Probabilistic stability analysis of narasimharaya sagar earthen dam by using geo-studio software

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Abstract: Since every potential failure scenario might result in significant losses in both lives and property, the construction of dams needs extensive research to ensure the safety and feasibility of these large engineering structures. In this article, the Analyses should be performed upon specifically to evaluate seepage, slope stability, and soil liquefaction of significant earthen dam. A numerical technique employing the finite element method (FEM) was used in this article. Finite element software (GEO-STUDIO 2022) was used to carry out both steady-state and transient seepage analyses and pseudo-static ground motion That deals with the present work behavior of the Narasimharaya Sagar (Gorakallu Balancing Reservoir) earthen dam which is in the earthquake prone area of Zone II (as per IS 1893-2002).Geostudio 2022's SLOPE/W, SEEP/W, and QUAKE/W tools examine the stability characteristics slope, seepage, and earthquake (finite element modelling based software). The model with the reservoir at full capacity is initially examined using SEEP/W to identify the piezometric line, which serves as the foundation for SLOPE/W to determine slope stability. Afterwards, it is exposed to a 0.1 peak ground acceleration earthquake motion using QUAKE/W to know its dynamic stability.

1. INTRODUCTION

Earthen dams are one of the most common types of dams used around the world. They are built by compacting layers of soil, clay, and other natural materials to create a barrier that holds a large quantity of water at the upstream side. These dams are often used for a variety of purposes, including water storage, flood control, and hydroelectric power generation. While earthen dams may seem simple in design, they are actually quite complex structures, requiring careful planning and engineering to ensure their safety and longevity. Earthen dams should be designed and constructed to withstand extreme weather conditions, earthquakes, seepage as well as erosion, structural instability, piping, internal cracks, rainfall, and other natural disasters which can reduce the storage capacity and increase the risk of flooding.

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So the failure of dam stability will result in the loss of property & lives of living beings. The normal operation of the clay core dam and leakage problems endangers hydraulic engineering in many aspects. Some serious leakage problems even result in dam breakage due to a variety of mechanisms such as fracturing and collapse. Recent years have seen an increase in the use of computer-based numerical models to test the stability of earth dams and to simulate the impact of all the factors that affect their safety. One of these essential factors is the materials employed in the construction of an earth dam. As a result, they are regarded as the study's major priority. Thus, it is crucial to accurately predict seepage through embankment dams for the safety of these earthen structures. A seismic study is done if the dam is located in an earthquake zone. When pushing forces to overwhelm opposing forces, slope collapses result. Gravity is usually the pushing force, while the shear strength of the slope material is the opposing force. Gravitational forces, seepage forces, earthquake forces, and loads from construction equipment are some of the forces that lead to slope failure. Dam collapse can be caused by a variety of factors. Dam failures can be caused by natural events like floods, landslides, earthquakes, etc. as well as external forces like seepage, foundation collapse, structural failure, etc. To determine the FOS, slope stability analysis is carried out. The Mohr-Coulomb method is used for the analysis.

[1] observed Safety evaluation of the chamrga earth dam for seepage deformation and stability analysis with GeoStudio 2012. Under seepage (seep/w), Steady state and Transient conditions were performed. The direction and quantity of water flux, existing gradient, and safety factor are found. Based on the findings, it can be concluded that the slope's stability during drawdown is significantly influenced by how quickly its pore water pressure decreases. [2] have explained various Methods for Slope Stability analysis.[3] examined the analysis of Earthen dam using Ansys and Geostudio software. Stress and strain pattern, seepage rate in core and upstream dam, tension variation throughout the dam were found and compared to both softwares. [4] observed the static and dynamic analysis of nailed slope. The stability of slope for particular inclination and height of slope is checked under static and seismic states. The variation of factor of safety along with protruding length and inclination of nail is determined. [5] done a experimental design of Slope stability optimization using reinforcement by Geoslope for 4 cases involving unreinforced dry slope, unreinforced wet slope, reinforced dry slope, reinforced wet slope by Morgenstern Price method, Janbu Stabilized method, Bishop Simplified Method in SLOPE/W. [6] studied the Stability Analysis of Souk-Tleta .Earth Dam, North Algeria using Plaxis software for 3 cases of reservoir filling, empty reservoir, steady-state water levels and low water level. The Factor safety is determined through plaxis for all cases discussed above. [7] has examined the slope stability of an earthen dam. Four scenarios were studied using the GEOSTUDIO 2007 software: an earth dam without a berm and one without a toe drain, an earth dam with a berm but no toe drain, an earth dam without a berm but one with a toe drain and an earth dam with a berm but one with a toe drain. The earth dam with berm and toe drain is, according to the four scenarios, the best one to increase the slope's safety factor. [8] have studied the dam break analysis of Kalyani dam using HEC-RAS model which results determined useful for evacuation planning, estimation of damages and post flood recovery in the area. [9] studied Simulation of seepage flow through an earthen dam with vertical drain and comparison of results with observations data (case study: Harreza dam-Algeria). Maximum seepage velocity and piping chances are less likely to occur and is within safety limits. [10] did the Numerical Model of Seepage Analysis and Slope Stability for Horan Dam in Iraq. Here, To study water seepage through the dam in a steady condition, a mathematical model is created. The Bishop, Janbu, Morgenstern-Price, and Ordinary techniques are used for evaluating the stability of the dam's upstream and

downstream slopes. [11] studied Numerical Analysis of Rapid Drawdown of an Embankment Dam. The lowering of the reservoir was performed at different depths between two scenarios, i.e. rapid lowering rate (0.25m/day), slow lowering rate (0.1m/day). The results of undrained shear strengths of these two are 30 KN/m^2 and 25 KN/m^2.

2. STUDY AREA

Gorukallu earthen dam (Narasimharaya dam) is an earthen dam which was located at Gorukallu Village in Panyam Mandal in Kurnool District of Andhra Pradesh State, India. It belongs to the Rayalaseema region a chronically famine-stricken area. It is located 55 Km towards East from District head quarters Kurnool of seismic zone –II with a zone factor 0.1g as per IS 1893- 2002). Tungabhadra and Krishna are the two major rivers that are the only nearest sources capable of commanding the portions of these areas. This is a balancing reservoir of Srisailam right channel of Krishna river. Which has 45.12m high from the MGL and retaining/storage capacity of 12.44TMC of water at theupstream side of the dam. The total length of Narasimha Rayasagar dam is 3626m which includes 1721 m comprising non-overflow concrete/colgrout and the remaining length of 1905m are compacted earthen dam.

Fig. 1: Location of Narasimharaya Sagar dam, India

Table 1: Salient Features of Dam

Gross storage at F.R.L	:	12.44TMC
Live Storage Capacity	:	10.29 TMC
Dead Storage Capacity	:	2.15 TMC
T.B.L	:	+265.60 m
T.B.L.C Fault Zone	:	+265.60 m
T.B.L	:	+267.00 m
F.R.L	:	+261.00 m
M.D.D.L	:	+235.342 m
Catchment Area	:	77.70 sq. Km
Discharge From Self Catchment	:	848 Cumecs
Deepest Bed Level	:	+220.00 m
Water spread Area at F.R.L	:	15.10 sq.Km
The total length of the Dam	:	3626 m
Comprising of non overflow concrete/ Colgrout	:	1721 m
Earth Dam (Zonal Section)	:	1905 m

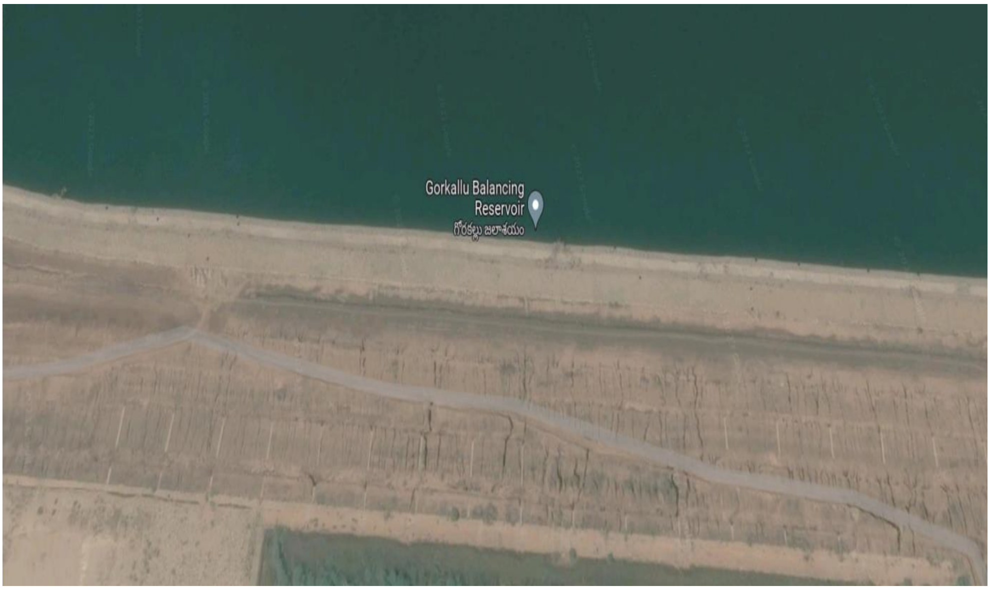

Fig.2: Narasimharaya Sagar Earthen Dam Satellite View

Fig.3: Sand drain with rockfill above @ toe drain

Fig.4: rip rap with hand picked stones at U/S (upstream side)

3. METHODOLOGY

The Geo-studio software includes numerous commands for analysis of slope stability, steady state, and transient seepage analysis, stress and deformation, quake/w for calculating excess pore water pressures and displacement due to earthquake motion, freezing effect, CTRAN/w for analyzing contaminant migration, and AIR/w for air transfer in mine dumps and other porous media. The limit equilibrium technique, finite element modeling, and numerical modelling are the 3 methods for assessing slope stability. The equilibrium limit This research makes use of the SLOPE/W command in GeoStudio and the Morgenstern Pricing method from 1965. In addition to assessing seepage rate and stability, the SEEP/W command also calculates seepage loss throughout the whole design life of the structure. changes at the old nodes.

SLOPE/W is utilised all over the world for the design and study of hydraulic structures that are susceptible to a range of natural and artificial factors, including as flood occurrences, fast drawdown, seismic loading, and changing hydrogeological systems. Although integration with SIGMA/W or QUAKE/W enables complex finite element stability and Newmark deformation assessments, comprehensive probabilistic and sensitivity analysis in 2D helps risk assessment.

3.1 SLOPE ANALYSIS USING MORGENSTERN PRICE METHOD

Slope stability analysis employs the Morgenstern-Price (MP) approach, which includes calculating the factor of safety (FOS) against slope collapse. To determine the FOS, the approach takes into account the slope's geometry and the soil's shear strength factors. Normal forces and interslice shear remain in a stable connection. To maintain a consistent shear-normal ratio that yields equal FOS for both of the equations illustrated in figure 5, trial and error is used. As a result, the equilibrium equations for moments and forces are fulfilled.

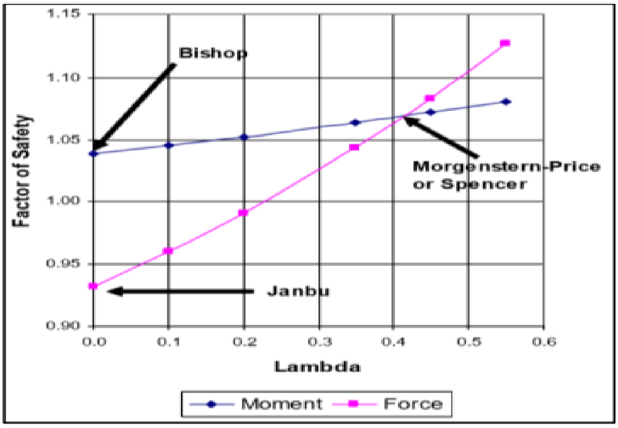

Fig. 5: FOS for above 3 methods

This approach yields a lower FOS than the other limit equilibrium methods since they do not account for the interslice pressures when calculating the safety factor. Except for the availability of different interslice force functions, the Spencer approach and this method are relatively comparable. The FOS for both the Spencer and MP procedures would be the same if the "constant" interslice force function was employed in the MP method.

3.2 SEEPAGE ANALYSIS

SEEP/W analysis is used to establish the piezometric line, and SLOPE/W analysis is used to determine the FOS at D/S & U/S. The SEEP/W tool is used to determine the seepage rate at any location along the structure's cross-section.

There are two different methods of seepage assessments that replicate the actual water level circumstances in the field. Transient seepage illustrates the abrupt decrease in water level that happens during floods, whereas steady-state seepage depicts the consistent storage of water level.

Mathematically, steady-state seepage is

$$\partial/\partial x\ (k_x\ \partial H/\partial x) + \partial/\partial y\ (k_y\ \partial H/\partial y) + Q = 0 \qquad (1)$$

Where H = total available hydraulic head difference, k_x = permeability in x-direction, t = time, Q = discharge, k_y = permeability in y-direction, m_w = slope at storage side, γ_w = unit weight of water.

3.3 PSEUDO-STATIC ANALYSIS

A steady vertical and horizontal acceleration earthquake motion is used to test a structure's seismic stability. The pseudo-static forces F_h and F_v, which are inertial forces produced by pseudo-static accelerations, act at the slope's centre of the critical slip surface.

$$F_h = (a_h W) / g = k_h W \tag{2}$$

$$F_v = (a_v W) / g = - k_v W \tag{3}$$

Where k_h , k_v are horizontal and vertical pseudostatic coefficients, a_h, a_v pseudostatic accelerations, W is weight of failure mass, g is gravity acceleration.

$$\begin{aligned} FOS &= \text{resisting force /driving force} \\ &= cl + ((W - F_v) \cos\beta - F_h \sin\beta) \tan\varphi / ((W - F_v) \sin\beta + F_h \cos\beta) \end{aligned} \tag{4}$$

Where l is length of failure plane, β is angle of failure plane with the horizontal.

3.4 EARTHEN EMBANKMENT OF NARASIMHARAYA SAGAR DAM / GORUKALLU DAM MODEL:

The frontal and posterior slopes of the conceptual model are covered with excavated material, and the impervious core is stretched out by semi-pervious material. Three filters, including coarse, transitional, and fine, are positioned on either side of the excavated material, allowing water to enter through them and then be collected via pipelines lowering the danger and lengthening the structure's lifespan.

Table 2 lists the index characteristics of the soil material. The Mohr-Coulomb material model is taken into account for model analysis. Eight areas that resemble the foundation, rockfill toe, excavated material, coarse, transitional, and fine filters, as well as semi-pervious material and impermeable core, make up the geometry. The model dam is shown in Figure 6.

SLOPE/W provides slope stability in terms of FOS, QUAKE/W is used to analyze the response to ground shaking due to earthquake motion, and transient seepage represents sudden drawdown condition prior to the earthquake. These analyses also include SEEP/W, which shows long-run steady-state seepage and transient seepage. As the piezometric line from the filters falls into the toe drain, a granular toe drain is positioned beneath the rockfill toe on the downstream side. Figure 6 depicts the model case study's finite element mesh, which includes 432 nodes and 241 elements. In graphical form, the shear modulus parameter utilized in the dynamic analysis is selected based on the kind of soil.

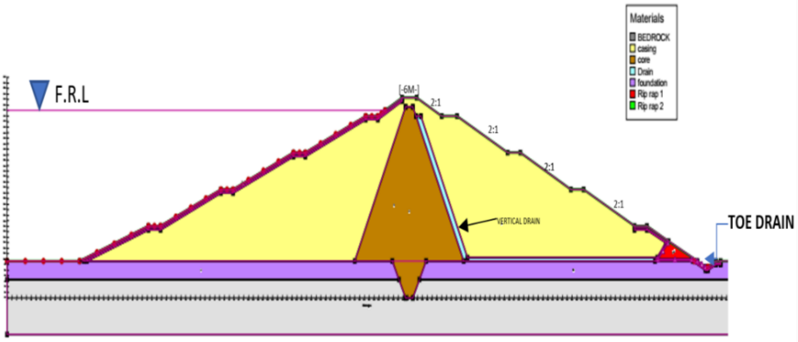

Fig.6: Simulation of earthen embankment

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Table 2: Soil properties in present study

Material	**Specific weight (KN/m^3)**	**Cohesion (KPa)**	**Permea - bility (m/s)**	**Internal Friction (^{0})**	**Saturated water content**	**Poisson ratio**	**Damping ratio**
Core	21	27	1e^{-08}	35	0.5	0.3	0.8
casing	19	10	1e^{-06}	33	0.46	0.3	0.3
Drain	16	0	0.001	45	0.42	0.16	0.17
Rip rap 1	19	0	0.0001	44	0.42	0.21	0.19
Rip rap 2	17	0	1e^{-05}	40	0.42	0.27	0.23
Rockfill	26	0	0.001	34	0.4	0.41	0.06
bedrock	22.7	5	5.5e^{-07}	36	0.48	0.29	0.37

4. RESULTS AND DISCUSSIONS

4.1 Static Analysis

In order to do the SEEP/W analysis and determine the flow rate in the drain, the piezometric line must first be determined. Volumetric water content, permeability, saturated water content, specific soil weight, angle of internal friction, and residual water content are required to determine the Seepage rate and factor of safety.

For seepage analysis, the Van Genuchten hydraulic conductivity function is employed. Figure 6 shows a steady-state seepage study for the lengthy course up to the FRL of the embankment. The Figure 7 depicts the rate of seepage flow. Figure 8 shows the discharge.

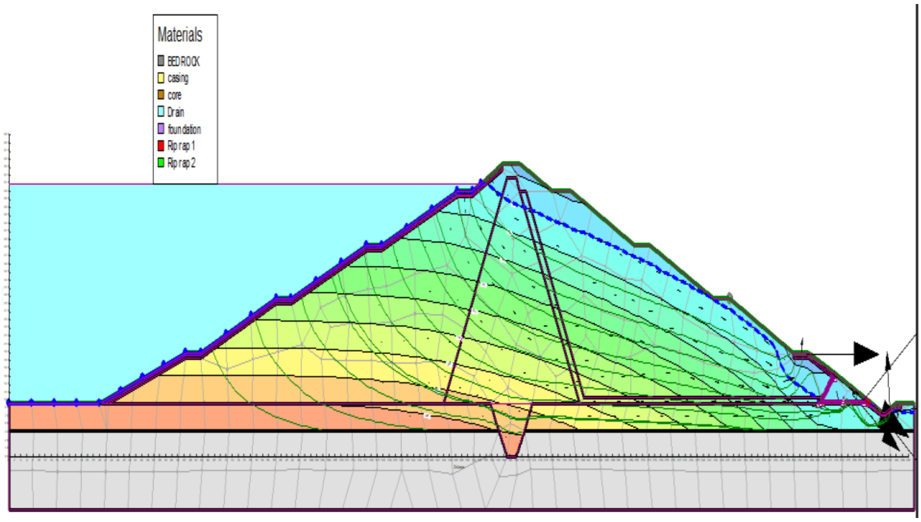

Fig. 7: steady-state seepage study for the lengthy course up to the FRL of the embankment.

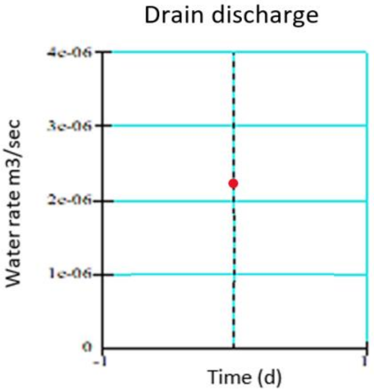

Fig. 8: Discharge Q ($2.173e^{-06}$ $m^3/s/m$) in the drain for Steady State seepage

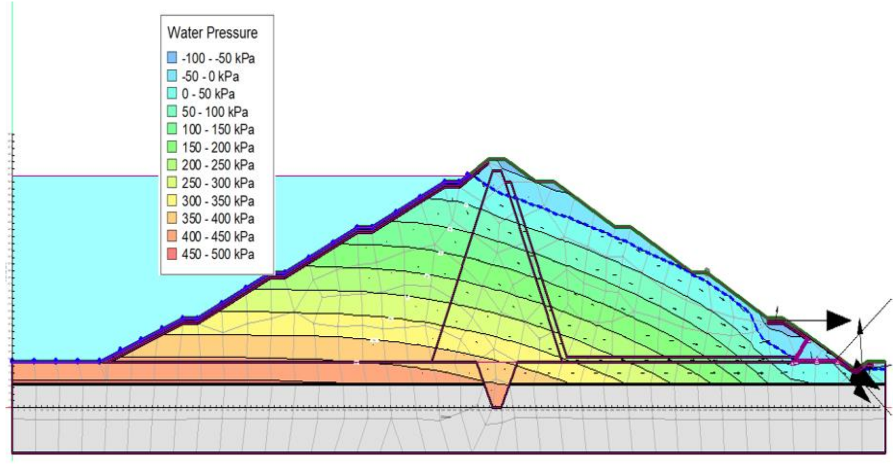

Fig. 9: Pore Water Pressure distribution in seepage flow

The figure 9 shows the steady-state seepage pore water pressure inside the dam. SLOPE/W was used to examine the slope stability both upstream and downstream, as illustrated in Figs. 10 and 11 respectively.

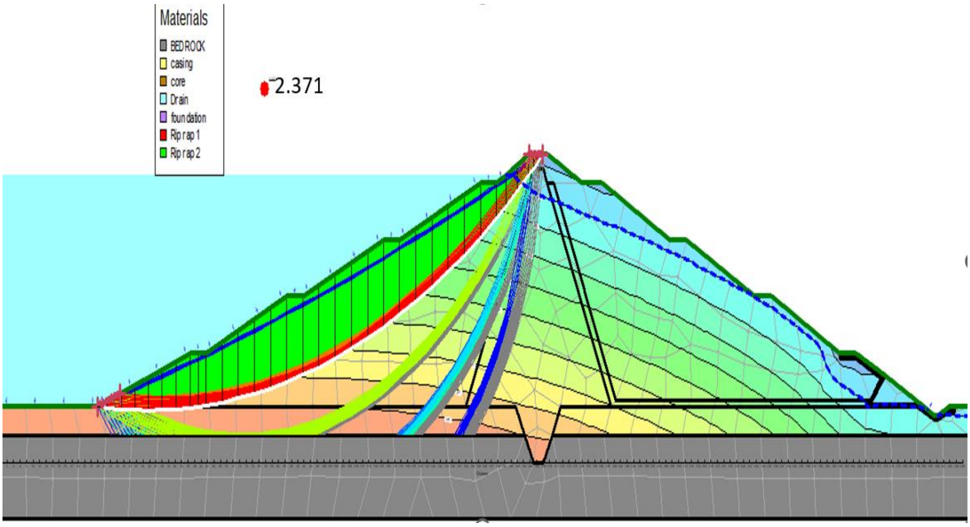

Fig. 10: Upstream FOS for slope stability analysis

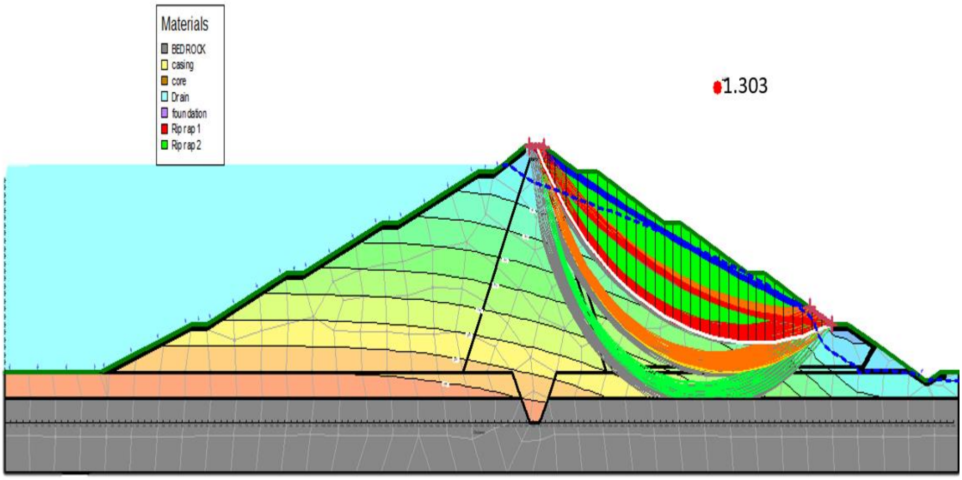

Fig. 11: Downstream FOS for slope stability analysis

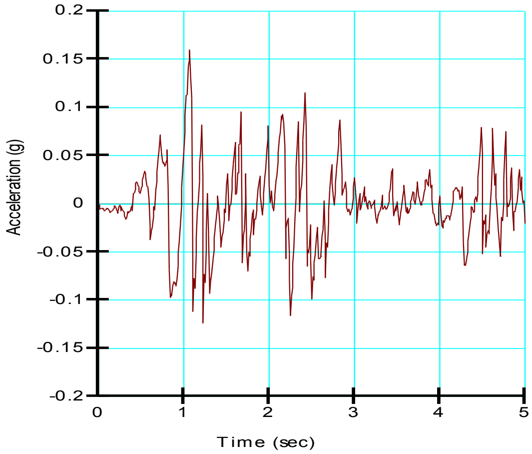

Fig. 12: EQ Time- history plot

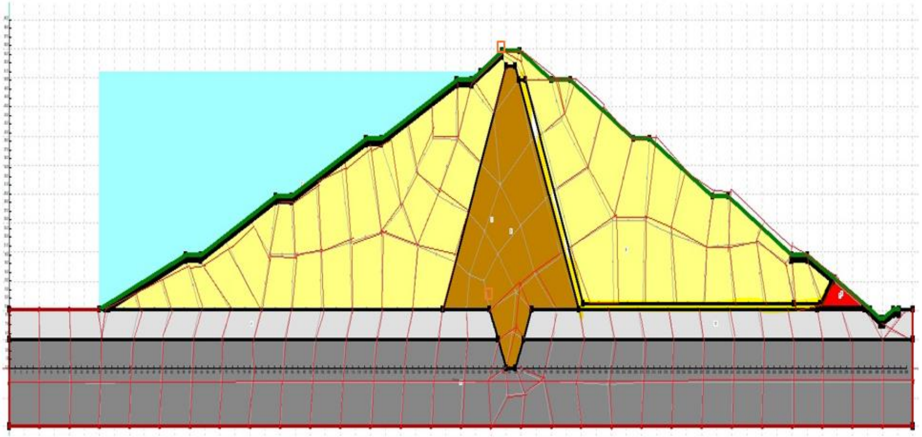

Fig. 13: Deformation in mesh format at 5 sec along with history nodes A,B

Red lines between nodes are finite elements and whole network represents deformation pattern of finite element mesh. Liquefaction is observed in fine sands represented with yellow color in Figure 14. Post FOS for upstream and downstream represented in the Fig.15 and Fig. 16 respectively.

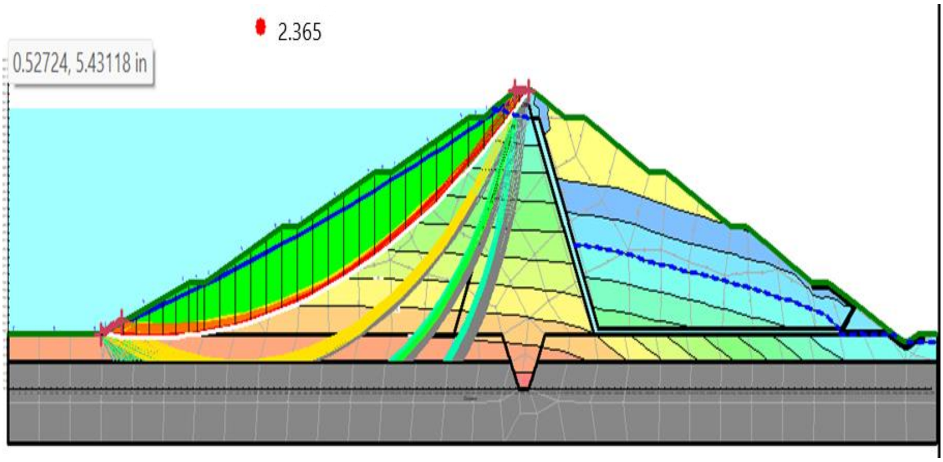

Fig.14: Post Earthquake FOS at upstream

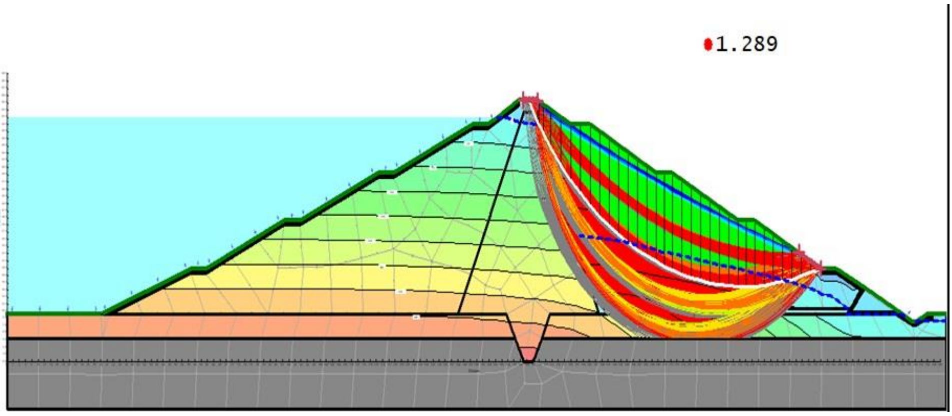

Fig. 15: Post Earthquake FOS at downstream

Table 3: Represents X- Displacements at History Nodes and post upstream FOS

EQ (pga)	Sec	Displacement (m) at A	Displacement (m) at B	Post Upstream FOS	Percentage reduction (%)
0.1	5	0.036	0.020	2.365	1.1
0.16	5	0.041	0.032	2.34	
0.1	10	0.0907	0.068	2.353	5.1
0.16	10	0.098	0.073	2.231	

5. CONCLUSIONS

The purpose of this article is to know the stability of the Gorukallu /Narasimharaya Sagar earthen dam in accordance to seepage, slope geometry, and dynamic motion.

1. The first step is to conduct steady state analysis, which acts as the basic analysis for SLOPE/W and QUAKE/W.
2. The second one is SLOPE/W to determine the FOS value during static SLOPE/W at upstream is 2.371, downstream is 1.303.
3. The last is QUAKE/W to find stability with respect to applied earthquake motion of 0.1 pga according to IS code 1893-2002 **[12]** for 5 seconds.
4. Permanent displacements due to earthquake motion are found at history nodes (A,B) 36, 20 mm along with post safety factor obtained at upstream, and downstream were 2.365,1.289 respectively.
5. The earthen dam of 0.1pga to 5 and 10 seconds with Post factor of safety and Horizontal Displacements at History Nodes are calculated.
6. The highest displacement is observed at history node A at 0.16 pga for 10 seconds. Factor of safety reduction for upstream after performing Quake/W analysis in comparison of 0.1g to 0.16g is for 5 seconds – 1.1% and for 10 seconds – 5.1%.
7. The dynamic Factor of safety for a stable situation should be greater than one, according to IS 1893:2002 **[12]**. It is concluded that embankment is safe against failures explored in the research after comparing obtained outcomes with allowable values.

References:

[1] Aldulaimi (2021), Safety evaluation of the chamrga earth dam. a seepage deformation, and stability analysis with GeoStudio in Proceedings of IOP Conference Series: Earth and Environmental Science ,**664** (1), May 2021.

[2] D.P. Salunkhe, R.N. Bartakke, G. Chvan and P.R. Kothavale, An overview on methods for slope stability analysis in Proceedings of International Journal of Engineering Research & Technology (IJERT), **6**(3), 2278-0181, 2017.

[3] A. Kamanbedast, A. Delvari, Analysis of earth dam: Seepage and stability using ansys and geo-studio software in Proceedings of World Applied Sciences Journal, **17**(9), 1087-1094 (2012).

[4] Ch.Srinivas, M. Padmavathi, Static and Dynamic Analysis of Nailed Slope in Proceedings of the Indian Geotechnical Conference **I,** 705-717, 2021.

[5] M. T. Ghalandary, F. Soltani, M. Anvar, Slope stability optimization using reinforcement by GEOSLOPE, 7-8, May 2014.

[6] R. Afiri, S.H. Abderrahmane, L. Djerbal, and S. Gabi, Stability Analysis of Souk-Tleta Earth Dam, North Algeria. In Numerical Analysis of Nonlinear Coupled Problems: Proceedings of the 1st GeoMEast International Congress and Exhibition, Egypt 2017 on Sustainable Civil Infrastructures **1** (32-40), 2018.

[7] S.S. Kar and L. B. Roy, Slope Stability Analysis of an Earthen Dam Using GEOSTUDIO 2007 Software. in Proceedings of the Indian Geotechnical Conference 2019, **I** (693-704), Singapore April 2021.

[8] Balaji, S.Kumar, Dam break analysis of Kalyani dam using HEC-RAS, in Proceedings of International Journal of Civil Engineering Technology, **9**(5), 372-380, 2018.

[9] M. Chouireb, Simulation of seepage flow through an earthen dam with vertical drain and comparison of results with observations data (case study: Harreza dam-Algeria), in Proceedings ofArabian Journal of Geosciences, **12**(13), 406, 2019.

[10] A.I. Mahmoud, Hussein, H. A., & Khaled, Z. S. , Numerical Model of Seepage Analysis and Slope Stability for Horan Dam in Iraq, in proceedings of IOP Conference Series: Materials Science and Engineering, **1076**(1), 012089, February 2021.

[11] H. Bhutto, G. S. Bhurgri, S. Zardari, M.A. R. Bhanbhro, and B.N. Memon, Numerical Analysis of Rapid Drawdown of an Embankment Dam, in proceedings of Engineering, Technology & Applied Science Research, **10**(2), 5496-5500, 2020.

[12] IS: 1893, Indian standards criteria for earthquake resistant design of structures New Delhi, India. Bureau of Indian Standard (BIS), **Part-1** (2002).