The joints are L_5/S_1 disk (lower lumber vertebra & sacrum) and L_4/S_5 disk. These disks act as cushions between the vertebral bones and S- shaped spine. Disks also help to protect the head and brain from the jarring impacts during working. The disks are composed of a gel like centre surrounded by onion like layers of fibres, separated from the bone by a cartilage and plate. Figure 5.30 (a) shows the normal state of vertebra, spinal cord and nerve root. The intervertebral disk is also normal. Depending on the pressure on the disk the movement of the fluid occurs between the gel centre and the surrounding tissue. Narrowing the disk space and the nerve root to be pinched is shown in the figure 5.30 (b). Due to heavy load and bending of the trunk, the disc space narrows and allows the vertebral bones to come closer and eventually even touch, causing irritation and pain. The disk herniation may happen due to same motion repetition, static posture and bending of trunk for long period of time. In the case of slipped disk, the fibre casing can be ruptured, allowing large amount of gel substance to extrude. These impinged upon the nerve root which is shown in the figure 5.30(c).

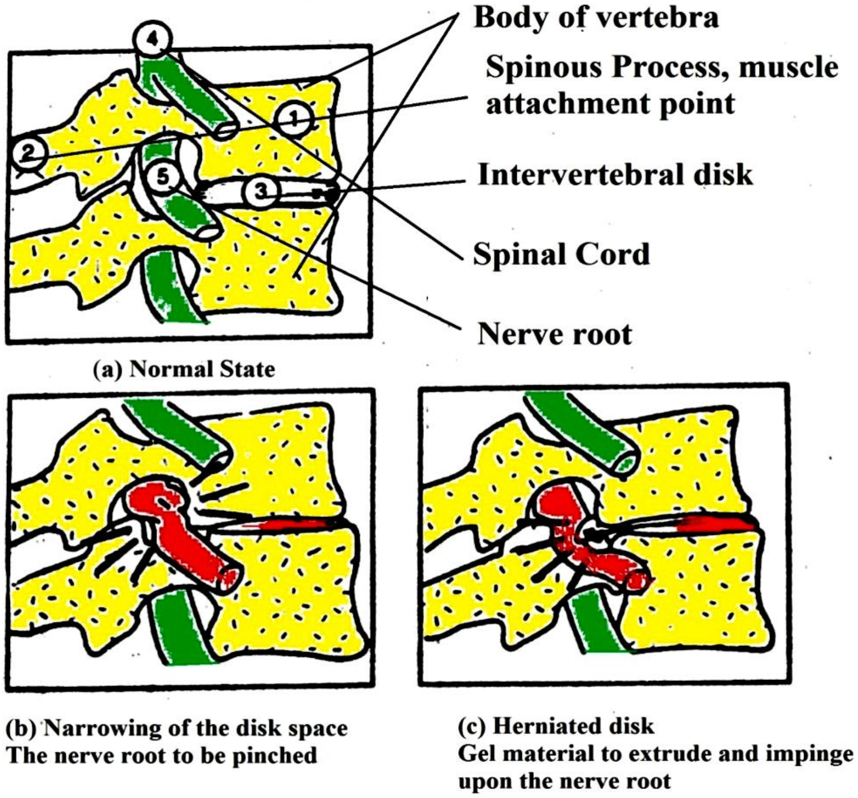


Figure 5.30 Anatomy of a vertebra and the process of disk degeneration

5.9.1 Effects on Disk due to Heavy Manual Work and Trunk Bending for Long Time in Static Posture

- Enclosing fibre becomes frayed.
- Cartilage end plate may be suffered.
- Releasing some of the gelatinous material.
- Reducing inner pressures.
- Allowing the centre to start drying up.
- Allowing the vertebra bones to come closer together and eventually even touch.
- Uneven pressure on disks.
- Irritation and pain.

It is shown from the figures 5.31(a) & (b) that due to poor knee postural position of welders, the intensity of stress in low back muscles was very high and it is denoted by red colours.

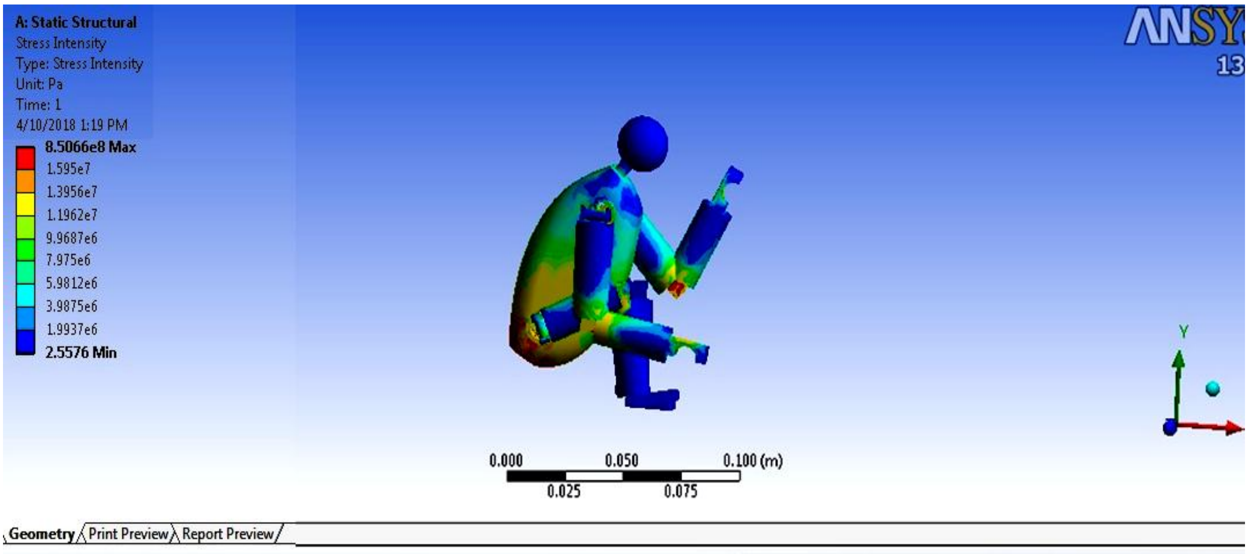


Figure 5.31(a) Side view of intensity of stress in low back in knee posture

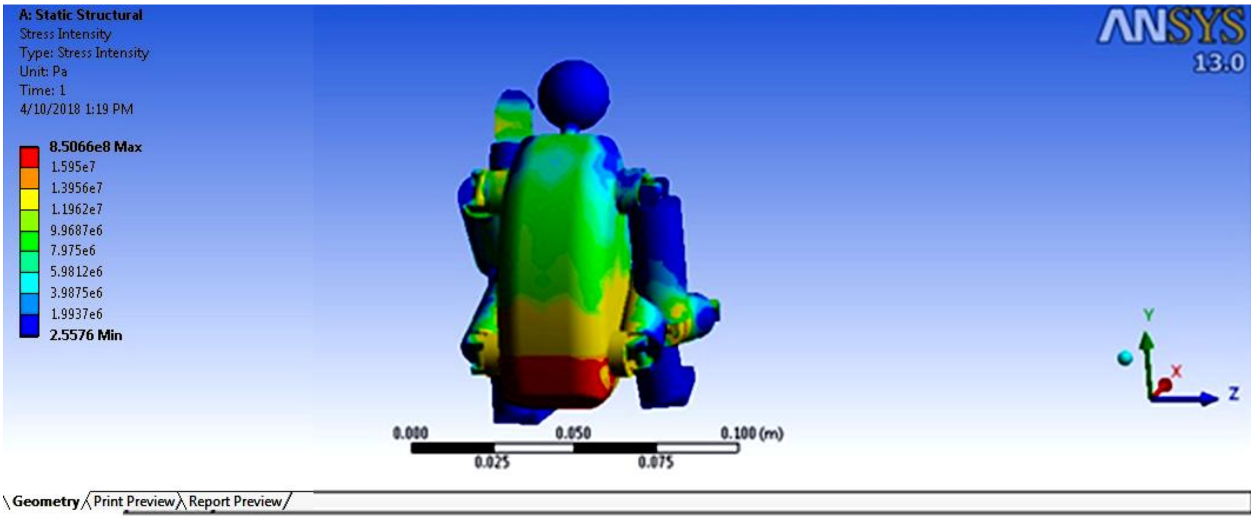


Figure 5.31(b) Back view of intensity of stress in low back in knee posture

5.9.2 A Case Study of Disc Degeneration in Lumbo Sacral Spine

Front view and side view of disc degeneration in lumbar and sacrum area are shown in the figure 5.32(a) and 5.32(b) respectively. This disc degeneration of welder occurred due to load and trunk bending for a long period of time.

The following points have been identified from the MRI report.

- Osteophytes and schmorls nodes were seen in multiple levels.
- Diffuse bulge of L_3-L_4 disc was seen with facetal hypertrophy and ligamentum flavum thickening causes thecal sac compression.
- Impinging on the right exiting nerve root was seen.
- Mild diffuse bulge of L_4-L_5 disc was seen with right foraminal disc protrusion causing thecal sac compression.
- Impinging on the bilateral exiting nerve roots was also seen.

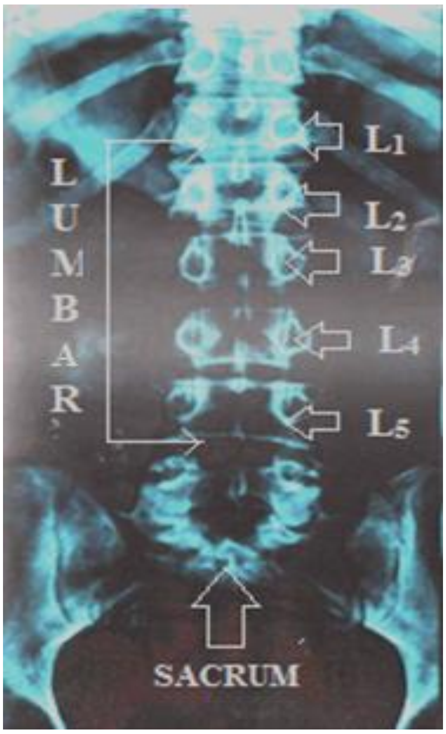


Figure 5.32(a)

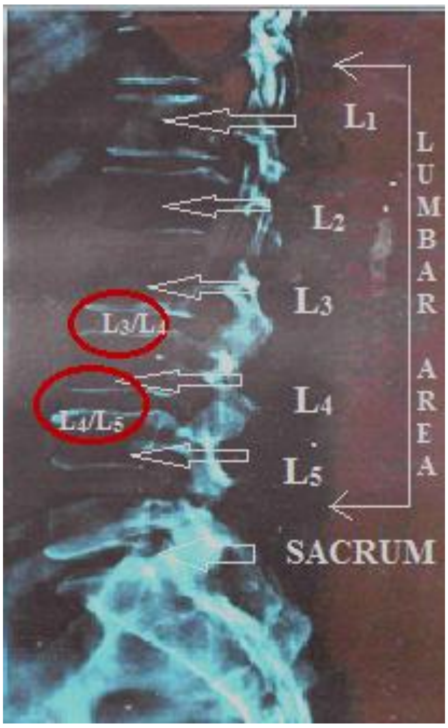


Figure 5.32(b)

Figures 5.32(a) front view and 5.32(b) side view of lumbar and sacrum area

The spinal canal measurements at various levels are as follows:

L_1-L_2 Level –Canal: 17.0 mm

L_2-L_3 Level –Canal: 17.5 mm

L_3-L_4 Level –Canal: 15.0 mm

L_4-L_5 Level –Canal: 12.5 mm

L_5-S_1 Level –Canal: 13.0 mm

From the above chart it is clear that the disc spaces (L_3-L_4, L_4-L_5 and L_5-S_1) were not normal due to disc degeneration in lumbo sacral spine, they became narrower and closer, causing irritation and pain.

5.10 Comparison of RULA Score in Three Different Postural Positions of Welders

(A) Knee Posture:

The knee postural position and value of RULA score are represented in the figure 5.33(a) and figure 5.33(b) respectively. The RULA score was 7 which indicated that investigations and changes were required immediately.

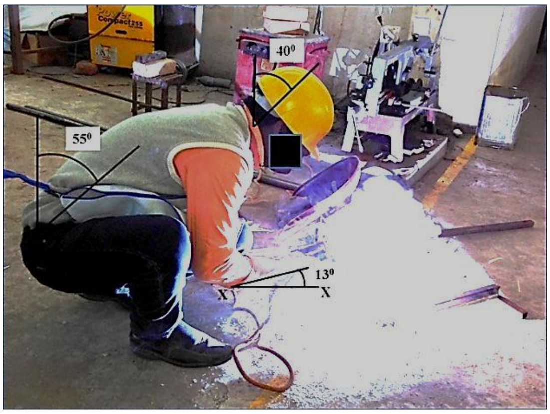


Figure 5.33(a) Knee posture of welder

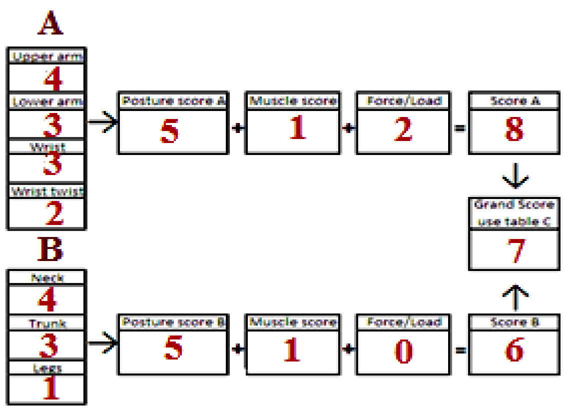
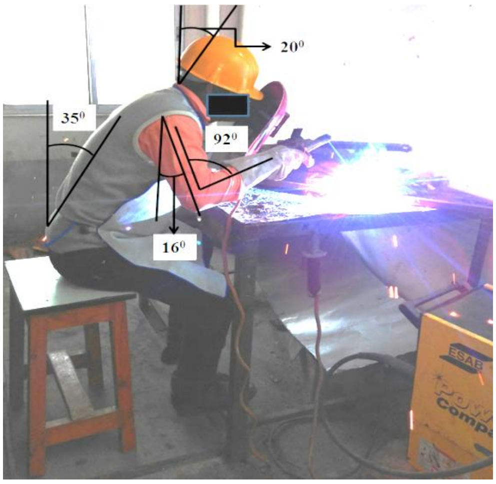


Figure 5.33(b) RULA score in knee posture

(B) Sitting Posture:

The sitting postural position and RULA score are also represented in the figure 5.34(a) and figure 5.34(b) respectively. The score was 6 which indicated that further investigations and changes were required soon.



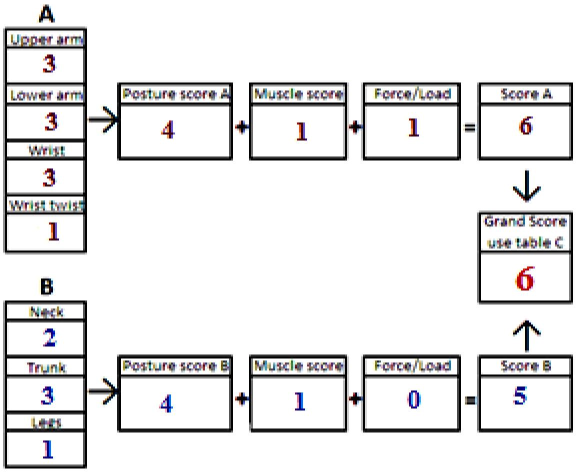


Figure 5.34 (a) Sitting posture of welder

Figure 5.34(b) RULA score in sitting posture

(C) Standing Posture:

The standing postural position and RULA score value are shown in the figure 5.35(a) and figure 5.35(b) respectively. The score was 3 which indicated that further investigations were required.

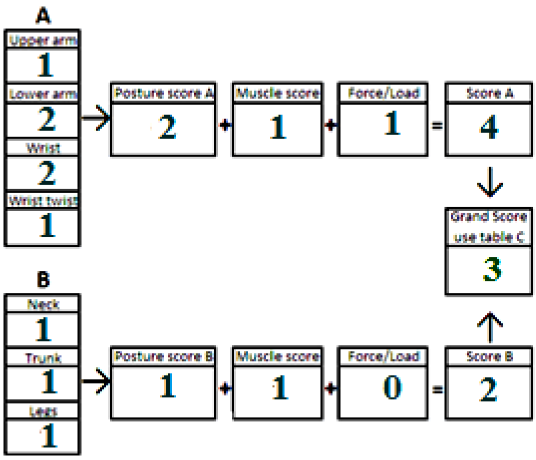


Figure 5.35(a) Standing posture of welder

Figure 5.35(b) Calculation of RULA score

(D) Graphical Representation of RULA Scores

The RULA scores of different postural positions are shown in the figure 5.36. Due to less bending of welder's body, the RULA score in standing posture was less compared to other postural positions of welders which may be accepted.

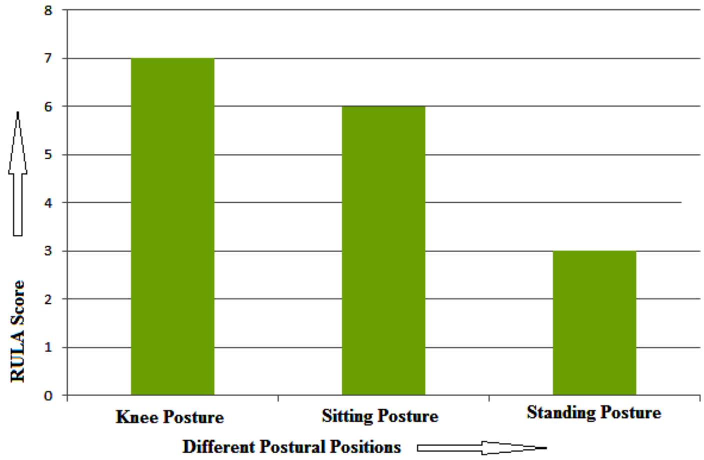


Figure 5.36 RULA score vs different postural positions of welder

5.11 Comparison of REBA Score in Three Different Postural Positions of Welders

(A) Knee Posture:

The value of REBA score knee in posture of welders is represented in the figure 5.37. The RULA score was 8 which indicated that investigations and changes were required soon.

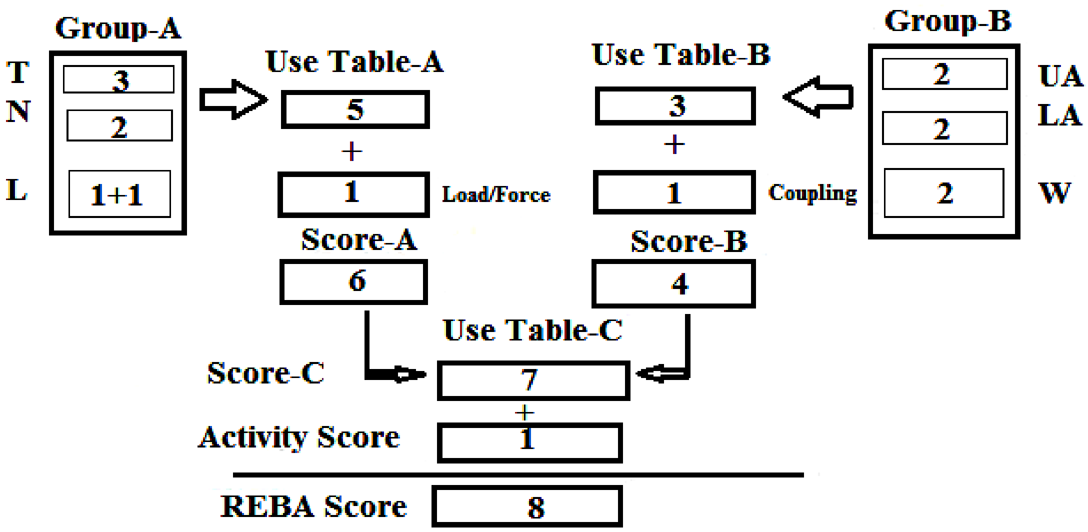


Figure 5.37 REBA calculation chart in knee posture

(B) Sitting Posture:

The value of REBA score in sitting posture of welders is represented in the figure 5.38. The RULA score was 5 which was under medium risk level zone and further necessary action must be taken.

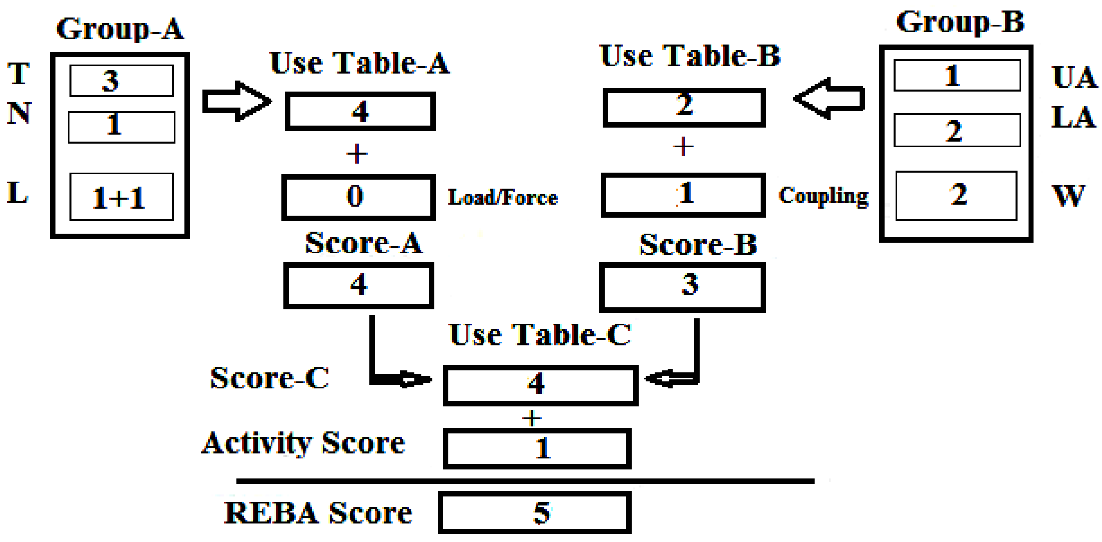


Figure 5.38 REBA calculation chart in sitting posture

(C) Standing Posture:

The value of REBA score in standing posture of welders is represented in the figure 5.39. The RULA score was 2 which was under low risk zone and necessary action may be taken.

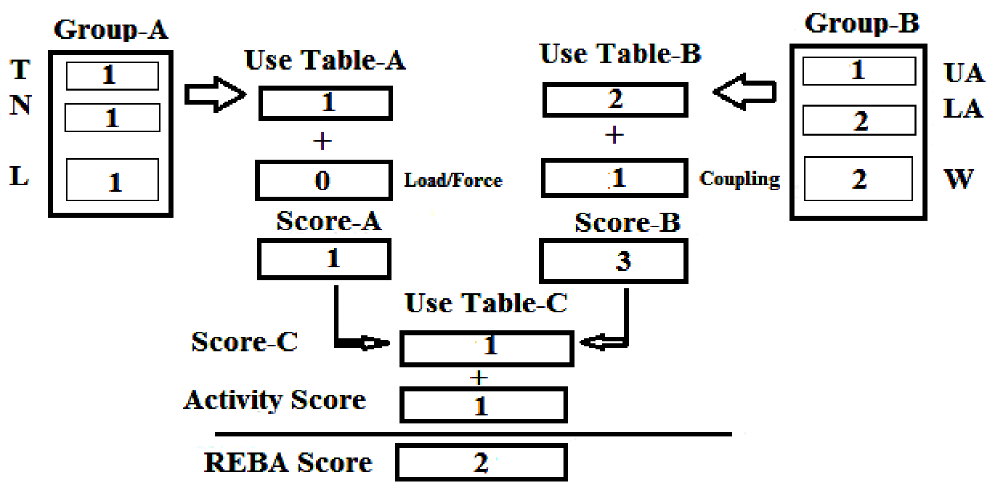


Figure 5.39 REBA calculation chart in standing posture

(D) Comparison of REBA Score

The comparison of REBA score of three different postural positions is shown in the figure 5.40.

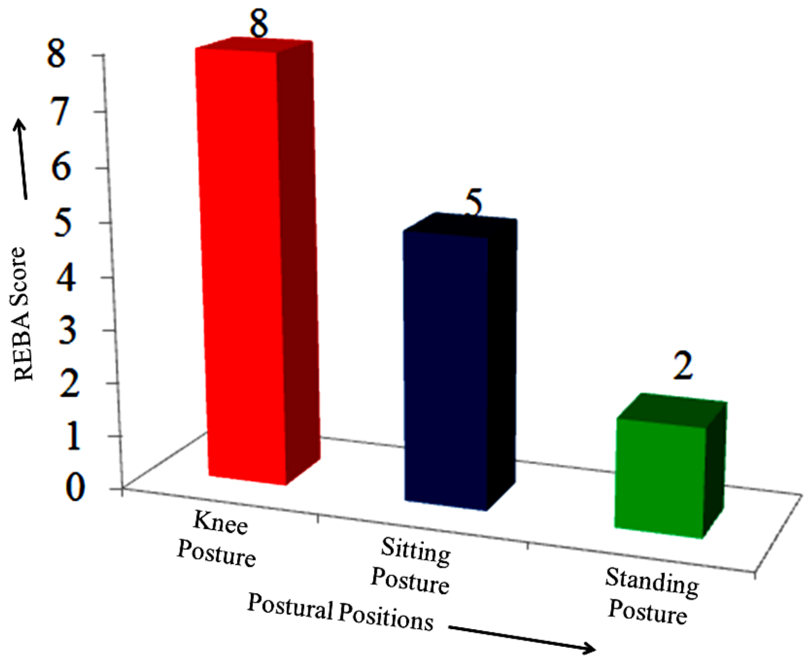


Figure 5.40 REBA score comparison

5.12 AHP Analysis and Discussion

There were three different levels of the decision hierarchy for selecting the best welding postural position. Here, in this research work, the chosen criteria were: Bodily Discomfort (criteria-1), Postural Stresses (criteria-2) and Pulse Rate (criteria-3) and the alternatives were different welding posture of welders. Figure 5.41describes the decision hierarchy of criteria and alternative of different postural positions in welding.

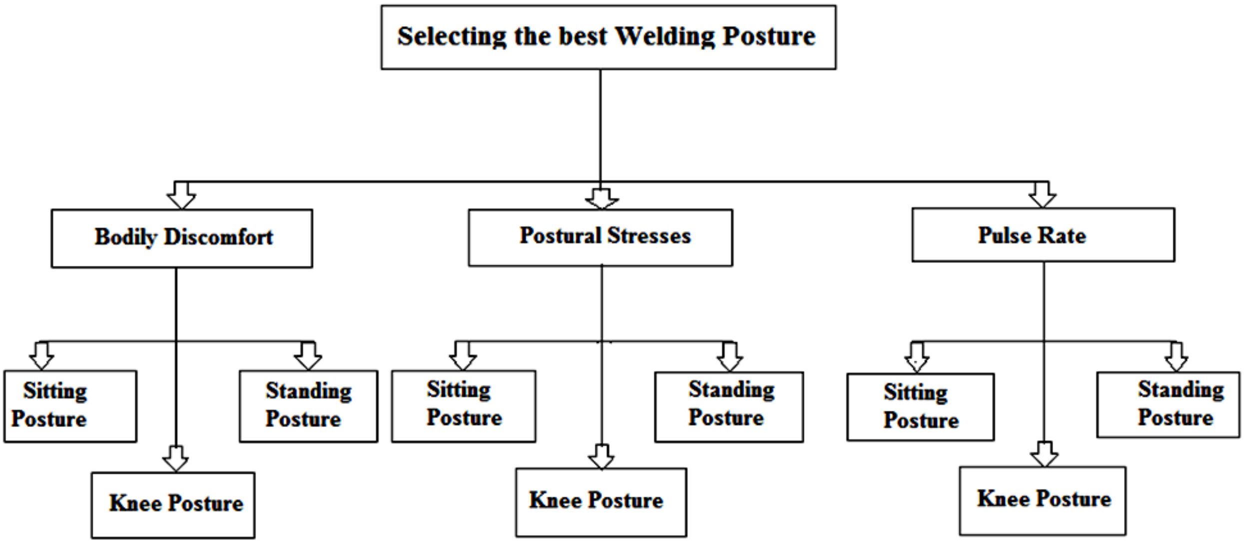


Figure 5.41 Decision hierarchy of criteria and alternative of postural positions in welding operation

In comparing the three criteria-bodily discomfort, postural stresses and pulse rate, it was decided that postural stresses was most important one. It was also recommended that postural stress was strongly preferred over bodily discomfort of welders. Postural stress was moderately preferred over bodily discomfort and pulse rate was moderately preferred over bodily discomfort of welders. Table 5.5 represents the pairwise comparison matrix with intensity judgments.

Table 5.5 Pair-wise comparison matrix with intensity judgments

Selecting the best welding posture	Bodily Discomfort	Postural Stresses	Pulse Rate
Bodily Discomfort	1	1/8	1/3
Postural Stresses	8	1	3
Pulse Rate	3	1/3	1

The 3X3 matrix contains all of the pair-wise for the criteria which is shown in the table 4.6

Table 5.6 Pair-wise comparison matrix in digital form

Selecting the best welding posture	Bodily Discomfort	Postural Stresses	Pulse Rate
Bodily Discomfort	1.000	0.125	0.333
Postural Stresses	8.000	1.000	3.000
Pulse Rate	3.000	0.333	1.000

The column labelled 3rd root of criteria in the matrix is shown in the table 4.7. The 3rd root of criteria values in each row were calculated as:

Bodily Discomfort: $(1.000 \text{ X } 0.125 \text{ X } 0.333)^{1/3}$=0.347

Postural Stresses: $(8.000 \text{ X } 1.000 \text{ X } 3.000)^{1/3}$=2.884

Pulse Rate: $(3.000 \text{ X } 0.333\text{X } 0.333)^{1/3}$=1.000

Each of the aforementioned 3rd root of criteria were then added together to get 4.231.

Table 5.7 Pair-wise comparison matrix with 3rd root of criteria

Selecting the best welding posture	Bodily Discomfort	Postural Stresses	Pulse Rate	3rd root of criteria
Bodily Discomfort	1.000	0.125	0.333	0.347
Postural Stresses	8.000	1.000	3.000	2.884
Pulse Rate	3.000	0.333	1.000	1.000
				4.231

Column labelled Priority Vector in the 3X3 matrix is shown in the table 5.8. The 3rd root of criteria and total values will be normalized to get the appropriate weights for each criterion. The weights for each criterion were calculated as follows.

Bodily Discomfort: (0.347/4.231)=0.082

Postural Stresses: (2.884/4.231)=0.682

Pulse Rate: (1.000/4.231)=0.236

Table 5.8 Pair-wise comparison matrix along with priority vector

Selecting the best welding posture	Bodily Discomfort	Postural Stresses	Pulse Rate	3rd root of product	Priority Vector
Bodily Discomfort	1.000	0.125	0.333	0.347	0.082
Postural Stresses	8.000	1.000	3.000	2.884	0.682
Pulse Rate	3.000	0.333	1.000	1.000	0.236
				4.231	1.000

The pairwise comparison values in each column were added together and each sum was then multiplied by the respective weight for that criterion which is shown in a tabulated form in table 5.9.

Table 5.9 Calculating and checking the consistency ratio (CR)

Selecting the best welding posture	Bodily Discomfort	Postural Stresses	Pulse Rate	3rd root of product	Priority Vector
Bodily Discomfort	1.000	0.125	0.333	0.347	0.082
Postural Stresses	8.000	1.000	3.000	2.884	0.682
Pulse Rate	3.000	0.333	1.000	1.000	0.236
Sum	12.000	1.485	4.333	4.231	1.000
Sum* PV	0.983	0.994	1.024	3.002	

The product of sum and priority vectors were added together to yield a total of 3.002 which is known as λ_{max} shown in the table 5.10. The consistency index (CI) was 0.001 for three different numbers of criteria being compared in this work. The consistency ratio (CR) was calculated as CR=CI/RI =0.001/0.58=0.001. The CR value was less than 0.10 so pairwise comparisons were relatively consistent.

Table 5.10 Calculation of λ_{max}, CI and RI value

Selecting the best welding posture	Bodily Discomfort	Postural Stresses	Pulse Rate	3rd root of product	Priority Vector
Bodily Discomfort	1.000	0.125	0.333	0.347	0.082
Postural Stresses	8.000	1.000	3.000	2.884	0.682
Pulse Rate	3.000	0.333	1.000	1.000	0.236
Sum	12.000	1.485	4.333	4.231	1.000
Sum* PV	0.983	0.994	1.024	3.002	
λ_{max}=	3.002				
CI=	0.001				
CR	0.001				

Now, the rating for each decision alternative for each criterion has been determined. So one pair- wise comparison matrix for each criterion has been chosen and rating has been done relative to other system accordingly. Bodily discomfort, postural stresses and pulse rate have been identified as criteria for selecting best weld posture. Three matrices -bodily discomfort, postural stresses and pulse rate have been developed accordingly. Within each of the aforementioned three matrices, a pair wise comparison has been done for each postural position against every other postural position relative to that criterion. Since there were three postural positions under evaluation, so each matrix must be of 3x3 pattern.

It was determined that bodily discomfort for sitting posture was moderately preferred to knee posture which was given a value 3. Bodily discomfort for sitting posture was extremely preferred to standing posture and the value was 9. Finally bodily discomfort for knee posture was strongly preferred to standing posture and was given a value 6. The remaining values in the form of matrix, represented the reciprocal pair-wise comparison relationships are shown in table 5.11.

Table 5.11Comparison with respect to bodily discomfort of welders

		Sitting Posture	Knee Posture	Standing Posture	3rd root of product	Priority Vector
Bodily Discomfort	Sitting Posture	1.000	3.000	9.000	3.000	0.664
	Knee Posture	0.333	1.000	6.000	1.260	0.278
	Standing Posture	0.111	0.167	1.000	0.265	0.058
	Sum	1.444	4.167	16.000	4.524	1.000
	Sum* PV	0.958	1.160	0.936	3.054	
	λ_{max}=	3.054				
	CI=	0.027				
	CR=	0.046				

The postural stresses for knee postural position was equally to moderately preferred to sitting postural position of welders. It was represented by a value 2. Very to extremely strong preference of postural stresses of standing postural position was given compared to sitting postural position. It was denoted by a value 8. The postural stresses for standing postural position of welding workers was strongly preferred to knee Postural position. It was indicated by a value 5. Table 5.12 describes the ratings of postural stresses for different postural positions of welders.

Table 5.12 Comparison with respect to postural stresses of welders

		Sitting Posture	**Knee Posture**	**Standing Posture**	**3rd root of product**	**Priority Vector**
Postural Stresses	**Sitting Posture**	1.000	0.500	0.125	0.397	0.087
	Knee Posture	2.000	1.000	0.200	0.737	0.162
	Standing Posture	8.000	5.000	1.000	3.420	0.751
	Sum	11.000	6.500	1.325	4.554	1.000
	Sum* PV	0.969	1.052	0.995	3.006	
	λ_{max}=	3.006				
	CI=	0.003				
	CR=	0.005				

The table 5.13 describes the ratings of pulse rate for different postural positions of welders. From the table 5.13 it was clearly stated that pulse rate for sitting postural position was equally preferred to knee postural position of welders. Strongly preference was given to pulse rate of sitting posture compared to standing postural position. It was denoted by a value 6. The pulse rate for knee postural position of welding workers was moderately preferred to standing postural position. It was indicated by a value 3.

Table 5.13 Comparison with respect to pulse rate of welders

		Sitting Posture	Knee Posture	Standing Posture	3rd root of product	Priority Vector
Pulse Rate	Sitting Posture	1.000	1.000	6.000	1.817	0.499
	Knee Posture	1.000	1.000	3.000	1.442	0.396
	Standing Posture	0.167	0.333	1.000	0.382	0.105
	Sum	2,167	2.333	10.000	3.642	1.000
	Sum* PV	1.081	0.924	1.048	3.054	
	λ_{max}=	3.054				
	CI=	0.027				
	CR=	0.046				

Table 5.14 Calculating overall priority

Criteria (Weights) / Alternatives	Bodily Discomfort (0.082)	Postural Stresses (0.682)	Pulse Rate (0.236)	Overall Priority (1.000)
Sitting Posture	0.664	0.087	0.499	0.232
Knee Posture	0.278	0.162	0.396	0.226
Standing Posture	0.058	0.751	0.105	**0.542**
	1.000	1.000	1.000	1.000

It was determined that the final scores for each postural position by multiplying the criteria weights by the ratings for the decision alternatives for each criterion and summing the respective products.

For Sitting Posture (alternative-1): (0.082 X 0.664) + (0.682 X 0.087) + (0.236 X 0.499) =0.232

Knee Posture (alternative-2): (0.082 X 0.278) + (0.682 X 0.162) + (0.236 X 0.396) =0.226

Standing Posture (alternative-3): (0.082 X 0.058) + (0.682 X 0.751) + (0.236 X 0.105) =**0.542**

The priorities of different alternatives are shown in the table 5.14.

Hence, from the above calculations it was clear that standing posture was the best welding postural position among all postural positions of welders during the operation because it possesses the highest value.

5.13 TOPSIS Analysis and Discussion

The TOPSIS analysis has been done to analyse the postural conditions of the welders on the basis of the parameters of intensity of stress in particular node points in different postural positions. Five crucial node points and the respective stress values have been taken for the analysis.

5.13.1 TOPSIS Analysis of Postural Stresses (Pa) [Intensity of Stress]

The decision matrix is shown in the table 5.15 where the postural stress values in Pascal (P_a) were arranged in respective columns and postural positions (P1, P2 and P3) were arranged in rows. The SOS ($\sum_{j=1}^{n} X_{ij}^2$) and RSOS ($\sqrt{\sum_{j=1}^{n} X_{ij}^2}$) were calculated using the respective formula.

Table 5.15 Decision Matrix

N O D E ⟶

P O S T U R E ↓

Criteria / Alternative	N 5791	N 11581	N 13511	N 15441	N 19301
P1(Knee)	60338	1637600	1906200	2744300	45299
P2 (Standing)	16565	2230800	208790	114790	944650
P3(sitting)	128950	2256100	257130	267250	38538

The weight of each criterion (value of intensity of stress of each node point in P_a) was taken as 0.2 for the formation of weighted normalized decision matrix which is shown in the table 5.16.

Table 5.16 Weighted normalized decision matrix

NODE →

POSTURE ↓

Criteria / Alternative	N 5791	N 11581	N 13511	N 15441	N 19301
P1(Knee)	0.4209	0.4586	0.9852	0.9944	0.0478
P2 (Standing)	0.0109	0.6247	0.1079	0.0415	0.9980
P3(sitting)	0.8996	0.6318	0.1329	0.0968	0.0407

In the final stage, the separation measures were calculated by using the equations $S_i^+ = \sqrt{\{\sum_{j=1}^{n}(v_{ij} - v_j^+)^2\}}$ and $S_i^- = \sqrt{\{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2\}}$. The values which indicated the relative closeness to the solution were obtained by equation $\mathbf{P_i} = \frac{S_i^-}{S_i^+ + S_i^-}$ $(0<P_i<1)$. The weighted decision matrix with positive and negative ideal solutions is shown in the table 5.17.

Table 5.17 Weighted decision matrix with positive and negative ideal solutions

N O D E →

P O S T U R E ↓

Criteria / Alternative	N 5791	N 11581	N 13511	N 15441	N 19301	S_i^+	S_i^-	P_i
P1(Knee)	0.08418	0.09172	0.15704	0.1988	0.00956	0.2447	0.2154	0.4651
P2 (Standing)	0.00218	0.12494	0.02158	0.0083	0.1996	0.19432	0.2936	**0.6017**
P3(Sitting)	0.17992	0.12636	0.02658	0.01936	0.00814	0.1814	0.2317	0.5608
V_i^+	0.00218	0.09172	0.02158	0.00830	0.00814			
V_i^-	0.17992	0.12636	0.15704	0.1988	0.1996			

The rankings of the postural positions are reached according to the performance index values. Sorting of the evaluated alternatives S_i^+, $S_i^-$and **P_i** values are shown in Table 5.18. If the performance index value is higher, it means that it is closer to the distance from ideal solution and it is further from the negative ideal solution.

Table 5.18 S_i^+, $S_i^-$and P_i values

Postural Position	S_i^+	S_i^-	P_i
P1(Knee)	0.2447	0.2154	0.4651
P2 (Standing)	0.19432	0.2936	**0.6017**
P3 (Sitting)	0.1814	0.2317	0.5608

After analyzing the data (stress values w.r.t node points) by TOPSIS method, it was found that standing welding posture was the best among the postures taken into consideration.

5.13.2 TOPSIS Analysis of Postural Stresses (Pa) [Equivalent (Von-Mises) Stress]

The decision matrix is shown in the table 5.19 where the equivalent stress values in Pascal (P_a) were arranged in respective columns and postural positions (P1, P2 and P3) were arranged in rows. The normalized decision matrix is also shown in the table 5.20 The SOS and RSOS were calculated using the respective formula.

Table 5.19 Decision matrix

Criteria / Alternative	N-5791	N-11581	N-13511	N-15441	N-19301
P_1(Knee Posture)	43026	1013400	1088400	2657800	240480000
P_2(Standing Posture)	59701	371620	212610	296120	39446000
P_3(Sitting Posture)	28471	12326000	382310	851460	11164000
$\sqrt{\sum_{j=1}^{n} X_{ij}^2}$	78905.2	12373170	1173021	2806523	243949282

Table 5.20 Normalized decision matrix

Criteria / Alternative	N-5791	N-11581	N-13511	N-1544	N-19301
P_1(Knee Posture)	0.545	0.0819	0.9278	0.94700	0.9857
P_2(Standing Posture)	0.7566	0.0300	0.18124	0.1055	0.16169
P_3(Sitting Posture)	0.360	0.996	0.3259	0.3033	0.0457
$\bar{X}_{ij} = \frac{X_{if}}{\sqrt{\sum_{j=1}^{n} X_{if}^2}}$					

The weight of each criterion (value of equivalent stress of each node point in P_a) was taken as 0.2 for the formation of weighted normalized decision matrix which is shown in the table 5.21.

Table 5.21 Weighted normalized decision matrix

Wt	0.20	0.20	0.20	0.20	0.20
Criteria / Alternative	**N-5791**	**N-11581**	**N-13511**	**N-1544**	**N-19301**
P_1 (Knee Posture)	0.109	0.1638	0.18556	0.1894	0.19714
P_2 (Standing Posture)	0.15132	0.006	0.036248	0.0211	0.0323
P_3 (Sitting Posture)	0.072	0.1992	0.06518	0.06066	0.00914

In the final stage, the separation measures were calculated by using the equations $S_i^+ = \sqrt{\{\sum_{j=1}^{n}(v_{ij} - v_j^+)^2\}}$ and $S_i^- = \sqrt{\{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2\}}$. The values which indicated the relative closeness to the solution were obtained by equation $\mathbf{P_i} = \frac{S_i^-}{S_i^+ + S_i^-}$ $(0<P_i<1)$.The weighted decision matrix with positive and negative ideal solutions is shown in the table 5.22.

Table 5.22 Weighted decision matrix with positive and negative ideal solutions

Criteria / Alternative	**N-5791**	**N-11581**	**N-13511**	**N-1544**	**N-19301**
P_1	0.109	0.1638	0.18556	0.1894	0.19714
P_2	0.15132	0.006	0.036248	0.0211	0.0323
P_3	0.072	0.1992	0.06518	0.06066	0.00914
V_j^+	0.072	0.006	0.036248	0.0211	0.00914
V_j^-	0.15132	0.1992	0.18556	0.1894	0.19714
S_i^+	0.2203	0.1993	0.0826		
S_i^-	0.1846	0.26963	0.3392		

The rankings of the postural positions were reached according to the performance index values. Sorting of the evaluated alternatives S_i^+, S_i^- and $\mathbf{P_i}$ values are shown in Table 5.23.

Table 5.23 Si+, S_i^- and Pi values

Postural Position	S_i^-	$S_i^+ + S_i^-$	$P_i = \frac{S_i^-}{S_i^+ + S_i^-}$
P1(Knee)	0.1846	0.4049	0.4559
P2 (Standing)	0.26963	0.4218	0.80417
P3(Sitting)	0.3392	0.46893	0.5510

If the performance index value is higher, it means that it is closer to the distance from ideal solution and it is further from the negative ideal solution.

5.14 Ergonomically Designed Workstation Based on Analysis of Posture

An Ergonomically designed work station was achieved based on postural stresses, working ability, score of RULA, REBA and other constraints defined by the user. While studying the welding job, welders assume different awkward postures like bending and sitting with cross legs, squatting posture (knee posture) with heel raise. During welding operation, there is tremendous pressure on tarsal and metatarsal region of the foot of welders as well as excessive moment created on the knee involving both quadriceps and hamstring. Since the welders experienced lot of pain and discomfort around the upper and lower legs also the lower back, the author has undertaken to design welder’s job table so that they can be relived from the awkward posture.

In view of the posture mentioned above and to resolve the problems experienced by the welders, author considered, the welding job to be performed on standing posture and accordingly a welder’s job table has been designed.

Since the author proposed to design a job table where the welders can perform their job with standing posture, Research communities in the field of Ergonomics always advocate for standing job and the work surface height should be at elbow height. Since the floor is contaminated with different scrap materials which may likely to injure the welders, hence author always recommends to use shoes while welding. As the welding job is considered to be heavy job, required much effort to be applied either downwards or sideways, so the recommendation offered by Grandjean [53] is taken in to account and can be expressed as

Job height to be = Mean elbow height ± 1.945xSD + Shoe height ± Recommended mid-range height w.r.t elbow height.

The mid-range height varies with the amount of force being applied on the object to be welded which range from 15 to 40 cm below elbow.

5.14.1 Design of Work Space:

It is a kind of a space where the activity of the workers is going on and defined by three dimensional characters. Considering the different extreme part of the body including the tool (electrode holder) or equipment being handled by the welders, the dimensions of the workspace should be taken as 167±SD.

While carrying out the research work, it is found that the welders usually handle the object owing between 12 to 17 Kgs.

5.14.2 Factors Related with Musculoskeletal Symptoms

It has been noticed that indication of musculoskeletal disorders of different body regions of welders were significantly related with welding type, working posture, working time and type of job table. The individual factors like age, gender and marital status were also associated with musculoskeletal problems for each body region. The major Ergonomic factors noticed to be associated with musculoskeletal problems that were discussed with the ultimate goal of developing guidelines for design of welding workstation to improve working posture and to reduce postural stresses.

(i) Welding Type

The prevalence rates of discomfort symptoms in the neck, back, arms, shoulder and thigh were statically higher of welding workers. It is shown from the figure 3.4 that the welding was done in the welding units on the ground for long period of time continuously. It was done on kneeling posture as the fixture used for welding was placed on the ground. It was observed that due to continuous welding, the neck as well as back was bent considerably and knees were completely folded so that welders got fatigued and musculoskeletal problems were identified.

(ii) Working Posture

Lack of work station adjustability in welding operation can be the main cause of constrained and challenging posture. For ground welding operation the job table was the determinant factor for neck, shoulder and arm postures. No attention had been given to easy adjustability of the job table and its easy rotation.

(iii) Daily Working Time

Daily working time was not usually fixed in welding units. Depending on the work load and situation it may be varied. Earning more money insisted the welders to work for longer period of time. This might be the cause of prolonged exposure to MSDs risk factors and an increased risk factor of sicknesses. More than 50% of the welders worked more than 8 hrs. per day and 20% of the welders worked 10 hrs. per day or more. The daily working hours have a direct association with MSDs symptoms and it was a significant factor for MSDs of all body parts of the welders.

(iv) Job Table

Welders' job table was one of the most significant factors for MSDs of all body regions of the welding workers. There was no proper job table in the welding work station during the operation. It has been observed from the Ergo Fellow as well as RULA, REBA and OWAS analysis that the musculoskeletal problems in the back, wrist, hands, legs and knees occurred in higher rates among welders. So job table was the significant factor retained in the models for musculoskeletal symptoms.

5.14.3 General Guidelines for Workstation Design

Based on the results of the present study, the following recommendations were suggested as general Ergonomic guidelines for design of welding work station. This guidance was towards the elimination of restrictions, awkward postures and improving working conditions, body stresses as well as improvement of the quality of jobs. The welder's job table and different parts are shown in the figure 5.42.

5.14.4 Special Features of Welder's Job Table

1. Height of job table and its dimension should be adjustable to permit a natural working posture to the welders.
2. Welding table should be folded type and easy to handle.
3. Top of table should be tilt maximum 20^0 towards the welders so that the trunk bent of welders should be minimum.

4. The controls for changing the dimensions of the welding job table should be easy to handle.

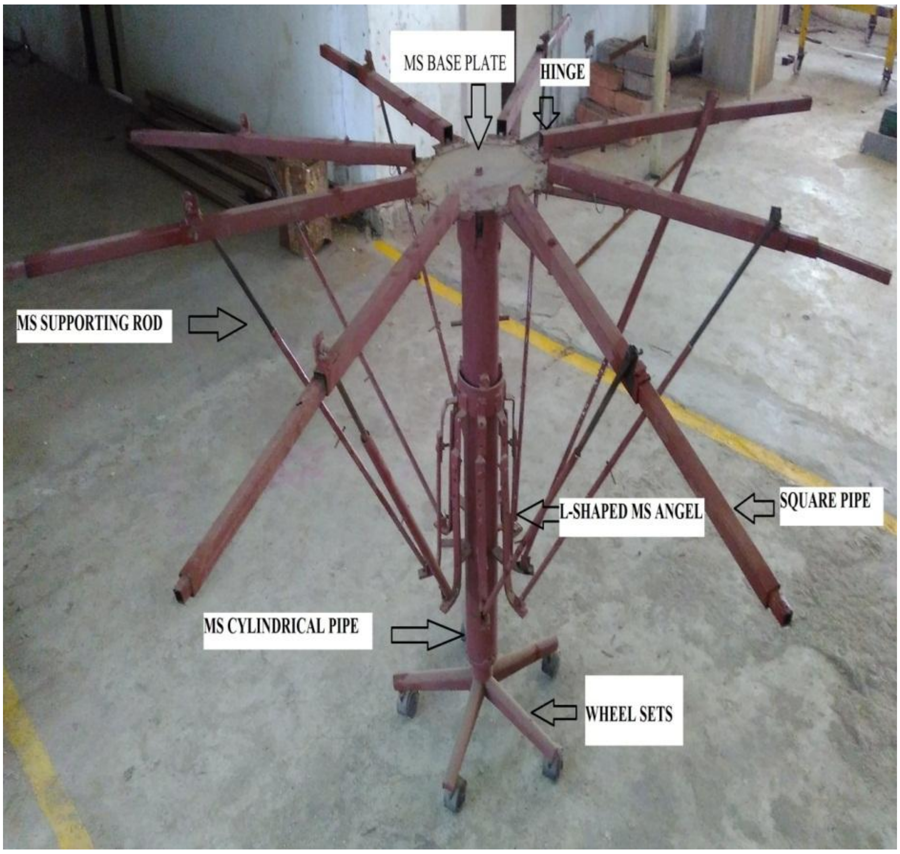


Figure 5.42 Designed & Fabricated Welder’s job table with different parts

CHAPTER-6

GENERAL CONCLUSIONS

6.1GENERAL CONCLUSIONS

There is no awareness about Ergonomics in welding industries and welding workstations among workers in West Bengal.

Based on the scope and limitations of the present investigation and research, the following conclusions may be drawn from the results analysis on welders throughout West Bengal.

i. It can be concluded that MSDs were present in the activities carried out in welding units where major number of workers were involved in bad work postures. From the comparison graph it was clear that the value of RULA score in standing postural position of welders decreased by 57% and 50% respectively, compared to knee and sitting posture. Similarly REBA score in standing posture reduced by 75% and 60% respectively, compared to knee and sitting posture of welders. So standing posture may be the acceptable posture.

ii. The FEA results showed that the Maximum intensity of stress in standing posture reduced by 48.69% and 3.56% respectively, compared to knee and sitting posture of welders. The FEA analysis also showed that maximum intensity of Von-Mises stress in standing posture decreased by 46.80% and 7.20% respectively, compared to knee and sitting posture of welders. So standing posture may be the acceptable posture.

iii. Based on the results of investigation this may be concluded that the disk compressive force in standing posture reduced by 38.16% and 16.12% respectively, compared to knee and sitting posture of welders. So this present research work is to give the researchers a better understanding about the different joints of the upper extremity of the human body and the most stressed muscle during welding operation.

iv. It may be concluded that the method AHP was quite capable and very easy to evaluate as well as it has selected the proper welding postural position from a given set of alternatives. In order to reach at the final ranking of the alternatives, this AHP method used the measures of the considered criteria with their relative importance. Thus, this popular MCDM method can be successfully employed for solving any type of decision-making problem having any number of criteria and alternatives in any engineering domain.

v. The selection of a proper body posture of workers for particular welding operation involves a large number of considerations. The use of TOPSIS method was observed to be quite capable and easy to evaluate and select the proper body posture from a given set of alternatives.

vi. The majority of Ergonomic shortcoming and important factors for musculoskeletal symptoms in welding operations originated from ill- designed welding workstations. It can therefore be concluded that any working conditions improvement programme in this industry has to focus on designing Ergonomic oriented welding workstations.

The new welding workstation based on the developed design guidelines was generally acceptable to the welders and contributed to an improved working posture. The results of the prototype test demonstrated that the newly design improved working conditions consequently, might reduce prevalence of MSDs symptoms. Although working posture and workstations adjustability have been considerably improved in this prototype, further work is needed to develop quantitative guidelines for optimizing the working posture.

6.2 Future Scope of Work

At this stage, author feels that further research and development work was needed in this area of postural analysis of welding workers in SSI of West Bengal.
So, the following suggestions on future work may be drawn:

i. Manufacturing is the back bone of any industrialized nation and welding is one of the main processes of manufacturing. In this research work body postures, bodily discomfort, low back compressive force and postural stress of welders were studied specially for arc welders. Therefore, similar types of analysis and studies like gas welding workers may be conducted. It was also found that there were many objects having different arms, making the objects to be more volume. Under these circumstances the design of job table in the present study will have some limitations.

ii. This research work would be very useful for the workers working in any unorganized small scale unit. The body stresses, physical and mental fatigue of welders for this working process can also be validated and then integrated in to work evolution system in the future.

However, the author believes that the present investigation and subsequent analyses on welders will provide fruitful and technical information to the researchers, scientists and engineers who are working in the area of postural analysis of workers in small scale industries.

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