13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 79

Dynamic Characteristics Of A Barrage At Various Stages Of Construction

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SUMMARY

The occurrence of an earthquake is a random phenomenon in space and time and possibility of occurrence of an earthquake at an intermediate stage of construction cannot be ruled out especially if the area is seismically active. A typical barrage located in a seismically active area (Zone V as per IS:1893-2002), is chosen for the present study and its dynamic behaviour is studied at various stages of construction. The mass and stiffness of the structure evolves with different stages of construction, modifying its dynamic characteristics at each stage. A total of fourteen stages were considered for the analysis. The construction of raft of depth 3m was considered to be constructed in a single lift and is identified as the first stage and the subsequent stages are each 1.5m of construction except the last two stages which are 4.8m and 3.7m respectively.

Dynamic analysis is performed at each stage identified as above. Spectrum analysis is performed using a site dependent spectra and a comparison of SRSS stresses in different stages is presented and discussed in this paper. The study indicates that intermediate stage stresses in both the piers and the raft are likely to exceed the stresses in the completed structure. The twelfth stage, identified as construction of 16.5m out of total 25m, is found to be most critical having stresses higher than stresses at complete stage.

INTRODUCTION

The barrage selected for the study is part of power development project in Beas Basin [1]. It is located 20 km upstream of Pandoh Dam at a distance of about 190 km from Shimla in the state of Himachal Pradesh. The barrage is 49.526 m long in the direction of flow, 85 m wide and 25 m high with 5 bays each bay is 11m wide, Figs. 1 and 2. There are two construction joints one between bay-2 and bay-3 and the other one between bay-4 and bay-5. The thickness of the single pier is 4m and that of double pier is 2.25m. The right wall consists of counter forts to resist the earth pressure due to back fill. The left wall consists of baffle walls to provide passage for fish. The barrage is resting on raft foundation, the thickness of the raft from bay-1 to bay-4 is 3m and that of bay-5 is 1m.

Diversion barrage rests partly on rock and partly on alluvium. Bay-1 to bay-4 rests on soil and bay-5 on rock stratum. The formation of the rock consists of grey dolomites and pink lime stones with black shale partings. The alluvium zone consists of over burden upto a depth of 20-30m comprising of boulders, cobbles, pebbles etc.

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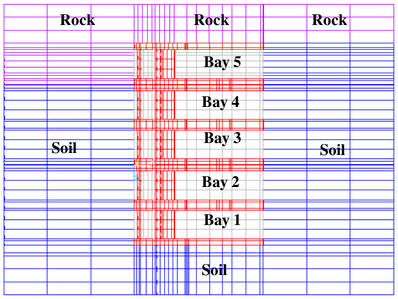


Fig. 1: Plan of the Barrage

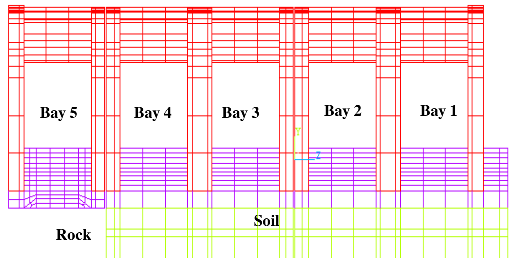


Fig. 2: Transverse section of the Barrage

MODELLING

Three separate FE models, Sasidhar [2] are considered for the study see table 1 –

Model A (BAY1&2)

In this model Bay1 and Bay2 of Barrage were considered. To take into the effect of the underlying soil, soil up to a depth of 80m from the crest level was considered. To take into the effect of the surrounding soil, soil up to 30m from both sides (pier and right abutment) equal to width of super structure, and soil up to 50m on both sides (upstream side and downstream side) equal to length of super structure were considered.

Model B (BAY3&4)

In this model Bay3and Bay4of Barrage were considered. To take into the effect of the underlying soil, soil up to a depth of 80m from the crest level was considered. To take into the effect of the surrounding soil, soil up to 30m towards Bay2 was considered and rock up to 30m towards Bay5 was considered, and soil up to 50m on both sides (upstream side and downstream side) were considered.

Model C (BAY5)

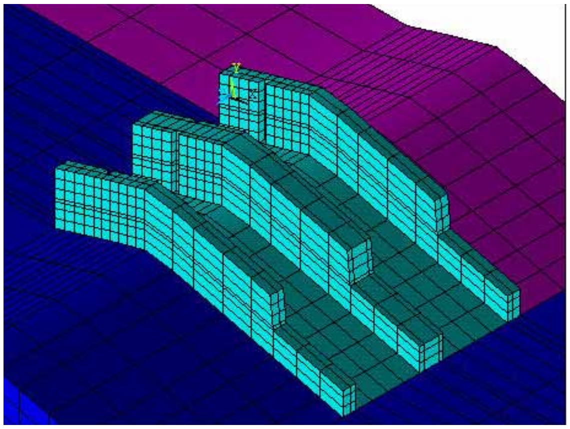
In this model Bay5 of Barrage was considered. To take into the effect of underlying rock, rock up to a depth of 80m from the crest level was considered. To take into the effect of the surrounding soil and rock, soil up to 30m towards Bay4 was considered and rock up to 30m from the left abutment was considered, rock up to 50m at the upstream side and soil up to 50m at downstream side were considered.

Table 1: Description of models

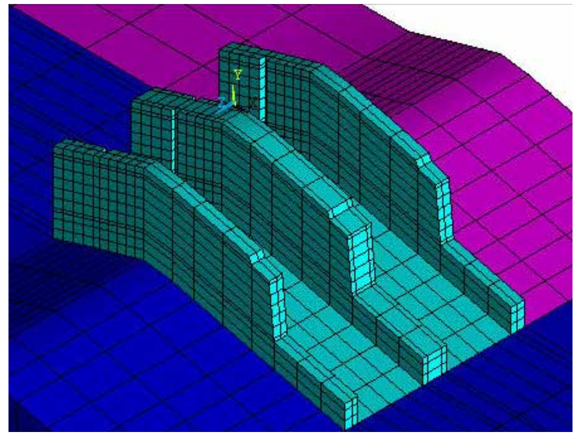
Model	Description	Comments
A	Bay1 & Bay2	Fully on Soil
B	Bay3 & Bay4	Partly on Soil, Partly on Rock
C	Bay5	Partly on Soil, Partly on Rock

Construction Stages

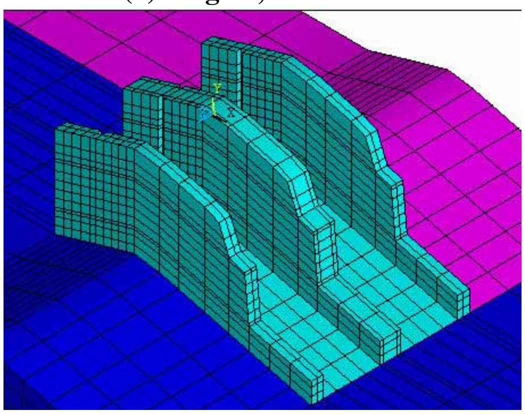
Construction of a Barrage structure cannot be completed in a single stage, the construction is staggered in multiple stages over a period of time with an interval of 21 days between every stage. A total of fourteen stages were considered for the analysis, Gupta [3]. The construction of raft of depth 3m was considered to be constructed in a single lift and is identified as the first stage and the subsequent stages are each 1.5m of construction except the last two stages which are 4.8m and 3.7m respectively. Typically for Model B the models at construction stages 7, 10, 12 and 14 are shown in Fig. 3. Final stage model of other bays are shown in Fig. 4 and 5. Construction height at stage-7 is 9m, at stage-10 13.5m, at stage-12 is 16.5m and at stage-14 it is 25.0m.



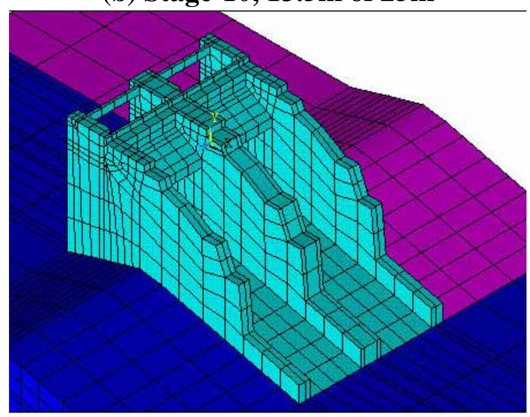
(a) Stage-7, 9m of 25m



(b) Stage-10, 13.5m of 25m



(c) Stage-12, 16.5m of 25m



(d) Stage-14, 25m of 25m

Fig. 3: FE models showing the superstructure and the surrounding soil and rock at different stages of construction of bay3-4 (Model B)

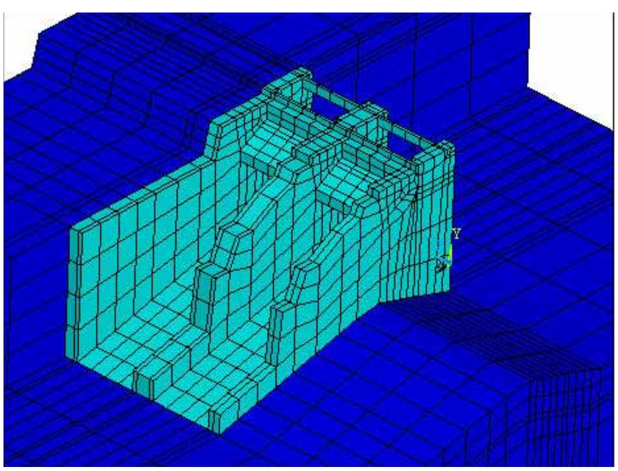


Fig. 4: FE model showing the superstructure and the surrounding soil at stage-14 of construction of bay1-2 (Model A)

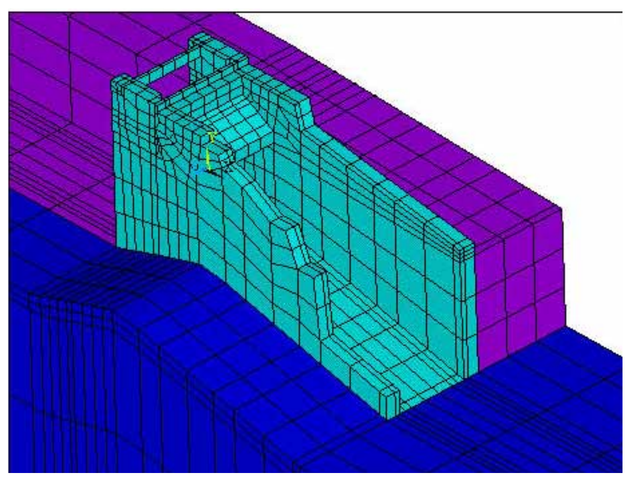
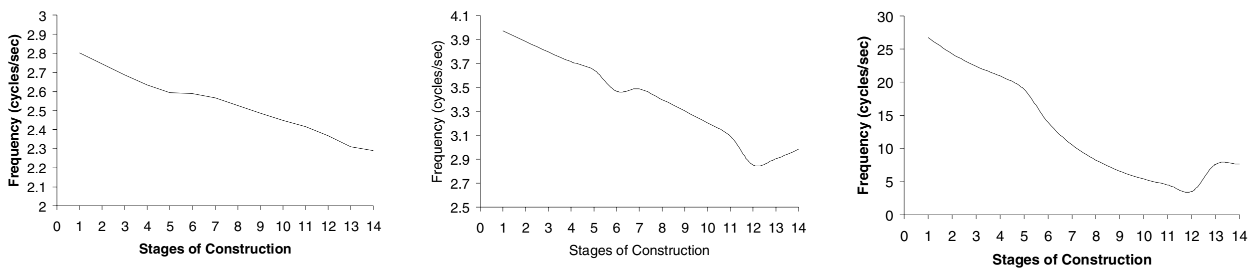


Fig. 4: FE model showing the superstructure and the surrounding soil and rock at stage-14 of construction of bay5 (Model C)

DYNAMIC ANALYSIS

Free Vibration Analysis

The results of free vibration analysis has been shown in Fig. 5 models A, B and C. Because Model C rests completely on Rock the fundamental frequency of Model C at all the stages is much higher than the other models. Model B has intermediate frequencies and, Model A which rests completely on soil has the lowest frequencies at different stages. As the structure is constructed mass is added to the structure and the frequency of the structure decreases at almost every stage of construction. This is clearly evident in Model A. However in Model B and C the frequency increase after the Stage 12 which is attributed to the construction of slab for the Breast Wall at the height of 16.5m which joins the two piers and hence increase the stiffness and the frequency. This change in the dynamic characteristic of the structure produces significant differences in between the stress state at Stage 12 and Stage 14, the final stage of construction. This is discussed in detail in the next section.



(a) Model A (b) Model B (c) Model C

Fig. 5: Fundamental frequency of the barrage structure at different stages of construction

Response Spectrum Analysis

The structure is located in a seismically active area, Zone V as per IS:1893-2002, BIS [4]. The site dependent response spectra, DEQ [5], has been used for simulating the earthquake excitation. For dynamic analysis the first 10 modes were considered. The dynamic stresses were then combined using SRSS method. The response spectra used for the analysis is shown in Fig. 6.

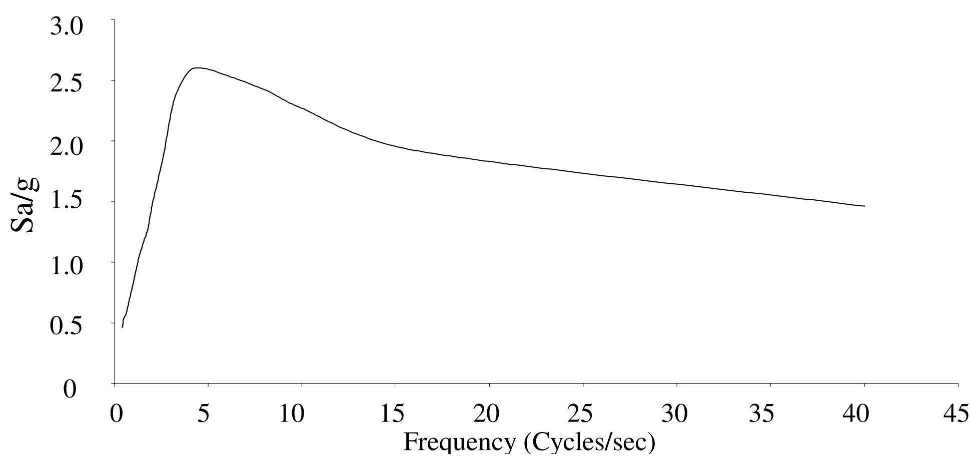
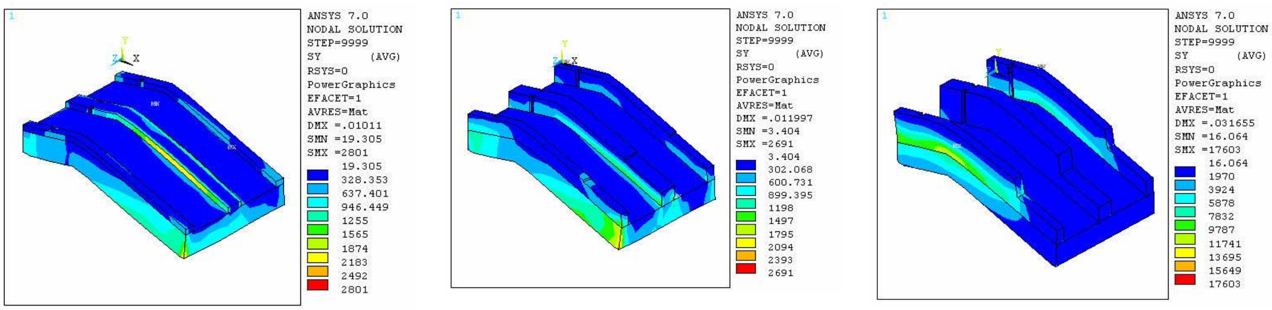


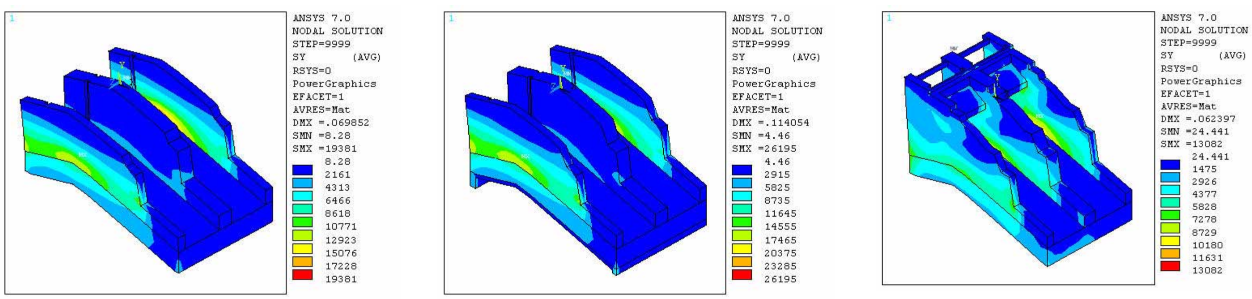
Fig. 6: Site dependent response spectra used for response spectrum analysis

The dynamic characteristics changes as the structure evolves and largely affects the stresses at different location in the structure. Typically, for Bay 3-4 (Model B) the stress contours for normal stress

SY at six construction stages are shown in Fig. 7. It is clear from the figure that the stresses are concentrated at the raft-pier interfaces and as the height of the piers increase the stresses also increase and tend to concentrate near the downstream side where the pier height is more. The maximum stress increase from a value of 2801 kN/m^2 at stage 2 to 26195 kN/m^2 at stage 12 and reduces to 13082 kN/m^2 at final stage. The stresses at stage-12 are much higher than at any other stage because in subsequent stages the construction of the breast-wall starts providing additional rigidity to the structure thus reducing the stresses. The maximum transverse displacements in the pier increase with the increase in the height of piers it has a value of 6.3 cm at stage 11, 10 cm at stage 12, 4.8 cm at stage 13 and 4.9 cm at stage 14. The displacement in piers is much higher at stage 12 and subsequently the connecting slab also helps to reduce the displacement in piers. Similar trends are observed for other stress and displacement components.



(a) Stage 2 (b) Stage 4 (c) Stage 7

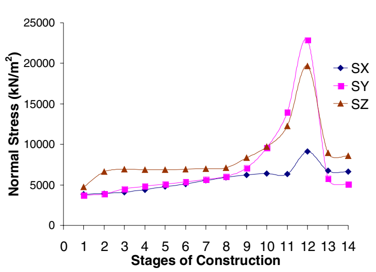


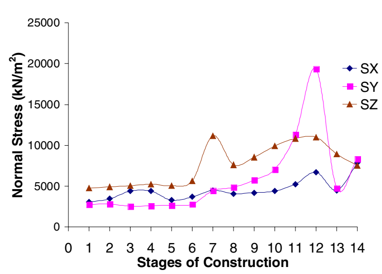
(a) Stage 11 (b) Stage 12 (c) Stage 14

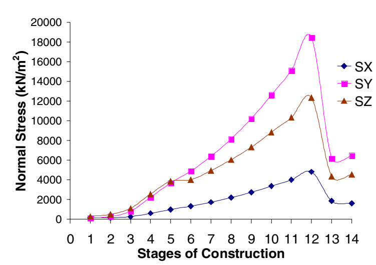
Note: The elements of surrounding soil and rock strata are hidden

Fig. 7: Stress distribution for normal stress Sy at typical stages of construction of Bay 3-4(Model B)

Two main components of the structure are the raft and the piers. The maximum stress in the two components are noted at every stage of construction and plotted in Figs. 8 and 9. It is clearly evident from the figures that stresses increase as the structure gains height but stresses in both the piers and the raft are highest at stage 12 which is identified as 16.5m of construction. Thus the intermediate stage 12 is critical to the safety of the structure.

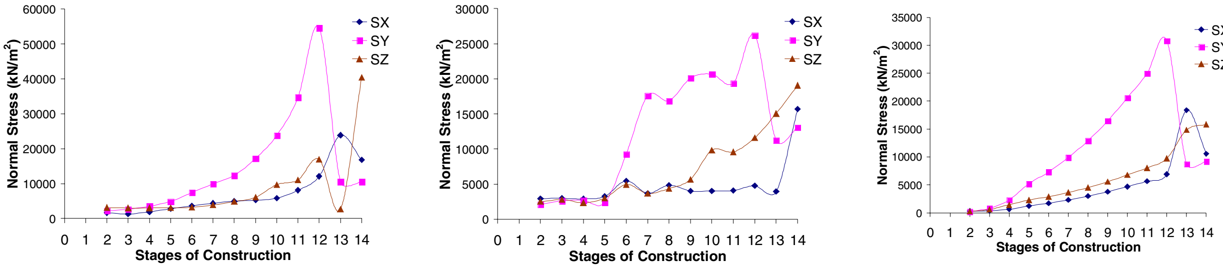






(a) Model A (b) Model B (c) Model C

Fig. 8: Variation of maximum value of normal stresses in the raft with stages of construction



(a) Model A (b) Model B (c) Model C

Fig. 9: Variation of maximum value of normal stresses in the piers with stages of construction

CONCLUSIONS

- From the free vibration analysis it is observed that the frequency of the structure decreases at subsequent stages.
- At the thirteen stage top of the piers are connected by the slab which changes the dynamic characteristic and the behavior of the structure.
- For all the models the values of the stress components are highest at twelfth stage of construction hence it is most critical for the design and safety of the structure.
- The foregoing indicates that such studies are necessary to examine the state of stresses at the postulated stages of construction, so that appropriate measures can be taken to ensure safety and integrity of the structure even during construction itself.

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