p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 07
June 2017

Evaluation of Stability and Seismic Analysis of Gravity Dam by Using Staad Pro

PULLELLA SAI SITARAMA PAVAN KUMAR[1] P.M.LAVANYA[2]

1M.Tech, Student, Civil Engineering Kakinada Institute Of Engineering And Technology. Yanam Road,, Matlapalem, Andhra Pradesh

2Assistant Professor, Civil Engineering, Kakinada Institute Of Engineering And Technology. Yanam Road,, Matlapalem, Andhra Pradesh

Abstract:

This paper presents the main features and organization of STAADPRO, a computer program that has been developed for the static and seismic stability evaluations of concrete gravity dams. STAADPRO is based on the gravity method using rigid body equilibrium and beam theory to perform stress analyses, compute crack lengths, and safety factors. Seismic analyses could be done using either the pseudo-static or a simplified response spectrum method. STAADPRO is primarily designed to provide support for learning the principles of structural stability evaluation of gravity dams. It could also be used for research and development on stability of gravity dams. In adopting several worldwide published dam safety guidelines, a large number of modeling options have been implemented regarding (a) crack initiation and propagation, (b) effects of drainage and cracking under static, seismic, and post-seismic uplift pressure conditions, and (c) safety evaluation formats (deterministic allowable stresses and limit states, probabilistic analyses using Monte Carlo simulations). Structural stability evaluation of a 30m dam is presented to illustrate the use of STAADPRO that is available free from the web site. . Finite element (FE) method of analysis was used by employing Lagrangian Eulerian formulation of 4node plain quadrilateral elements, with modal analysis. The loadings were determined based on codebook, while the FE model is being implemented using the Staad Pro tool.

Keywords—Seismic, Stability, Analysis Gravity Dams Staad Pro

International Journal of Research
Available at https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 07
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I. INTRODUCTION

The purpose of this manual is to provide technical criteria and guidance for the planning and design of concrete gravity dams wi th s ei s mi c a n al ys i s for civil works projects. Specific a re a s covered include design considerations, load conditions, stability requirements, methods of stress analysis, seismic analysis guidance, and miscellaneous structural features. Information is provided on the evaluation of existing structures and methods for improving stability.

A gravity dam is a solides,trmucatduer of concrete or masonry, constructed across a river to create a reservoir on its upstream. The section of the gravity dam is approximately triangular in shape, with its apex at its top and maximum width at bottom. The section is so proportioned that it resists the various forces acting on it by its own weight. Most of the gravity dams are solid, so that no bending stress is introduced at any point and hence, they are sometimes known as solid gravity dams to distinguish them from hollow gravity dams in those hollow spaces are kept to reduce the weight. Early gravity dams were built of masonry, but nowadays with improved methods of

construction, qcuoalnittry ol and curing, concrete is most commonly used for the construction of modern gravity

dams. A gravity dam (Figure.1.) is generally straight in plan and, therefore, it is also called straight gravity dam. The upstream face is vertical or slightly inclined. The slope of the downstream face usvuaarilelys betwe en 0.7: 1 to 0.8: 1. Gravity dams are particularly suited across gorges with very steep side slopes where earth dams might slip. Where good foundations are available, gravity dams can be built up to any height. Gravity dams are also usually cheaper than earth dams if suitable soils are not available for the construction of earth dams. This type of dam is the most permanent one, and requires little maintenance.

1.2 Scope

a. This manual present's analysis and design guidance for concrete gravity dams. Conventional concrete and roller compacted concrete (RCC) are both addressed. Curved gravity dams designed for arch action and other types of concrete gravity dams are not covered in this manual. For structures consisting of a section of concrete gravity dam within an embankment dam, the concrete section will be designed in accordance with this manual.

b. The procedures in this manual cover only dams on rock foundations. Dams on pile foundations should be d e s i g n e d a c c o r d i n g t o E n g i n e e r M a n u a l (EM) 111022906.

c. Except as specifically noted throughout the manual, the guidance for the design of RCC and conventional concrete dams will be the same.

1.3 Applicability

This manual applies to all HQUSACE elements, major subordinate commands, districts, laboratories, and field operating activities having responsibilities for the design of civil works projects.

Any structure that is constructed will undergo many forces such as wind, seismic, self-weight or forces like ice/snow etc. Among these, seismic forces are natural and as we know earthquake is a natural calamity and is so unpredictable.inorder to prevent the structure from being collapse, it's very important to adopt earthquake resistant design philosophy while designing the structure. Waves which arise during Seismic event carries very massive speed and when it struck with any structure it travels through foundation to the top roof resulting In-elastic deformation. there may be the possibility of collapse of whole structure or probably it will survive depending upon the design adopted but surely the structure will have some major repairing and strengthening works which will be costly. Sometimes damages caused by earthquake vibrations are very high that goes

Beyond repair works. Generally hydraulic structures like concrete gravity dam, canals and RCC multi-storied structures are sufficiently stiff and ductile. These structures undergo large

Deformations in its inelastic region. Concrete gravity dam is massive structure having many forces acting on it. It's very important for the dam to survive against seismic vibrations. This

Paper is mainly focused on behavior of concrete gravity dam with nonlinear characteristics using seismic time history analysis. In order to study the precise behavior of structures, seismic time.

NATURAL RESPONSE

The structural response of a material to different loads determines how it will be economically utilized in the design process. Earthquake is a natural disaster that has claimed so many lives and destroyed lots of property. Earthquake h a za r d s had caused the collapse and damage to continual functioning of essential services such as communication and transportation facilities, buildings, dams, electric installations, ports, pipelines, water and waste water systems, electric and nuclear power plants with severe economic losses. Earthquake is a major source of seismic forces that impinge on structures others are Tsunami, seethe etc. Earth wall is chosen as a material for the dam since its major constituent earth is abundantly available and provides a sustainable solution. This necessitates the seismic analysis of concrete gravity dam. Finite element has been widely used in seismic analysis of concrete gravity dams (Waltz 1997, Lotfi 2003) with a defined approach as presented in this programme.Earthquakes had caused severe damages and consequently huge economic losses including losses of lives. The analytical computation of the modal approach procedure has been carried out and implemented using STAAD PRO tool. The pseudo static seismic coefficient method was adopted in computing the seismic loads on the dam. The dam used as a case study was assumed to be in seismic zone 1 with seismic coefficient ranging between 0.0 and 0.05. The dam was analysed seismically using the decoupled modal approach and the results were compared with that of the concrete gravity dam

II. LITERATURE REVIEW

A simplified single approach methodology has been adopted here in obtaining the optimized transverse cross section of a concrete gravity dam. As this article addresses the parametric modeling of dams in India, the proportioning methods are a combination of provisions of the Indian Standard (IS) codes of Practice, along with newly developed empirical relations and already established results of the United States Bureau of Reclamation (USBR). The empirical relations have been obtained from regression analysis of 50 samples of already commissioned dams. In this way, a realistic model is proposed, conforming to the IS codes of Practice. This model is further optimized for safety and economy. Economy is assumed to be inversely proportional to the area of the dam section

The different parameters that govern the design of concrete gravity dam section, has had numerous research works involved in the past decades. United States Bureau of Reclamation (USBR, 1977), provided a criterion for considering material properties when no tests or published data are available. The value of compressive strength of concrete for initial proportioning of dam section was in the range – 20.7 to 34.5 Map. The tensile strength and shear strength were considered to be 5 to 6 percent and 10 percent of the compressive strength respectively. US Army Corps of Engineers (1995) recommended the design of gravity dam, through an iterative procedure involving preliminary layout of the structure followed by stability and stress analysis. If the dam fails in meeting safety criterion, the layout is modified and re-analyzed. Royet (2002) observed that in case of small dams, an increase in depth by one meter in a 10 meter high dam, would lead to an increase in horizontal thrust by 21 percent and increase in overturning moment by 33 percent.
The literature review establishes that, dam design procedure is iterative, in order to satisfy economic and safety criterion. The parametric modeling of dam needs to address with expertise, as slight changes in a single parameter may lead to a large difference in thrusts and overturning moments and hence affects stability. The current work, thus, aims at providing a single approach iterative methodology for initial proportioning and obtaining a safe optimized dam section

Basic layout

The basic shape of a concrete gravity dam is triangular in section (Figure 1a), with the top crest often widened to provide a roadway (Figure 1b).

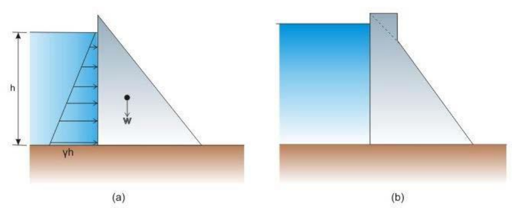

FIGURE 1 : Concrete gravity dam section (a) Basic triangular shape (b) Modified shape

FIGURE 1: Concrete gravity dam section (a)Basic triangular shape(b)Modified shape

The increasing width of the section towards the base is logical since the water pressure also increases linearly with depth as shown in Figure 1a. In the figure, ***h*** is assumed as the depth of water and γh is the pressure at base, where γ is the unit weight of

International Journal of Research
Available at https://edupediapublications.org/journals

p-ISSN: 2348-6848
e-ISSN: 2348-795X
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June 2017

water (9810 N/m³), ***W*** is the weight of the dam body. The top portion of the dam (Figure 1b) is widened to provide space for vehicle movement. A gravity dam should also have an appropriate spillway for releasing excess flood water of the river during monsoon months. This section looks slightly different from the other non-overflowing sections. A typical section of a spillway is shown in Figure 2.

Water pressure on dam

The pressure due to water in the reservoir and that of the tail water acting on vertical planes on the upstream and downstream side of the dam respectively may be calculated by the law of hydrostatics. Thus, the pressure at any depth **h** is given by **γh** kN/m² acting normal to the surface. When the dam has a sloping upstream face, the water pressure can be resolved into its horizontal and vertical components, the vertical component being given by the weight of the water prism on the upstream face and acts vertically downward through the centre of gravity of the water area supported on the dam face.

In spillway section, when the gates are closed, the water pressure can be worked out in the same manner as for non–overflow sections except for vertical load of water on the dam itself. During overflow, the top portion of the pressure triangle gets truncated and a trapezium of pressure acts below fig

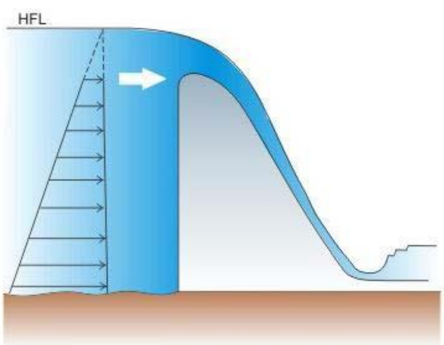


FIGURE 24. Horizontal water force on spillway block during flood water overflow

FIGURE 23: Horizontal water force on spillway block during flood water over flow

The pressure due to tail water is obtained in a similar manner as for the upstream reservoir water.

In case of low overflow dams, the dynamic effect of the velocity of approach may be significant and deserve consideration.

4.11 ANALYSIS

STRESS ANALYSIS

a. General.

b. A stress analysis of gravity dams is performed to determine the magnitude and distribution of stresses throughout the structure for static and dynamic load conditions and to investigate the structural adequacy of the substructure and foundation.

c. Gravity dam stresses are analyzed by either approximate simplified methods or the finite element method depending on the refinement required for the particular level of design and the type and configuration of the dam. For preliminary designs, simplified methods using cantilever beam models for two-dimensional analysis or the trial load twist method for three-dimensional analysis are appropriate as described in the US Bureau of Reclamation (USBR), "Design of Gravity Dams" (1976).The finite element method is ordinarily used for the feature and final design stages if a more exact stress investigation is required.

d. Finite element analysis.

e. Finite element models are used for linear elastic static and dynami analyses and for nonlinear analyses that account for interaction of the dam and foundation. The finite element method provides the capability ofmodeling complex geometries and wide variations in material properties. The stresses at corners, around openings, and in tension zones can be approximated with a finite element model. It can model concrete thermal behavior and couple thermal stresses with other loads. An important advantage of this method is that complicated foundations involving various materials, weak joint son seams, and fracturing can be readily modelled. Special purpose computer programs designed specifically for analysis of concrete gravity dams are CG-DAMS (Anatech1993), which performs static, dynamic, and nonlinear analyses and includes a smeared crack model, and MERLIN(Saouma 1994), which includes a discrete cracking fracture mechanics model.

f. Two-dimensional, finite element analysis is generally appropriate for concrete gravity dams. The designer should be aware that actual structure response is three dimensions a land should review the analytical and realistic results to assure that the two-dimension approximation is acceptable and realistic. For long conventional concrete dams with transverse contraction joints and without keyed joints, a two-dimensional analysis should be reasonably correct. Structures located in narrow valleys between steep abutments and dams with varying rock module which vary across the valley are conditions that necessitate three-dimensional modelling.

Measurement of Water Level on Upstream and Downstream Side

This measurement is useful for calculating the water pressure on the upstream face and downstream face of the dam.
A typical set of piezometer installations for an embankment dam is shown in Figure

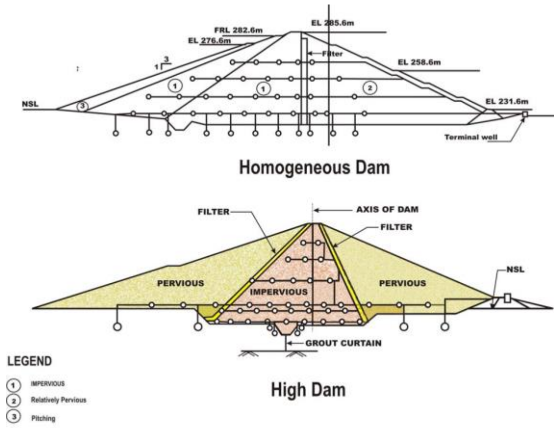


FIGURE 45. Typical installation of piezometers in embankment dams

FIGURE 31: Typical installation of piezometers in embankment dams

DESIGN PROCEDURE

Pressure of any permanent tailwater above the plane considered is:

$$P_{wh'} = \frac{\gamma_w z_2^2}{2}$$

with $P_{wv}' = \gamma_w$ (area A_2).

design gravity dam

Loads on concrete dams

Loads can be classified in terms of applicability/relative importance as **primary loads**, **secondary loads**, and **exceptional loads**.

Primary Loads: are identified as those of major importance to all dams, **irrespective of type**,

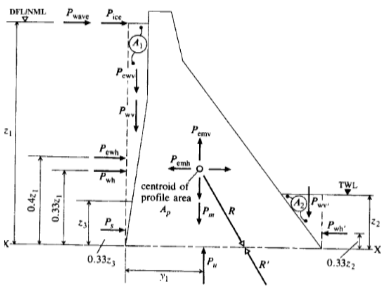
e.g. water and related seepage loads, and self-weight loads.

Secondary Loads: are universally applicable although of lesser magnitude (e.g. sediment load) or, alternatively, are of major importance only to certain types of

dams (e.g. thermal effects within concrete dams).

Exceptional Loads: are so designed on the basis of limited general applicability or having a low

$P_{wv} = \gamma_w$ (average A_1) acting through centroid of A_1.



probability ofoccurrence

(e.g. tectonic effects, or the inertia loads associated withseismic activity).

loading diagram on gravitydams

Primary Loads
Water Load

Hydrostatic distribution of pressure with horizontal resultant force P_1

Vertical component of load will also exist in the case of an upstream face batter
Hydrostatic distribution of pressure with horizontal resultant force P_1

Vertical component of load will also exist in the case of an upstream face batter

$$P_{wh} = \gamma_w \frac{z_1^2}{2} \quad \text{acting at } z_1/3 \text{ in KN/m}$$

Where γ_w = unit weight of water = 9.81 KN/m³

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 07
June 2017

$$P_s = K_a \frac{\gamma'_s \, z_3^2}{2} \qquad [KN/m]$$

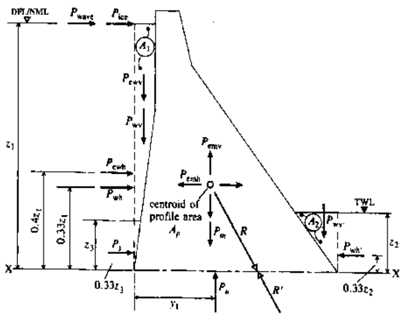
Seepage loads/uplift

The uplift is supposed to act on the whole width of

where Φ_s is the angle of shearing resistance of the sediment.

Representative values of $\gamma_s = 18 – 20$ KN/m³ and $\Phi_s = 30°$.

the foundation



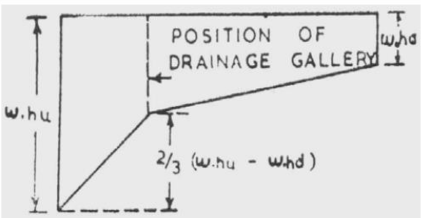


FIGURE:32 Uplift pressure distribution for perfectly tight cutoffwall

Value of area reduction factor	Suggested by
0.25 to 0.40	Henry
1.00	Maurice Levy
0.95 to 1.00	Terzaghi

Uplift pressure distribution for perfectly tight cutoff wall

$$P_u = \eta A_h (u_{wavg}) \qquad [KN/m]$$

Secondary loads

Sediment Load

The gradual accumulation of significant ***deposits of finesediment***, notably silt, against

$$y_1 = \frac{T}{3} \frac{2z_2 + z_1}{z_2 + z_1} \text{ (m).}$$

the face of the dam generates a resultant horizontal force, $\mathbf{P_s}$.

Hydrodynamic wave

The upper portions of dams are subject to the impact of waves, P_{wave}.

The dimensions and force of waves depend on the **extent of water surface, the velocity of wind**, and other factors

6.4 Input data for analysis

Structure information

Structure Type	SPACE FRAME

Number of Nodes	16	Highest Node	16
Number of Elements	13	Highest Beam	13
Number of Plates	11	Highest Plate	24

Number of Basic Load Cases	3
Number of Combination Load Cases	2

Included in this printout are data for:

All	The Whole Structure

Beams

Beam	Node A	Node B	Length (m)	Property	β (degrees)
1	1	2	5.000	2	0
2	2	3	2.000	2	0
3	3	4	5.000	2	0
4	4	5	30.232	2	0
5	4	1	2.000	2	0
6	1	7	20.000	2	0
7	2	8	20.000	2	0
8	3	9	20.000	2	0
9	4	10	20.000	2	0
10	5	11	20.000	2	0
11	6	12	20.000	2	0
12	7	8	5.000	2	0
13	8	9	2.000	2	0

p-ISSN: 2348-6848
e-ISSN: 2348-795X
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Plates

Plate	Node A	Node B	Node C	Node D	Property
14	8	9	3	2	1
15	11	10	4	5	1
16	10	4	3	9	1
17	7	1	2	8	1
18	12	11	5	6	1
19	12	15	13	6	1
20	8	15	13	2	1
21	11	5	14	16	1
22	5	6	13	14	1
23	15	16	10	7	1
24	13	14	4	1	1

Section Properties

Prop	Section	Area (cm^2)	I_{yy} (cm^4)	I_{zz} (cm^4)	J (cm^4)	
2	Rect 0.30x0.20	600.000	20E+3	45E+3	47E+3	C(

Plate Thickness

Prop	Node A (cm)	Node B (cm)	Node C (cm)	Node D (cm)	Material
1	25.000	25.000	25.000	25.000	CONCRETE

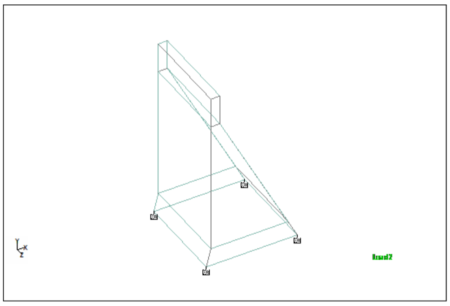


Figure.5 MODEL STRUCTURE

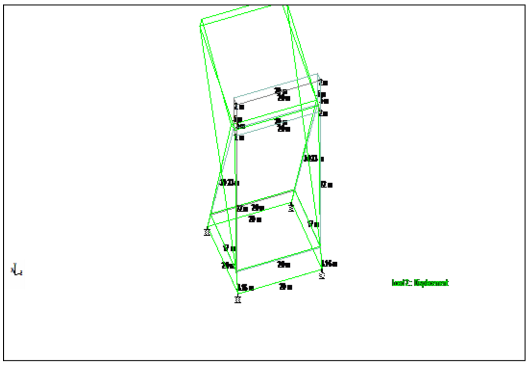


Figure.6. **STRUCTURE WITH DIMENSION**

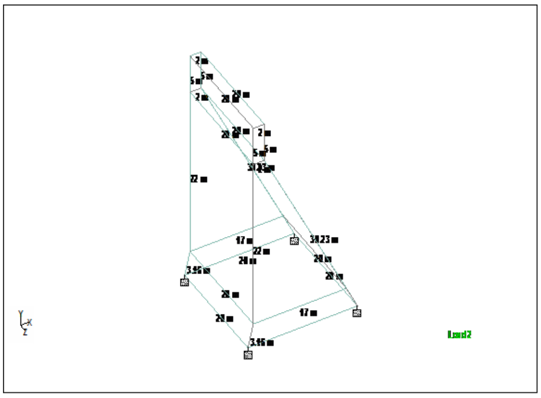


Figure.7. **STRUCTURE WITH 3D VIEW**

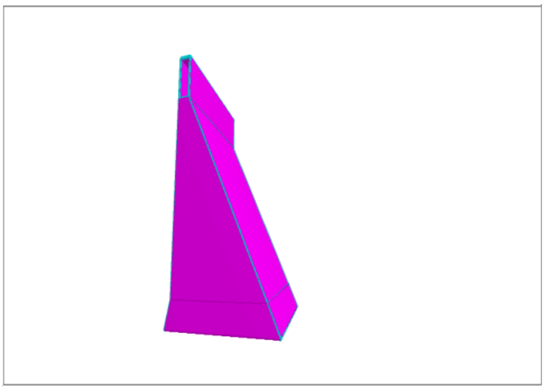
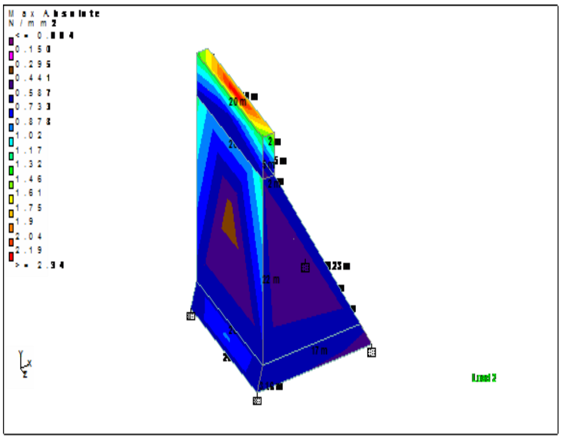


Figure.8. **STRUCTURE WITH**

DISPLACEMENT



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e-ISSN: 2348-795X
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RESULTS & GRAPHS

1. **Result Of Plate Principal Stresses**

LOAD CASE	MAXIMUM		MINIMUM	
	Seismic	Gravity	Seismic	Gravity
DEAD LOAD	1.434	1.434	-0.17	-0.17
LOAD COMBINATION 1	15.9	15.9	-2.4	-2.4
LOAD COMBINATION 2	67.39	48	-8.33	-5
EQX	0.54	-	-0.07	-
EQY	0.15	-	-0.059	-

Reactions for Seismic Analysis

Node	X	Y	Z	Mx	My	Mz
6	8.627	-337	48	791	11.5	209
12	32	356	53	600	15.6	6
5	238.9	338	128.1	936	605	289
11	204.2	326.3	123.5	919.8	595	3.39

Reactions for Gravity Analysis

Node	X	Y	Z	Mx	My	Mz
6	719.783	5242.9	84.9	6523.7	210	11223.4
12	537.59	3976	317	1123	56	5623
5	1125.4	1969	317	545.8	90.2	10248
11	943	2909	84.7	493.04	435.8	184.5

Displacements

Node	Seismic		Gravity	
	X (mm)	Z (mm)	X (mm)	Z (mm)
2	295	185	197	123
1	88	153	58	102
13	1.5	16	1.5	12
16	527	274	351	351

CONCLUSION

STAADPRO gives an extremely adaptable figuring condition to learn or explore displaying suspicions and computational procedures identified with the static and seismic basic soundness of gravity dams in light of the gravity technique. It has been appeared in this paper a few suspicions identified with load conditions, splitting criteria, elevate weights powers and examination method could be utilized for static, seismic, and post-seismic security appraisals when all is said in done, the calculations are mind boggling to perform because of the coupling between the inspire weight and break length. In a genuine circumstance, parametric examinations are regularly performed to cover instabilities in quality and stacking parameters to take proper choice concerning a specific structure.

The creators have effectively utilized STAADPRO as a computational research facility in workshops, to engineers from practice, required in dam security assessment STAADPRO is likewise utilized for modern applications and R&D in dam designing and has been broadly approved amid the previous years. The association of the program and the specific elements that have been introduced thus are helpful for those intrigued by the improvement and utilization of PC supported dependability examination of gravity dams.

p-ISSN: 2348-6848
e-ISSN: 2348-795X
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1M.Tech, Student, Civil Engineering Kakinada Institute Of Engineering And Technology. Yanam Road,, Matlapalem, Andhra Pradesh

2Assistant Professor, Civil Engineering, Kakinada Institute Of Engineering And Technology. Yanam Road,, Matlapalem, Andhra Pradesh

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