FINITE ELEMENT ANALYSIS OF INFINITE RESERVOIR WITH EFFECT OF SURFACE WAVE

A thesis paper submitted by

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CERTIFICATE OF RECOMMENDATION

This is to certify that JYOTIRMAY BISWAS (Exam Roll No., Registration No. 160040 of 2021-2022) has carried out the thesis work entitled "**FINITE ELEMENT ANALYSIS OF INFINITE RESERVOIR WITH EFFECT OF SURFACE WAVE**" under my direct supervision and guidance. He has carried out this work independently. I hereby recommend that the thesis be accepted in partial fulfilment of the requirements for awarding the degree of "**MASTER OF ENGINEERING IN CIVIL ENGINEERING (STRUCTURAL ENGINEERING)**".

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CERTIFICATE OF APPROVAL

This foregoing thesis is hereby approved as a creditable study of an engineering subject carried out and presented in a manner satisfactory to warrant it's acceptable as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made, opinion expressed or conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

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DECLARATION

I, JYOTIRMAY BISWAS, Master of Engineering in Civil Engineering (Structural Engineering), Jadavpur University, Faculty of Engineering and Technology, hereby declare that the work being presented in the thesis work entitled, **"FINITE ELEMENT ANALYSIS OF INFINITE RESERVOIR WITH EFFECT OF SURFACE WAVE"**, is an authentic record of work that has been carried out in the Department of Civil Engineering, Jadavpur University, Kolkata under **Mr. SANTOSH KUMAR DAS**, Assistant Professor, Department of Civil Engineering, Jadavpur University. The work contained in this thesis has not yet been submitted in parts or full to any other university or institute or professional body for award of any degree or diploma or any fellowship.

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DEDICATED TO MY RESPECTED PARENTS AND SPECIALLY TO MY THESIS GUIDE

SYNOPSIS

A gravity dam store huge water. Retained water is utilised for agriculture, hydroelectric power production and flood control. A major challenge in dam design is the accurate prediction of hydrodynamic pressure on the dam. When analysing a structure like dam with an irregular geometry, the most effective tool is finite element analysis. The modelling of a reservoir using a displacement-based technique may produce spurious modes with no real-world use. Hydrodynamic pressure is calculated using an Eulerian technique to get around this issue. The number of nodal unknown parameters is minimised in this pressure-based method. Due to the indefinite length of reservoir, calculating the hydrodynamic pressure on a concrete gravity dam becomes quite challenging. The reservoir is truncated at a fixed distance from the dam face in order to solve this problem. The reservoir bottom is taken to be rigid in order to simplify the analytical process, even though this does not accurately reflect the true behaviour. Due to the fact that some of the energy of hydrodynamic waves is absorbed by the silt that is deposited at the bottom of reservoir, this assumption overestimates the magnitude of hydrodynamic pressure. The value of hydrodynamic pressure is significantly impacted by the effect of surface wave.

In present analysis, fluid is assumed as linearly compressible and non viscous. Bottom absorption effect is considered. In order to shorten the computation time, the infinite reservoir is truncated to a certain length. Pressure based approach is used to determine hydrodynamic pressure at dam i.e., pressure is the only nodal unknown parameter. Finite element method is used to discretize the reservoir medium. Dam reservoir interface is considered as vertical. The analysis is restricted to two dimensional. A MATLAB code is developed for analysis purpose. The hydrodynamic pressure coefficient is obtained for considering the effect of surface wave and without surface wave. Hydrodynamic pressure distribution and time history plot of hydrodynamic pressure coefficient is evaluated for harmonic excitation. Velocity profile plot of fluid is obtained for considering the effect of surface wave and neglecting surface wave for particular instant of time. When the impact of the surface wave is taken into account, the hydrodynamic pressure at the heel of dam decreases. It has been found that at the face of dam the deflection of free (top) surface is higher and velocity profile is irregular when considering the effect of surface wave and the deflection is less and velocity profile is regular and quiet uniform when the effect of surface wave is neglected. It has been also found that the disturbance of top surface is high when effect of surface wave is considered.

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CHAPTER 1

INTRODUCTION

Dams are typically constructed with a drain or similar mechanism to control water level in an impoundment of normal maintenance for emergency purposes. Dam is useful for hydroelectric power, flood control protection and recreational amenities. Dams and large reservoirs constructed on the area with high seismicity, pose a high-risk potential for downstream life and property. Hydrodynamic pressure due to ground shaking from earthquake can damage the dam. So, Hydrodynamic pressure on the upstream face of the concrete dam under the effect of earthquake is one of the most important parameters. Hydrodynamic pressure depends upon geometrical property and behaviour of reservoir adjacent to dam. To determine hydrodynamic pressure different methods are presented which are divided into two main groups. One is Eulerian and the other one is Lagrangian. In, Eulerian approach, pressure is main unknown parameter and for Lagrangian approach main unknown parameter is nodal displacement. The dam and reservoir systems are modelled using the finite element method. In order to shorten the computational time, an unbounded reservoir is truncated to an appropriate length. As the hydrodynamic pressure depends on the truncation boundary condition, it is crucial to apply the proper non-reflective boundary condition along the truncated face. The hydrodynamic pressure is also influenced by the reservoir bottom absorption coefficient. Different factors affect the hydrodynamic pressure include the height of the reservoir, inclination of bottom of reservoir with horizontal, angle of the dam-reservoir interface and the effect of surface wave.

In the present study, the two-dimensional geometry of the reservoir is discretized using eight node isoparametric elements. The nodal unknown parameter is pressure. Dam is considered as rigid. Dam reservoir interface is considered as vertical. Fluid is assumed as linearly compressible and non-viscous. Reservoir bottom is considered as rigid and absorptive. At the truncation surface, an appropriate non-reflecting boundary condition which is developed by Gogoi and Maity, 2006 is used. Hydrodynamic pressure is determined by applying harmonic excitation. Hydrodynamic pressure is obtained at the face of dam for different conditions like considering the effect of surface wave and neglecting the surface wave. Time history plot of hydrodynamic pressure is also evaluated with the effect of surface wave and neglecting the surface wave. Velocity and deflection profile plot of fluid is obtained for considering the effect of surface wave and neglecting surface wave for particular instant of time. For the purpose of analysis, a MATLAB code is created. The dynamic equilibrium equation is solved using Newmark's integration technique.

LITERATURE REVIEW

2.1 GENERAL

Following Literature review of published research on hydrodynamic pressure of dam reservoir system is done to identify the gaps and establish the context .Observation of literature and scope of work is done later with the help of review of literature.

2.2 REVIEW OF LITERATURE

WESTERGAARD (1933) did the first extensive and rigorous analysis of pressure on upstream face of vertical dam. Vibration was assumed horizontal i.e., orthogonal to the upstream face of dam. He obtained a formula having series of sine. Later on, he made it into a simpler approximation with the help of a simpler formula.

CHAKRABARTI AND CHOPRA (1973) investigated the hydrodynamic pressure and earthquake response of a concrete gravity dam including dam-reservoir interaction. The earthquake responses of the horizontal and vertical components were compared. In this analysis, the frequency response for dam displacement, acceleration, and lateral hydrodynamic force is assessed. The dam-reservoir system's motion is confirmed to be two dimensional. To evaluate the time history of reactions at various heights, the Fourier transformation method is used. In this analysis, the complex frequency response is calculated. The dam is recognised as stiff when the relationship between the dam and reservoir is being negotiated. This experiment demonstrates the excitation caused by the vertical components of the ground accelerations at the EI Centro, California earthquake. In this study, the vertical components of earthquake ground motion are also developed. It has been demonstrated that the hydrodynamic force of the dam depends on the elastic modulus.

CHWANG AND HOUSNER (1978) evaluated hydrodynamic pressure on sloping dam on the basis of momentum balanced principles. He found that hydrodynamic pressure reduces when the slope reduces for any said height (fixed) and for a fixed slope hydrodynamic pressure increases with depth under the water surface and always attain a highest value at the bottom of the reservoir. His results also showed that it exactly matched with von karman results when upstream becomes vertical.

CHWANG (1978) determined hydrodynamic pressure during earthquake on a rigid sloping dam by two-dimensional potential flow theory. Distribution of the hydrodynamic pressure parallel to the Sloping Dam was determined. It was also noted that the normal force coefficient is more or less practically constant (0.5) for all slopes. He showed that for any fixed height both the pressure based on exact theory and momentum method reduces as the inclination angle reduces. His result also showed that for fixed values of inclination angle the exact theory gives the highest pressure at some distance above reservoir base except when inclination angle is 90° while momentum method said maximum pressure occurs at base of reservoir. He also showed that when upstream side is vertical the exact theory gives same result as westergaard's (1933) result while momentum method gives same results as von karman's(1933) results.

SAINI, BETTESS AND ZIENKIEWICZ et al. (1978) presented the application of the finite element method for analysing the two-dimensional response of reservoir-dam systems subjected to horizontal ground motion. The dam reservoir interaction and compressibility of fluid is considered. The whole system is analysed considering two sub systems namely the reservoir and the dam. Dam is considered as finite one where as reservoir is considered infinite and it has been converted in to finite one by some techniques. It is concluded that the effect of radiation damping is considerable at high frequencies of excitation.

CHOPRA AND CHAKRABARTI (1981) presented a general procedure for analysis of the response of concrete gravity dams including the dynamic effects of impounded water and flexible foundation rock. The system is analysed under the assumption of linear behaviour for the concrete, foundation rock and water. The complete system is considered as composed of three substructures-the dams, represented as a finite element system, the fluid domain, as a continuum of infinite length in the upstream direction, and the foundation rock region as a viscoelastic half-plane. The generalized displacements due to earthquake motion are computed by synthesizing their complex frequency responses using Fast Fourier Transform procedures. The stress responses are calculated from the displacements.

KUO (1982) represented a dam-reservoir system to examine the hydrodynamic effect including the incompressible fluid in the system. The hydrodynamic impact of the reservoir is calculated using the added mass method. The geometry of the concrete dam is calculated using the generalised Westergaard formula and the Galerkin finite element method by analysing the added mass matrix. The Westergaard formulation calls for a number of assumptions, including that the dam is two-dimensional, that fluid particle displacement is kept to a minimum, and that only horizontal ground motion is relevant. The hydrodynamic pressure components are combined into an equivalent hydrodynamic nodal force component in the Galerkin finite element method. The dam-reservoir interface is discretized into 2D finite elements and the reservoir domain into 3D finite elements. The system's response is acknowledged to be non-linear.

FENVES AND CHOPRA (1983) suggested a substructure method to analyse hydrodynamic pressure of dam-reservoir interface with consideration of flexible foundation rock. The impact of the sediment at the reservoir's bottom was also considered in this study. The dam-reservoir system was viewed as a two-dimensional system with linear behaviour. To validate the solution's findings, an earthquake study was performed. The computation times for many scenarios were noted, and it was determined that the bottom absorption effect's computation times were very short.

SHARAN (1985) developed a technique to model radiation damping effect in finite element analysis of hydrodynamic pressure subjected to a harmonic horizontal ground motion on dam. He developed simple boundary condition to model the radiation damping effect in finite element analysis of vibration of an infinite reservoir. He used two-dimensional approximation and assumed that bottom of reservoir is rigid and horizontal and the motion of ground is horizontal and harmonic. In this method, a very short length along infinite reservoir is needed to be considered in discretization. A length equal to one-tenth of height of reservoir is found to be sufficient as compared to the necessity of a length equal to twice of height in the use of sommerfield. So, it reduces computation, he also showed that excitation frequencies less than natural frequency of dam, the normal pressure gradient the length is directly proportional to the pressure but not in time rate of change of pressure. His work is not justified for frequency-dependent radiation condition.

TSAI AND LEE (1987) used finite element analysis for dam and boundary element for the fluid for the three-dimensional analysis of the dam-reservoir system. In order to increase computational efficiency and accuracy, fundamental solution satisfying the free surface boundary condition and quadratic elements are used. They obtained singular terms by using a solution of the governing equation of fluid domain. In order to save computing time, it is required to retain the banded and symmetric characteristic of the mass matrix which is obtained by the non-symmetric and full added mass matrix induced from the symmetrized of the reservoir substructure. They concluded that much less time and more accurate result is obtained by using the half space fundamental solution and using quadratic elements can give good accuracy.

SHARAN (1987) proposed a damper for time domain analysis of a compressible fluid domain. This damper is use to model the effect of radiation damping in the finite element analysis of generated hydrodynamic pressures due to small amplitude vibration of a structure submerged in a compressible fluid. He assumed two-dimensional domain and neglect the effect of surface waves. He also considered pressure to be nodal unknown and an implicit direct integration scheme solved the discretized equation of motion. As the analysis of several cases, he found that the proposed damper is effective and efficient for wide range of period of excitation. Implementation of proposed damper did not require any extra computational effort. Advantage of proposed technique is that the cost of computation is greatly reduced and infinitely fluid domain may be reduced at a comparable very short distance from the structure as compared to the sommerfield damper.

X.LI et. al (1995) dam-reservoir system by finite element analysis using far boundary condition. A nonlocal link between velocity potential and its derivative on far boundary condition was thought to occur in a reservoir with constant depth and flexible foundation. Comparatively speaking, the proposed far boundary condition has more parameters and series of terms that influence the precision of the outcomes' numbers. It is extremely effective for both normal and abnormal dams. It is also possible to utilise this study to analyse data in three dimensions and throughout time.

CALAYIR, DUMANOGLU AND BAYRAKTAR (1996) performed both Eulerian and Lagrangian approaches to analyse two-dimensional earthquake effect on gravity dam. Firstly, they investigated the effect of variation of fluid compressibility. Thereafter, response of earthquake of a dam-reservoir system is investigated using the lagrangian approach. They compared Eulerian and Lagrangian solutions of the dam reservoir system. For various fluid bulk modulus, the modal response analyses of gravity dam-reservoir were carried out. Then the results of these analysis were compared with each other as well as Eulerian solutions with basis of incompressible fluid assumption. They showed that it is possible to get closer to incompressible fluid solutions with the lagrangian approach though the lagrangian approach is based on compressible fluid assumption. But his approach is insignificant if the has large bulk modulus.

MAITY AND BHATTACHARYYA, (1999) The work in this paper is focusing on time domain analysis of a dam reservoir system using a novel far-boundary condition to model infinite fluid domain to a finite one assuming only pressure to be nodal unknown variable and fluid is compressible. They showed that accuracy and effectiveness of far boundary condition depends on the period of excitation. Limitation in this research manuscript is that it assumes soil to be rigid. Lastly, we can say it is simple and effective to develop to model the effects of radiation dumping in the finite element analysis of hydrodynamic pressure of compressible fluid on dams which is subjected to harmonic ground motion.

GHAEMIAN et. al (1999) proposed staggered solution method to model dam-reservoir interaction intime domain. To examine the cracking and response of the dam, a smeared analysis approach based on nonlinear mechanics' crack propagation was applied. When the dam-reservoir interaction is simulated using the additional mass method, a distinct fracture pattern is projected. The concrete-gravity-dam nonlinear response analysis is found to require accurate modelling of the dam-reservoir interaction.

BHATTACHARYYA AND MAITY (2005) The work in this paper focused on finite element analysis of infinite reservoir using novel far-boundary condition. Effect on the development of hydrodynamic pressure due to geometry of reservoir bed and the adjacent structure had been studied and it showed that there is a considerable effect on the development of hydrodynamic pressure at the dam -reservoir interface due to geometry of reservoir bed and adjacent structures. Limitation in this research manuscript is that it assumed water as inviscid and incompressible. At last, we can say it is simple and effective boundary condition that derived to model infinite reservoir into an equivalent finite reservoir, resulting great computational advantages.

KUCUKARSLAN (2005) used finite element method to analyse vibrating structure in an unbounded and incompressible and inviscid fluid with dam-reservoir interaction. The assumption used to derive the boundary condition was that the dam would vibrate along the normal direction of the vertical dam-reservoir contact. Additionally, the fluid's bottom was hard and horizontal. An issue with modelling a reservoir with an unlimited domain developed in the finite element formulation. The unbounded domain must be trimmed at a specific distance from the structure in order to solve this problem. By roughly approximating the analytical solution of the hydrodynamic pressure, a precise boundary condition along the truncating surface of an unbounded reservoir domain was created. To compare the outcomes of Sommerfeld and Sharan's boundary conditions, numerical research was conducted.

GOGOI AND MAITY (2006) proposed truncation boundary condition and also showed the efficiency of proposed boundary condition. They considered Sedimentary material in reservoir bottom which absorbs energy and that will affect the hydrodynamic pressure due to sediment is the reflection coefficient. They determined wave reflection coefficient based on sediment layer thickness, material property of dam and excitation frequencies. They assumed two-dimensional system and considered horizontal ground excitation and water is linearly compressible, inviscid. They expressed governing equation in terms of pressure only to reduce the degree of freedom. They presented effect of depth of sediment layer on reflection coefficient. They evaluated truncation boundary condition in complex form and it can account for excitation frequencies beyond the fundamental frequency of the reservoir. They investigated the effect of reservoir bottom absorption on the development of hydrodynamic pressure because of horizontal ground motion. They observed that proposed boundary condition produces accurate results for all ranges of excitation and the convergence is attained at very short distance away from dam reservoir interface. They also found that an increase in depth of sedimentation layer would reduce the reflection coefficient. If the frequency of the ground excitation is high then it is necessary to incorporate the effect of frequency dependent reflection coefficient in the analysis procedure.

SAMMI AND LOTFI (2007) suggested two different modal approaches for dynamic analysis gravity dam-reservoir system. The coupled and decoupled modal methods are two separate modal approaches. Mode calculation using the coupled modal technique is complicated by the accompanying unsymmetrical Eigen issue. Every step of the coupled modal technique allows for an efficient response to be obtained. However, in decoupled modes of the system, responses are simply determined by conventional eigenvalue solvers. This method also effectively solves the equation of motion. To evaluate the precision and effectiveness of the methodologies, a representative dam-reservoir system is also examined using both approaches.

SARKAR, PAUL AND STEMPNIEWSKI (2007) used concrete damaged plasticity model to simulate the damage induced in the dam body under a real- time earthquake motion. Non-linear concrete properties had been taken into consideration. They also showed influence of reservoir and foundation material on the dynamic response of concrete gravity dam. The model they used considered compressible reservoir water and linear elastic homogeneous foundation material. The damage in concrete due to tensile stress is simulated by the plasticity model and incorporated in ABAQUS. For simplicity, they considered only a separate monolith under the plane stress condition and assumed two-dimensional system to model compressible infinite reservoir domain. They used absorbing boundary condition along foundation-reservoir interface and viscous damping in form of stiffness-proportional damping also used. This model can't take into incorporation of anisotropicity of the material and shear strength of crack section. They concluded that the reservoir has no significant effect on the dynamic behaviour of the dam structure if reservoir depth is less than 0.7 times full reservoir depth. They showed that crack initiates at the point of slope change in the downstream side of the dam structure.

BIRK AND RUGE (2007) developed a approach to solve dam-reservoir interaction problem. It was modelled as a semi-infinite fluid-channel and analysis was done in time domain. With regard to the direction of wave propagation, a rigorous analytical solution was used to account for radiation damping. A system of linear equations in the frequency domain can be used in place of a rational function to approximate the resulting modal flux-pressure connection, which is a crucial step in the approach. On the basis of an iterative solution to the nonlinear optimisation problem that had been proposed, they offered an improved approximation approach. The finite element equations of the system's bounded portion can be coupled to the first-order differential equation system. After that, a direct time-domain analysis of the entire dam-reservoir system is possible. The suggested concept calls for a semi-infinite fluid channel with a constant cross-section that corresponds to parallel fluid layers produced via semi-discretization. Polar coordinates, or more broadly scaled boundary coordinates, were preferred to describe the semi-infinite fluid region in order to broaden the method's applicability.

PASBANI et al (2008) evaluated a finite element method to analyse dam-reservoir system. It was presumptuous that the fluid was non-viscous and incompressible. It is assumed that the reservoir's bottom is rigid and horizontal. The contact between the dam and reservoir is depicted as vertical. For both the vertical and horizontal earthquake components, the governing equation was used. Using Galerkin's method and eight-node elements, a finite element model was created. The proposed model is used to apply the Sommerfield boundary condition and the perfect damping boundary condition at the truncation boundary. The outcomes of the two boundary conditions are contrasted with the conclusions drawn from the analysis. Conclusion: Both the Sommerfield and perfect damping boundary conditions are accurately predicted by the suggested boundary condition. Additionally, it is determined that for greater accuracy, the distance of the truncated surface should be at least twice as much as the depth of the reservoir.

MOHAMMADI, AMIRI, NEYA AND DAVOODI (2009) evaluated hydrodynamic pressure in dam-foundation-reservoir systems and studied advantage and disadvantage of both Eulerian and Lagrangian method. They presented hydrodynamic pressure and dam crest point displacement with consideration of its interaction with reservoir and foundation. They evaluated dam displacement under earthquake for various dimensions. They showed Lagrangian method has greater answer in compare of response that Eulerian method. They concluded that increasing young's modulus of foundation, vibration period of system will decrease and with decreasing the depth of reservoir horizontal acceleration of earth response will decrease and reservoir depth has greater influence on the dam-reservoir foundation system. They also showed that reservoir bottom has little effect on response of the system and increasing upstream dam faced slope, the displacement of system will decrease.

BOUAANANI AND LU (2009) used finite element formulation to analyse earthquake excited dam-reservoir system. For the purpose of validating the potential-based finite element approach, frequency and time domain analysis were conducted. The effects of reservoir bottom absorption and fluid structural interaction were shown through the system's dynamic response. To support the proposed potential-based finite element formulation, they also presented a case study of a typical dam-reservoir interaction subjected to seismic excitation.

KOOHKAN, ATTARNEJAD AND NASSERI (2010) proposed a semi-analytical method to study the interaction between reservoir and concrete gravity dam. They assumed that reservoir is unbounded at the far end and the solution is seek for incompressible and in-viscid fluid. He showed that use of differential quadrature method, with a few grid points in conjunction with the finite difference method, yields an acceptable convergence of results. The gravity dam was modelled as variable beam section ignoring inclination of neutral axis. DQM is used for solution of the dam-reservoir interaction. The number of grid points was picked out in accordance with the order of derivatives in the equation. Delta points are used to get more accurate results.

GHORBANI AND PASBANI (2011) used finite element method. They examined the dam-reservoir system while assuming that the fluid was irrotational, incompressible, and non-viscous. The reservoir's bottom was viewed as being stiff and horizontal. By creating a symmetric matrix equation, the weighted residual standard Galerkin technique with eight node finite elements was applied to study the dam reservoir system. The development of the finite element algorithm solely took into account the vertical and horizontal earthquake components. In order to demonstrate that energy is lost in the reservoir in an infinitely upstream direction by radiation, a new boundary condition for an infinite fluid was created at the truncation surface. The suggested model allowed for the creation of a perfect damping boundary condition. To verify the method's correctness, the outcomes of both boundary conditions were compared with those of the analytical analysis.

LIU, LIN, QIANG AND YONG, (2012) analysed the system of the gravity dam-reservoir-foundation using the scaled boundary finite element method. The unbounded foundation is customized by a higher order transmitting boundary on the basis of continued-fraction solution of the dynamic stiffness matrix. They derived the equation of the dynamic-stiffness matrix of an unbounded domain on the basis of continued fraction using SBFEM. They showed that the method possesses high accuracy. They compared results with mass-less base model. They demonstrate that to obtain the response of gravity dam foundation reservoir system in frequency domain, the high order transmitting boundary method is effective and suitable.

DEMIREL (2012) used two-dimensional computational model for the hydrodynamics analyses of horizontal ground excited dam-reservoirs. The model is on the basis of finite volume solution of Navier-stokes equation and compressibility effects due to sudden change in pressure field during earthquake was taking into consideration. In order to track nonlinear free-surface waves in the reservoir, volume of fluid method is used. He compared numerical results with existing semi-analytical solutions to demonstrate the competence of the computer code for the pragmatic simulation of earthquake excited dam-reservoir.

GAHLOT AND GAJBHIYE (2013) had given the methods of seismic analysis of dam. This paper examines the seismic analysis case study of the Totaladoh Dam in Maharashtra's Vidarbha region using the IS coding approach. The findings of this approach's stress analysis were compared to those of the finite element method in the context of the IS code, and the dam's cross section was modelled as a cantilever beam with variable thickness. A finite element method was created for dam seismic analysis. This suggested model took into account the vertical and cross-stream components of pressure and assumed that water may be compressed

ALTUNISIK AND SESLI (2015) used to determine dynamic response of concrete gravity dams using various modelling approaches such as westergaard, Lagrange and Euler. They performed linear transient analysis using ANSYS software to determine the structural response of the dam. They used gauss numerical integration technique to compute element matrices and also used Newmark method in the solution of equation of motion. At the end of the analysis, they got dynamic characteristics, maximum displacements, maximum-minimum principal stresses and maximum-minimum principal strain and compared with each other for westergaard, Lagrange and Euler approaches. He also found that maximum and minimum principal stresses and strain are nearly equal for westergaard and Lagrange, but the values obtained from Euler is quite smaller than others. He concluded that more general results can be obtained with westergaard approach, whereas Lagrange and Euler approach can be used to obtain real behaviour of dam structures.

ERHUNMWUN AND AKPOBI (2017) proposed finite element technique to evaluate well pressure distribution of a unbound reservoir. The diffusivity equation was adopted for analysing the reservoir's pressure distribution. To conduct the study across the reservoir's cross-section, finite element method was used. The reservoir's pressure distribution was predicated on being uniform. Comparing the outcome to Chatas and Lee corroborated the correctness of the finding. The analysis reveals a significant positive connection between the two approaches. Dimensionless pressure was seen to diminish from the well bore to the exterior border.

ROZAINA et. al. (2017) suggested the finite element technique for earthquake analysis of concrete dam to analyse the performance and behaviour of the dam. To carry out the process, a computer programme called LUSAS 14.3 was employed. In light of the concrete dam's linear dynamic analysis, 5 dam form modes were used. This research analysed Sg. Kinta Dam. The study's findings about stress behaviour do not go above the permitted level of stress. The obtained normal stress and share stress, which were less than the permitted stress capacity of 800KN/m2, were 221.248KN/m2 and 436.499KN/m2, respectively. Additionally, maximum displacement produces good outcomes. The analysis's maximum displacement was 3.48mm in the mode shape 5. The findings of this study demonstrate the capability of LUSAS 14.3 for seismic analysis of concrete gravity dams.

WANG et. al (2017) proposed scaled boundary finite element method, finite element method and infinite eement method to model the system of reservoir. The water pressure on the dam's upstream face was calculated using the scale boundary finite element technique (SBFEM). In this study, the impact of radiation dampening on the reservoir's foundation was taken into account. The Koyna gravity dam was used to calculate the dynamic water pressure upstream of the dam. For various elastic moduli, the temporal evolution of seismic displacement and dam response was found. It was determined that the reaction of the dam rises as the elastic modulus increases by comparing the displacement result of the infinite element model for various elastic moduli. SBFEM was used to determine the dynamic water pressure. The endless reservoir was modelled using the finite element technique. This study demonstrates that SBFEM may be useful and efficient for the examination of the interaction between water and dams.

WANG, CHEN, WU AND SONG (2018) performed the time domain analysis of gravity dam of five different height on the basis of fluid-structure coupling model. Then they compared the results from FSCM and found that the maximum hydrodynamic pressures on the dam was significantly smaller than that from classical westergaard formula. They showed that the location of maximum hydrodynamic pressure to be surely raised along the upstream surface of the dam but not at the heel of the dams as in the westergaard formula. So, they revised westergaard formula with consideration of elasticity of dam and influence of height of dam and also the absorption property of the reservoir bottom on the hydrodynamic pressure. He also showed that absorption behaviour of reservoir bottom can reduce vibration as well as hydrodynamic pressure on dam. Many factors like nonlinearity of the dam, shape of the valley, sediment of the reservoir and the characteristics and shape of foundation were not taken into account.

FALCO, MORI AND SEVIERI (2018) calculated hydrodynamic pressures using different modelling approaches such as rigid barrier, deformable dam with added masses and fluid-structure interaction. They had been carried out frequency domain analyse by applying a horizontal acceleration to the dam base both on plane strain models and on more refined 3D models. They demonstrated that simplified 2D added-mass models may be over-conservative compared to 3D fluid structure simulation. They concluded that realistic 3D geometry of the reservoir makes the fluid behaviour highly complex and in 3D the added mass model may produce even more different results from the full fluid structure modelling.

LOKKE AND CHOPRA (2019) established the direct FE method for 2D dam-water-foundation systems. For computing distant earthquake analysis of 2D free-field systems, detailed instructions are presented. An idealised dam-water-foundation system's transient response and frequency response functions are computed to verify the approach. The 3D systems can use this direct FE approach. The free-field systems' boundaries can be used to calculate effective earthquake forces. For big 3D models, this method necessitates considerable bookkeeping and data transport. Convenient simplifications of the process are suggested to lessen these requirements, and their efficacy is shown. Nonlinear processes and energy dissipation (damping), two of these studies' most significant factors, were taken into account for practical modelling. The results are extremely useful for energy dissipation modelling and calibrating damping values for concrete dam assessments.

MOHAMMADNEZHAD et. al (2019) suggested an appropriate direct finite element method to model the mass radiation damping and wave propagation using ABAQUS. In order to represent a semi-infinite reservoir exposed to earthquakes, far field boundary conditions are needed. Analytical findings are used to validate the software's outcome. Using the EAGD-84 programme, the outcomes for massed and massless foundation were also confirmed. The conclusion is that the massless foundation technique causes displacement and stress to be accurately estimated. This overestimation raises unneeded costs for building new dams. Thus, while building a new dam, the foundation's mass should be taken into account.

SHARMA et. al (2019) suggested a space-time finite element method for the seismic analysis of dam-reservoir-soil system. The major unknown is a first order time derivative of hydrodynamic pressure. Pressure and displacement are regarded as secondary unknowns. Consistent temporal integration of the initial main unknowns is used to calculate these secondary unknowns. Numerous algebraic expressions are produced by this system, which may be resolved using a block iterative approach. Two systems of linear equations, one for the velocity field and the other for the auxiliary field, are solved in each step of the procedure.

AHMAD AND AHMET (2021) incorporated a reliable finite element method to model mechanical interaction between structure-foundation-reservoir and discretized these regions. Lagrangian fluid finite elements in two dimensions are used to simulate the reservoir region, which includes the compressibility effect and surface sloshing motion of water. In three different scenarios—structure-reservoir interaction with rigid foundation, structure-reservoir interaction with finite region of flexible foundation, and structure-reservoir interaction with including the infinite region of flexible foundation—the structure's dynamic responses to specific ground motions are determined. Only the radiation conditions towards infinity and the foundation's energy dissipation are simulated during the dynamic analysis using infinite elements in the infinite area of the flexible foundation. Without taking into account the radiation conditions in the infinite region of the constant depth reservoir, the dynamic analysis results from the interaction of the structure, foundation, and reservoir are displayed.

LÉGER A AND BHATTACHARJEE (2021) proposed to provide a consistent and rational transition from time-domain models appropriate for nonlinear seismic analysis to linear-frequency-domain models of concrete gravity dam, foundation, and reservoir systems. They take into account two different reservoir model types. These include an additional mass method based on the Westergaard method and a finite element formulation that represents the reservoir using displacements as nodal variables. Reduced degrees-of-freedom are required to accurately describe the reservoir and foundation thanks to the usage of coordinate reduction techniques. Boundary dampers are placed at the interface of the various media, together with additional stiffness and mass matrices, to reduce the complexity of the time-domain model of energy dissipation in the reservoir and the foundation. The additional system matrices are calibrated to deliver low level (elastic) time-domain response comparable to that attained by utilising frequency-dependent system features.

AKBARI AND LOTFI (2023) studied the non-linear dynamic analysis of concrete gravity dams. To detect the spread of cracks, an isotropic continuum damage model is used, which includes two internal damage variables for tension and compression. The suggested model may be validated by uniaxial tension, compression, and tension-compression tests because it is based on the strain equivalence and damage evolution criteria. They have defended the usage of damage variables within a specific time for tension and compression in the aforementioned damage model. The non-linear dynamic analysis of the Koyna concrete gravity dam is carried out using this model. By using three separate damping algorithms, the Hilbert-Hughes-Taylor (HHT) time integration approach is propelled through a finite element programme. It is demonstrated that each scenario in this study uses HHT α-factors

2.3 OBSERVATION OF LITERATURE

1. From previous literatures it has been found that finite element technique is suitable for discretisation of regular and irregular geometry of dam and reservoir.
2. Most of the researcher used displacement-based model for analysis of dam. Pressure-based model has been used for analysis of reservoir to overcome the problem related to zero frequency mode.
3. Most of the researcher assumed as bottom of the reservoir horizontal and face of the dam as vertical.
4. Previous researchers truncated the infinite reservoir at a suitable distance to save the computational time.
5. Different researcher has proposed different truncation boundary conditions. Application of appropriate boundary condition is very much important for analysis of unbounded reservoir subjected to earthquake excitation.
6. Most of the researchers have neglected the effect of surface wave on the reservoir.

2.4 OBJECTIVE

Dynamic analysis of infinite reservoir using finite element technique with the effect of surface wave.

2.4 SCOPE OF WORK

1. Finite element discretisation of unbounded reservoir domain.
2. Application of appropriate truncation boundary condition at the truncated surface of reservoir
3. Study on hydrodynamic pressure of unbounded reservoir for considering absorption co-efficient of reservoir bottom.
4. Study of hydrodynamic pressure with and without consideration of surface wave effect.

CHAPTER 3

THEORITICAL FORMULATION

3.1 THEORETICAL FORMULATION FOR RESERVOIR ANALYSIS

Reservoir geometry is considered as two dimensional. Fluid is considered as non-viscous and linearly compressible. The hydrodynamic pressure distribution of the reservoir is determined from following pressure wave equation:

$$\nabla^2 p(x, y, z) = \frac{1}{c^2} \ddot{p}\ (x, y, t) \tag{1}$$

Where *c* is wave velocity, *x* and *y* are space variable, *p* (x, y, t) is hydrodynamic pressure, '*t*' is time variable.

The boundary condition of free surface (Surface I) considering the effect of surface wave is taken as follows:

$$\frac{1}{g} \ddot{p} + \frac{\partial p}{\partial y} = 0 \tag{2a}$$

Boundary condition of free surface neglecting the effect of surface wave can be expressed as follows:

$$p\left(x, H_f\right) = 0 \tag{2b}$$

Where, H_f is the depth of the reservoir

The hydrodynamic pressure at dam-reservoir interface (Surface II) may be obtained from the following equation:

$$\frac{\partial p}{\partial n} (\ 0, y, t) = \ -\rho_f a e^{i\omega t} \tag{3}$$

Where $ae^{i\omega t}$ is the horizontal component of the ground acceleration, ω is the circular frequency of vibration and $i = \sqrt{-1}$, *n* is the outward directed normal to the elemental surface along the interface and ρ_f is the density of the fluid.

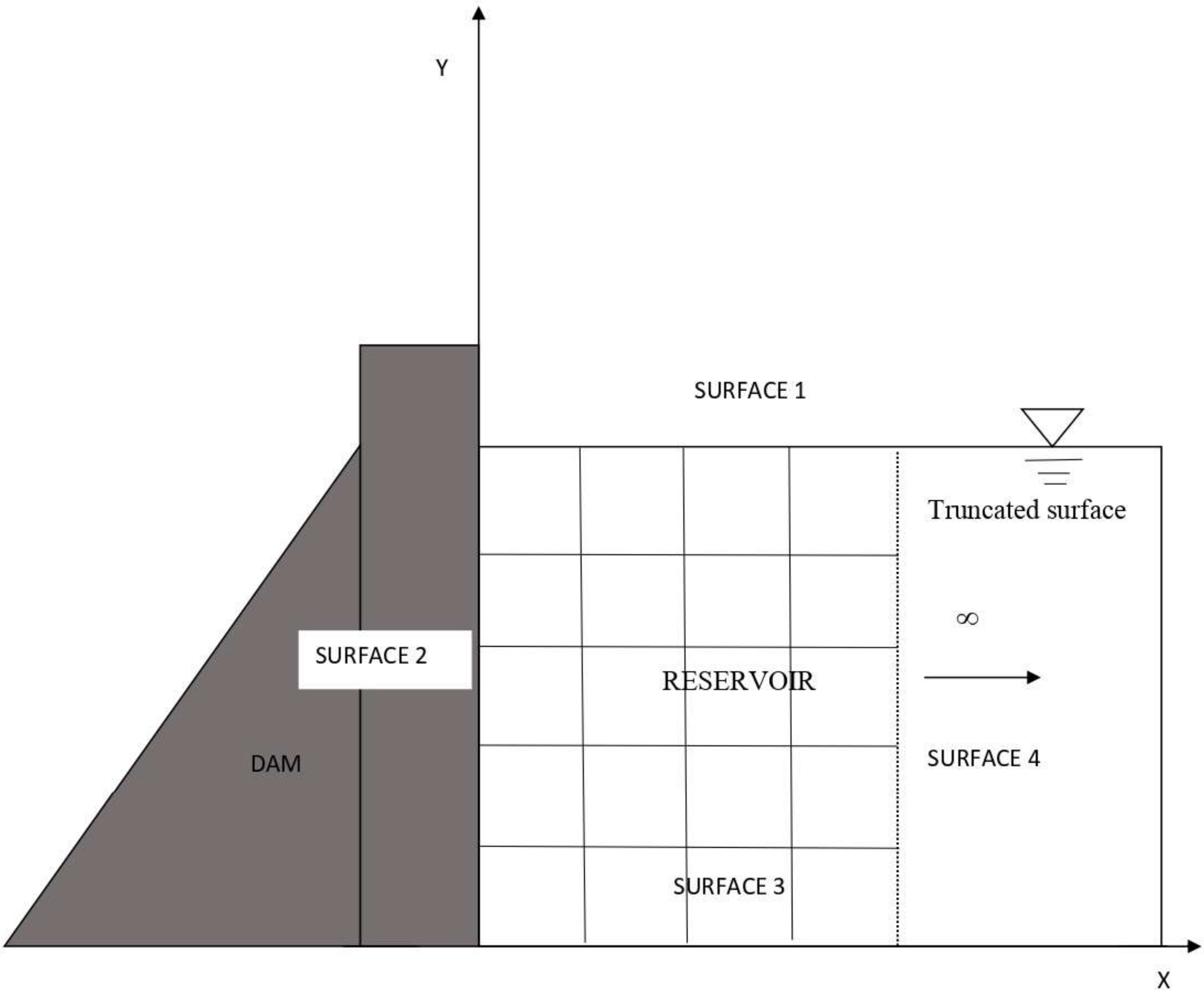

Figure 1:dam reservoir system

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The hydrodynamic pressure at the bottom (Surface III) of the reservoir considering bottom absorption effect can be obtained from following equation:

$$\frac{\partial p}{\partial n}(x, 0, t) = -i\omega q\dot{p}(x, 0, t) \quad (4)$$

Where the coefficient q is given as.

$$q = \frac{1}{c}\left(\frac{1-\propto}{1+\propto}\right) \quad (5)$$

Here $\propto$ is frequency independent reflection coefficient.

The boundary condition at truncation surface (Surface IV) can be given as follows.

$$\frac{\partial p}{\partial n} = \left(\xi_m - \frac{1}{c}\right)\dot{p} \tag{6}$$

According to Gogoi and Maity (2006), ξ_m can be obtain from the following equation.

$$\xi_{\mathrm{m}} = -\frac{\mathrm{i}\sum_{\mathrm{m}=1}^{\infty}\frac{\lambda_{\mathrm{m}}^{2}\mathrm{I}_{\mathrm{m}}}{\beta_{\mathrm{m}}}\mathrm{e}^{-\mathrm{k}_{\mathrm{m}}\mathrm{x}}(\Psi_{\mathrm{m}})}{\Omega\,\mathrm{c}\sum_{\mathrm{m}=1}^{\infty}\frac{\lambda_{\mathrm{m}}^{2}\mathrm{I}_{\mathrm{m}}}{\beta_{\mathrm{m}}\mathrm{k}_{\mathrm{m}}}\mathrm{e}^{-\mathrm{k}_{\mathrm{m}}\mathrm{x}}(\Psi_{\mathrm{m}})} \tag{7}$$

The value of χ is taken zero when the effect of gravity waves is neglected.

Assuming pressure as unknown variable and following Galerkin approach, the discretized form of Eq. (1) is given as below.

$$\int_{\Omega} \mathrm{N_{rj}}\left[\nabla^2 \sum \mathrm{N_{ri}}\mathrm{p_i} - \frac{1}{\mathrm{c}^2}\sum \mathrm{N_{ri}}\ddot{\mathrm{p}}_{\mathrm{i}}\right] \mathrm{d}\Omega = 0 \tag{8}$$

Where, *Ω* is the region under consideration, N_{rj} is the interpolation function for the reservoir. Using Green's theorem Eq. (15) may be written to as follows.

$$-\int_{\Omega}\left[\frac{\partial N_{rj}}{\partial x}\sum\frac{\partial N_{ri}}{\partial x}p_i + \frac{\partial N_{rj}}{\partial y}\sum\frac{\partial N_{ri}}{\partial y}p_i\right] d\Omega - \frac{1}{c^2}\int_{\Omega} N_{rj}\sum N_{ri}\, d\Omega\ddot{p}_i + \int_{\Gamma} N_{rj}\frac{\partial N_{rj}}{\partial n} d\Gamma p_i = 0 \tag{9}$$

where *i* varies from 1 to total number of nodes and *Γ* represents the boundaries of the fluid domain. The last term of the above equation is given as follow.

$$\{\mathrm{F}\} = \int_{\Gamma} N_{rj}\frac{\partial p}{\partial n} d\Gamma \tag{10}$$

The whole system of equation may be written in a matrix form as follows.

$$[\overline{\mathrm{M}}]\{\ddot{\mathrm{p}}\} + [\overline{\mathrm{K}}]\{\mathrm{p}\} = \{\mathrm{F}\} \tag{11}$$

Here,

$$[\overline{\mathrm{M}}] = \frac{1}{\mathrm{c}^2}\sum\int_{\Omega} [\mathrm{N_r}]^{\mathrm{T}}[\mathrm{N_r}]\,\mathrm{d}\Omega \tag{12}$$

$$[\bar{K}] = \sum \int_{\Omega} \left[\frac{\partial [N_r]^T}{\partial x}\frac{\partial [N_r]}{\partial x} + \frac{\partial [N_r]^T}{\partial y}\frac{\partial [N_r]}{\partial y}\right] d\Omega \tag{13}$$

$$\{F\} = \sum \int_{\Gamma} [N_r]^T \frac{\partial p}{\partial n} d\Gamma = \{F_f\} + \{F_{fs}\} + \{F_{fb}\} + \{F_t\} \tag{14}$$

Where subscripts f, t, f_s and f_b stand for free surface, truncation surface, fluid-surface interface and Fluid-bed interface respectively.

For surface wave, $\{F_f\}$ can be written in finite element form as below.

$$\{F_f\} = -\frac{1}{g}[R_f]\{\ddot{p}\} \tag{15}$$

In which,

$$[R_f] = \sum \int_{\Gamma_f} [N_r]^T [N_r] \, d\Gamma \tag{16}$$

At the fluid-structure interface, where $\{a\}$ is the vector of nodal accelerations of generalized coordinates, $\{F_{fs}\}$ may be expressed as given below.

$$\{F_{fs}\} = -\rho_f [R_{fs}]\{a\} \tag{17}$$

In which,

$$[R_{fs}] = \sum \int_{\Gamma_{fs}} [N_r]^T [T][N_s] \, d\Gamma \tag{18}$$

Here, N_s is the shape function of dam structure and $[T]$ is the transformation matrix at fluid structure interface.

At the reservoir bed interface, $\{F_{fb}\}$ may be expressed as given below.

$$\{F_{fb}\} = i\omega q \, [R_{fb}]\{p\} \tag{19}$$

here,

$$[R_{fb}] = \sum \int_{\Gamma_{fb}} [N_r]^T [N_r] \, d\Gamma \tag{20}$$

At the truncated surface $\{F_t\}$ may be expressed as given below.

$$\{F_t\} = \left(\xi_m - \frac{1}{c}\right)[R_t]\{p\} \tag{21}$$

here,

$$[R_t] = \sum \int_{\Gamma_t} [N_r]^T [N_r] \, d\Gamma \tag{22}$$

Substitution of all term in Eq. (11) we get the following equation.

$$[M]\{\ddot{p}\} + [C]\{\dot{p}\} + [K]\{p\} = \{F_r\} \tag{23}$$

here,

$$[M] = [\overline{M}] + \frac{1}{g}[R_f] \tag{24}$$

$$[C] = \frac{1}{c}[R_t] \quad (25)$$

$$[K] = [\overline{K}] + \xi_m[R_t] - i\omega q\,[R_{fb}] \quad (26)$$

$$\{F_r\} = -\rho_f[R_{fs}]\{a\} \quad (27)$$

Hydrodynamic pressure can be obtained by solving equation (23) using Newmark's integration method.

3.2 ISOPARAMETRIC FORMULATION: -

Eight node isoparametric element has been used for the present study. The shape functions of the standard eight node element two-dimensional element have given below.

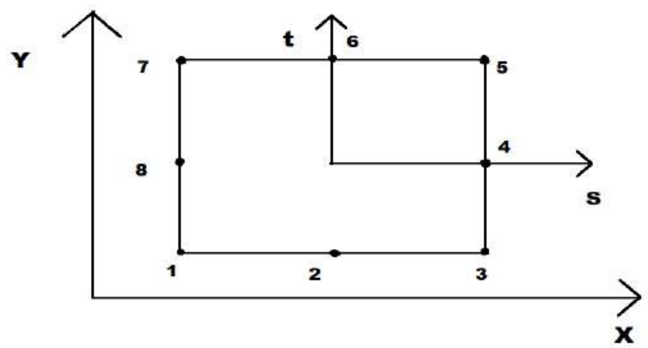

Figure 2: Eight node isoprarametric element

Shape function of various node

N_1 =0.25*(1-s) *(1-t) *(-s-t-1)

N_3=0.25*(1+s) *(1-t) *(s-t-1)

N_5=0.25*(1+s) *(1+t) *(s+t-1)

N_7=0.25*(1-s) *(1+t) *(-s+t-1)

N_2=0.5*(1-t) *(1+s) *(1-s)

N_4=0.5*(1+s) *(1+t) *(1-t)

N_6=0.5*(1+t) *(1+s) *(1-s)

N_8=0.5*(1-s) *(1+t) *(1-t)

3.3 TWO POINT GAUSSIAN QUADRATURE: -

2nd order gauss quadrature is used in isoparametric formulation of eight node elements. Gauss quadrature order and corresponding points and weights are given below

Table 1 Gauss point and respective weights

ORDER	POINTS U_i	WEIGHTS W_i
2	± 0.57735	1.00

3.4 NEWMARK'S BETA METHOD: -

The Newmark-beta method is a method of numerical integration used to solve certain differential equations. It is widely used in numerical evaluation of the dynamic response of structures and solids such as in finite element analysis to model dynamic systems. The semi-discretized structural equation is a second order ordinary differential equation system.

$$M\ddot{u} + C\dot{u} + f^{\text{int}}(u) = f^{\text{ext}}$$

Here M is mass matrix;

C is damping matrix;

f^{int} & f^{ext} are internal force per unit displacement and external forces, respectively.

Using the extended mean value theorem, the Newmark-β method states that the first time derivative (velocity in the equation of motion) can be solved as,

$$\dot{u}_{n+1} = \dot{u}_n + \Delta t\, \ddot{u}_\gamma$$

here,

$$\ddot{u}_\gamma = (1-\gamma)\ddot{u}_n + \gamma\ddot{u}_{n+1} \quad 0 \leq \gamma \leq 1$$

Therefore,

$$\dot{u}_{n+1} = \dot{u}_n + (1-\gamma)\Delta t\ \ddot{u}_n + \gamma\Delta t\ \ddot{u}_{n+1}.$$

Because acceleration also varies with time, however, the extended mean value theorem must also be extended to the second time derivative to obtain the correct displacement. Thus,

$$u_{n+1} = u_n + \Delta t\ \dot{u}_n + \tfrac{1}{2}\ \Delta t^2\ \ddot{u}_\beta$$

here again,

$$\ddot{u}_\beta = (1-2\beta)\ddot{u}_n + 2\beta\ddot{u}_{n+1} \quad 0 \le 2\beta \le 1$$

The discretized structural equation becomes

$$\begin{aligned}
\dot{u}_{n+1} &= \dot{u}_n + (1-\gamma)\Delta t\ \ddot{u}_n + \gamma\Delta t\ \ddot{u}_{n+1} \\
u_{n+1} &= u_n + \Delta t\ \dot{u}_n + \frac{\Delta t^2}{2}\left((1-2\beta)\ddot{u}_n + 2\beta\ddot{u}_{n+1}\right) \\
M\ddot{u}_{n+1} &+ C\dot{u}_{n+1} + f^{\text{int}}(u_{n+1}) = f^{\text{ext}}_{n+1}
\end{aligned}$$

Explicit central difference scheme is obtained by setting $\gamma = 0.5$ and $\beta = 0$;

Average constant acceleration (Middle point rule) is obtained by setting $\gamma = 0.5$ and $\beta = 0.25$

3.5 COMPUTATION OF VELOCITY OF FLUID: -

The following equation is used to determine the fluid particles' acceleration after computing the produced hydrodynamic pressure inside the fluid domain:

$$p_i + \rho_f \dot{v}_i = 0,$$

where ρ_f is the mass density of fluid and $\dot{v}_i$ is the acceleration of fluid particle.

Using the well-known Gill's time integration technique, which appears to be stable and takes less calculation time than other schemes, the velocity of the fluid particle may be calculated from the known values of acceleration at any instant of time. The velocity at any point in time t will be

$$v_t = v_{t-\Delta t} + \Delta t \dot{v}_t$$

Velocity vectors are shown in the fluid domain based on the velocities calculated at the Gauss points of each individual constituent.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 VALIDATION OF PROPOSED ALGORITHM

A MATLAB programme has been developed to determine the hydrodynamic pressure distribution on the dam face. Geometry and material characteristics of the dam are taken as taken by Sami and Lotfi (2007) in order to validate the current algorithm. The reservoir is taken as 116.19 m. deep. Mass density of water is taken as 1000 kg/m^3. The acoustic velocity (c) in water is assumed to be 1440 m/s. the reservoir is truncated at a distance of 200.0 m. The results of Sami and Lotfi (2007) are compared with the results of free vibration analysis. In table-2, the first five natural frequencies are listed.

Table 2 Comparison of natural frequencies of the reservoir

Mode Number	Natural frequency (Hz)	Natural frequency (Hz)
	present study	Samii and Lotfi
1	3.118	3.115
2	4.776	4.749
3	7.858	7.796
4	9.307	9.300
5	9.986	9.958

4.2 CONVERGENCE STUDY

Hydrodynamic pressure developed in the unbounded reservoir is determined by applying the Newmark's integration approach to the Eq. no. 23. Reservoir is regarded as rigid. L/H ratio is taken as 0.5 and reservoir height is assumed to be 80 metres. A non-reflecting boundary condition (Gogoi and Maity, 2006) is used at the truncated face. Unit weight of water is taken as 10 kN/m^3. It is assumed that the acoustic velocity (c) in water is 1440 m/s. the reservoir geometry is discretized by using eight node isoparametric elements. Reservoir bottom is considered fully rigid and absorptive, Newmark's integration approach is used to resolve dynamic equilibrium equation and harmonic excitation was used to perform the analysis. For finite element discretization, convergence study has been conducted and the findings are shown in the Table 3. N_h and **Nv** represents number of elements in horizontal and vertical direction respectively. c_P is the pressure coefficient. For the further study we consider value of N_h is 4 and **Nv** is 8. The results of convergence study for time step have been provided in Table 4. For the further study the time step *t* is take as T/32

Table 3:- Convergence test for meshing of dam and reservoir

N_h	Nv	c_P
2	8	0.743092
3	8	0.743109
4	8	0.743114
5	8	0.743114

Table 4: - Convergence test for time step

T/t	c_P
16	0.7445
32	0.7431
48	0.7431

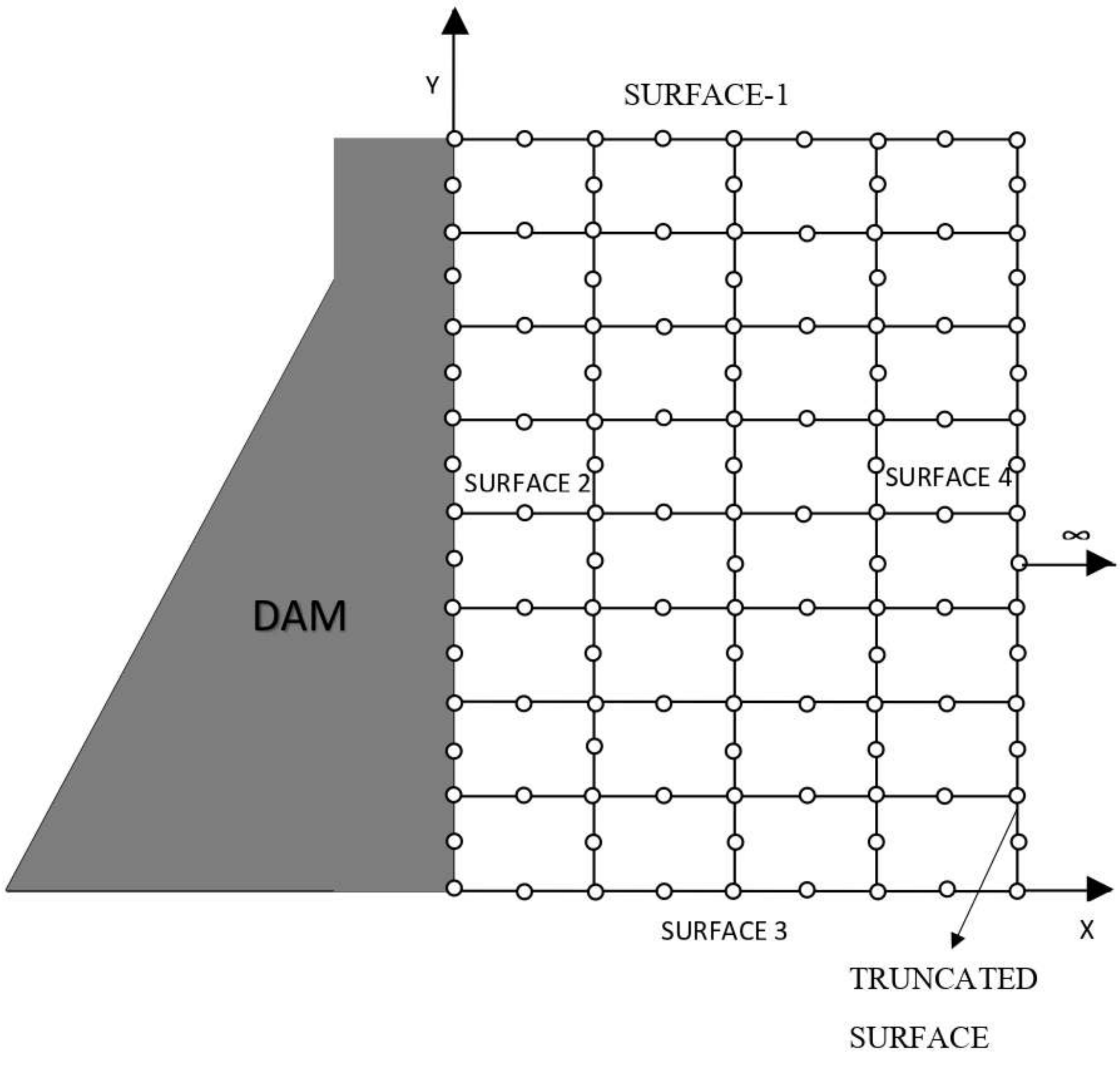

Figure 3: Finite element mesh of reservoir

4.3NUMERICAL RESULTS

Hydrodynamic pressure co-efficient (C_p)at heel of dam is computed applying harmonic excitation. Amplitude of the excitation is taken as equal to the Gravitational acceleration (g= 9.81 m/s^2). Fluid in considered as in-compressible and non-viscous in this study. Height of the reservoir is taken as 80 m. L/H_f ratio is taken as 0.5 and at the truncated face a non-reflecting boundary condition (Gogoi and Maity, 2006) is applied. Reservoir bottom is considered fully rigid and absorptive. Unit weight of water is taken as 10 kN/m². The acoustic velocity of water (c) is taken as 1440 m/s. Tc/H is taken as 100. Using Newmark's approach, the dynamic equilibrium equation is solved. The analysis has been carried with and without the effect of surface wave. The outcomes are displayed in fig. 4. From the Fig. 4 it is evident that when the impact of the surface wave is taken into account, the hydrodynamic pressure at the heel of dam decreases.

Figure 4: Time history of hydrodynamic pressure coefficient (c_P) at heel

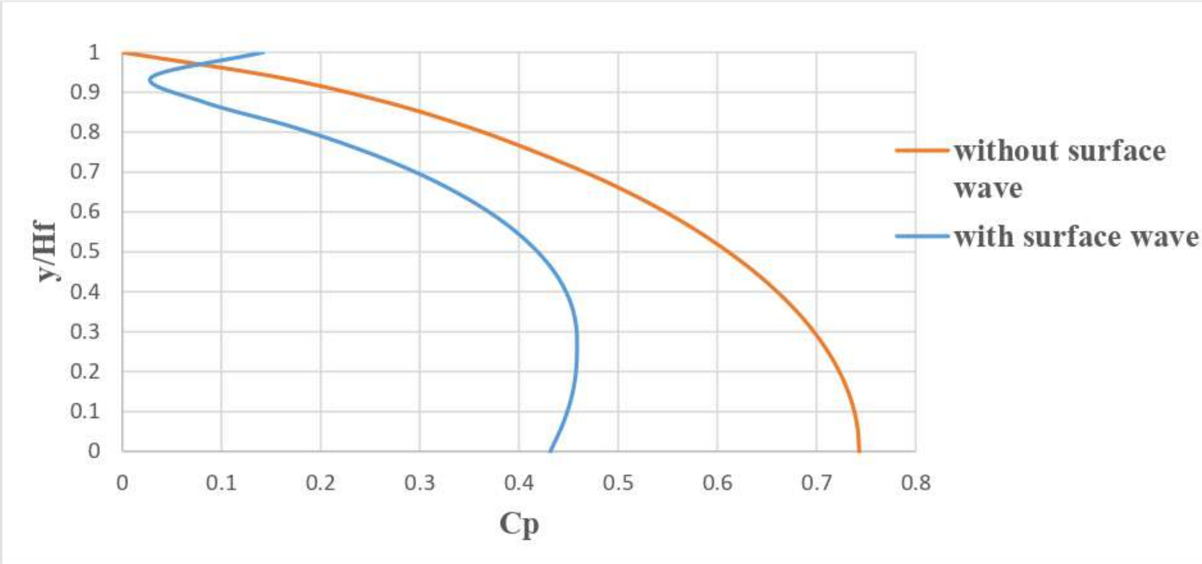

Figure 5: Distribution of hydrodynamic pressure coefficient (C_p) at face of dam

Fig. 5 shows the distribution of hydrodynamic pressure co-efficient (c_P) at the heel of dam with considering the effect of surface wave and without considering the effect of surface wave. From this figure, it clear that hydrodynamic pressure decreases if the effect of surface wave is taken into account.

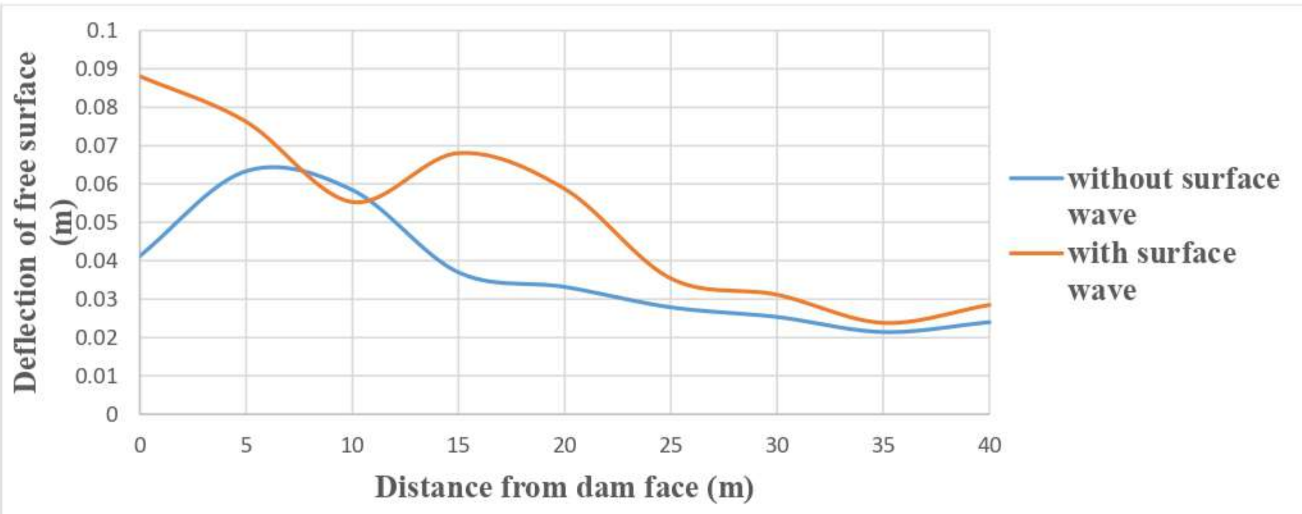

Figure 6: Deflection profile of the free surface of water at t=4.16s.

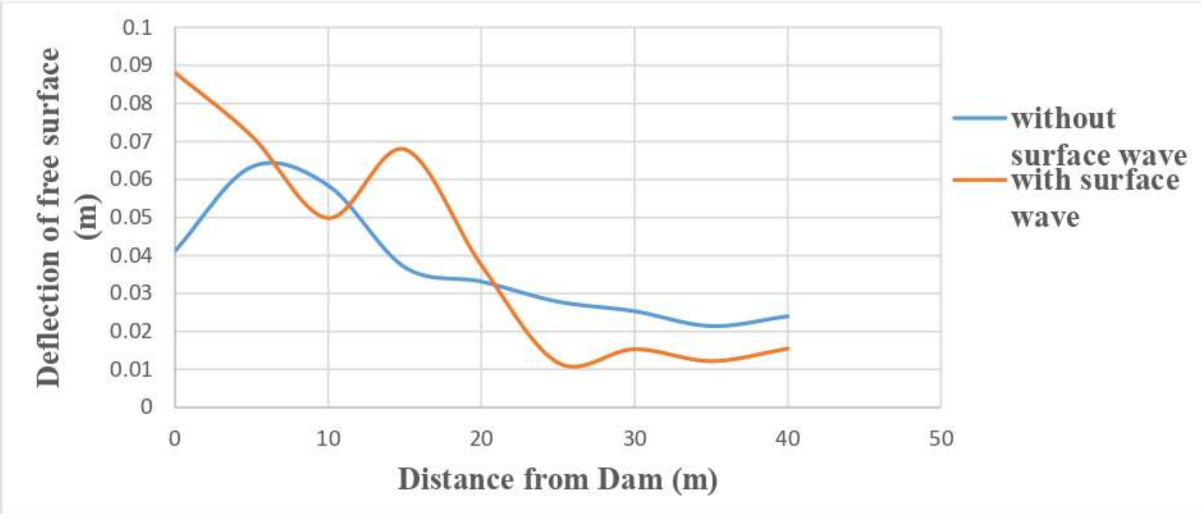

Figure 7: Deflection profile of the free surface of water at t=6.94s.

From the Fig. 6 and Fig. 7, it has been seen that at the face of dam the deflection of free (top) surface is higher when considering the effect of surface wave and the deflection is less when the effect of surface wave is neglected. It has been also found that the disturbance of top surface is high when effect of surface wave is considered.

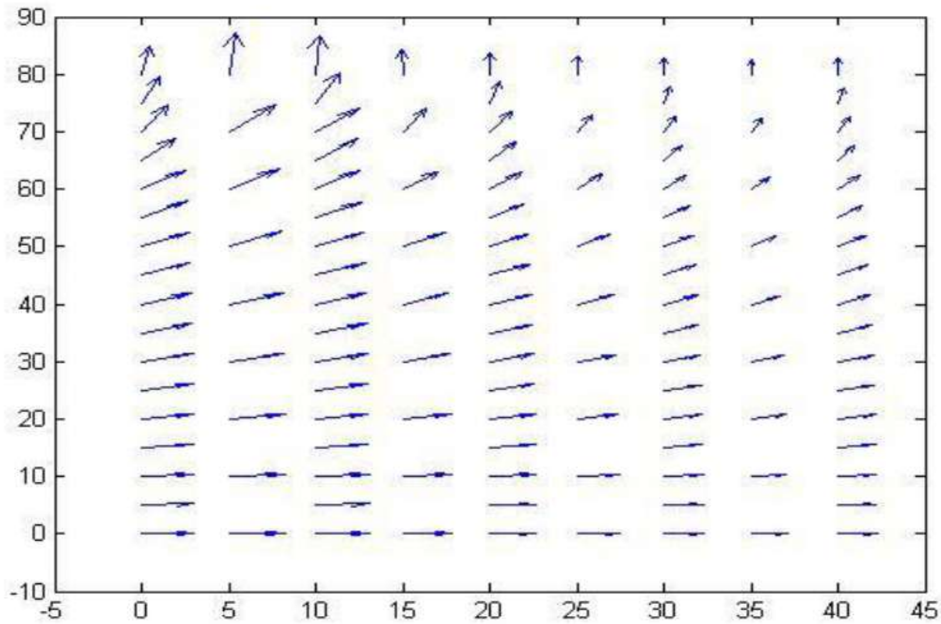

Figure 8: Velocity profile of water at t=3.16 sec without surface wave

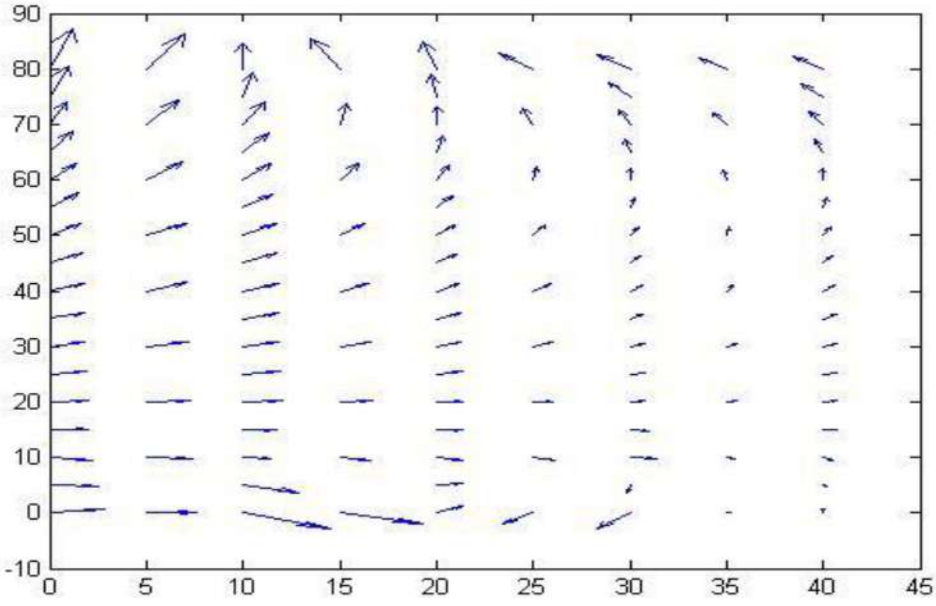

Figure 9: Velocity profile of water at t=3.16 sec with surface wave

Velocity profile of fluid has been presented in Fig.8 to Fig11.The results show that the velocity profile of water is quite regular and almost uniform at a particular instant of time when the effect of surface wave is neglected. The velocity profile of the reservoir is irregular and non-uniform at a particular instant of time when surface wave is considered.

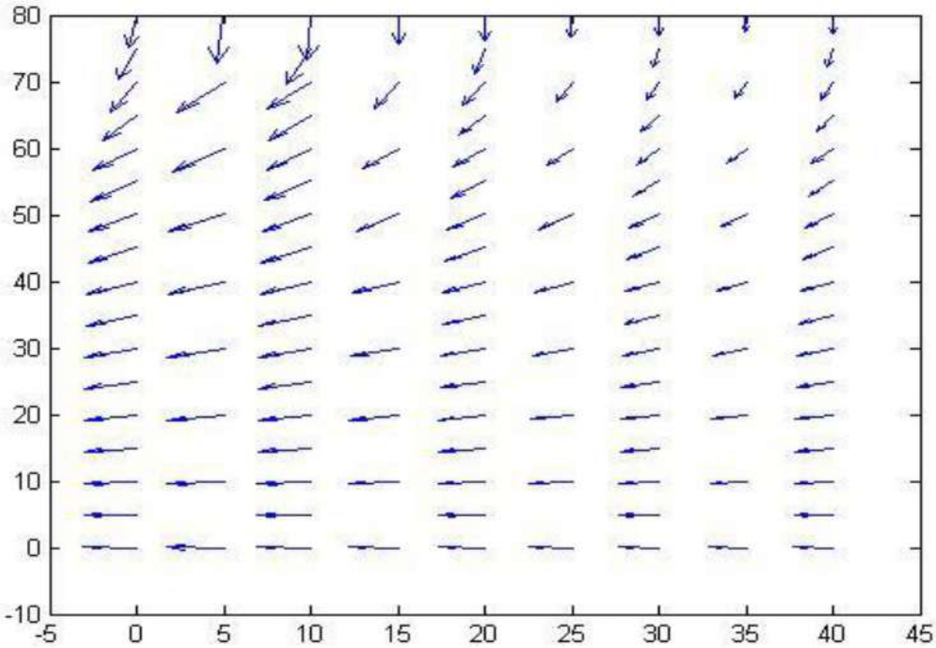

Figure 10: Velocity profile of water at t=6.94 sec without surface wave

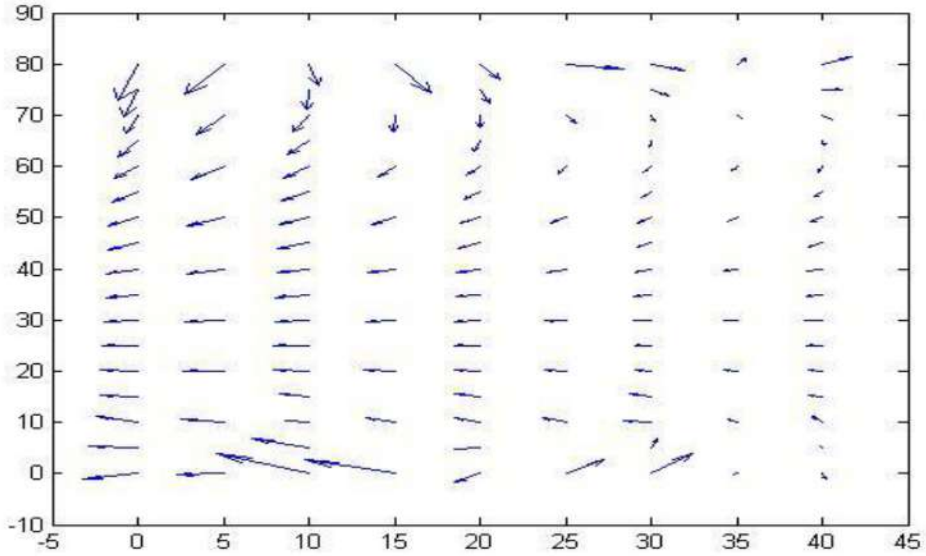

Figure 11: Velocity profile of water at t=6.94 sec with surface wave

CHAPTER 5

CONCLUSION AND SUGGESTION FOR FUTURE SCOPE OF WORK

5.1 CONCLUSION

For the safety and stability of the concrete gravity dam, computation of hydrodynamic pressure is necessary. Because the hydrodynamic pressure on the structure is very sensitive for the responses of the gravity dam during earthquake. The application of the far-boundary condition is one of the most crucial components in the development of reservoir model. The finite element approach is used to discretize the governing equation for the reservoir. In the current study, an effective boundary condition at the truncation surface of the infinite reservoir is applied for finite element analysis of reservoir. In present study, Hydrodynamic pressure coefficient is studied for different conditions i.e., considering the surface wave and without considering the surface wave for harmonic excitation. The main findings of the present study are listed below.

1. Hydrodynamic pressure coefficient at heel of the dam effected by the effect of surface wave.
2. If the effect of surface wave is considered then hydrodynamic pressure coefficient reduces.
3. At face of the dam, the hydrodynamic pressure distribution is approximately parabolic.
4. At face of dam the deflection of top surface is greater when considering with surface wave and smaller for without surface wave condition.
5. Velocity profile of water is quite regular pattern at a particular instant of time when surface wave is not taken in to account.
6. Velocity profile of water is irregular pattern at a particular instant of time when surface wave is considered
7. When surface wave is considered undulation of top surface is higher than without surface wave condition.
8. As the hydrodynamic pressure coefficient is reduced for considering surface wave condition, we can neglect the effect of surface wave for better conservative design of gravity dam.

5.2 SUGGESTION OF FUTURE SCOPE OF WORK

Depending on the results of the present study some useful suggestions for future scope of work has been given below.

1. To obtain a more accurate result, additional research is needed for various truncation boundary conditions.
2. Hydrodynamic pressure has to be studied further for different truncation length
3. Research can be done for various reservoir bottom absorption coefficient values.
4. Hydrodynamic pressure variation can be studied for different inclination of reservoir bottom.
5. Study of hydrodynamic pressure with inclusion of dam-reservoir interaction may be done.
6. Study of hydrodynamic pressure with inclination of dam-reservoir interface is needed.
7. Research can be done with combination of inclined reservoir bottom and inclination of dam face.

CHAPTER 6

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