Review of Analysis of a Dam Structure Considering Hydrostatic Pressure

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Abstract - *This study explores the stress distribution in gravity dams, emphasizing the role of self-weight. Two 3D models of a gravity dam with identical geometry were analyzed using STAAD.Pro V8i SS5. One model considered only hydrostatic pressure, while the other included the self-weight of the dam. Finite Element Analysis (FEA) was performed to compute bending (MXY), membrane (SXY), and shear stresses (SQX, SQY), offering insights into internal forces within the structure.*

The analysis identified critical areas of stress concentration and highlighted the influence of self-weight on overall stress patterns. By examining key stress parameters, this study underscores the importance of considering self-weight in gravity dam design to ensure structural integrity.

Key Words: Gravity dams, hydrostatic pressure, self-weight, shear stress, bending stress, structural analysis, STAAD.Pro.

1.INTRODUCTION

Massive monolithic structures known as gravity dams use gravity's unstoppable force to withstand the tremendous pressures that impounded water exerts. The material known for its compressive strength, concrete, is usually used to build these enormous engineering feats. Their design is based on a simple but profound fundamental principle: the massive weight of the dam counteracts the horizontal thrust generated by the water body, ensuring stability and averting catastrophic failure. The precise calculation and optimization of this weight-water pressure equilibrium ensures the structural integrity of the dam for the duration of its intended life.

Although the idea behind gravity dams may seem straightforward, designing and building them requires a thorough understanding of soil mechanics, hydrodynamics, structural engineering, and materials science. The dam's dimensions, shape, and material composition are greatly influenced by a multitude of factors, including the hydrological conditions, seismic activity, geology of the site, and environmental considerations. It is crucial to analyze the stresses in these structures to guarantee their durability and safety. Preventing structural failures requires an understanding of the distribution of forces, especially those caused by the weight of the dam and water pressure. This study explores the complexities of stress analysis in gravity dams by simulating and assessing the behavior of these enormous structures under a range of loading scenarios using sophisticated computational tools. Through the comparison of stress patterns in dam models under varying load combinations, our goals are to clarify the influence of self-weight on the overall stress distribution, pinpoint critical stress areas, and further advance the continuous improvement of principle of gravity dams. To guarantee the stability and safety of gravity dams over the long term, a thorough understanding of the stress distributions inside the structures is necessary. Through the application of diverse loading scenarios to these structures, engineers are able to determine the critical stress zones and evaluate the design adequacy of the dam.

This study performs complex finite element analyses using the sophisticated capabilities of STAAD.Pro V8i SS5, yielding a precise and comprehensive representation of stress patterns. This study attempts to quantify the impact of gravity on the overall stress field by comparing dam models with and without self-weight considerations, thereby aiding in the development of more resilient and effective dam designs.

2. TYPE OF ANALYSIS

Stress analysis

A crucial area of engineering called stress analysis studies the internal forces and deformations that occur in a structure or component when it is subjected to external loads. It is necessary to guarantee the dependability and safety of structures. Engineers analyze the distribution of stress, pinpoint high-stress areas, and forecast probable failure points using computational tools and mathematical models. In order to determine stress and strain values, the procedure usually entails defining the geometry of the structure, applying loads and boundary conditions, choosing suitable material properties, and solving the governing equations. Engineers can prevent structural failures, optimize designs, and use less material by using stress analysis.

Dynamic analysis

The behavior of structures under time-varying loads, such as vibrations, shocks, or earthquakes, is the focus of dynamic analysis. It entails forecasting a structure's motion, stresses, and deformations by analyzing how it reacts to dynamic excitations. For structures like machinery, buildings, and bridges, where dynamic loads can have a major 9

impact on performance and safety, dynamic analysis is essential. A popular method in dynamic analysis for figuring out a structure's natural frequencies and mode shapes is modal analysis. In order to prevent excessive vibrations, these parameters help identify possible resonance conditions and guide design modifications. An additional technique for examining how a structure reacts to particular time-varying loads, like ground motions from an earthquake, is time-history analysis.

Finite element analysis

A numerical technique for approximating solutions to engineering problems involving fluid flow, heat transfer, stress, strain, and other physical phenomena is called finite element analysis (FEA). It entails breaking down a complicated structure into smaller, more manageable components known as finite elements. The behavior of each element is represented by mathematical equations, and these elements are connected at nodes. FEA is widely used because of its accuracy and versatility in a wide range of engineering fields. It enables engineers to study intricate geometries, model real-world conditions, and forecast how structures will respond to various loading scenarios. Static, dynamic, and nonlinear problems can all benefit from the use of FEA, which offers insightful information for troubleshooting and design optimization. To provide comprehensive information about stress distributions, displacements, and other pertinent parameters, FEA is frequently used in conjunction with dynamic analysis and stress analysis.

3. OBJECTIVE OF THE RESEARCH

The main objective of the research are-

- To design and analyse the structure of gravity dam using STAAD.Pro software.
- To check the performance and effect of gravity dams.
- To analyze causes of failure of structure of dams.
- To compare two structure of dams on the basis of several parameters such as shear, bending etc.

4. LITERATURE REVIEW

Urmila Sarde et al (2017), this paper uses STAAD-PRO to present the dynamic time history analysis of a concrete gravity dam. Here, the dam is analyzed using the finite element method. To conduct the time history analysis, a concrete gravity dam model is created in STAAD-PRO, and a comparison is made between the dams with and without galleries, or openings. Both dams with galleries and dams without galleries are subjected to seismic analysis. According to IS 6512:1984, different basic loads and load combinations are used in the analysis of concrete gravity dams. Basic loads and load combinations used in the analysis are shown in the observed results.

According to the study, the dam with a gallery experiences lower compressive and tensile stresses at the heel and toe than the dam without a gallery. The primary benefit is that the slopes can be planned in accordance with the stress pattern and the stress variation through the dam body can be thoroughly examined. We can infer from the dam's response that the construction of the gallery has an impact on the stress variation in the dam. The most practical and less laborious dynamic analysis tool is STAAD-PRO, which offers a computational environment for examining modeling presumptions and computational procedures associated with the seismic and static structural stability of gravity dams.

Mettu Rajesh Reddy et al (2017), the dam is analyzed in this paper using the Staad.Pro software. A common application for multi-story buildings with beams and columns is Staad.pro. But in addition to beam members, Staad.Pro can analyze any kind of element, including plates, shells, and solids. Thus, the dam is modeled with solid elements in the software using the appropriate data. The paper's conclusion includes a description of the stresses' results and stress contours. The purpose of this paper is to use STAAD.Pro to have a direction for dam analysis that takes solid elements into account.

As per the findings it was concluded the strcuture of the dam is analyzed CODE-IS -6512-1984, the variable deflection was found to be very small roughly 0.002 meters and is therefore negligible. When the analysis is completed and the errors are found to be zero, it indicates that the structure's design is significant and that standard loads are used to analyze wind and live loads. The results of Staad-pro must be practically optimized in order to implement structure finalization in the future.

P. Pallavi Santhoshi et al (2017), the primary functions and structure of STAADPRO, a computer program designed for assessing the seismic and static stability of concrete gravity dams, are explained in this paper. STAADPRO is based on the gravity method and calculates crack lengths, safety factors, and stress analyses using beam theory and rigid body equilibrium. Either the simplified response spectrum method or the pseudo-static method could be used for seismic analyses. The main purpose of STAADPRO is to aid in the understanding of the fundamentals involved in evaluating the structural stability of gravity dams. It might also be applied to the study and creation of gravity dam stability. Numerous modeling options have been implemented in relation to (i) crack initiation and propagation, (ii) drainage and cracking effects under static, seismic, and post-seismic uplift pressure conditions, and (iii) safety evaluation formats (deterministic allowable stresses and limit states, probabilistic analyses using Monte Carlo simulations) in the process of adopting several internationally published guidelines for dam safety. To demonstrate how to use STAADPRO, which is free to download from the website, a structural stability evaluation of a 30-meter dam is shown. Lagrangian Eulerian formulation of 4node plain quadrilateral elements with modal analysis was employed in the finite element (FE) method of analysis. The Staad Pro tool is being used to implement the FE model, and the loadings were established using the codebook.

Several concerns regarding load conditions, splitting criteria, elevate weights powers, and examination methods have been observed in this study. These concerns could be applied to seismic, post-seismic, and static security assessments; however, when all is said and done, the computations become extremely complex due to the coupling between the inspire weight and break length. In real-world situations, parametric analyses are frequently carried out to address quality and stacking parameter instabilities in order to make the right decision regarding a particular structure. In order to provide engineers from the practice with the computational research facility needed for dam security assessment, the creators of STAADPRO have done a great job. STAADPRO has received widespread approval in the past few years and is also used for contemporary applications and research and development in dam design.

Ms.Varsha V Deshpande et al (2019), in this paper, solid elements in STAAD.Pro are used to create a three-dimensional finite element model of an overflow dam. For the majority of adverse cases, all forces are computed and applied as loads and combinations of loads. The study's goal is to determine whether the dam is stable under the different load scenarios listed in IS 6512-1984. Analysis of the model is done taking into account both static and dynamic conditions. The findings demonstrate that the dam is secure against uplift, sliding, and overturning. It is possible to see the area of stress concentration around the drainage gallery and trunion.

The tensile stresses generated at the heel are the primary cause for concern regarding dam stability, according to the findings. Under extreme loading conditions, a small amount of tensile stresses are permitted at the heel. After testing the dam's safety against all forces in accordance with IS 6512-1984 for all possible combinations, it was determined to be both acceptable and safe. Given that the section is cracked, high tensile stresses will result in reinforcement.

Ujwal Kurzekar et al (2021), the design and stability analysis of the concrete gravity dam Kawlewada, located in the Gondia district's Kawlewada village, as well as its constituent parts, are presented in this paper. It has been noted over the difficult years that dam failures resulting from a variety of causes are frequent. Therefore, it is crucial to analyze the different parts of the dam against all of its potential failure modes, external forces, and uncontrollable disasters like earthquakes, disasters, etc. This involved gathering the initial design-related information about the dam, including control levels, dimensions, crest and base widths, etc., through the Inspection Engineer stationed at the Dhapewada Lift Irrigation Office in Tirora, District of Gondia.

The basic and practical profiles of the dam were estimated using the data that was gathered. All major and minor force forces acting on the dam were also calculated, and the STAAD PRO software was used to conduct a stability analysis of the designed dam against all modes of failure and for various load combinations. The results were verified for allowable limits.

In conclusion, this study uses STAAD PRO software to account for the design and stability analysis of concrete gravity dams under various loads and failure scenarios. Along with displacement and B.M., STAAD PRO offers the ability to analyze gravity dams for all potential stresses that could act on them, such as absolute maximum stress, shear stress, normal stress, etc. A well-thought-out spillway offers a way to remove extra floodwater from a reservoir without endangering the dam. Because of the high kinetic energy of the water flowing through it, the stilling basin acts as an energy dissipator, preventing scouring of the river bed downstream. The storm water runoff is contained and redirected by an earthen dam. Increased infiltration, detention, and retention facilities are other uses for it. A canal that was built with peak discharge management in mind serves as a vital link for the local crops. Therefore, a well-designed dam project generally has a benefit-to-cost ratio above one and eventually contributes to the development and welfare of people supporting transportation, agriculture, and fisheries, among other industries.

Mrunalini A. Deshmukh et al (2022), this paper reviews the modern Particle Swarm Optimization (PSO) and the new advanced Finite Element Method (FEM). The fundamental PSO algorithm with several methods and FEM is included in the paper. Additionally, it provides an explanation of the simulation outcome that was achieved using PSO on benchmark functions for either single- or multi-objective optimization. The direction for improving PSO performance in the future is shown by the literature review. It is possible to examine how dam structures actually behave under different loads by using the finite element method. To comprehend how the distribution of base contact stress can be somewhat understood through the use of finite element modeling. When using the assumption of plane strain, 2D analysis is carried out; however, 3D analysis enables the determination of the specific portion of the dam body and the severe force applied to the foundation.

This paper reviews two different approaches for the results. A 1995 review is conducted on the Particle Swarm Optimization method and the Advanced Finite Element Method. The behavior of FEM-based Staad Pro for stability against seismic loads of gravity was examined. As advised in codebooks, the behavior of gravity dams must be determined to be safe by examining stability with regard to overturning, sliding, and shear friction factors. Numerous researchers have conducted the aforementioned studies, which come to the conclusion that FEM enables engineers to closely model and investigate a gravity dam's real behavior under a range of loads and the interaction between the dam and its foundation. A virtual scale model was used to facilitate the execution of the FEM analysis. Developing or modifying the scale modeling of a large structure like a gravity dam was difficult and time-consuming. By avoiding these drawbacks, the PSO approach could produce faster, more accurate, and more effective results.

Divya Sinha et al (2020), they were given literature reviews pertaining to dam analysis in this paper. The purpose of dam construction is to store large amounts of water for later use. Large storage has resulted in heavy loads acting over the dam's upstream side. During earthquakes, additional massive loads act on the dam due to ground motions. It might cause the structure to collapse, which would lead to fatalities as well as social, economic, and environmental problems. The behavior of a concrete gravity dam must be ascertained on the same basis in order to minimize the seismic vibration that is created during an earthquake through the appropriate application of engineering principles.

The researchers concluded that lateral stability in a structure minimizes the bending moment and forces generated due to loads and its age, which results in an increase in structure life with stability and safety. The results show that lateral resisting members are required for seismic force resistivity in order to provide a safe design.

Nagaraj S Kumbar and V B Sulebhavi (2020), a number of concepts have been attempted to be applied to the actual size of the "Bellary Nala Irrigation Project (Belagavi)" dam in this paper. The purpose of the first simulation step is to validate the developed models by contrasting them with results obtained manually. ANSYS APDL18.1 is used to propose a two-dimensional Finite Element Model (FEM) of a gravity dam through Finite Element Analysis (FEA). Analysis is done on dams in both full and empty reservoir conditions. Along the dam's crest, normal stress, principal stress, shear stress, and deflection are all noted. Traditional calculation techniques and material mechanics are two significant complex factors that impact the dam's stability. These require a significant amount of computation time, so they are unable to provide a more thorough analysis. Therefore, a lot of people use finite element simulation technology. As a result, there are numerous varieties of finite element software, with ANSYS software being one of them.

It has been noted that the direction of vertical acceleration influences the displacement of the dam's crest but has no discernible effect on the stress distribution outcomes when the reservoir is empty. Compared to a rigid base, a flexible base develops more stresses. Additionally, higher stresses are induced by the dam's openings when the reservoir is full.

Arnab Banerjee et al (2014), this paper's goal was broken down into two categories. Initially, a program called "Optidam" for cost-based dam section optimization or design was introduced. An optimized concrete gravity dam section was designed by the Optidam program using the pseudo static analysis suggested by the Indian standard. The safety of a single dam section, which was created using the "Optidam," is then verified and examined using non-linear seismic analysis. Ultimately, a parametric analysis was carried out in order to suggest design guidelines for dams. After constructing 1080 dams with heights ranging from 50 to 300 meters and locations on various foundation types, empirical relationships between the various geometric parameters of an optimized concrete gravity dam section with cohesion and internal friction angle of soil/rock foundation are assessed.

Regression analysis results in a set of guidelines for dam design. The parametric analysis confirms that the dam's base width is inversely correlated with cohesion and internal friction angle and proportional to height. To estimate the tensile damage, non-linear finite element analysis is also carried out. Tensile damage up to 15 meters is visible on the dam's heel, and for MCE and DBE shaking levels, 7 meters is visible at the upstream face. But the fact that the stability of the dam section was unaffected in both DBE and MCE indicates the safety of the dam sections created by Optidam. Designed dams have a maximum downstream slope of 0.8 and a maximum upstream slope of 0.35, which are the general characteristics of optimized dam sections. The optimized section produced by the Optidam program is parametrized for a range of heights, cohesion, and internal friction angle. On the 1080 planned dam sections, a regression analysis is carried out.

Shiva KHOSRAVI et al (2023), in this paper, finite element analyses of gravity dams are conducted with consideration to 11 geometry variables. For every geometry and gravity dam, the 11 geometric variables are modeled. The dam is taken into consideration 17

in 4 distinct scenarios to check and validate the model and guarantee the assumptions made during the modeling process: I) Dam with a rigid foundation and an empty reservoir. III) Dam with a flexible foundation and an empty reservoir. II) Dam with a solid foundation and an entire reservoir. IV) Dam with a flexible foundation and an entire reservoir. The modal analysis and mode shapes of the Pine Flat, Koyna, and idealized triangular Dams are examined, and the results are compared with other reference results, in order to evaluate the accuracy of this modeling.

The numerical outcomes demonstrate the effectiveness of the proposed method for gravity dam shape simulation. It is also discovered that a safe gravity dam design heavily depends on taking the dam, water, and foundation rock interaction into account. The numerical results demonstrate that the gravity dam's proper, ideal design is achievable. It has been noted that the interactions between gravity dams and foundation rock, as well as those between gravity dams and water, are significant factors in arch dam design, and ignoring these effects may result in an incorrect design. Furthermore, it is evident that the dam's main frequency is maximized in case 1 (the reservoir is empty and the foundation is rigid). Moreover, taking into account the dam water-foundation rock interaction (case 4) results in a minimum value for the main frequency. Additionally, numerical results show how well the hybrid meta-heuristic optimization performs when it comes to designing concrete gravity dams with the ideal shape.

3. METHODOLOGY

The study employed STAAD.Pro V8i SS5 to model and analyze the stress distribution in a gravity dam. Two models with identical geometries were developed:

1. Hydrostatic Model: This model simulated the dam under hydrostatic pressure alone, representing the force exerted by the retained water.

2. Self-Weight Model: In addition to hydrostatic pressure, this model included the gravitational load of the dam's own weight.

The methodology involved the following steps:

Model Development: Accurate 3D models of the gravity dam were created, incorporating precise geometry and material properties of concrete.

Boundary Conditions: Appropriate supports and boundary conditions were applied to replicate real-world scenarios.

Load Application: Hydrostatic pressure was applied to both models, while the self-weight of the dam was included in the second model as an additional loading condition.

Finite Element Analysis (FEA): A robust FEA approach was used to compute stress distributions, including bending (MXY), membrane (SXY), and shear stresses (SQX, SQY).

Result Extraction: Stress values were extracted at key locations for both models to identify and compare critical areas of stress concentration.

4. CONCLUSION

The analysis revealed distinct differences in stress distribution between the two models. The inclusion of self-weight in the second model significantly influenced the internal stress patterns, particularly in regions experiencing high bending and shear forces. Key findings include:

- The self-weight of the dam contributes notably to stress concentration in critical areas, which could impact structural integrity.
- Ignoring self-weight in design analyses may underestimate stresses and compromise safety margins.

This study underscores the importance of incorporating self-weight in the design and analysis of gravity dams to ensure accurate stress evaluation and long-term structural reliability.

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