iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 2 **Issue:** XI **Month of publication:** November 2014

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Seismic & Stability Analysis of Gravity Dam

Miss. Meghna S. Bhalodkar [1]
[1] *Assistant Professor, Department of Civil Engg., COET, Akola*

***Abstract*— The aim of the study is to analyse the dam for stability and seismic forces. Dam being one of the mega structure it becomes prime important to design and analyse such structure with keen observation considering various factors affecting them. As it is one of the lifesaving structures, it is again important to analyse such structure for major forces like earthquake. Keeping this in mind, in this paper the study is done for finding out the result that makes dam stable against forces acting on it with and without considering seismic forces. The study is done considering the hypnotically dam subjected to pre decided geographical factors like type of soil, its density, seismic zone etc. further this experimental work is done for dam full (with and without considering uplift pressure) and empty condition. This designing is done following IS code criteria. Further in paper work various such gravity dams subjected to different factors are analysed. The results of analysis are tabulated over here and the various forces responsible for failure of dam are highlighted in conclusion.**

***Keywords*— Gravity Dam, Seismic Forces, Sliding, Stability, Analysis**

I. INTRODUCTION

Gravity dams are solid concrete structures that maintain their stability against design loads from the geometric form, mass and potency of the concrete. The purposes of dam creation may comprise routing, flood damage reduction, hydroelectric power creation, fish and wildlife improvement, water superiority, water supply, and amusement. The plan and assessment of concrete gravity dam for earthquake loading must be based on suitable criterion that be a sign of both the preferred level of safety and the variety of the design and evaluation events.

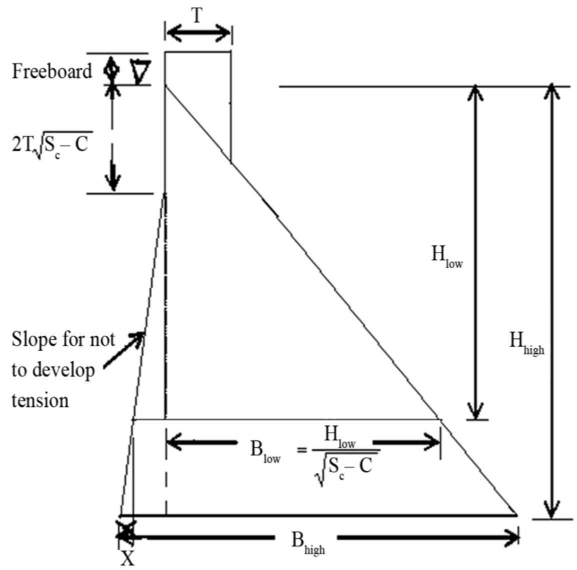
Basically, a gravity concrete dam is defined as a formation, which is planned in such a means that its own weight resists the outer forces. It is principally the weight of a gravity dam which prevents it from being upturned when subjected to he thrust of impounded water. This type of formation is strong, and requires very little repairs. Gravity dams typically consist of a non-overflow section and an spill over section or spillway. The two common concrete construction methods for concrete gravity dams are conventional positioned mass concrete and RCC. Gravity dams, built in stone masonry, were built even in earliest times, often in Greece, Egypt, and the Roman Empire. Nevertheless, concrete gravity dams are favored these days and frequently constructed. They can be constructed with ease on any dam site, where there exists a natural base strong enough to bear the massive load of the dam. Such a dam is in general straight in plan, even though sometimes, it may be a little curve. The line of the upstream face of the dam or the line of the coronet of the dam if the upstream face in slanting, is taken as the orientation line for layout purpose, etc. and is known as the “Base line of the Dam” or the “Alignment of the Dam”. When appropriate environment are on hand, such dams can be constructed up to huge heights. The ratio of base width to height of high gravity dams is generally less than 1:1

II. SCOPE

Over here the seismic and stability Analysis of RCC gravity dam is done which is trapezoidal in shape

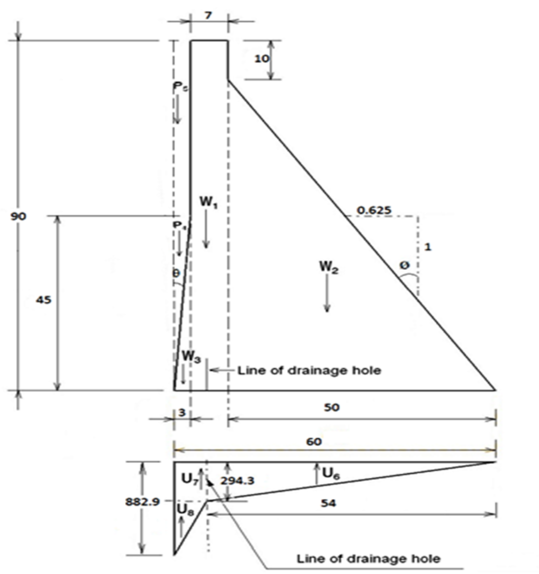
III. DESIGN PHILOSOPHY

Such a dam is generally straight in plan, although sometimes, it may be to some extent curve. The line of the upstream side of the dam or the line of the coronet of the dam if the upstream side in slanting, is considered as the orientation line for plan purposes, etc. and is known as the “Base line of the Dam” or the “Axis of the Dam”. When appropriate circumstances are on hand, such dams can be constructed up to immense heights. The ratio of base width to height of high gravity dams is generally less than 1:1. A typical cross-section of a high concrete gravity dam is shown in figure alongside. The upstream face may be kept throughout perpendicular or partially slanting for some of its length. A drainage passage is usually provided in order to lessen the uplift pressure formed by the seeping water. Purposes valid to dam creation may include routing, flood damage reduction, hydroelectric power creation, fish and wildlife improvement, water superiority, water supply, and amusement. Several concrete gravity dams have been in use for more than five decades, and over this phase significant advances in the methodologies for assessment of natural phenomena hazards have caused the design-basis events for these dams to be revised upwards. Older existing dams may fail to meet revised safety criteria and structural rehabilitation to meet such criteria may be costly and difficult. The identified causes of failure, based on a study of over 1600 dams are: Foundation problems (40%), Inadequate spillway (23%), Poor construction (12%), Uneven settlement (10%), High poor pressure (5%), Acts of war (3%), Embankment slips (2%), Defective materials (2%), Incorrect operation (2%), and Earthquakes (1%). Other surveys of dam failure have been cited by [5], who estimated failure rates from 2×10^{-4} to 7×10^{-4} per dam-year based on these surveys.



IV. EXPERIMENTAL WORK

Check the stability of gravity dam section shown in fig. For reservoir empty and full condition considering seismic forces assume reasonable value of uplift and a line of drain holes 6m downstream of the upstream face for the purpose of this check assume water level at the top of dam and no tail water. Also find principal and shear stresses at the toe & heel of dam.Take unit weight of concrete 24 KN/M^3 shear strength of concrete as 2200 KN/M^2 and μ=0.7.



Solution:

Stability check of dam without considering seismic forces

CASE I:- Reservoir empty condition.

When reservoir is empty only self weight of dam will be acting as force. Other forces such as water pressure & uplift will be zero. The resulting force $\sum V_1$ and resulting moment $\sum M_1$ for this case has worked out as follows:

Volume 2 Issue XI, November 2014
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Sr. No.	Item description	forces	Lever arm	moment at toe		
		Vertical	Horizontal		+ve	-ve
1.	W_1 90×71×24	15120		53.5	808 920	
2.	W_2 ½ ×50×80×24	48000		33.3 3	159 984 0	
3.	W_3 ½ ×3×90/2×24	1620		58	939 60	
		$\sum V_1 =$ 64200			$\sum M_1$= 2502720	
	WATER PRESSURE					
4.	P_4 3×45× ½×9.81	662.175		59	390 68.3 2	
5.	P_5 3×45×9.81	1324.35		58.5	774 74.4 7	
	H $½×90^2×9.81$		39730.5	90/3		1191915
					$\sum M_2$ = 1427347.8	
	UPLIFT FORCES					
6.	U_6 882.9/3×54× ½	-7946.1		36		286059.6
7.	U_7 882.9/3×6×1	-1765.8		57		100650.6
8.	U_8 2×882.9/3×6 ×1/2×1	-1765.8		58		102416.4
		$\sum V_3$=54 708.82			$\sum M_3$ =938221.2	

Position of resultant from toe

$$X = \sum M_1 / \sum V_1 = 2502720/64200 = 38.98\text{m}$$

Its distance from centre is

$$e = b/2 - X = 60/2 - 38.98 = -8.98\text{m}$$

(i.e. the resultant falls to the left of the center)

Normal compressive stress at toe

$$P_n = \sum V_1 / b\ (1+6e/b) = 64200/60\ (1+ 6×(-8.98)/60) = 109.14\ \text{KN/m}^2\ (0.109\text{N/mm}^2)$$

Normal compressive stress at heel

$$P_n = \sum V_1 / b\ (1-6e/b) = 64200/60\ (1- 6×(-8.98)/60) = 2030.86\ \text{KN/m}^2 (2.030\ \text{N/mm}^2)$$

Principal stress at toe

$\sigma_1 = P_n \sec^2 \Phi$ where $\tan \Phi = 0.625$

$= 109.14 \times 1.39$ $\sec^2 \Phi = 1.39$

$= 151.7\ KN/m^2\ (0.151\ N/mm^2)$

Principal stress at heel

$\sigma = P_n \sec^2\theta$ where $\tan\theta = 3/45 = 0.07$

$= 2030.86 \times 1$ $\sec^2\theta = 1$

$= 2030.86\ KN/m^2\ (2.030\ N/mm^2$

Shear stress at toe

$\tau = P_n \tan\Phi$

$= 109.14 \times 0.625$

$= 68.21\ KN/m^2\ (0.068\ N/mm^2)$

Shear stress at heel

$\tau = P_n \tan\theta$

$= 2030.86 \times 0.07$

$= 142.16\ KN/m^2\ (0.142\ N/mm^2)$

CASE II :- Reservoir full with no uplift

Calculation of stresses

$\tan\Phi = 0.625$, $\sec^2\Phi = 1.39$

$\tan\theta = 0.07$, $\sec^2\theta = 1$

Position of resultant from toe

$X = \sum M_2 / \sum V_2 = 1427347.8/66186.52 = 21.56m$

Position of resultant from the centre of the base is

$e = b/2 - X = 30 - 21.56 = 8.44m$

Normal compressive stress at toe

$P_n = \sum V_2/b\ (1+6e/b)$

$= 66186.52/60\ (1 + 6\times 8.44/60)$

$= 2034.13\ KN/m^2\ (2.034\ N/mm^2)$

Normal compressive stress at heel

$P_n = \sum V_2/\ b\ (1-6e/b)$

$= 66186.52/60\ (1 - 6\times 8.44/60)$

$= 172.08\ KN/m^2\ (0.172\ N/mm^2)$

Principal stress at toe

$\sigma_1 = P_n \sec^2\Phi$

$= 2034.13 \times 1.39$

$= 2827.44\ KN/m^2\ (2.827\ N/mm^2)$

Principal stress at heel

$\sigma = P_n \sec^2\theta - P \tan^2\Phi$

$= 172.08 \times 1 - (9.81\times 90)\ x4.9 \times 10^{-3}$

$= 167.75\ KN/m^2\ (0.167\ N/mm^2)$

Note:- This is the value for minor principal stress at the heel. The value of major principal Stress at heel $= 9.81 \times 90 = 882.9\ KN/m^2$

Shear stress at toe

$\tau = P_n \tan\Phi = 2034.13 \times 0.625 = 1271.33\ KN/m^2$

Shear stress at heel

$\tau = -(P_n - P) \tan\theta = -(172.08-882.9) \times 0.07$

$= 49.75\ KN/m^2$

The factor of safety against sliding and overturning should be found out only when reservoir is full & Full uplift acts, since the condition of sliding & overturning will be more critical in that case.

CASE III:- Reservoir full with uplift

Position of resultant from toe

$X = \sum M_3 / \sum V_3 = 938221.2/54708.82 = 17.14m$

Position of resultant from the centre of the base is

$e = b/2 - X = 30 - 17.14 = 12.86m$

Normal compressive stress at toe

$P_n = \sum V_3/b\ (1+6e/b)$

$= 54708.82/60\ (1 + 6x12.86/60)$

$= 2084.40\ KN/m^2\ (2.084\ N/mm^2)$

This compressive stress is greater than that obtained for case II, hence this is worst case.

Normal compressive stress at heel

$P_n = \sum V_3/ b\ (1-6e/b)$

$= 54708.82/60\ (1 - 6x12.86/60)$

$= -260.77\ KN/m^2\ (-0.260\ N/mm^2)$

Principal stress at toe

$\sigma_1 = P_n \sec^2 \Phi$

$= 2084.40 \times 1.39$

$= 2897.31\ KN/m^2\ (2.897\ N/mm^2)$

Principal stress at heel

$\sigma = P_n \sec^2\theta - P \tan^2 \Phi$

$= 260.77 \times 1 - (9.81x90) \times 4.9 \times 10^{-3}$

$256.44\ KN/m^2\ (0.256\ N/mm^2)$

shear stress at toe

$\tau = P_n \tan \Phi = 2084.4 \times 0.625 = 1302.75\ KN/m^2$

Shear stress at heel

$\tau = -(P_n - P) \tan \theta = -(260.77-882.9) \times 0.07$

$= 43.54\ KN/m^2$

Calculation of factor of safety

Factor of safety against overturning

$= \sum M(+)/ \sum M(-) = 2619262.8/1681041.6$

$= 1.55 > 1.5$ Hence safe

Factor of safety against sliding

$= (\mu \sum V_3)/ \sum H = (0.7 \times 54708.82)/39730.5$

$= 2.33 > 2$ Hence safe

Shear friction factor

$S.F.F. = (\mu \sum V_3 + b \times c)/\sum H$

$= (0.7 \times 54708.82 + 60 \times 2200)/39730.5$

$= 4.28 > 4$ Hence safe

Saftey against sliding as per IS 6512-1984

Taking $f_\Phi = 1.5$ & $f_c = 3.6$ for loading combination B,

$F = [((\mu \sum V)/ f_\Phi) + (cb/ f_c)]/\sum H$

$= [((0.7 \times 54708.82)/1.5) + ((2200 \times 60)/3.6)]/39730.5$

$= 1.56 > 1.$

Hence safe

Stability check of dam by considering seismic forces:

ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

For worst condition consider that,

a) Horizontal earthquake acceleration acts upstream.

b) Vertical earthquake acceleration acts downwards.

Hydrodynamic pressure due to water caused by earthquake can be found out from zangers formula. Since the slope is upto middle depth, approximate value of θ can be found out by joining heel to the upstream edge.

$\tan \theta_1 = 3/90 = 0.033$ or $\theta_1 = 1.89°$

$C_m = 0.735\times(1-(1.89°/90°)) = 0.72$

At base $C = C_m$

Therefore $p_e = C_m \alpha_h w h$

By clause 3.4.2.3 of IS 1893-1984

$\alpha_h = \beta I \alpha_0$

$\beta = 1$ (By table 3)

$I = 3$ (By table 4)

$\alpha_0 = 0.02$ (considering zone II in table2)

$\alpha_h = 1\times3\times0.02 = 0.06$

Now by clause 7.3.1

for dams upto 100m height

the value of $\alpha_h = 1.5\times \alpha_h$

$\alpha_h = 1.5\times 0.06 = 0.09$

and $\alpha_v = 0.75\times \alpha_h$

$\alpha_v = 0.75\times 0.06 = 0.045$

$p_e = C_m \alpha_h w h$

$= 0.719\times0.09\times9.81\times90$

$= 57.13$ KN/m^2

Total pressure $P_e = 0.726\, p_e h$

$= 0.726\times57.13\times90$

$= 3732.87$ KN

Moment due to this force at base,

$M_e = 0.299\, p_e h^2$

$= 0.299\times57.13\times90^2$

$= 138363.14$ KN-m

Calculation of forces and moments due to inertial earthquake force is done below:-

Additional forces and their moments due to earthquake

Sr. No.	Item	Description	Forces(KN)	Lever arm(m)	Moment of toe(KN-m)		
Vertical	Horizontal	+ VE	- VE				
		Inertial force due to earquake on weight of dam					
1	$\sum V1$	$\sum V1\times\alpha_v$	-2889				

2.	W1	W1×αh			1360.8	45	
3	W2	W2×αh		4320	26.66		115171.2
4	W3	W3×αh		145.8	15		2187
5	Pe	Hydrostatic pressure		3732.87			138363.14
		Total	∑V=-2889	∑H=8559.47			∑M=-428674.97
		Sum of forces and moments from previous table	$\sum V_3$=54708.82	∑H=39730.5		2619262.8	-1681041.6
+2619262.8	-2109716.57						
		Sum	$\sum V_4$=57597.82	∑H=48289.97		$\sum M_4$=509546.23	

Position of resultant from toe

$X = \sum M_4 / \sum V_4 = 509546.23/57597.82 = 8.84m$

Hence the resultant does not lie within the middle third.

Position of resultant from the centre of the base is

$e = b/2 - X = 30 - 8.84 = 21.16m$

(i.e. the resultant falls to the right of the center)

Normal compressive stress at toe

$P_n = \sum V_4/b\,(1+6e/b) = 57597.82/60(1 + 6\times21.16/60)$

$= 2991.24\ KN/m^2\ (2.991\ N/mm^2)$

Normal compressive stress at heel

$P_n = \sum V_4/b(1-6e/b) = 57597.82/60\ (1 - 6\times21.16/60)$

$= -1071.31\ KN/m^2\ (-1.071\ N/mm^2)$

Since the resultant does not fall within middle third and the value of tensile stress is Substantial (>$0.2f_c$ for M_{15} concrete) the dam is unsafe under seismic condition.

Principal stress at toe

$\sigma_1 = P_n \sec^2\Phi$

$= 2991.24 \times 1.39$

$= 4157.82\ KN/m^2\ (4.157\ N/mm^2)$

Principal stress at heel

$\sigma = P_n \sec^2\theta - (P+P_e)\tan^2\theta$

$= -1071.31 \times 1 - ((9.81x90)+57.13) \times 4.9 \times 10^{-3}$

$= -1075.91\ KN/m^2\ (-1.075\ N/mm^2)$

Hence unsafe

shear stress at toe

$\tau = P_n \tan\Phi = 2991.24 \times 0.625 = 1869.525\ KN/m^2$

Shear stress at heel

$\tau = -(P_n-(P+P_e))\tan\theta$

Calculation of factor of safety

Factor of saftey against overturning

$= \sum M(+)/ \sum M(-) = 2619262.8/2109716.57$

$= 1.24 < 1.5$ Hence unsafe

Factor of saftey against sliding

$= (\mu \sum V_4)/ \sum H = (0.7\times57597.82)/48289.97$

$= 0.83 < 1.5$ Hence unsafe

Shear friction factor

$S.F.F.=(\mu\sum V_4+b\times c)/\sum H$

$= (0.7\times57597.82+60\times2200)/48289.97$

$= 3.56 > 3$

Safety against sliding as per IS 6512-1984

Taking $f_\Phi=1.2$ & $f_c=2.7$ for loading combination E,

$F=[((\mu\sum V)/ f_\Phi)+(cb/ f_c)]/\sum H$

$=[((0.7\times57597.82)/1.2)+((2200\times60)/2.7)]/48289.97$

= 1.7 > 1 Hence safe

V. RESULT AND OBSERVATION

Comparative results are tabulated for problem analysed with and without seismic forces manually

Comparative table for manual problem

Sr. No	Action/ consideration	Magnitude	Effect	Check	Comment
In absence of Seismic forces					
1	F.O.S.against overturning	1.55	Overturning	safe	stable
2	F.O.S.against sliding	2.33	Sliding	safe	stable
3	Shear friction factor	4.28	Shearing	safe	stable
4	Safety against sliding As per IS 6512-1984	1.56	Sliding	safe	stable
Seismic forces effect					
1	F.O.S.against overturning	1.24	Overturning	unsafe	unstable
2	F.O.S.against sliding	0.83	Sliding	unsafe	unstable
3	Shear friction factor	3.56	Shearing	safe	stable
4	Safety against sliding As per IS 6512-1984	1.75	Sliding	safe	stable

Volume 2 Issue XI, November 2014
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Comment on stability & instability parameter on the basis of results obtained using staad pro softwere for different Zones

FACTOR OF SAFTEY	ZONE II	ZONE III	ZONE IV	ZONE V
FACTOR OF SAFTEY AGAINST OVERTURNING	UNSAFE	UNSAFE	UNSAFE	UNSAFE
FACTOR OF SAFTEY AGAINST SLIDING	UNSAFE	UNSAFE	UNSAFE	UNSAFE
SHEAR FRICTION FACTOR	SAFE	SAFE	SAFE	SAFE
FACTOR OF SAFTEY AGAINST SLIDING AS PER IS 6512-1984	SAFE	SAFE	SAFE	SAFE

All the results are obtained using following basic load cases and their combinations with the help of staad pro softwere.

Total no of Nodes = 30

Total no of Plates = 70

Plate thickness = 15cm

All the bottom nodes are considered as fixed.

Materials

Mat	Name	E (kN/mm^2)	n	Density (kg/m^3)	a (1/°K)
3	STEEL	205.000	0.300	7.83E 3	12E -6
4	ALUMINUM	68.948	0.330	2.71E 3	23E -6
5	CONCRETE	21.718	0.170	2.4E 3	10E -6

Basic Load Cases

Number	Name
1	EQX
2	EQZ
3	DL1
4	WATER PRESSURE
7	UPLIFT PRESSURE

Combination Load Cases

Comb.	Combination L/C Name	Primary	Primary L/C Name	Factor
5	COMBINATION LOAD CASE 5	3	DL1	1.00
		4	WATER PRESSURE	1.00
		7	UPLIFT PRESSURE	1.00
6	COMBINATION LOAD CASE 6	1	EQX	1.00

		3	DL1	1.00
8	COMBINATION LOAD CASE 8	2	EQZ	1.00
		3	DL1	1.00
9	COMBINATION LOAD CASE 9	1	EQX	1.00
		3	DL1	1.00
		4	WATER PRESSURE	1.00
		7	UPLIFT PRESSURE	1.00
10	COMBINATION LOAD CASE 10	2	EQZ	1.00
		3	DL1	1.00
		4	WATER PRESSURE	1.00
		7	UPLIFT PRESSURE	1.0

VI. CONCLUSION

The behavior of Gravity dam for stability and response towards seismic forces are studied in this paper. With problem consideration the stability analysis of gravity dam is done in absence of seismic forces initially. Thus analysis highlighted that in presence of various loads like dead load, water/ hydrostatic pressure, uplift pressure, total cumulative values of +ve moment and -ve moment, summation of horizontal and vertical forces are overall responsible for dam stability.

Further with analysis it is clear that moment resulting due to self weight act as resistive moment against moment produced due to water, uplift pressure etc. Which means that stability against overturning is achieved when +ve moment is greater than -ve moments. Whereas stability against sliding depends upon coefficient of friction, sum of all vertical forces and all horizontal forces. Thus sliding is governed by uplift pressure.More friction coefficient & more summation of vertical forces results stability against sliding. However, if horizontal force increases stability against sliding decreases if vertical forces remain approximately same.

Third stability of dam is on basis of shear friction factor, this depends upon coefficient of friction, summation of all vertical forces, summation of all horizontal forces, geometry of dam and materials shear strength. For same problem material shear strength, geometry friction remains unchanged, thus stability should depend upon sum of all vertical forces and all horizontal forces. For problem considered in study, dam achieves stability against all factors i.e. overturning, sliding & shearing.

Further same dam is analysed considering seismic forces. With introduction of seismic forces, there is change in behavior of dam against stability. From study it is very clear that for considered problem the value of +ve moment remained unchanged. Whereas value of -ve moment changed.

As resistivity i.e. +ve moment is unchanged -ve moment increased thus, dam is unstable against overturning for seismic force consideration. Again value of summation of vertical forces and summation of horizontal forces increased. This resulted instability against sliding, however stable against shear force (as material, geometry & shear strength is constant in both cases). Thus, it can be concluded that for gravity dam considered over here in study reflects that the dam was stable against overturning, sliding and shearing in absence of seismic forces. But, with introduction of seismic forces dam turned unstable against overturning and sliding.

The study is further carried out to observe the change in analysis values of moments, vertical and horizontal actions with change in seismic zones. For same loading and geometry consideration, when analysis is done for various seismic zone, it is observed that values of +ve moment remains constant where as the value of –ve moment increased with increase in earthquake severity zone wise. This highlights instability against overturning. Again, it is observed that value of vertical forces remained unchanged but seismic forces increases value of horizontal forces which resulted in instability against sliding.

REFERENCES

[1] Adedeji, A. A. (2004); Finite Element Method, CVE 567 Lecture Notes, Department of Civil Engineering, University of Ilorin, Ilorin.

[2] IS:1893:1984, ″Criteria for Earthquake Resistant Design of Structures″.

[3] IS:6512:1984, ″Criteria for Design of Solid Gravity Dams".

[4] G. B. Baecher, M. E. Gregory and R. de Neufville, "Risk of Dam Failure in Benefit-Cost Analysis," *Water Re- sources Research*, Vol. 16, No. 3, 1980, pp. 449-456.

[5] Dr. Martin Wieland (2007); Earthquake safety of concrete dams and Seismic design criteria for major dam projects.

[6] Yoshikazu Yamaguchi and Robert Hall (2004); Seismic performance evaluation of concrete gravity dams.

[7] M. Leclerc and R. Tinawi (2002); computer aided stability analysis of gravity dams.

[8] Sharique Khan and V. M. Sharma (2011); Stress Analysis of a Concrete Gravity Dam with Intersecting Galleries,International Journal of Earth Sciences and Engineering ISSN 0974-5904, Volume 04, No 06 SPL, October 2011, pp. 732-736.

[9] Shou-yan JIANG and Cheng-bin DU(2012); Seismic stability analysis of concrete gravity dams with penetrated cracks.

[10] Kaushik Das and Pankaj kumar Das (2011); Seismic Response of Concrete Gravity Dam.

[11] Major, A. (1980); Dynamics in Civil Engineering, Vol. I IV, Second Edition, Collet'sHoldings Ltd, London.

[12] Bathe, K. J. (1996); Finite Element Procedures, Seventh Edition, PrenticeHall Inc, New Jersey.

[13] Wieland M. (2002): Lessons learnt from the earthquake behaviour of large dams and their implications on seismic design criteria, Proc. Third International Conference on Dam Engineering, Editors: M. Wieland and J.S.Y. Tan, CI Premier Pte Ltd., Singapore, March 20-22, 2002.

[14] Wieland M. (2003): Seismic aspects of dams, General Report Question 83: Seismic aspects of dams; International Commission on Large Dams; Proc. 21st Congress of ICOLD, Montreal, Canada, June 16-20, 2003.

[15] S. K. Garg, "Irrigation Engineering and Hydraulic Struc- tures," 16th Edition, Khanna Publishers, Delhi, 2002, pp. 960-1020.

[16] C. N. Zangar, "Hydrodynamic Pressures on Dams Due to Horizontal Earthquake Effects," Engineering Monograph, No. 11, Bureau of Reclamation, 1952.

[17] N. Smith, "A History of Dams," Peter Davies, London, 1971.