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DESIGN OF GRAVITY DAM BY USING SEISMIC COEFFICIENT METHOD IN DIFFERENT ZONES

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Abstract: Dam is one of the biggest structures built on the Earth. It is known as a life line structure, as it serves the purpose of irrigation, hydro-electric power generation, flood control, domestic and industrial water supply etc., which are important for human existence. This makes dam as a reliable structure. For this reason, dam should always be designed for highest safety. Engineers in India must pay special and careful attention to the problem of earthquake loading in the design of dam.Gravity dams are preferred these days and mostly constructed. They can be constructed with ease on any dam site, where there exists a natural foundation strong enough to bear the enormous weight of the dam. Such a dam is generally straight in plan, although sometimes, it may be slightly curve. When suitable conditions are available, such dams can be constructed up to great heights. The main objective of the present study is Design of gravity dam by using seismic coefficient method in different zones in India. A case study of Totladoh dam situated in Vidarbha region of Maharashtra which is analyzed by seismic coefficient method according to IS: 1893-1984 criteria for earthquake resistance design of structures (Part-v dams). The Results obtained by this method will be compared by masonry and concrete in all zones in India.

I. INTRODUCTION

Basically, a gravity dam is defined as a structure, which is designed in such a way that its own weight resists the external forces. It is primarily the weight of a gravity dam which prevents it from being overturned when subjected to the thrust of impounded water. This type of structure is durable, and requires very little maintenance. The two general concrete construction methods for concrete gravity dams are conventional placed mass concrete and RCC. However, concrete gravity dams are preferred these days and mostly constructed. They can be constructed with ease on any dam site, where there exists a natural foundation strong enough to bear the enormous weight of the dam. Such a dam is generally straight in plan, although sometimes, it may be slightly curve. The line of the upstream face of the dam or the line of the crown of the dam if the upstream face in sloping, is taken as the reference line for layout purposes, etc. and is known as the “Base line of the Dam” or the “Axis of the Dam”. When suitable conditions are available, such dams can be constructed up to great heights. We must pay special and careful attention to the problem of earthquake loading in the design and evaluation of almost all permanent civil of gravity dam. the present study is Design of gravity dam by using seismic coefficient method in different zones in India. A case study of Totladoh dam situated in Vidarbha region of Maharashtra which is analyzed by seismic coefficient method according to IS:1893-1984 criteria for earthquake resistance design of structures(Part-v dams) and calculated results obtained by this method will be compared by masonry and concrete in all zones in India.

II. LITERATURE REVIEW

2.1 GENERAL

N.P. Gahlot, Dr. A.R. Gajbhiye (2013),Observed to the some of finding about one concrete types. What will happen to dams during severe earthquake shaking? It is obvious that at present engineers cannot answer this question with any certainty. But we are very much aware of the threat of disastrous losses of life and damage to property if dams should fail, and we are making great effort to increase our understanding of this complex topic. This Paper deals with the case study of Totladoh Dam Situated in Vidarbha Region of Maharashtra for Seismic Analysis by I.S.Code method (Simple Beam Analysis method). This also includes future scope of analyzing the same dam for Seismic safety by very accurate method i.e. finite element method.

Sreedevi, Shreedhar (2014), the main aim of this study is to design high concrete gravity dams based on the U.S.B.R. recommendations in seismic zone II of India, for varying horizontal earthquake intensities from 0.10 g - 0.30 g with 0.05 g increment to take into account the uncertainty and severity of earthquake intensities and constant other design loads, and to analyze its stability and stress conditions using analytical 2D gravity method. Feasibility studies are carried out to design a concrete gravity dam for horizontal earthquake intensity greater than 0.30 g without changing other loads and or dimension of the dam and keeping provision for drainage gallery to reduce the uplift pressure significantly.

Indrani Goigoi and Damodar Maity (December 2013),The aim of this study is that the ageing of a concrete gravity dam presents a new challenge for the development of a methodology that can adequately predict the stability of the dam under seismic excitations and identify those structures where remedial measures are to be taken. A numerical algorithm is presented for the seismic analysis of a concrete dam in the vicinity of an infinite reservoir with the application of damage mechanics considering fluid-structure interaction. The time dependent degradation of concrete owing to environmental factors and mechanical loading in terms of isotropic damage index is considered. The results obtained from the analyses can indicate the vulnerability of the dam to seismic excitation. This procedure can be very effective for practicing engineers to assess the structural safety and to decide the importance of retrofitting or decommissioning the dam.

2.2 Earthquake zones of India:
There are World maps which are divided into different zones according to the severity of earthquake. According to IS: 1893-1984, India was divided into zones : zone I, Zone II, Zone III, Zone IV, Zone V. However, according to its revised version (IS 1893-2002, criteria for earthquake resistant design of structures), the seismic zone map is revised with four zones, instead of five. Erstwhile Zone I has been merged to Zone II. Hence zone I does not appear in the new zoning map; only zone II, III, IV, V appear. The Killari area has been included in zone III and necessary modifications made, Keeping in view the probabilistic hazard evaluation. The bellary isolated zone has been removed. The part of eastern coast areas have shown similar hazard to that of Killari area; the level of zone II has been enhanced to zone III and connected with zone III of Godavari Graben area.

2.3 Spectra of Earthquake: Acceleration Spectra
Spectrum of an earthquake is the representation of the maximum dynamic response of idealized structure during an earthquake.. The maximum response is plotted against the natural period of vibration (T) and can be expressed in terms of the following

- Maximum absolute acceleration
- Maximum relative velocity
- Maximum relative displacement

For the purpose of design, acceleration spectra are very useful as they give the seismic force on the structure directly by multiplying it with the generalized or modal mass of the structure, i.e. Force = mass × earthquake acceleration. The earthquake acceleration is usually designed as fraction of the acceleration due to gravity.

III. THEORETIAL BACK GROUND

3.1 GENERAL
GRAVITY DAM: A gravity dam is a masonry or concrete dam which resists the forces exerted upon it by its own weight. Its cross – section is approximately triangular in shape.

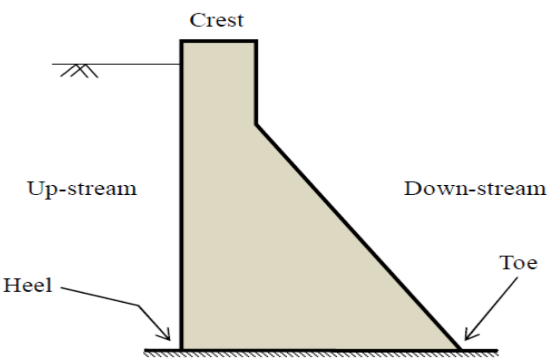

Fig 3.1 parts of dam

3.2 ADVANTAGES OF GRAVITY DAMS:
i) More strong and stable than earth dams. Suitable across gorges with steep slopes
ii) Well adopted as spillway dams
iii)Constructed for any height, if suitable foundations available
iv) Specially suited to areas with heavy down pour
v) Requires least maintenance and failure not sudden
vi) Deepest sluices can be used to retard sedimentation
Totladoh dam in Maharashtra situated on Pench river. A case study of Totladoh dam hydraulic particulars are considered in this project Seismic analysis of dam by using seismic coefficient method for all zones are calculated in two different materials like concrete and masonry.

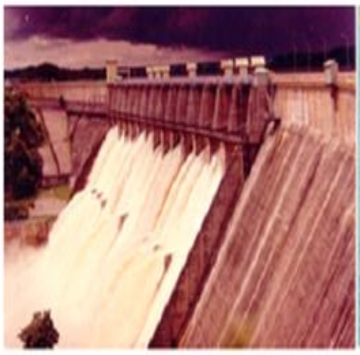


Fig:3.2 Totladoh dam in Fig:3.3 Totladoh dam on Maharashtra Pench river

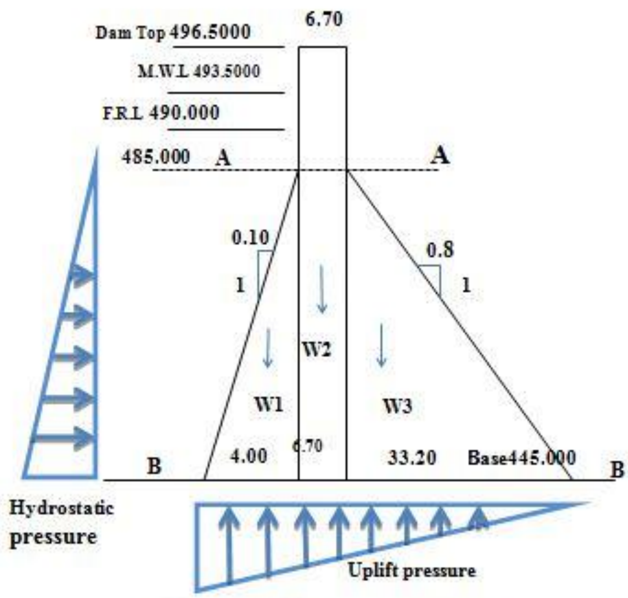

Fig: 3.4 Totladoh dam cross sectional view

3.3 DETAILS OF PROJECT

Name of the dam	Totladoh dam
River	Pench
State	Maharashtra
Basin name	godavari
Seismic zone	II
Maximum water level	493.600 m
F.R.L.	490.000 m
M.D.D.L.	464.000 m

Gross storage capacity	1241 Mm^3
Live storage capacity	1091 Mm^3
Dead storage capacity	150 Mm^3
Submergence area(Th.Ha)	7.771
Catchment area(Sq.Km)	4273
Total height of dam	51.5 m
Length of dam	680 m
Crest level of spillway	482.000 m
T.B.L.	495.500 m
Width at top	6.70 m
Width at base	43.90 m
U/s slope	0.10:1.00
D/s slope	0.83:1.00

IV. IV.METHODOLOGY AND DESIGN PROCEDURE

4.1 Concrete or Masonry Gravity dams

4.1.1 Concrete or Masonry inertia force due to horizontal earthquake acceleration

Seismic coefficient method (dams up to 100 m height)

The base shear,V_B and $M_B$base moment may be obtained by the following formulae:

$V_B = 0.6 \times W \times \alpha_h$

$M_B = 0.9 \times W \times \bar{h} \times \alpha_h$

Where

W = total weight of the masonry or concrete in the dam in kg,

$\bar{h}$ = height of the center of gravity of the dam above the base in m, and

α_h = design seismic coefficient

For any horizontal section at a depth y below top of the dam shear forceV_y, and bending moment M_y, may be obtained as follows:

$Shear\ force\ V_y = C_V' V_B$

$Bending\ Moment\ M_y = C_m' M_B$

4.1.2 Effect of vertical earthquake acceleration

The effect of vertical earthquake acceleration is to change the unit weight of water and concrete or masonry. An acceleration upwards increases the weight and an acceleration downwards decreases the weight. To consider the effect of vertical earthquake acceleration, the vertical seismic coefficient would be as follows:

For seismic coefficient method of design: At the top of the dams it would be 0.75 times the α_h value.

4.1.3 Effect of earthquake acceleration on uplift forces

Effect of earthquake acceleration on uplift forces at any horizontal section is determined as a function of the hydrostatic pressure of reservoir and tail-water against the faces of the dam. During an earthquake the water pressure is changed by the hydrodynamic effect. However, the change is not considered effective in producing a corresponding increase or reduction in the uplift force. The duration of theearthquake is too short to permit the building up of pore pressure in the concrete and rock foundations.

4.1.4 Effect of earthquake acceleration on dead silt loads

It is sufficient to determine the increase in the silt pressure due to earthquake by considering hydrodynamic forces on the water up to the base of the dam and ignoring the weight of the silt.

V. DESIGN OF GRAVITY DAM

5.1 DESIGN OF CONCRETE GRAVITY DAM

Design of concrete gravity dam in ZONE-III

Forces on the body of the dam

A) Calculations of Stresses due to horizontal component of earthquake:

Step1: Earthquake forces

(As per IS: 1893-1984, Clause 7.3.1)

the height of dam is less than 100 m. the analysis is to be done by the seismic coefficient method.

The horizontal seismic coefficient α_h can be calculated as

(As per IS: 1893-1984, Clause 3.4.2.3)

Horizontal seismic coefficient$\alpha_h = \beta I \alpha_0$

Where $-\beta$ coefficient depending upon the soil foundation system

β = 1.00 for Dams (As per IS: 1893-1984, Clause 3.4.3, from Table 3)

I– Importance factor,

I = 3.00 for dams (all types) (As per IS: 1893-1984,Clause 3.4.2.3 and 3.4.4, from Table 4)

$\alpha_0 -$ basic horizontal seismic coefficient

(As per IS: 1893-2002, Clause 3.4.2.1,3.4.2.3 and 3.4.5, from Table 2)

$\alpha_0 = 0.04$for zone III in seismic coefficient method

$\therefore\ \alpha_h = 1.00 \times 3.00 \times 0.04 = 0.12$

Weight of dam per meter length = 27226.25 KN

(As per IS: 1893-1984, Clause 7.3.1)

At the top of dam horizontal seismic coefficient shall be taken as $1.5 \times \alpha_h = 1.5 \times 0.12 = 0.18$

And reduces linearly zero at base

$\therefore \bar{h}$

$$= \frac{\{\left[6.7 \times H \times \left(\frac{H}{2}\right)\right] + \left[\frac{1}{2} \times 4 \times H \times \left(\frac{h}{3}\right)\right] + \left[\frac{1}{2} \times \bar{b} \times h \times \left(\frac{1}{3} \times h\right)\right]\}}{\{(6.7 \times H) + \left(\frac{1}{2} \times 4 \times h\right) + \left(\frac{1}{2} \times \bar{b} \times h\right)\}}$$

$$= \frac{\{\left[6.7 \times 51.5 \times \left(\frac{51.5}{2}\right)\right] + \left[\frac{1}{2} \times 4 \times 51.5 \times \left(\frac{40}{3}\right)\right] + \left[\frac{1}{2} \times 33.2 \times 40 \times \left(\frac{1}{3} \times 40\right)\right]\}}{\{(7.6 \times 51.5) + \left(\frac{1}{2} \times 4 \times 40\right) + \left(\frac{1}{2} \times 33.20 \times 75\right)\}}$$

$\therefore \bar{h} = 17.5$ m.

Step2: Concrete or masonry inertia force due to horizontal earthquake acceleration

(As per IS: 1893-1984, Clause 7.3.1.1, from point 3)

The base shear,V_B and base moment M_B may be obtained by the following formulae:

$V_B = 0.6 \times W \times \alpha_h$

$M_B = 0.9 \times W \times \bar{h} \times \alpha_h$

Where
W = total weight of the masonry or concrete in the dam in kg,
$\bar{h}$= height of the center of gravity of the dam above the base in m, and
α_h= design seismic coefficient

$Base\ Shear\ V_B = 0.6 \times W \times \alpha_h$
$= 0.6 \times 27226.25 \times 0.12$
$= 1960.29$ KN

$Base\ Moment\ M_B = 0.9 \times W \times \bar{h} \times \alpha_h$
$= 0.9 \times 27226.25 \times 17.5 \times 0.12$
$= 51457.612$ KN.m

$Stress\ at\ Base\ p = \left(\pm \frac{6M}{T^2}\right)$
$= \left(\pm \frac{6 \times 51457.612}{43.90^2}\right) = \pm 160.203\ KN/m^2$

B) Calculations of Stresses due to vertical component of earthquake :
(*As per IS: 1893-1984, Clause 7.3.1.2, from point a)*
$\alpha_v = 0.75 \times \alpha_h$
$\alpha_v = 0.75 \times 0.12 = 0.09$
Stress calculations:
$\bar{X} = \frac{M1 + M2 + M3}{w1 + w2 + w3}$

Table 5.1 Load calculations

Loads	Weight of segment (KN)	$W \times \alpha_v$	Lever arm (m)	Moment (KN.m)
W1	2000	90	41.23	3710.7
W2	8626.25	388.18	36.55	14187.979
W3	16600	747	22.133	16533.351
Total	27226.25	1225.18		34432.03

$\bar{X} = \frac{68864.133}{2450.362} = 28.104\ m$
$e = \bar{X} - \frac{B}{2} = 28.104 - \frac{43.90}{2} = 6.154\ m$
$e \le \frac{B}{6}$
$\frac{B}{6} = \frac{43.90}{6} = 7.317\ m$
$\therefore 6.154 \le 7.317$
$p_{max} = \frac{W \times \alpha_v}{B}(1 + \frac{6e}{B})$
$p_{max} = \frac{2450.362}{43.90}\left(1 + \frac{6 \times 6.154}{43.90}\right)$
$= \frac{2450.362}{43.90}(1 + 0.841)$
$= 102.759\ KN/m^2$
$p_{min} = \frac{W \times \alpha_v}{B}(1 - \frac{6e}{B})$
$p_{min} = \frac{2450.362}{43.90}\left(1 - \frac{6 \times 6.154}{43.90}\right)$
$= \frac{2450.362}{43.90}(1 - 0.841)$
$= 8.875\ KN/m^2$

Earthquake forces on the body of water
C) Calculations of stresses due to Hydro dynamic pressure of horizontal Earthquake acceleration
(*As per IS: 1893-1984, Clause 7.2.1)*
$p = C_s \alpha_h wh$
As per IS: 1893-1984, Clause 7.2.1.1)
$C_s = \frac{C_m}{2}\{\frac{y}{h}\left(2 - \frac{y}{h}\right) + \sqrt{\frac{y}{h}(2 - \frac{y}{h})}\}$
At section AA:-
$y = 8.50, h = 48.50,\ \frac{y}{h} = 0.175$(*As per IS: 1893-1984, Clause 7.2.1.1, from fig.10)*

$C_m = 0.70$
Substitute C_m value in above formula
$C_s = 0.26$
$\therefore p = 0.26 \times 0.18 \times 10 \times 48.5 = 22.698$ KN /m^2
(*As per IS: 1893-1984, Clause 7.2.1.3)*
$V_h = 0.726py$
$M_h = 0.299py^2$
$V_h = 0.726 \times 22.698 \times 8.50 = 140.069\ KN$
$M_h = 0.299 \times 22.698 \times 8.50^2 = 490.339\ KN.m$
$Stress\ p = \frac{W}{T} \pm \frac{6M}{T^2}$
Here W=0
$Stress\ p = 0 \pm \frac{6 \times 490.339}{6.70^2} = 65.539\ KN/m^2$

At section BB:-
$C_m = 0.70$
Substitute C_m value in above formula
$C_s = 0.70$
$\therefore p = 0.7 \times 0.18 \times 10 \times 48.50 = 61.11$ KN /m^2
$V_h = 0.726 \times 61.11 \times 48.50 = 2151.744\ KN$
$M_h = 0.299 \times 61.11 \times 48.50^2 = 42980.053\ KN.m$
$Stress\ at\ base\ p = \frac{W}{T} \pm \frac{6M}{T^2}$
Here W=0
$Stress\ at\ base\ p = 0 \pm \frac{6 \times 42980.053}{43.90^2}$
$= 133.810\ KN/m^2$

D) Calculations of stresses due to Hydro dynamic pressure of Vertical Earthquake acceleration

(*As per IS: 1893-1984, Clause 7.3.1.2)*

Stresses due to vertical component are obtained by multiplying the tresses due to hydrostatic pressure by a factor $\pm\alpha_v\ i.e.\ 0.09$

At section AA
Stress due to hydrostatic pressure =27.84 KN/m^2
$\therefore stress\ due\ to\ vertical\ component\ of\ earthquake$
$= 27.84 \times 0.09$
$= 2.506\ KN/m^2$

At section BB
Stress due to hydrostatic pressure = 22.35 KN/m^2
$\therefore stress\ due\ to\ vertical\ component\ of\ earthquake$
$= 22.35 \times 0.09 = 2.011\ KN/m^2$

Calculation of stresses:

$\tan\varphi = 0.83, \sec\emptyset = 1.29$
$\tan\theta = \frac{4}{40} = 0.1, \sec\theta = 1$
Distance where resultant acts from toe is

$$\bar{x} = \frac{\sum M}{\sum V} = 14.8$$

Distance e from the center of the base $e = \frac{b}{2} - \bar{x}$

$$= \frac{43.90}{2} - 14.83 = 7.12$$

Consider all loads on dam with considering earthquake loads
$\sum V = 20929.25\ KN, \sum H = 15168\ KN$
$\sum M = 1230571.237\ K.m, \sum M_R = 775821.237\ KN.m$
$\sum M_O = 454750.78\ KN.m$
Normal stress at toe

$$p_n = \frac{\sum V}{b}[1 + \frac{6e}{b}]$$

$$p_n = \frac{20929.25}{43.90}\left[1 + \frac{6 \times 7.12}{43.90}\right] = 939.193\ KN/m^2$$

Normal stress at heel

$$p_n = \frac{\sum V}{b}[1 - \frac{6e}{b}]$$

$$p_n = \frac{20929.25}{43.90}\left[1 - \frac{6 \times 7.12}{43.90}\right] = 14.30\ KN/m^2$$

Principal stress at toe (there is no tail water)

$$\sigma_1 = p_n sec^2\varphi$$

$$= 939.193 \times 1.29^2 = 1562\ KN/m^2$$

$$= 1.562\ N/mm^2$$

Its direction is parallel to downstream face.
Principal stress of heel is:

$$\sigma_1 = p_n sec^2\varphi - (p + p_e)tan^2\theta$$

Where p = water pressure at base = $48.5 \times 10 = 485\ KN/m^2$
p_e = Hydrodynamic pressure at base = 61.11 KN/m^2

$$\sigma_1 = 14.30[1 + 1.01] - [485 + 61.11]0.01$$

$$\sigma_1 = 10.828\ KN/m^2$$

Hence the dam become safe as the concrete can withstand the tensile stresses.
Shear stress at toe

$$\tau = p_n \tan\varphi$$

$$\tau = 1562 \times 0.83 = 1296.46\ KN/m^2$$

Shear stress at heel

$$\tau = -[p_n - (p + p_e)\tan\theta$$

$$\tau = -[14.30 - (485 + 61.11).1$$

$$\tau = 40.311\ KN/m^2$$

Calculation of factor of safety

a) Factor of safety against overturning

$$\frac{\sum M_R}{\sum M_O} = \frac{(+)M}{(-)M} = \frac{775821.237}{454750.78} = 1.7 > 1.5\ (safe)$$

Therefore the dam section is safe against the overturning.

b) Factor of safety against the sliding

As per IS: 6512-1984 design of solid gravity dam from table 1
For load condition E, taking $F_\varphi = 1.2$, and $F_c = 2.4$ we get
As per IS:6512-1984 design of solid gravity dam from clause 5.12.2.1

$$F = \frac{\frac{\mu \sum V}{F_\varphi} + \frac{cb}{F_c}}{\sum H} = \frac{\frac{0.75 \times 20929.25}{1.2} + \frac{1400 \times 43.90}{2.4}}{15618} = 2.55 > 1(safe)$$

Therefore the dam section is safe against sliding.
According to the above procedure all zones are calculated.

VI. RESULTS & DISCUSSION

Stress comparison between concrete and masonry gravity dams in different zones

Table 6.1 stress due to horizontal component of earthquake

Stress (KN/m^2)	ZONE-II	ZONE-III	ZONE-IV	ZONE-V
At section AA(concrete)	309.5	619.0	773.8	1238.009
At section AA(masonry)	288.4	576.9	721.1	1153.824
At section BB(concrete)	80.1	160.2	200.24	320.407
At section BB(masonry)	74.6	149.3	186.63	298.619

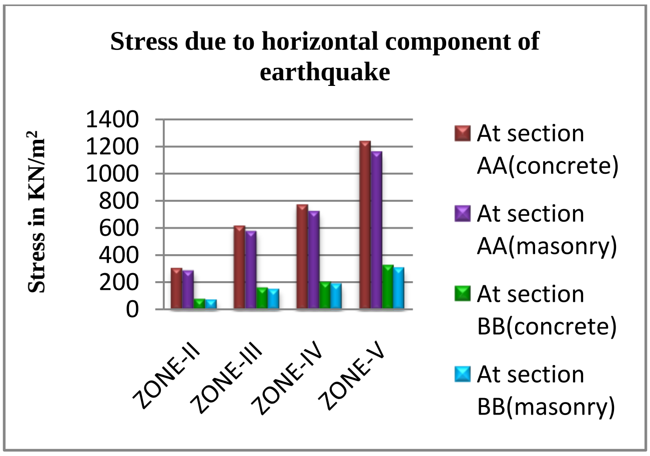

Fig: 6.1 stress due to horizontal component of earthquake

Table 6.2 Stress due to vertical component of earthquake

Stress (KN/m^2)	ZONE-II	ZONE-III	ZONE-IV	ZONE-V
Pmax(concrete)	51.379	102.759	127.878	205.518
Pmax(masonry)	47.886	95.771	119.183	191.543
Pmin(concrete)	4.437	8.875	11.044	17.749
Pmin(masonry)	4.136	8.271	10.293	16.543

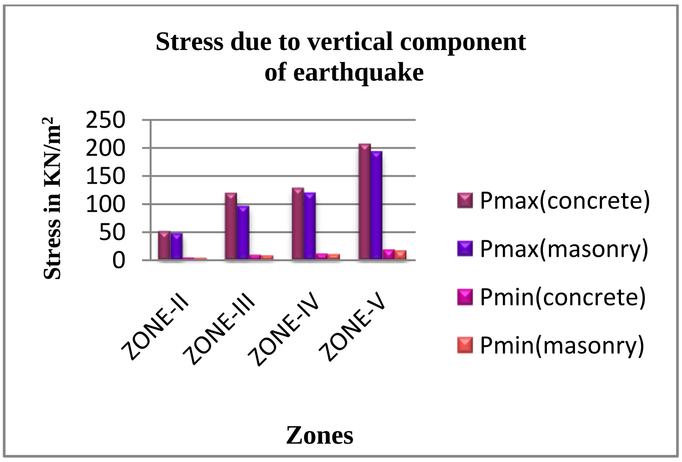

Fig: 6.2 Stress due to vertical component of earthquake

Table 6.3 Shear due to horizontal component of earthquake

Shear(KN)	ZONE-II	ZONE-III	ZONE-IV	ZONE-V
At section AA(concrete)	196.0	392.1	490.1	784.1
At section AA(masonry)	182.7	365.4	456.7	730.8
At section BB(concrete)	980.1	1960.3	2450.4	3920.6
At section BB(masonry)	913.5	1826.9	2283.7	3653.9

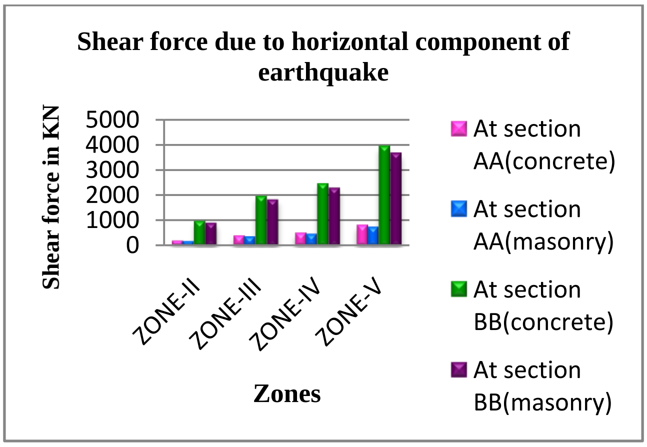

Fig: 6.3 Shear force due to horizontal component of earthquake

Table 6.4 Moment due to horizontal component of earthquake

Moment (KN.m)	ZONE-II	ZONE-III	ZONE-IV	ZONE-V
At section AA(concrete)	2316	4631	5789	9262
At section AA(masonry)	2158	4316	5395	8633
At section BB(concrete)	25729	51458	64322	102915
At section BB(masonry)	23979	47959	59948	95917

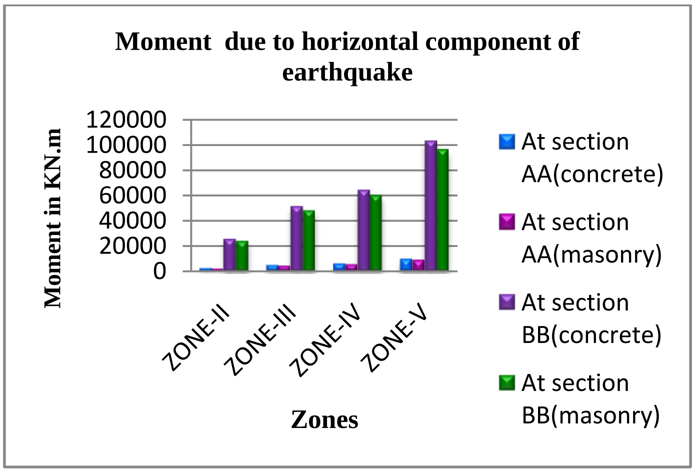

Fig: 6.4 Moment due to horizontal component of earthquake

VII. CONCLUSION

Present study deals with

- Design of Totladoh dam by using seismic coefficient method according to the IS: 1896-1984 Earthquake resistant design of structures (part-V).
- Seismic loads of concrete and masonry are compared by all different zones in India.
- Primary, secondary and also seismic loads are considered in concrete gravity dam in Zone-III.
- Reinforcement details are provided for concrete gravity dam in Zone-III.
- Stress due to horizontalcomponent of earthquake and Stress due to vertical component of earthquake are in Zone-III is 50% greater than Zone-II in concrete and masonry gravity dams.
- Stress due to horizontalcomponent of earthquake and Stress due to vertical component of earthquake inZone-IV is 60% greater than Zone-II in concrete and masonry gravity dams.
- Stress due to horizontalcomponent of earthquake and Stress due to vertical component of earthquake inZone-V is 75% greater than Zone-II in concrete and masonry gravity dams.
- Stress due to horizontalcomponent of earthquake and Stress due to vertical component of earthquake in Zone-IV is approximately 20% greater than Zone-III in concrete and masonry gravity dams.
- Stress due to horizontalcomponent of earthquake and Stress due to vertical component of earthquake in Zone-V is approximately 37.50% greater than Zone-IV in concrete and masonry gravity dams.
- Stress due to horizontalcomponent of earthquake and Stress due to vertical component of earthquake in Zone-V is 50% greater than Zone-III in concrete and masonry gravity dams.
- Shear due to horizontalcomponent of earthquake and Moment due to horizontal component of earthquake are in Zone-III is 50% greater than Zone-II in concrete and masonry gravity dams.
- Shear due to horizontalcomponent of earthquake

and Moment due tohorizontal component of earthquake in Zone-IV is 60% greater than Zone-II in concrete and masonry gravity dams.

- Shear due to horizontalcomponent of earthquake and Moment due to horizontal component of earthquake in Zone-V is 75% greater than Zone-II in concrete and masonry gravity dams.
- Shear due to horizontal component of earthquake and Moment due to horizontal component of earthquake in Zone-IV is approximately 20% greater than Zone-III in concrete and masonry gravity dams.
- Shear due to horizontal component of earthquake and Moment due to horizontal component of earthquake in Zone-V is approximately 37.50% greater than Zone-IV in concrete and masonry gravity dams.
- Shear due to horizontalcomponent of earthquake and Moment due to horizontal component of earthquake in Zone-V is 50% greater than Zone-III in concrete and masonry gravity dams.

SCOPE OF FUTURE STUDY

The scope of this study is limited to:

- The present study is based on analysis of two-dimensional (2D) models of a typical cross-section of the dam. Analysis of three-dimensional solid model is kept outside the scope of the present study.
- The present study is based on according to IS: 1893-1984 criteria for earthquake resistance design of structures (Part-v dams). Seismic analysis of gravity dam is possible due to availability of various computer programs is kept outside the scope of the present study.
- The present study has not considered the value of response reduction factor for the dam structure. However, response reduction factor is important aspect of seismic design and the values given in the IS 1893:2002 are for the building structure only. There is the scope to study detail about the response reduction factor with regard to Concrete Gravity Dam.

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