INTERACTION EFFECT IN GRAVITY DAM WITH EARTH BACKING

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ABSTRACT

The paper describes the method of analysis and earthquake response of a typical masonry dam with earthbacking on its downstream face. The analysis shows that under probable maximum earthquake, a depth of about 20% of dam below the top of earthbacking could lose contact during vibrations. The model tests on shake table indicate separation in a depth comparable with the calculated depth. On the whole it is concluded that, though the earthbacking has the effect of increasing damping. It does not prevent the cracking of the dam to any appreciable extent.

INTRODUCTION

There are a large number of old masonry dams in India and elsewhere which are either not designed for earthquake force at all or the design seismic coefficients adopted are inadequate as indicated by present aseismic strength needs. Provision of earthbacking on down stream face is often considered an economic proposal for strengthening such dams against future earthquake motions so as to avoid overstressing and failure. To investigate the behaviour of such composite dams under vibratory conditions, one dam in Maharashtra (India) situated 90 km north of Koyna dam has been studied analytically and by model tests. This dam is a masonry structure in 1:2 lime crushed-sand mortar. A section of the dam with the proposed earth backing is shown in Figure 1. In this problem the most important point to know is how far the contact between the dam and earth backing would be maintained during vibrations caused by earthquake motion. The whole problem has been studied as follows:

(a) Analytical Study: Here the dynamic analysis of composite section is carried out for Transverse Component of Koyna Earthquake of December 11, 1967 and stresses on the section of the masonry dam are calculated without and with earth backing.

(b) Experimental Study: Free vibration and shake table tests under sinusoidal steady state vibrations have been carried out on the dam model without as well as with earth backing.

DYNAMIC ANALYSIS OF COMPOSITE SECTION

In order to determine the behaviour of the earth backing together with masonry dam, a simplified dynamic analysis approach has been adopted in which the interacting forces between them are considered as reversible. Both bending and shear deformations are considered for masonry portion while only shear deformations are considered for earth backing. The following additional assumptions are made:

(i) Masonry dam and earth backing are treated as two vertical cantilevers A and B connected together by rigid links (Fig.2) capable of transmitting only horizontal forces.

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(ii) The soil could take up dynamic tension which might be caused by dynamic decrement in the earth pressure (This assumption is made to obtain linear analysis and would be valid if the dynamic tensions are less than static compressions existing before the earthquake motion, Otherwise the results would need adjustment).

(iii)The two portions always remain in contact and have the same displacements at all sections at any instant of time.

The procedure for determining dynamic characteristics of the composite section is based on the flexibility coefficient method. The various equations are described below:

For loads $[\ulcorner P \lrcorner]$ applied to cantilever A of the composite system (Fig. 2b), the redundant forces $[R]$ and the deflection matrix of the composite structure $[x]$ are obtained as follows:

$$[R] = [G]^{-1}[\delta][P] \qquad \ldots \quad 1$$

$$[x] = [\delta]([P] - [R]) \qquad \ldots \quad 2$$

where

$$[G] = [\delta] + [\Delta] \qquad \ldots \quad 3$$

$[\delta],[\Delta]$ = influence coefficient matrices of structures A and B respectively each taken alone.

Similarly for loads $[\ulcorner Q \lrcorner]$ acting on structure,B, the redunance force matrix $[S]$ and deflection matrix $[X]$ of the composite structure are given by

$$[S] = -[G]^{-1}[\Delta][\ulcorner Q \lrcorner] \qquad \ldots \quad 4$$

$$[X] = [\Delta]([\ulcorner Q \lrcorner] + [S]) \qquad \ldots \quad 5$$

For $[\ulcorner P \lrcorner] = [I]$ and $[\ulcorner Q \lrcorner] = [I]$, $[x]$ equals $[X]$ and will give the matrix of combined influence coefficients. Let

$$[\ulcorner P \lrcorner] = [\ulcorner mp^2 y \lrcorner] \text{ and } [\ulcorner Q \lrcorner] = [\ulcorner Mp^2 y \lrcorner] \qquad \ldots \quad 6$$

in which $[m]$, $[M]$ are mass matrices of structures A and B respectively each taken alone, p the natural frequency of the system and y the modal displacement of the composite structure caused due to forces given by euation (6). Thus

$$\{y\} = p^2 \left([x][\ulcorner m \lrcorner] + [X][\ulcorner M \lrcorner]\right)\{y\} \qquad \ldots \quad 7$$

$$\text{or } \{y\} = p^2 \; [x][\ulcorner \bar{M} \lrcorner]\{y\} \qquad \ldots \quad 8$$

In Eq. 8, $[x]$ is put equal to $[X]$, and $[\ulcorner \bar{M} \lrcorner] = [\ulcorner m \lrcorner] + [\ulcorner M \lrcorner]$. The natural frequencies and mode shapes could be obtained by solving eigen values and eigen vectors from equation (8). The modal redundant forces $\{R\}$ can now be obtained from the equation,

$$\{R\} = p^2 \left([R][\ulcorner m \lrcorner] + [S][\ulcorner M \lrcorner]\right)\{y\} \qquad \ldots \quad 9$$

The redundant forces between the soil mass and the masonry dam give the contact forces between the two parts A and B and if the lumped forces are distributed on the length of corresponding segments, it would give the contact pressures. At different instants of time, the dynamic contact pressure will have positive or negative value. The maximum value of the pressure or the separating force will be given by the spectral value. Such dynamic 'increment' and 'decrement' have been determined here for the first mode of vibration.

STRESSES IN DAM UNDER VARIOUS CONDITIONS

The vertical normal stresses on four horizontal sections of the dam at elevations 62.50, 73.2, 86.8 and 99.0m are calculated for various combinations of loads described in Table 1, using the simple bending theory. The stresses in existing dam without earth backing are presented in Table 2 and those in dam with earth backing in Table 3.

DYNAMIC EARTH PRESSURE

The dynamic increment or decrement in earth pressure obtained from the analysis of composite section based on first mode of vibration is shown in Fig. 3. This figure also shows the distribution of static pressure at rest. In the case of dynamic decrement the resultant of static and dynamic pressures in the upper portion of the dam indicates tension. As the tension cannot actually be taken by the soil, there will be separation between fill and dam above R.L. 108.2m, and a depth of 19% of the dam below the top of earth backing could lose contact during vibrations. While calculating the stresses due to dynamic decrement, the readjustment in the pressure diagram is made as indicated in Fig. 3, such that the area of pressure diagram neglected above R.L. 108.2 is added between R.L. 62.5 and R.L. 91.4.

MODEL TESTS

A geometrically similar model of dam having scale factor 1/75 was tested under free and steady state sinusoidal vibrations. The details of model tests are described elsewhere (1). The results of vibration testing showed that the frequency of dam decreased while damping increased with the addition of earth backing, both the effects being advantageous in reducing the dynamic response. Dynamic increment or decrement of pressure did not show variation with the frequency of vibration. It tended to increase with the acceleration and then become uniform. The contact between sand and the dam was maintained at all points except near the top of the dam where visual observation showed a separation over a small depth.

RESULTS

A study of the stresses presented in Tables 2 and 3 reveals varying amount of tensile stresses in the dam in various load combinations. The safe tensile stress for the dam could be taken as 8.8 kg/cm^2. The main results of this study may be summarised as follows:

1. The theoretical determination of dynamic earth pressure is corroborated by model tests in that both show a separation between dam and earth backing over a small depth near the top. The contact is maintained elsewhere along the depth although there could be reduction in static earth pressure during shaking at certain instants of time.

2. The analytical results show that earth backing does not improve the stress conditions under earthquake forces. When earth backing is used, the tensile stresses in the dam are increased under low reservoir condition. Under the full reservoir conditions, the tensile stresses are reduced only in the bottom 2/3 height of the dam by varying amounts. Earth backing does not reduce the tensile stresses in the upper one-third height because contact of earth is lost with the masonry during shaking. At all points, the tensile exceeds the allowable tensile stress.

CONCLUSIONS

From the analytical study and model test results, it can be concluded that earth backing has the beneficial effect of increasing damping but does not prevent the cracking of dam to any appreciable extent particularly in the top quarter height. It is however expected that the resistance to complete failure is increased, a point which needs further investigation.

ACKNOWLEDGEMENTS

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REFERENCE

1. Arya, A.S. and Thakkar, S.K., "Feasibility Study of Strengthening a Masonry Dam by Earth Backing against Earthquake Forces", Symp. on Earth and Earth Str., University of Roorkee, March, 1973.

TABLE 1 - CASES CONSIDERED FOR COMBINATION OF STRESSES IN DAM

Case No.	Case Description
1.	Dead load + Full reservoir (R.L. 117.3) + Uplift
2.	Dead load + Minimum reservoir (R.L. 91.4) + Uplift
3.	Case 1 + Horizontal earthquake u/s to d/s ± Vertical Earthquake
4.	Case 2 + Horizontal earthquake d/s to u/s ± Vertical earthquake
5.	Case 1 + Earth pressure at rest
6.	Case 2 + Earth pressure at rest
7.	Case 5 + Horizontal earthquake d/s to d/s ± Vertical earthquake + Dynamic decrement of earth pressure
8.	Case 6 + Horizontal earthquake d/s to u/s ± Vertical earthquake + Dynamic increment of earth pressure

TABLE 2 - VERTICAL NORMAL STRESSES IN DAM WITHOUT EARTH BACKING
Tensile stress + (kg/cm^2), Compressive stress - (kg/cm^2)

R.L. of Section m	Case 1		Case 2		Case 3		Case 4	
	u/s	d/s	u/s	d/s	u/s	d/s	u/s	d/s
99.1	1.05	-5.79	-5.77	-0.75	25.60	-30.83	-24.89	17.89
86.9	2.74	-8.34	-8.13	0.04	18.48	-24.88	-17.97	9.88
73.2	2.70	-8.85	-8.44	-0.07	16.02	-22.88	-18.26	8.79
62.5	3.69	-11.40	-8.31	-1.73	15.79	-24.45	-18.28	7.29

TABLE 3 - VERTICAL NORMAL STRESSES IN DAM WITH EARTH BACKING
Tensile stress + (kg/cm^2), Compressive stress - (kg/cm^2)

R.L. of Section m	Case 5		Case 6		Case 7		Case 8	
	u/s	d/s	u/s	d/s	u/s	d/s	u/s	d/s
99.1	-0.96	-5.15	-7.74	0.11	25.21	-31.82	-30.05	21.58
86.9	-1.80	-7.70	-12.71	-0.66	16.47	-26.79	-26.88	14.11
73.2	-4.00	-8.75	-15.15	0.05	11.70	-25.15	-27.93	11.94
62.5	-4.10	-12.4	-16.11	-2.75	10.50	-27.45	-28.48	8.67

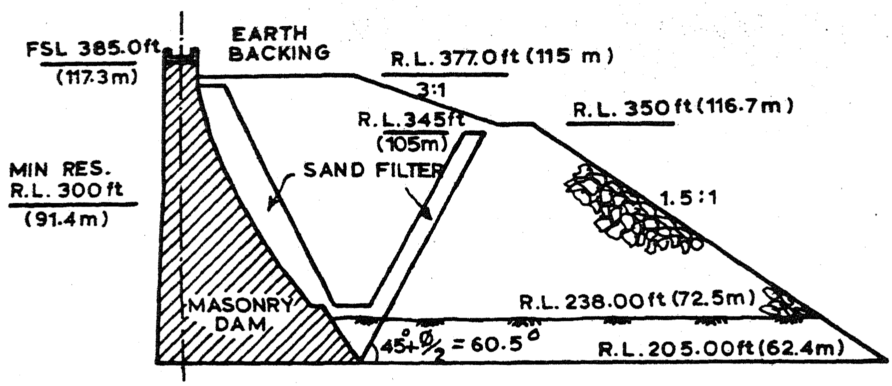
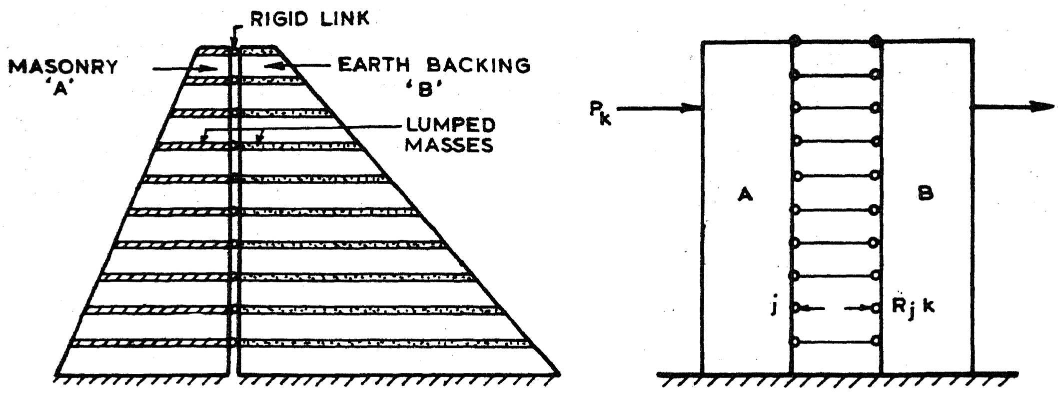


FIG. 1 _ SECTION OF DAM WITH EARTHBACKING



a _ Parallel cantilevers b _ Lumped masses & links

FIG. 2 _ MATHEMATICAL MODEL OF COMPOSITE STRUCTURE

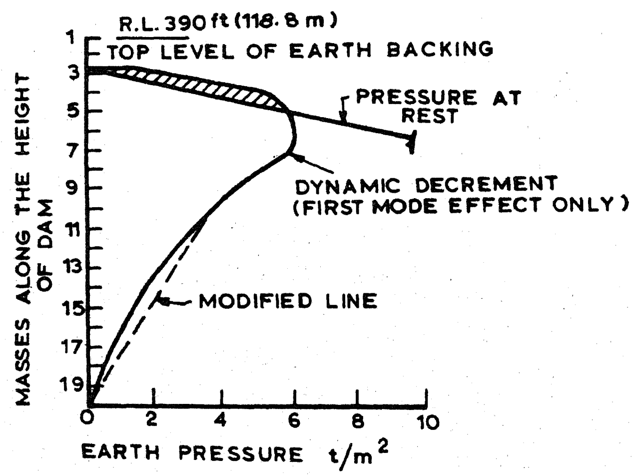


FIG. 3 _ DYNAMIC DECREMENT IN EARTH PRESSURE

DISCUSSION

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The authors have carried out (i) Dynamic Analysis and (ii) Model Tests to find out interaction effect in gravity dams and earth backing. From model tests they conclude that the frequency of the dam decreased after earth backing and hence the effect of earth backing is advantageous to gravity dams from consideration of dynamic response. But the conclusion which appears to be based on dynamic analysis says that the dam is not safe against cracking, perhaps this is due high stresses worked out on the basis of dynamic analysis. The discussor thinks that the damping will be helpful in reducing the cracking potential also and hence this aspect needs further careful consideration.

Author's Closure

The model tests as well as dynamic analysis indicate that during vibrations, contact between the earth backing and original masonry dam gets lost on the upper elevations for certain intervals of time. Thus since the earth support is lost, the high dynamic stresses near the top of the dam are sufficiently large to cause cracking of the dam. There is definitely some beneficial influence of earth backing, that is, increase in period as well as damping, but it is not adequate to contract the dynamic amplification of earthquake forces fully.