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Non-linear dynamic analysis of the Long Valley Dam

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ABSTRACT: The results of dynamic non-linear finite element analyses of the Long Valley Dam in California subjected to a real measured earthquake are presented. A simple elastic perfectly-plastic constitutive soil model is used to describe the stress-strain response of the soil and Rayleigh damping is applied to increase the level of hysteretic damping. The results are compared to the real response of the dam and to results presented by previous authors.

1 INTRODUCTION

In 1980 a series of earthquakes in the Mammonth Lakes area close to the Long Valley Dam in California were monitored. The dam is instrumented with a multi-channel central-recording accelerograph system with all instruments tied together. During the series of earthquakes 22 of the accelerographs on or near to the dam triggered, providing an extensive array of earthquake acceleration time histories. The largest earthquake experienced by the dam occurred on 27^{th} May 1980 resulting in a peak upstream/downstream horizontal and vertical crest accelerations of $0.47g$ and $0.19g$ respectively.

Previous finite element analyses of the Long Valley Dam have been performed by Lai & Seed (1985) using an equivalent linear method to describe the change in the shear modulus and damping ratio with strain. Griffiths & Prevost (1988) used a kinematic model (Prevost 1981 and 1987) to describe the stress-strain behaviour of the soil and obtained very good agreement between the measured and computed response. Griffiths & Prevost (1989) later showed that small changes in the stress-strain response of the soil in the kinematic model can significantly influence the computed acceleration time histories of the dam.

The work presented in this paper assumes that the dynamic behaviour of the dam can be modelled by a two-dimensional plane strain analysis with a simple elastic perfectly-plastic soil model to describe the stress-strain behaviour of the soil. Rayleigh damping is used to increase the level of hysteretic damping and the results of the dynamic finite element analysis are compared to the real response of the dam and to the results presented by Griffiths & Prevost (1988).

2 NUMERICAL ALGORITHM

An implicit Newmark γ, β method was used with $\gamma = 0.55$ and $\beta = 0.28$, representing a small amount of numerical damping. This was considered justified, since the finite element discretization and the elastic-perfectly plastic assumption would generate some spurious high frequency noise. The time step chosen for the analysis was $\Delta t = 0.02$, which was the same time interval step of the accelerographs.

Two-dimensional and three-dimensional natural frequency analysis of the Long Valley Dam have been performed by Griffiths & Prevost (1988) and Woodward and Griffiths (1991). The two-dimensional fundamental frequency of the dam was found to be $f_{fund} = 1.76Hz$ and the first mode of vibration was in the upstream/ downstream direction. The three-dimensional natural frequency analysis indicated that the narrow valley sides of the dam create a stiffening effect, increasing the fundamental frequency. This stiffening effect is however, not considered in the present work. The finite element mesh used in the analysis is shown

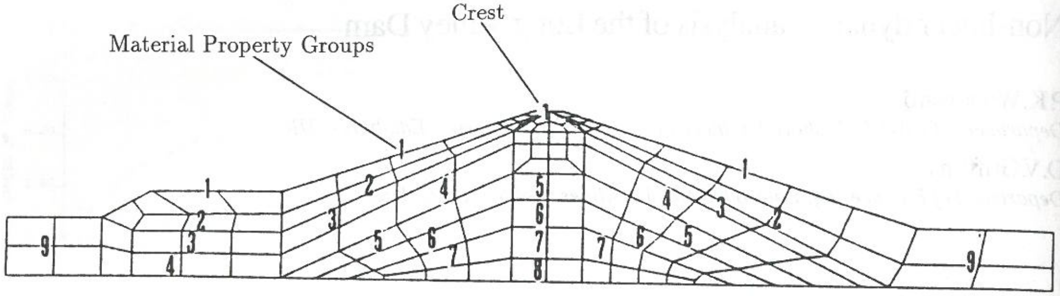

Figure 1 Mesh used for dynamic analysis

in Figure 1. Also shown in Figure 1 are the material property groups (Table 1), which are the same as those used by Griffiths & Prevost (1988). A density of $\rho = 2000 kg/m^3$ was assumed for all the material property groups.

Table 1: Material Property Groups for Long Valley Dam Analysis

Group	E kPa	ν	ϕ^o	c kPa
1: drained	1.6E5	0.3	40	0
2: drained	2.1E5	0.3	40	0
3: undrained	4.0E5	0.45	39	45
4: undrained	5.0E5	0.45	39	45
5: undrained	5.5E5	0.45	39	45
6: undrained	5.9E5	0.45	39	45
7: undrained	6.2E5	0.45	39	45
8: undrained	6.5E5	0.45	39	45
9: elastic	4.9E6	0.3	-	-

3 INPUT MOTION

Figures 2 & 3 show the measured bedrock horizontal acceleration time history and secondary response spectra at 5% damping respectively. The time history peaks at an acceleration of $0.18g$ and the secondary response spectra shows a rapid rise in response at a frequency close to $1.8Hz$, which is close to the fundamental frequency of the dam.

Figures 4 & 5 show the measured bedrock vertical acceleration time history and secondary response spectra at 5% damping respectively. The time history peaks at $0.089g$ and the secondary response spectra shows a broader range of frequency content, peaking at a frequency of $3.5Hz$.

4 DYNAMIC ANALYSIS

Figures 6 & 7 show the horizontal and vertical peak accelerations of the crest with increasing Rayleigh damping ratio's. For the horizontal direction, damping ratio's of $\xi > 12\%$ are required to reduce the peak acceleration to a value close to the measured peak acceleration and is due to the main frequency content of the input motion peaking close to the fundamental frequency of the dam, thus amplifying the response. In the vertical direction damping ratio's of $\xi > 7\%$ generated excessive damping and the peak accelerations after this level of damping are lower than the measured values.

Figures 8 & 9 show the computed horizontal and vertical acceleration time histories compared to the measured acceleration time histories for a Rayleigh damping coefficient of $\xi = 12\%$. The computed response accurately followed the horizontal acceleration time history, however the vertical acceleration time history was not accurately reproduced. This is demonstrated further by examining the corresponding horizontal and vertical secondary response spectra at 5% damping (Figures 10 & 11) for these acceleration time histories. The analysis captured the correct horizontal frequency content, but not the correct vertical frequency content. It is worth noting that Griffiths & Prevost (1988) also failed to capture the correct vertical frequency content. Figure 12 shows the deformed mesh at $T = 6secs$ and shows that the dam is responding strongly in its fundamental mode (upstream/ downstream motion). At the end of shaking some permanent displacement had occurred, however no slip surface has developed.

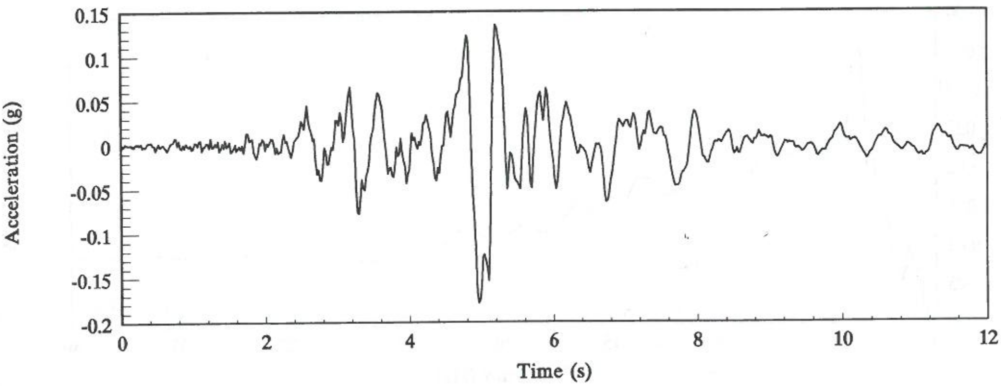

Figure 2 Input horizontal acceleration time history

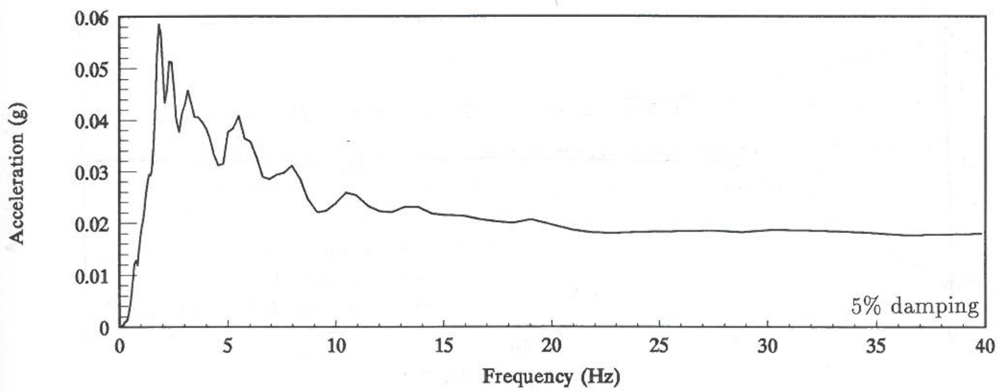

Figure 3 Input horizontal secondary response spectra

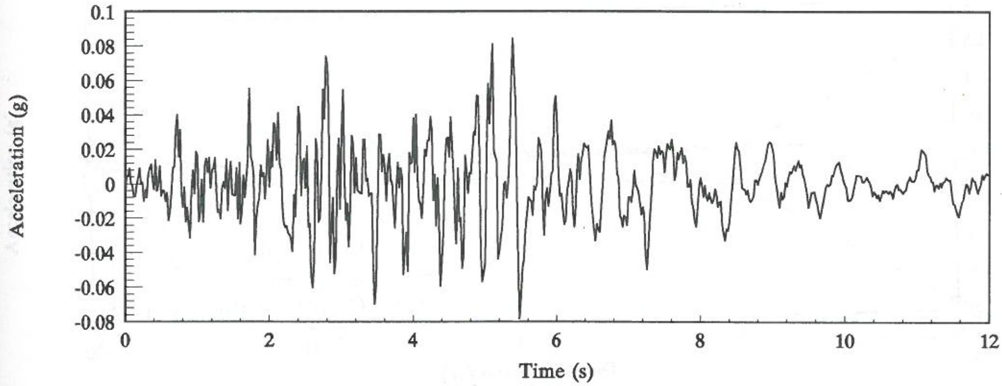

Figure 4 Input vertical acceleration time history

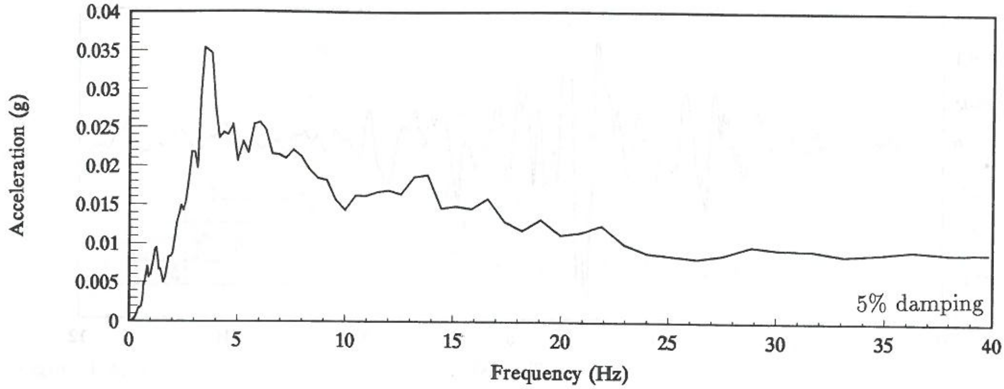

Figure 5 Input vertical secondary response spectra

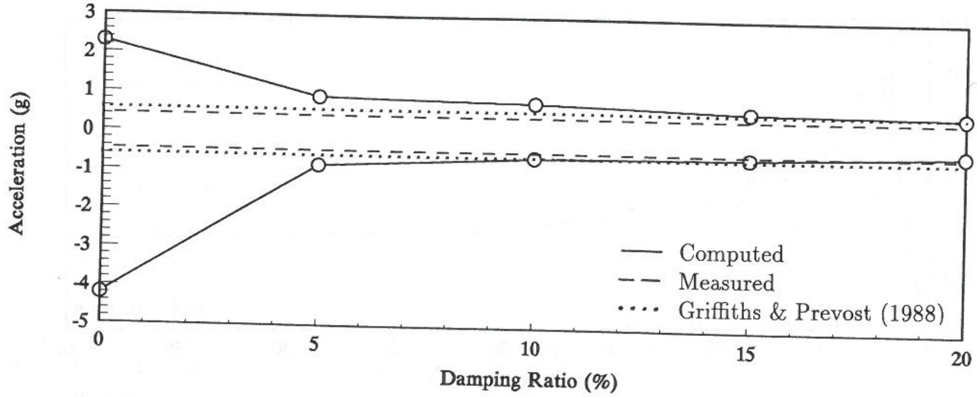

Figure 6 Computed horizontal peak accelerations with Rayleigh damping ratio

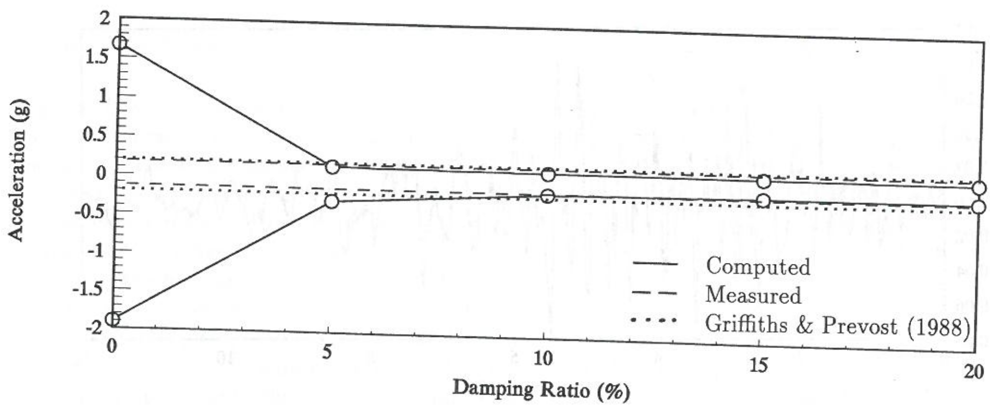

Figure 7 Computed vertical peak accelerations with Rayleigh damping ratio

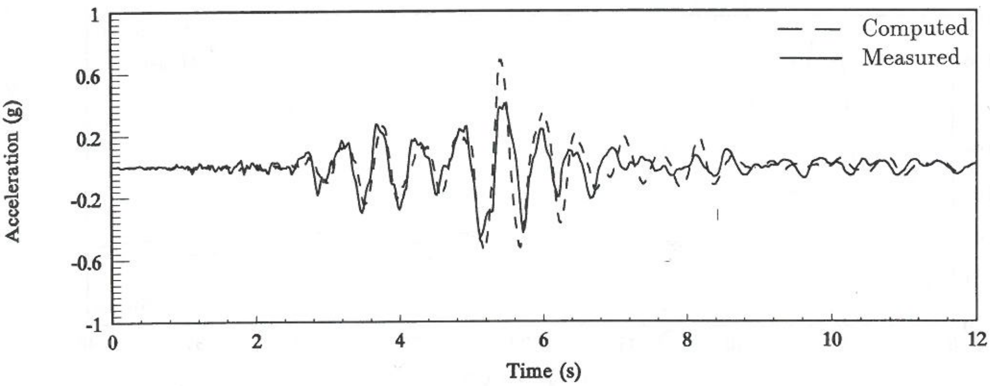

Figure 8 Comparison of measured/ computed horizontal crest acceleration time histories

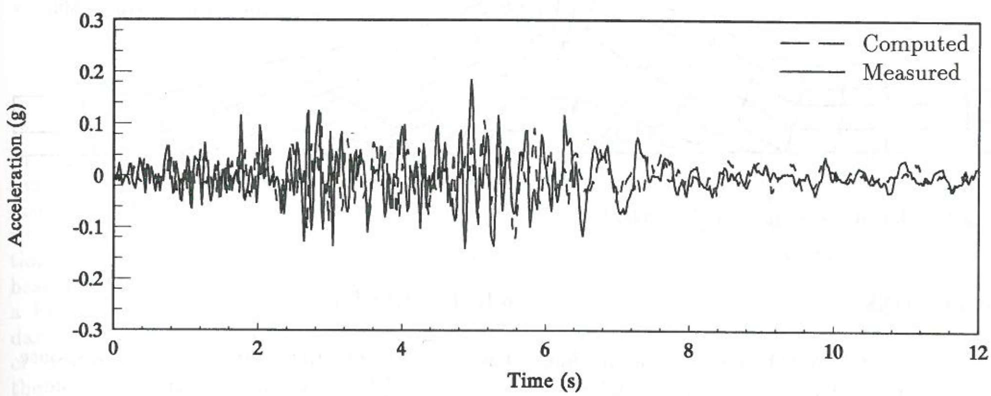

Figure 9 Comparison of measured/ computed vertical crest acceleration time histories

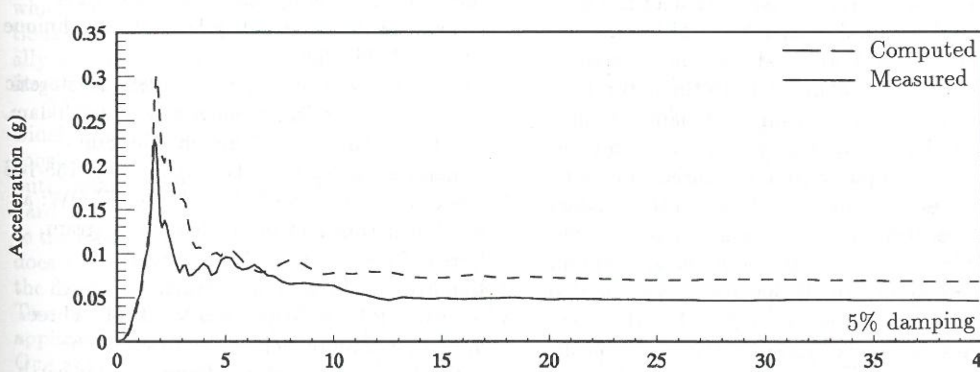

Figure 10 Comparison of measured/ computed horizontal crest secondary response spectra

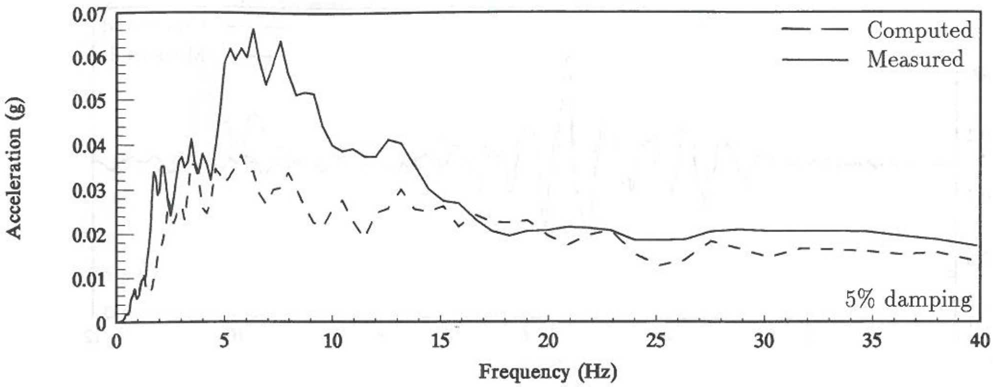

Figure 11 Comparison of measured/ computed vertical crest secondary response spectra

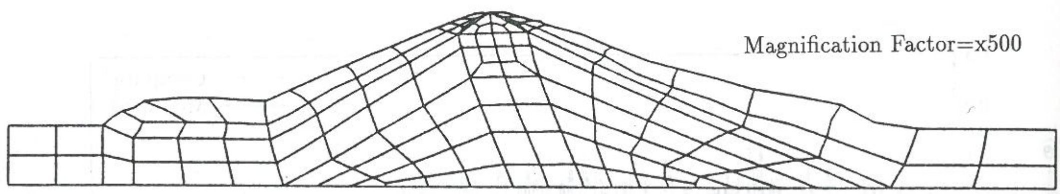

Figure 12 Displaced mesh at time $T = 6secs$

5 CONCLUSIONS

The work presented in this paper showed that a simple elastic perfectly-plastic soil model with Rayleigh damping can give a reasonably good approximation to the real dynamic response of the Long Valley Dam. A damping ratio of $\xi = 12\%$ was however required to reduce the horizontal peak acceleration of the crest close to that of the measured peak horizontal acceleration. This is a direct consequence of the horizontal frequency content of the input motion peaking close to the natural frequency of the dam, resulting in dynamic amplification. Although good agreement was observed between the computed and measured horizontal secondary response spectra, the vertical secondary response spectra were in general, in poor agreement. This could be due to the Rayleigh damping curve damping out the higher frequencies or that the mesh was not refined enough. Also, the material properties may not have behaved isotropically or they may have been inconsistencies in the measured data.

6 REFERENCES

Lai, S.S. & Seed, H.B. 1985 Dynamic response of Long Valley Dam in the Mammoth Lake earthquake series of May 25-27 1980. Report No. UCB/EERC-85/12, Earthquake Engineering Research Center.

Griffiths, D.V. & Prevost, J.-H. 1988 Two- and three-dimensional dynamic finite element analyses of the Long Valley Dam. Geotechnique 38, No. 3, 367-388

Griffiths, D.V. & Prevost, J.-H. 1989 Hysteretic damping in the seismic analysis of an earth dam. Fourth International Conference on Soil Dynamics and Earthquake Engineering, 155-166

Prevost, J.-H. 1981 and 1987 DYNAFLOW: a non-linear transient finite element program. Report 81-SM-1, Civil Engineering Department, Princeton University.

Woodward, P.K..& Griffiths D.V. 1991 Three-dimensional finite element analyses of the natural frequencies of non-homogeneous earth dams. Fifth International Conference on Soil Dynamics and Earthquake Engineering, Karlsruhe, 377-388