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REVIEW: GRAVITY DAM STABILITY ANALYSIS BY FEM AND PSO.

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ABSTRACT

The assessment of the structural stability of the gravity dam plays a vital role as far as the safety of the dam is concerned. There are many conventional methods like gravity, slab analogy, etc., for analyzing gravity dams against primary loads (self-weight, hydrostatic pressure, uplift pressure, sediment pressure, seismic pressure, etc.). This paper reviews the new advanced Finite Element Method (FEM) and modern Particle Swarm Optimization (PSO). The paper contains the basic PSO algorithm with various techniques and FEM. It also describes the simulation result carried out on benchmark functions of single-objective or multi-objective optimization with the help of PSO. The study of literature shows the future direction to enhance the performance of PSO. The finite element method allows studying the actual behavior of dam structures against various loads. To understand how Finite element modeling can give some insight into the distribution of base contact stress. The 2D analysis is done when the assumption of plane strain is used, but 3D analysis allows the identification of the severe fortitude of forces applied to the foundation and what part of the dam body.

INTRODUCTION

The analysis of concrete gravity dam is a complex problem due to the dam-reservoir interaction under seismic forces. In the design of dams, an essential factor is the consequence of hydrodynamic pressure on the upstream and downstream face of the dam due to trembling ground motions. Its interaction with the reservoir influences the seismic response of a gravity dam. The Design Manual For Concrete Gravity Dams (1976) published by the United States Bureau of Reclamation (USBR), Chapter III Gravity dams (2016) by Federal Energy Regulatory Commission (FERC), IS: 6512-1984 Indian Standard Criteria for Design of Solid Gravity dams and numerous other guiding principle are existing internationally for the design and analysis of concrete gravity dams. Structural stability has to be checked for various intervals and modes of failure in the conventional analysis for static loads, such as 1) Overturning at a parallel plane at the base within the structure or a plane below the base. 2) Sliding on any horizontal or near horizontal plane within the structure at the base or any rock seam in the foundation, and 3) permissible unit stresses in the concrete or the foundation material shall not be exceeded (Dawlatzai and Dominic, 2018). The Bureau of Indian Standards code IS 6512-1984 "Criteria for design of solid gravity dams" mentions that a gravity dam should be analyzed and designed for the most adversative load condition using the safety factors. There are many two-dimensional and three-dimensional methods like the Gravity method, Slab Analogy method, pseudo-dynamic method, etc., to analyze gravity dams. FEM is a recently developed method that can determine the stress distributions in two-dimensional analysis and study grouted joints in three-dimensional analysis. The response of a structure is defined as its behavior resulting from an earthquake disturbance. The response is usually represented as a measure of the structure's displacement acceleration or velocity (Ganji and Alembagheri 2018). The PSO is a heuristic global optimization method proposed by Dr. Kennedy and Eberhart in 1995. It initially took its inspiration from the biological examples of swarming, flocking, and herding phenomena in vertebrates. PSO has many similarities with some evolutionary computation techniques like Genetic algorithms (GA). WHILE FINDING OPTIMAL SOLUTIONS, the PSO algorithm follows an animal society with no leader work system (Alam *et. al.,* 2012). The purpose of optimization is to curtail the section of the dam monolith, assuring its safety. The parameters of a dam section like the height of the dam (H), the height of reservoir water (H_u), Peak ground acceleration (A_h), and minimum width of the crest (B_2) are optimized. It is generated to perform the optimization using the dynamic programming method based on IS: 1893-1984 (Dubey *et al.* 2013).

The review of the two methods is explained below :

1. Finite Element Method (FEM)
2. Particle Swarm Optimization Method (PSO)

Finite Element Method (FEM)

The Finite Element Method (FEM) analysis allows modeling of the dam and the foundation rock below the dam. (Shou-yan and Cheng-bin 2012). The literature review was carried out with an interpretation to understand how the virtual scale modeling in FEM can give insight into the dispersal of base contact stress. Two-dimensional finite element analysis is adaptable to gravity dam analysis when the assumption of plane strain is used. The three-dimensional analysis allows the rigorous determination of what forces should apply to the foundation and what part of the dam body. (Shahir and Dhurvey 2017).

Ganji and Alembagheri (2018) evaluated a gravity dam's structural stability and safety located on a heterogeneous rock foundation. They analyzed the self-weight, hydrostatic, and uplift pressures using overstress and sliding safety indices. The relative arrangement of the foundation was changed into two main groups by inserting one or two single large joints or fault planes. The coupled stress–seepage problem was unraveled precisely to obtain the seepage regime and the uplift forces. The safety and stability of the gravity dam concerning the position of the footing joint, mechanical, absorptivity properties of the rock, and the uplift forces were assessed.

Dawlatzai and Dominic (2018) analyzed the stability of a non-overflow section of the Koyna dam using the Gravity method. Dam-foundation-reservoir interaction was neglected, and the dam was assumed to be fixed at the base. The various forces like dynamic seismic forces and their stresses were evaluated at different heel and toe points. The 2D finite element model analysis was carried out using ANSYS APDL R.18.2.

Shahir and Dhurvey (2017) performed a stability analysis of a concrete gravity dam under seismic loading. In Afghanistan, currently, no specific seismic design codes are available. Therefore, they performed a complete two-dimensional stability analysis using the 2D gravity Method and a three-dimensional finite element stability analysis of concrete gravity dam using ANSYS software and compared the results. Their analysis selected Kabul and Herat cities of Afghanistan and determined their peak ground acceleration (PGA). Both cases were found to give safe results for the selected section under tension development (causing ultimate failure by crushing).

Dragan *et. al.* (2017) analyzed the mechanical, thermal, and filtration process in a large gravity dam and surrounding rock mass. They aimed to create the finite element model and conduct analyses of stability to find the object's current state after more than 45 years of exploitation. The dam was thoroughly modeled to detect potential flaws or failures of specific parts of the dam system. Additionally, dam stability was analyzed during the potential failure of specific drainage system parts. All the loads influencing the dam in exploitation conditions (mechanical, thermal, and filtration loads) were applied to the model.

Sarde and Jaiswal (2017) analyzed the concrete gravity dam using dynamic time history and STAAD-PRO. A virtual dam model is organized in STAAD-PRO to perform the time history analysis, and a comparison is made between a dam with a gallery (openings) and a dam without a gallery. Seismic analysis is performed for dams with a gallery and dams without a gallery. As per Table.1, IS 6512:1984 various primary loads and load combinations are used to analyze concrete gravity dam. Authors concluded that: a) compressive and tensile stresses at the heel /toe of the dam with a gallery are less than the dam without a gallery. b)stress variation in dam body had studied and design slopes asper their patterns are specified. c) stress variation found in the dam due to the construction of the gallery. d) STAAD-PRO is the most convenient and less tedious for dynamic analyses, and it provides a computing environment to investigate modeling assumptions and computational processes related to the static and seismic structural stability of gravity dams. as per their

Reddy and Rao (2017), the author analyzed the dam using Staad.Pro software. Staad. Pro is widely used for multi-storied buildings with beams and columns. However Staad. Pro can analyze any element such as plate, shell, or solid in addition to beam members. So, the dam is modeled with solid elements in the software with relevant data. Results of stresses and stress contours are described at the end of the paper. The paper's objective is to have a direction of analysis of the dam considering solid elements using STAAD.Pro.

Ganji and Alembagheri (2018), The numerical analysis of 122m high non-overflow monolith Pine Flat concrete gravity dam with a crest length of 560 m was studied as a case study. A concrete gravity dam's structural stability and safety against sliding on an inhomogeneous rock foundation with parallel two fault models without seepage were carried out.

Azevedo, (2018), The hydrodynamic stability analysis of concrete gravity dam against shear sliding failure situation using maximum design earthquake (MDE) was performed. The numerical analysis of two dams with varying heights and two different dam-foundation conditions as (i) dam-foundation edge dynamic behavior and elastic behavior of fractured rock mass area and (ii) nonlinearity in dam-foundation edge the joints in fractured rock mass area both. Hence, the shear sliding failure with high stiffness rocks is more, but shear sliding displacement is reduced. The "Kalhovd" concrete buttress dam was numerically analyzed with 49 buttresses in Norway.

Ulfreg, (2019). The analysis used certain vital factors as interlocking between foundation and buttress. Using FEM, the dam was found safe in overturning and sliding failure. Results demonstrated an increase in load-carrying capacity with some additional rock bolts, which increases stability in overturning.

Sinha *et.al.*, (2020)The different tools in the finite element method for analyzing gravity dam structure were reviewed. The forces and moments are generated due to various external loads. The safety evaluation for dam structure increases the life of the structure.

The above studies executed by many researchers conclude that FEM permits the engineer to closely model and study the actual behavior of a gravity dam against various loads and dam interaction with its foundation. FEM analysis was executed with the help of a virtual scale model. The Scale modeling of immense structures as a gravity dam was complex and tedious to develop or make changes. The PSO method could avoid these limitations, which should provide more efficient and accurate results in less time.

PARTICLE SWARM OPTIMIZATION (PSO)

It is a heuristic global optimization method put forward initially by Dr.Kennedy and Eberhart in 1995. As per Urade and Patel (2011), the PSO algorithm evaluates the optimum solution inspired by animal social behavior such as bird flocking. PSO works the "NO LEADER" principle. PSO is a user-friendly and straightforward method.

Eberhart & Shi (2001) reviewed various literature on the working of the PSO algorithm method. PSO gives population topologies (neighborhoods) and the PSEUDO CODE. The PSO algorithm can deal with both unconstrained, constrained, continuous mathematical problems with many local minima and continuous and integer /discrete structural design problems with constraints. (Venter *et. al.*, 2003) .PSO performs well in two dimensions as compared to ten dimensions. Thus, the multi-objective optimization problem will be solved by Dynamic PSO in the plan. (Urade and Patel, 2011). Modification over existing PSO is developed for solving the fundamental PSO problem. Modified variant PSO helps the PSO process other conditions that cannot be solved by the basic PSO (Rini *et. al.*, 2011).

ARAUJO *et. al.*(2019) authors focused on shape optimization of gravity dam non-overflow section using Genetic Algorithm. In this algorithm, an objective function is a cross-section of a dam, and the design variable is the geometric properties of the dam. This GA was carried out using MATLAB. The check against sliding, overturning, and floating is applied in the program.

Khudair *et al.* (2018) optimized the cross-section of the channel and height of upstream and downstream cofferdam with minimum construction costs for diversion works. It was solved by the PSO method using MATLAB. The optimization model was applied to prepare the optimal design graphs. It can be noticed, at any design flow rate, optimal water flow depth, bed width, and height of upstream and downstream cofferdams decrease with an increase of the side-slope.

Dou *et al.* (2017) introduced a novel “Adaptive Fireworks Algorithm” (AFWA) for inverse analysis of parameter identification of concrete gravity dams. Researchers suggested that parameter identification was important in structural health monitoring and damage identification for concrete dams. The researcher's numerical analysis showed that swarm intelligence algorithms were powerful tools for parameter identification of concrete structures. He applied the Fireworks algorithm to inverse analysis of hydraulic structures and the parameter selection problem.

Alimollaie and Shojaee (2017) presented a new technique called “Group Method of Data Handling” (PSO-GMDH) for optimization of the shape of the concrete arch dam and the modification by achieving safety against dynamic design loads. In the first stage, a preliminary optimization was done using PSO. In the next stage, the neural network, GMDH, replaced the ANSYS analysis with the lowest error and less number of iterations, respectively, to get the optimum result.

Wang and Zhenyue (2017) stated a new reliability method named SACPSO-FORM. It combined the “First Order Reliability Method” (FORM) and “Hybrid Particle Swarm Optimization” (SACPSO) for the reliability optimization calculation. It was utilized for those complex reliability problems with correlated non-normal variables and implicit performance functions. The stability reliability analysis on the complicated rock foundation of a practical gravity dam was demonstrated. SACPSO-FORM method was accurate, stable, flexible, and efficient for reliability analysis in engineering applications.

Chutani and Singh (2017) demonstrated a typical PSO to achieve the optimal design of a supported reinforced concrete beam. Optimal cross-sectional sizing of an RC beam results in cost-saving, but optimal sizing cannot be standardized for various factors that influence a given design. An algorithm has been developed to get a minimum cost solution that satisfies Indian codal requirements for RC beams.

Khudair *et al.*, (2018). The authors optimized the channel cross-section and height of upstream and downstream cofferdam with a minimum cost of construction by PSO using MATLAB. The authors concluded that optimum bed width, water flow depth, and height of cofferdam are inversely proportional to side slope. In addition, the cost of construction is directly proportional to the side slope.

Si *et.al.* (2019), an improved PSO was applied for the dynamic changing pattern of Inertia Weight “w” of a non-overflow section of a gravity dam. In the early stage of Improved PSO, the inertia weight value was high, but in the further stage, it reduces by improving the global searching ability and meeting the algorithm's performance. The convergence rate of improved PSO was 31.8% higher than SPSO. Hence, improved PSO is better and suitable for the design optimization of massive hydraulic structures.

Yang *et. al*. (2019) executed a back analysis of the elastic modulus of the dam body and dam foundation using improved PSO. PSO algorithms with modified parameters are used in back analysis with high accuracy.

Yang *et.al.* (2021) analyzed a high concrete dam using a hybrid modeling method and improved PSO to predict the hydrostatic pressure deformation of the dam. The hybrid hydraulic-seasonal-time (HHST) model simulates the effects of structural effects in operation conditions. The improved PSO algorithm is used by improving PSO with the help of inertia weight, dynamic learning factors, etc.

From the literature review, it has been found that very few studies have been carried out using PSO for the stability analysis of gravity dams.

Conclusion:

The two distinct methods are reviewed in this paper. The advanced Finite Element Method and Particle Swarm Optimization method are reviewed from 1995. The behavior for stability against seismic loads of gravity using FEM-based Staad. Pro was reviewed. The behavior of gravity dams found must be safe by checking stability concerning overturning, sliding, and shear friction factors as recommended in codebooks. The above studies executed by many researchers conclude that FEM permits the engineer to closely model and study the actual behavior of a gravity dam against various loads and dam interaction with its foundation. FEM analysis was executed with the help of a virtual scale model. The Scale modeling of a massive structure as a gravity dam was complex and tedious to develop or make changes. The PSO method could avoid these limitations, which provides more efficient and accurate results in less time.

References

[A] Books, Manuals, and Indian Standard codes:

1. Design Manual For Concrete Gravity Dams (1976), "Design Of Gravity Dam" by A Water Resources Technical Publication Denver, Colorado. Published by the United States Bureau of Reclamation (USBR).
2. Federal Energy Regulatory Commission (FERC) (2016), "Chapter III Gravity dams," Engineering Guidelines for the Evaluation of Hydropower Projects
3. The Division of Dam Safety and Inspections has revised Engineering Guidelines Chapter 3, Gravity Dams.
4. Garg S.K (2002), " Irrigation Engineering and Hydraulic Structures," Khanna Publishers, PP 960-1020.
5. IS 6512-1984: Indian Standard Criteria for Design of Solid Gravity dams. (First Revision) First Reprint SEPTEMBER 1998
6. IS:1893-1984: Indian Standard CRITERIA FOR EARTHQUAKE RESISTANT DESIGN OF STRUCTURES (Fourth Revision) First Reprint JULY 1999.

[B] Research Publications:

1. Alimollaie S. and Shojaee S.(2017), "Optimal Design Of Arch Dams By Combining Particle Swarm Optimization And Group Method Of Data Handling," International Journal Of Optimization In Civil Engineering, 7(4): 493-514.
2. ARAUJO L., Vieira A., Gutstein D., (2019), "Optimization Study For The Cross-Section Of A Concrete Gravity Dam: Genetic Algorithm Model And Application.", SCIPEDIA, Revista Internacional de Métodos Numéricos para Cálculo y Diseño en Ingenierí.
3. Chutani S. and Singh J.(2017), "Design Optimization Of Reinforced Concrete Beams," Journal of Institution of Engineers (India), Series A (December 2017) 98(4): 429-435, DOI 10.1007/s40030-017-0232-0.
4. Dawlatzai K. and Dr. Dominic M.(2018) "Structural Stability And 2d Finite Element Analysis of Concrete Gravity Dam", International Journal of Engineering Science Invention (IJESI) ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726, Volume 7 Issue 1, January 2018, PP.09-20.
5. Dou S., Li J. and Kang F.(2017), "Parameter Identification Of Concrete Dams Using Swarm Intelligence Algorithm," Emerald publication, Stockholm University Library.
6. Dragan R., Milan B., Vulović S., Živković M., Divac D. and Nikola M.(2017), "Stability Analysis Of Concrete Gravity Dam Using Fem" International Conference and Workshop Remoo-2017 Energy For Tomorrow 10–12 May 2017, Venice / Italy Remoo–2017 — 03.063.1
7. Ganji H. and Alembagheri M.(2018), "Stability of Monolithic Gravity Dam Located on Heterogeneous Rock Foundation," Arab Journal of Science and Engineering, 43:1777–1793.
8. Khudair B., Mahmood R., Sadeq N.(2018), "Optimal Economic Design of Diversion Structures during Construction of a Dam by Particle Swarm Optimization," International Journal of Science and Research (IJSR), ISSN (Online): 2319-7064, Index Copernicus Value (2016): 79.57 | Impact Factor (2015): 6.391
9. Shahir E. and Dhurvey P.(2017), "Stability Analysis of Concrete Gravity Dam for Seismic Loading in Afghanistan," International Journal of Engineering Technology Science and Research (IJETSR), ISSN 2394 – 3386, Volume 4, Issue 6, June.
10. Wang G. and Zhenyue M.(2017), "Hybrid Particle Swarm Optimization For First Order Reliability Method," ELSEVIER / Science Direct/ Computers and Geotechnics 81(2017) 49-58.
11. Sarde U. and Jaiswal A. (2017), "Time History Analysis of Concrete Gravity Dam with Gallery and Dam without Gallery by Using STAAD.Pro," IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 14, Issue 2 Ver. VIII (Mar. - Apr. 2017), PP 35-39 www.iosrjournals.org
12. Reddy M. and Rao M. (2017), "Design And Analysis Of Gravity Dam –A Case Study Analysis Using Staad-Pro," An IJREAS Volume 2, Issue 4 (2017, April) (Issn-2455-6300) Online Anveshana's International Journal Of Research In Engineering And Applied Sciences.
13. Yang L., Su H., Wen Z., "Improved PLS and PSO methods-based back analysis for the elastic modulus of the dam," 2019 published by Elsevier.
14. Yang G., Gu H., Chen X., Zhao K., Qiao D., "Hybrid hydraulic-seasonal-time model for predicting the deformation behavior of high concrete dams during the operational period," Wiley Online Library, The Journal of the International Association for Structural Control Health Monitoring, First published: 05 January 2021.