Study of Seismic Design for Concrete Dam

Mr. Sparsh Kumar[1] And Mr. Sagar Paruthi[2]

[1]Student , Dept. of Civil Engineering, DPGITM, Sec-34, Gurugram, Haryana, India; Email ID: sparshkumar9697@yahoo.com
[2] Head of Department, Dept. of Civil Engineering, DPGITM, Sec-34, Gurugram, Haryana, India;
Email ID: sparuthi57@gmail.com

ABSTRACT

Earthquake analysis and earthquake resistance design of dams is of major importance because of the catastrophic consequences if such a structure is to fail. In India we don‟t have any guidelines to take into account the seismic load for the analysis of Dam. In the absence of any well-defined method, design offices generally use an empirical method which does not consider the dynamic properties of dam and different earthquake zone. This study is an attempt to develop guidelines to consider seismic force for the analysis of concrete gravity dam. An equivalent static method for seismic design of concrete gravity dam is developed considering the dynamic properties of the dam as well as different earthquake zones. For this to achieve, a family of concrete gravity dam with varying height, base-width and side slope is analysed using finite element software ANSYS. Dams are modelled with 2-D plane strain elements. Dynamic properties of all the selected dams are evaluated. A regression analysis is carried out on the modal properties obtained from the finite element analysis in order to develop empirical relation between time period, height and base width. The minimum number of modes that must be taken into for the analysis is decided by considering the mass participation ratios. Design base shear is calculated by using the Design horizontal acceleration spectrum value and Seismic weight of the building. A method is proposed to distribute the calculated base shear over the height of the Dam.

Keywords: Concrete Gravity Dam, Earthquake analysis, Seismic load, ANSYS Software, Base Shear, Spatial Distribution of Base Shear

INTRODUCTION

Basically, a concrete 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. Gravity dams typically consist of a non-overflow section(s) and an overflow section or spillway. The two general concrete construction methods for concrete gravity dams are conventional placed mass concrete and RCC. Gravity dams, constructed in stone masonry, were built even in ancient times, most often in Egypt, Greece, and the Roman Empire.

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. The ratio of base width to height of high gravity dams is generally less than 1:1. But the earlier dams are constructed with the ratio of about 1.5 to 3. This is due to the low grade of concrete and low density of compaction achieved. Engineers in India must pay special and careful attention to the problem of earthquake loading in the design and evaluation of almost all permanent civil engineering structures. The significant effects caused by earthquakes on dams are not only those directly related to the seismic motions but also those directly associated with the ground displacement along the fault line. In the country with 5,100 large dams and 1,040 active faults covering 57% of land mass making prone to earthquakes, there is always a possibility that a severe earthquake in highly seismic zones might affect the performance of dam. However, analysing dam for seismic forces is not a simple problem. Like all other structure, concrete gravity dam requires nonlinear, dynamic and probabilistic study to evaluate the internal forces due to seismic loading.

It is not always possible to obtain rigorous mathematical solutions for engineering problem. In fact, analytical solution can be obtained only for certain simplified situations. For the Problems involving complex material properties, loading and boundary conditions, the engineer introduce assumptions and idealization deemed necessary to make the problem mathematically manageable, but still capable of providing sufficiently approximate solutions and the satisfactory results from point of view of safety and economy. The link between the real physical system and the mathematically feasible solution is provided by the mathematical model which is the symbolic designation for the substitute idealized system including all the assumptions imposed on the physical problem.

Dynamic analysis of Buildings and Dams are very complex phenomena. In order to solve this complex phenomenon, we use mathematical modal including all the assumptions imposed on the physical problem. However, unlike building and other structures, there is no simplified standard procedure to analyse concrete gravity dam for seismic loading. This is the underlying motivation of the present study.

MODELING USING ANSYS 13.0

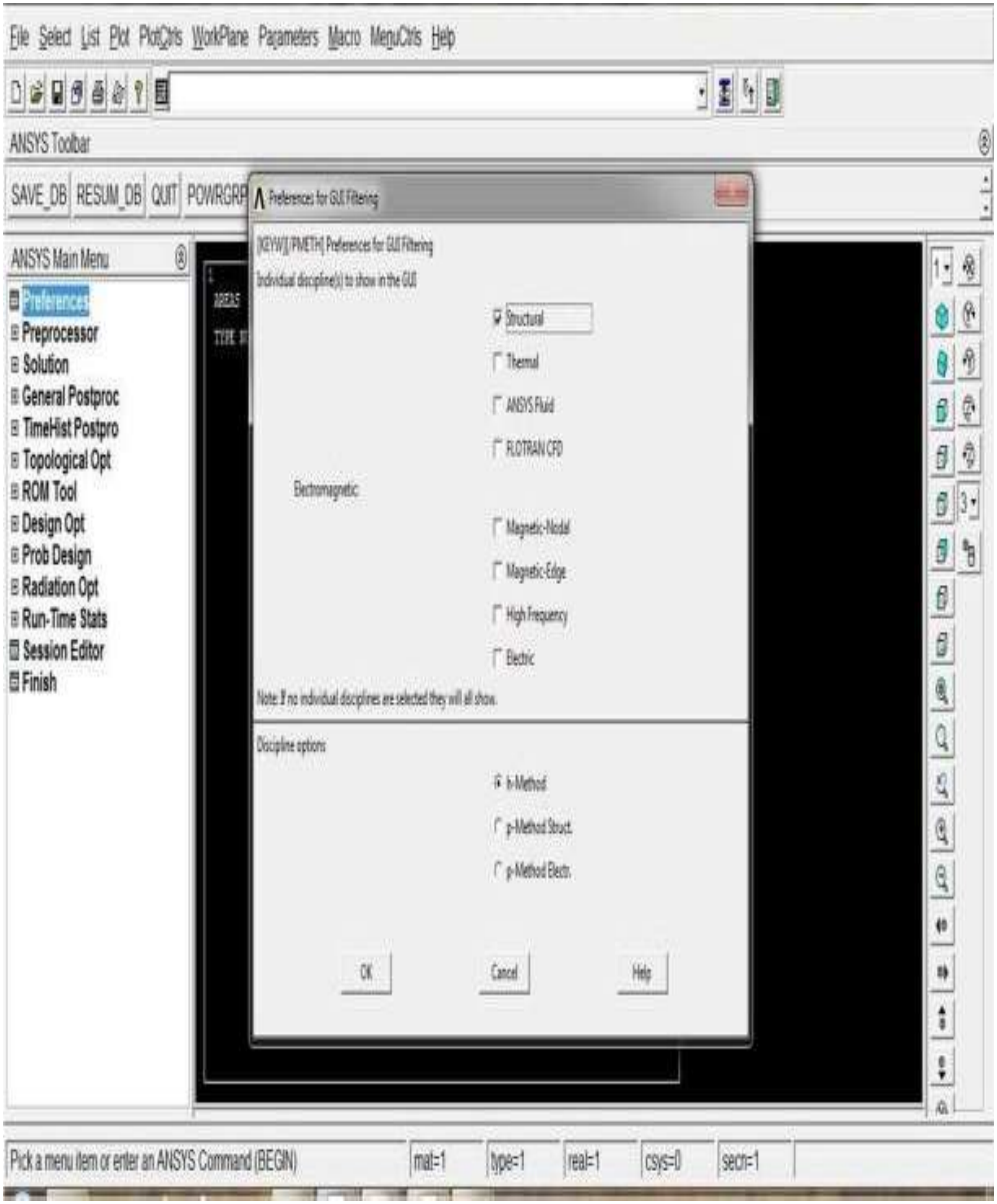
ANSYS MODEL

The 2D cross-section of the dam was modeled using a commercially available finite element package, ANSYS 13.0 according to ANSYS user‟s manual. The natural frequencies and mode shapes of the 2D dam model are obtained by modal analysis. The element type used is „Solid 8 node 183 plane strain‟ solid elements which is an 8 noded structural shell, suitable for analysing thin to moderately thick structures. The element has 8 nodes with 6 degrees of freedom at each node. The whole domain is divided into 8* 8 meshes for all the cases. The boundary condition is given fixed at the bottom of the Dam. This condition closely resembled the field situation.

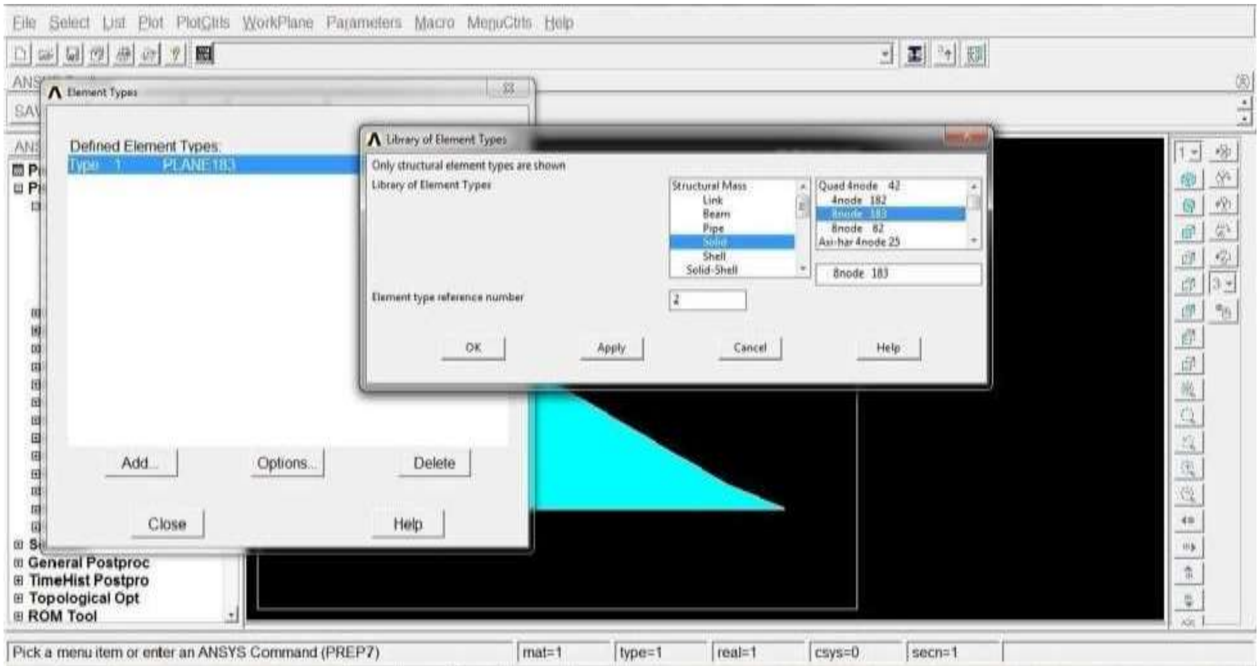
PROCEDURAL STEPS FOR MODELLING

The step by step procedure for modeling the dam in ANSYS 13.0 is explained as follows:

1. Preferences →Structural →Ok



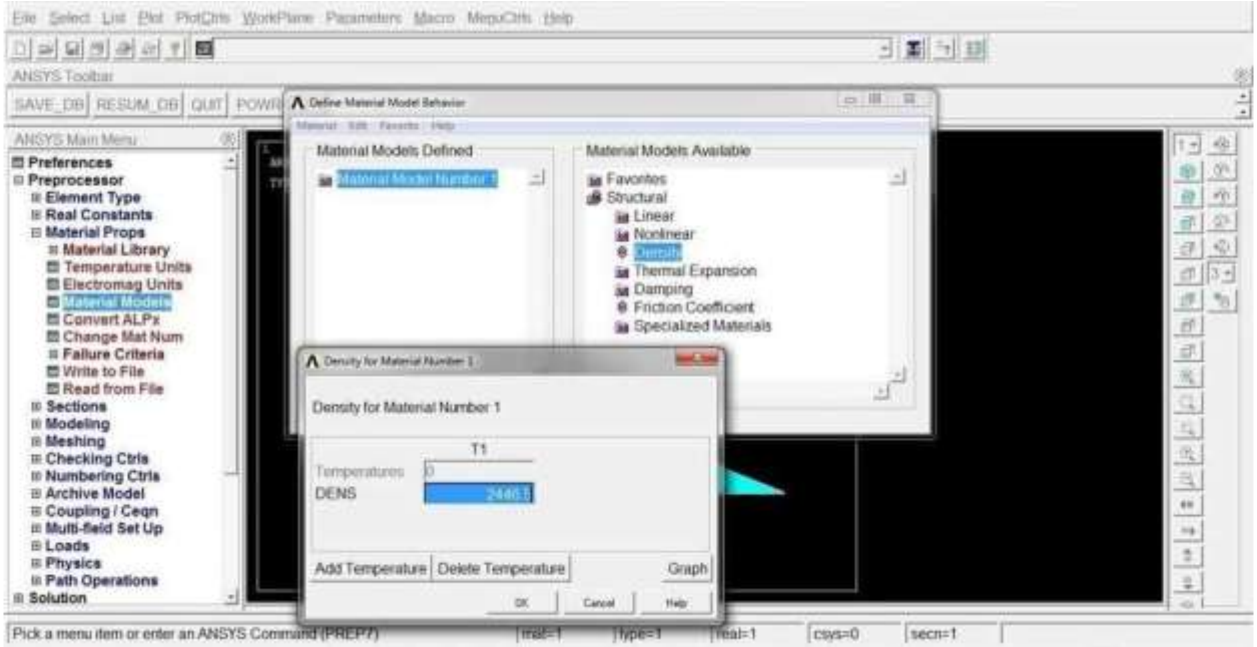
2. Preprocessor→Element type→Add→Solid→Shell→8node 183→Ok



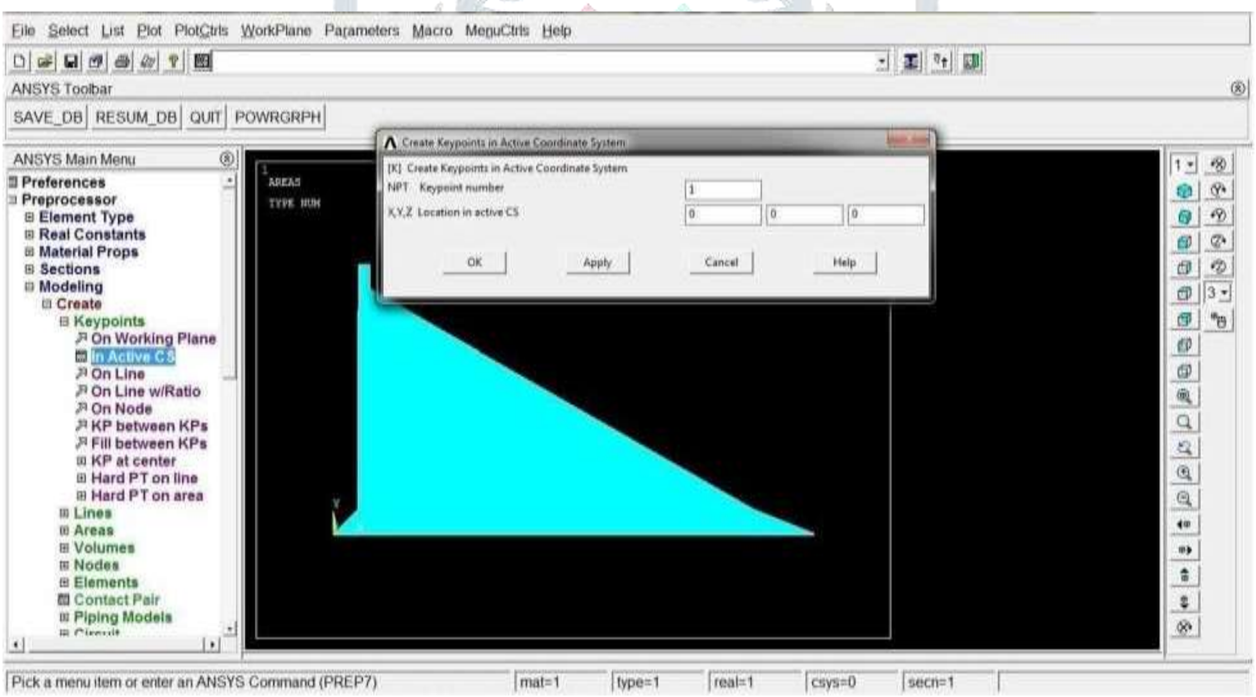
3. Preprocessor→Material Properties→Material Models→Structural→Linear→Elastic→Isotropic

4. Enter the Linear Isotropic Material Properties and press Ok.

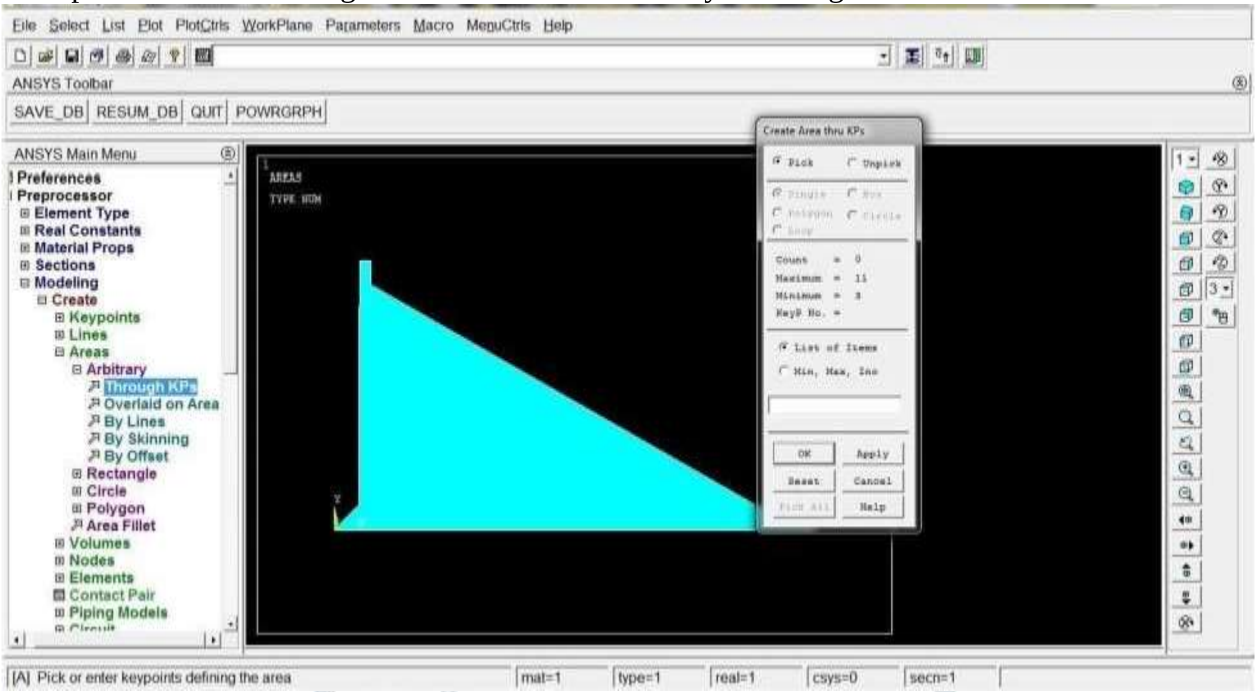
5. Material Models Available→Density→Enter the density of the Dam→Ok



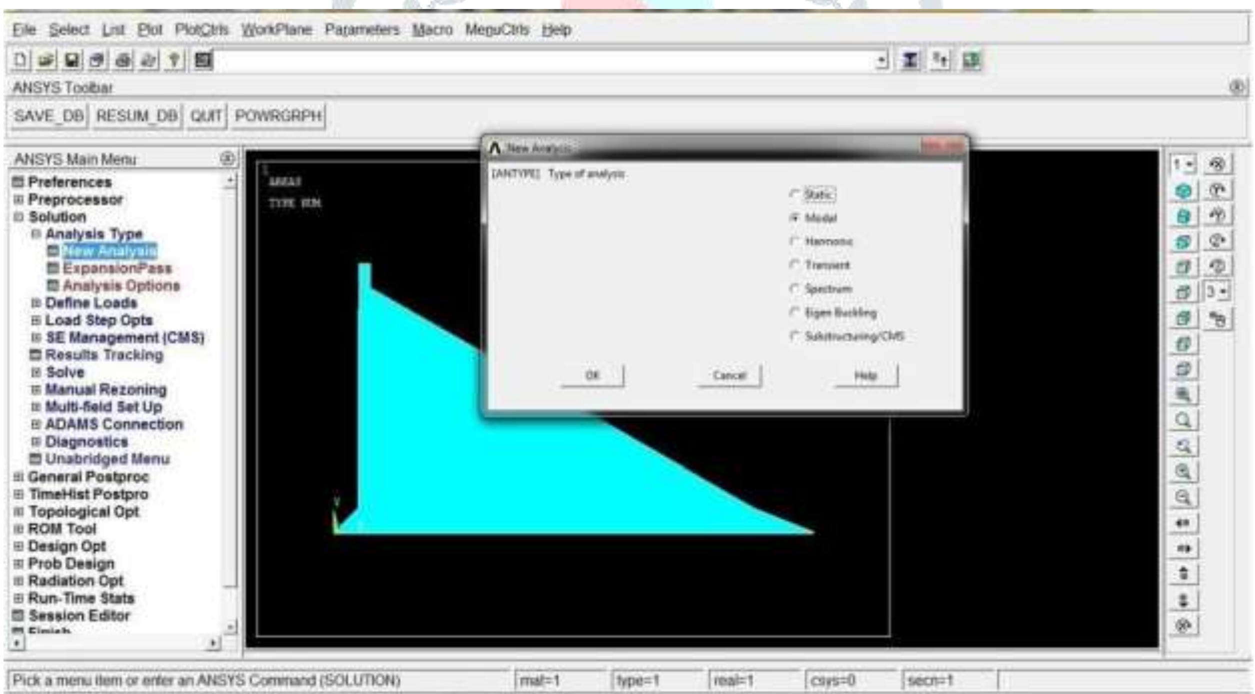
6. Preprocessor→Modeling→Create→Key points→In Active CS→Center the coordinate"s →Ok



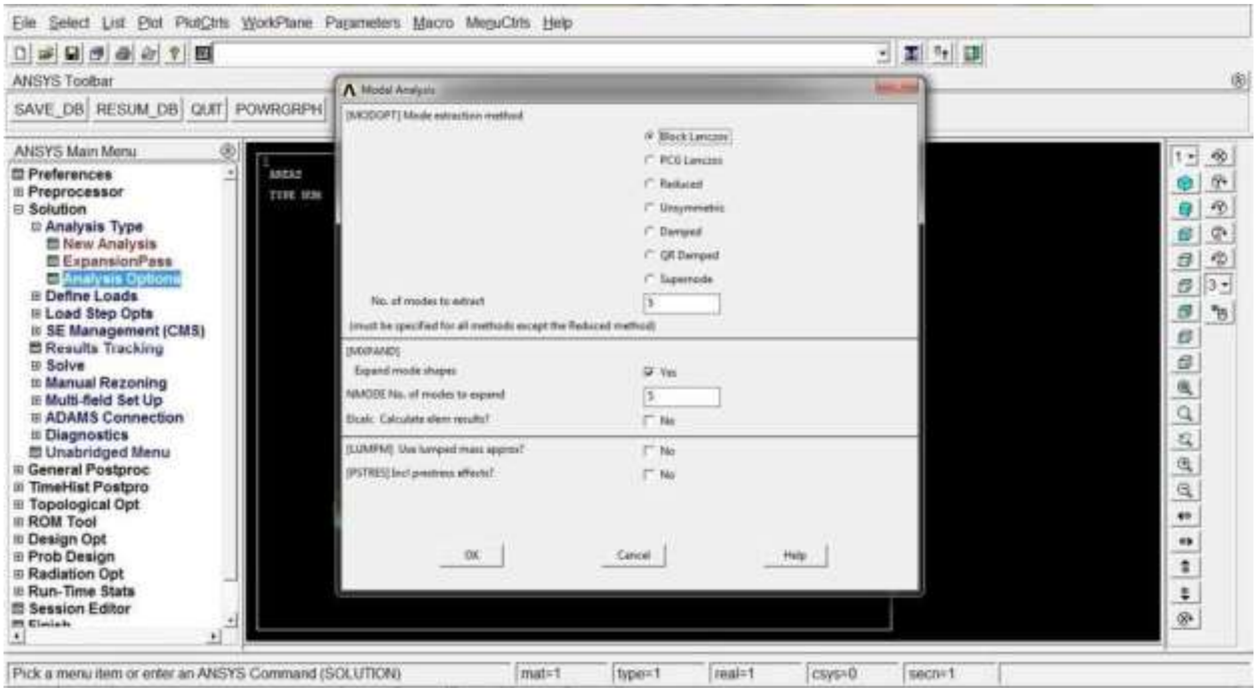
7. Preprocessor →Modeling →Create→Areas→Arbitary→Through KPs



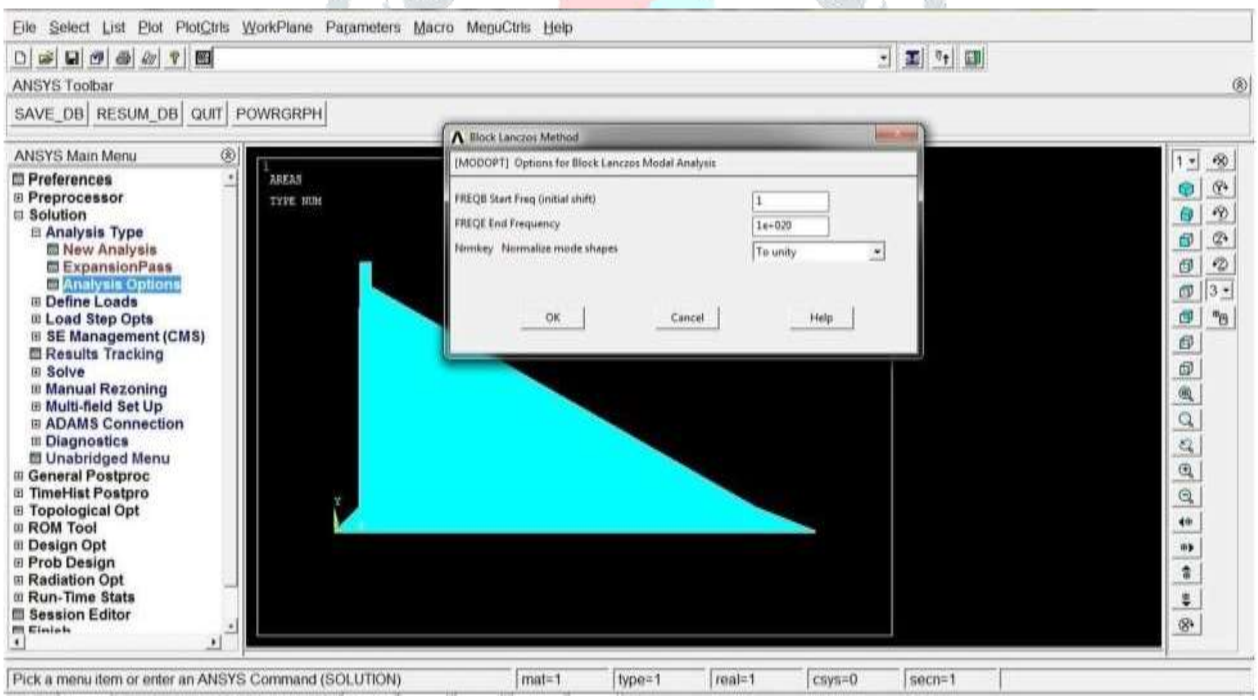
8. Solution →Loads →Analysis Type →New Analysis →Type of analysis – Modal →Ok



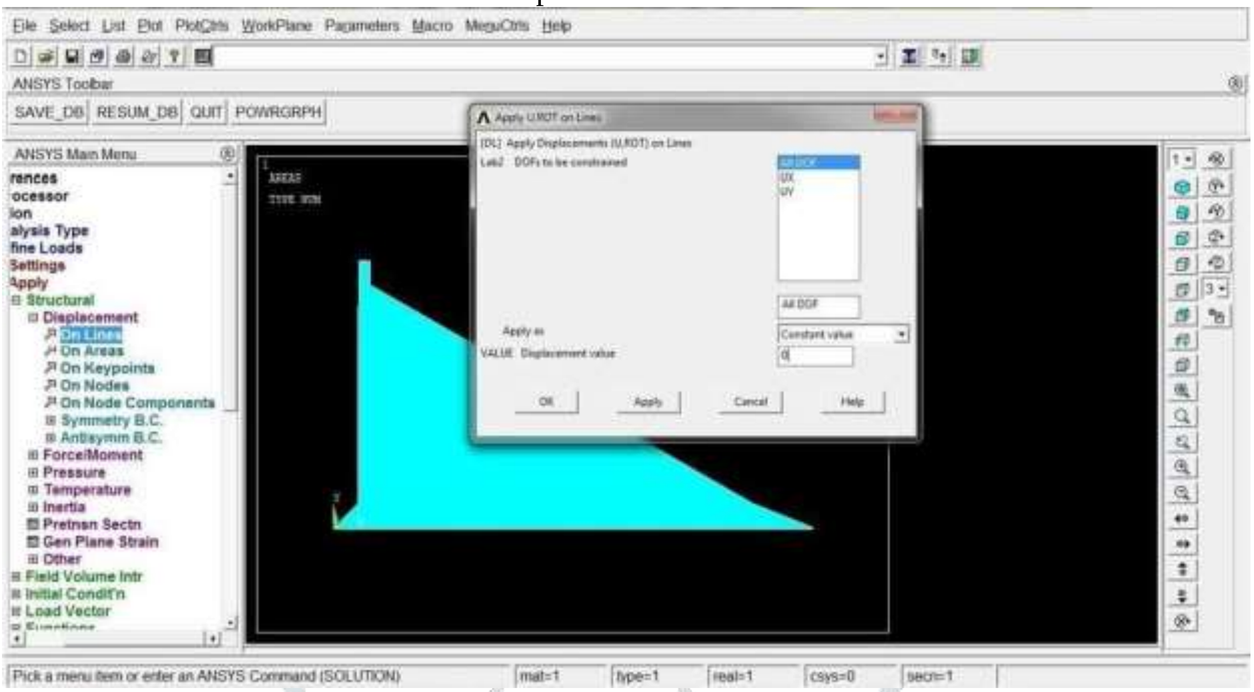
9. Solution →Loads →Analysis Type →Analysis Options →Mode extraction method – BlockLanczos →No. of modes to extract - 5 →Ok



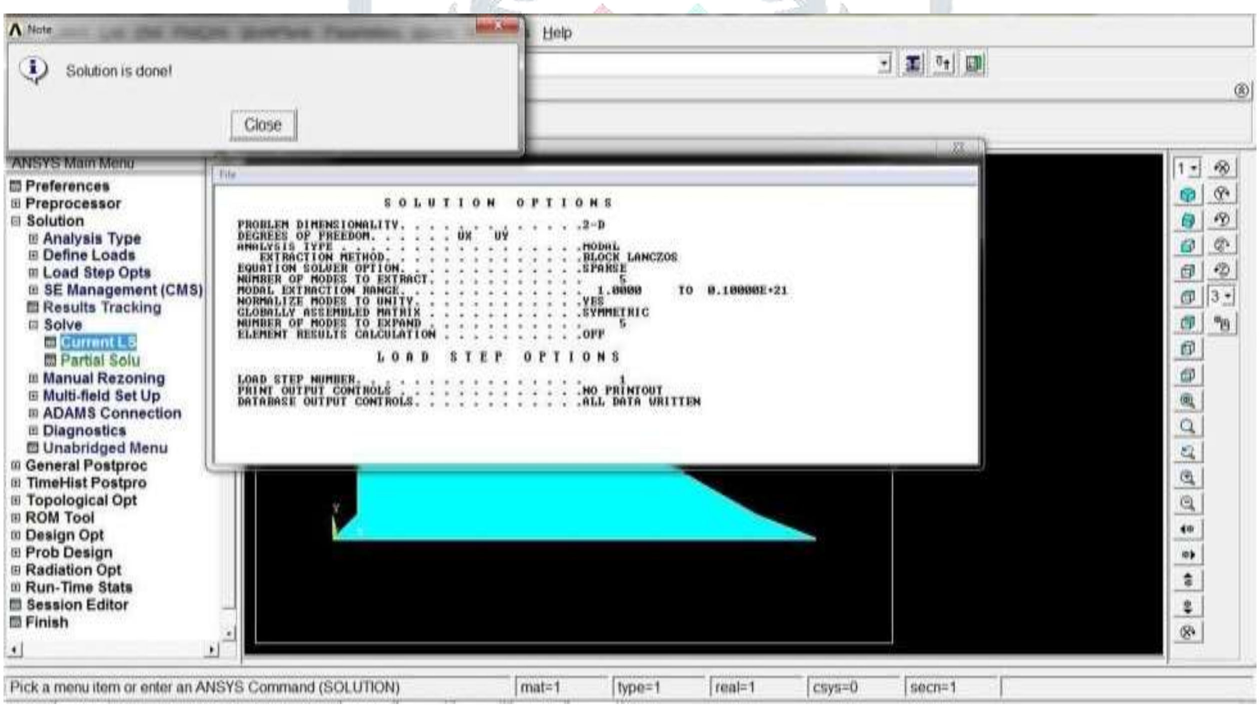
10. Block Lanczos Method →Enter the start and end frequency →Ok



11. Solution →Define load→ Structural→Displacement→ On Lines →Ok



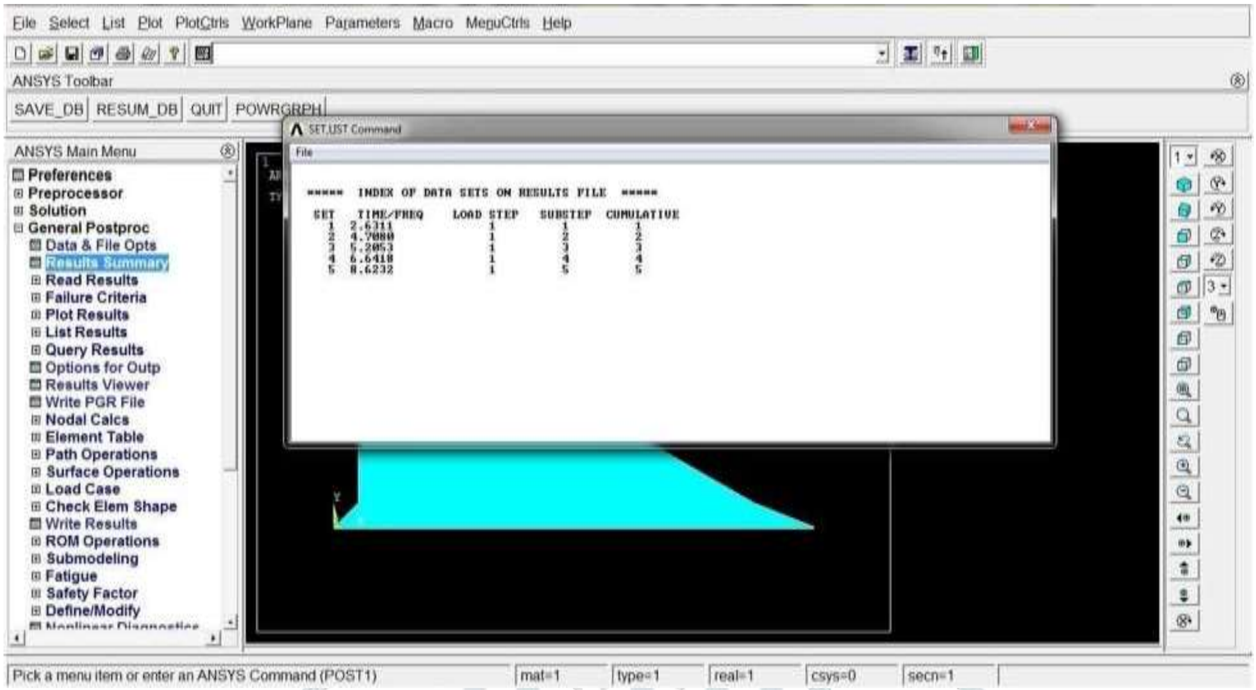
12. Enter the degree of Freedom to be constrained.



13. Solution →Solve →Current LS →Press ok in the Solve Current Load Step window

Once the solution is done a window displaying that solution is done is displayed. Close the window.

14. For viewing the results, follow the step given below:General Postprocessing →Results Summary



15. Steps to get nodal displacement.

Select Entities→Node→Line→Ok→Select line→Plot line →Select entities→Nodes→ Attached to→Lines all→Reselect→Ok→Plot node → General post.→Read result→First set→List

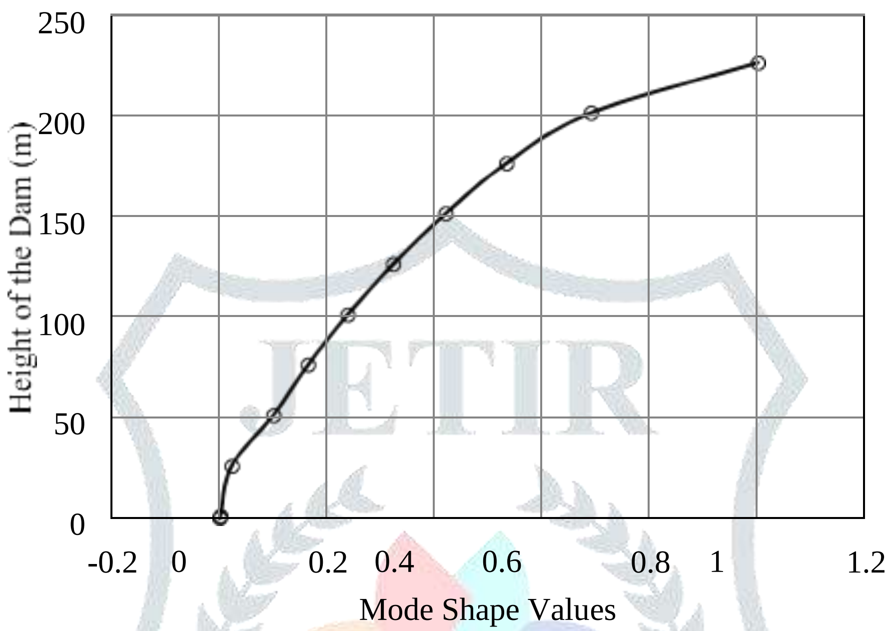
RESULTS AND DISCUSSIONS

In order to get empirical formula for Natural Time period, a family of concrete gravity Dam is selected. The dams that are taken into consideration are of varies depth, base width and side slope. The detailed modal analysis procedure for dam is explained in Chapter 3. The height and base width of the selected dams are given in Table 4.4. After analyzing 10 dam, the modal mass ratio of all the dam of the different period is tabulated as shown in Table 4.5. Now the big question arises, how many modes are required to calculate the base shear? Table 4.5 will provide the answer of the above question. From Table 4.5, it can be concluded that the 1st and the 2nd mode of the dam are required for calculation of the Base Shear as it contribution is lies from 75%-95%. Other modes can be neglected as their contribution to the modal mass ratio is not very high. So, for the calculation of base shear first two natural time periods are going to be used.

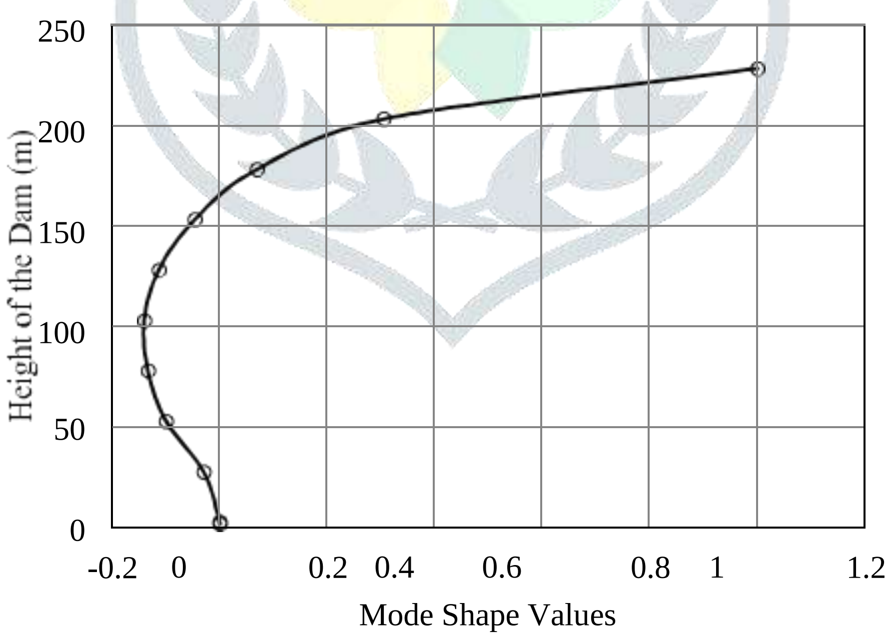
Table 4.4: Dimensions of Dams

Dam ID	Height (m)	Base Width (m) BW	Top Width (m) TW	Ratio=BW/TW
Dam 1	100	180	10	1.80
Dam 2	125	225	10	1.80
Dam 3	150	270	10	1.80
Dam 4	175	320	10	1.83
Dam 5	150	180	10	1.20
Dam 6	150	135	10	0.90

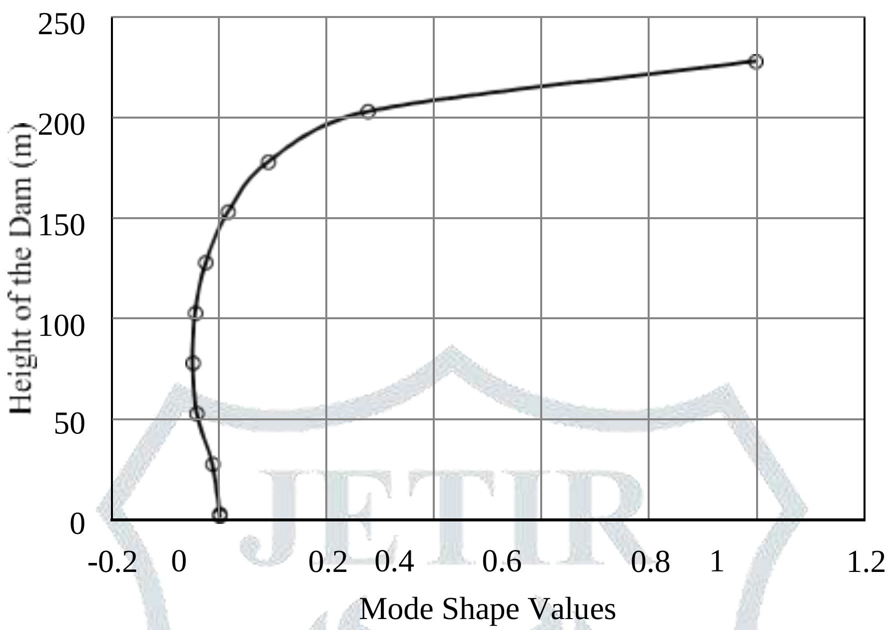
Dam 7	200	360	10	1.80
Dam 8	50	90	10	1.80
Dam 9	250	450	10	1.80



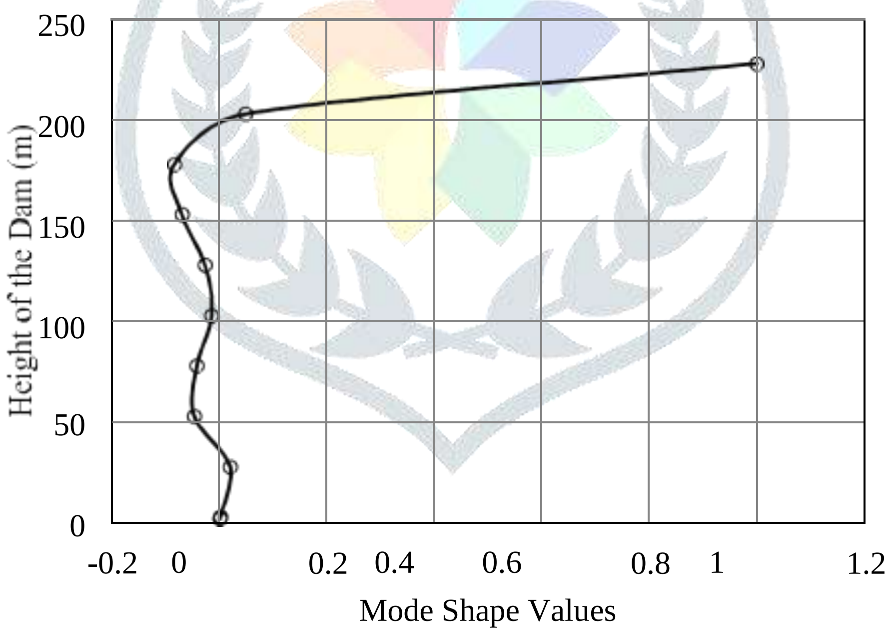
(a) 1 Mode Shape (UX=45%)



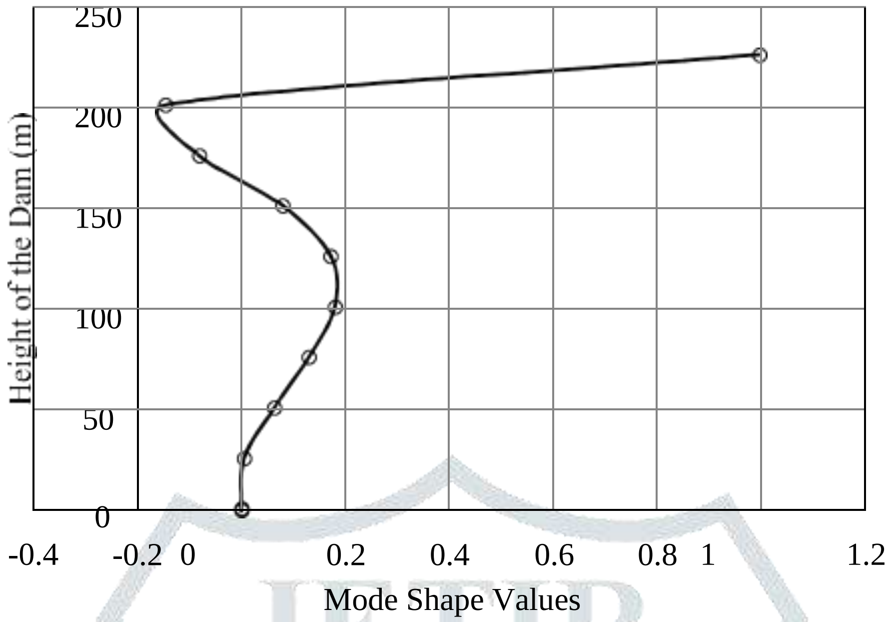
(b) 2 Mode Shape (UX = 31%)



(b) 3 Mode Shape (UX=3%)



(d) 4 Mode Shape (UX=13%)



(e) 5 Mode Shape (UX=7%)

Fig. 4.4: Different modes shapes of Bhakra Dam

Table 4.5: Range of Modal Mass Ratio

Mode Number	Range of Modal Mass Ratio
1	45-55
2	35-50
3	0-15
4	0-15
5	0-10

ESTIMATION OF NATURAL PERIOD

Relation between Dam Height and Time Period

Each time it is not possible to calculate the natural time periods through ANSYS analysis. In order to simplify the problem, a relation between natural time period, height and base width is formulated. The relationship between the height and natural time period of the selected dams having constant slope (*i.e.*, 1.80) is shown in Table 4.6. In order to derive the relationship between height and time period, a plot between the dam height and time period is drawn as shown in Fig. 4.5. It can be seen from Fig. 4.5 that time period of dam increases with increase in height for a constant ratio of bottom width to height. Hence, it can be concluded that fundamental time period of dam is functions of its overall height.

Table 4.6: Relation between the dam height and time period

Height (m)	1st Period (s)	2nd Period (s)	3rd Period (s)
100	0.18	0.11	0.09
125	0.22	0.12	0.11
150	0.26	0.16	0.13
175	0.30	0.17	0.15
200	0.34	0.19	0.17
226	0.38	0.21	0.19

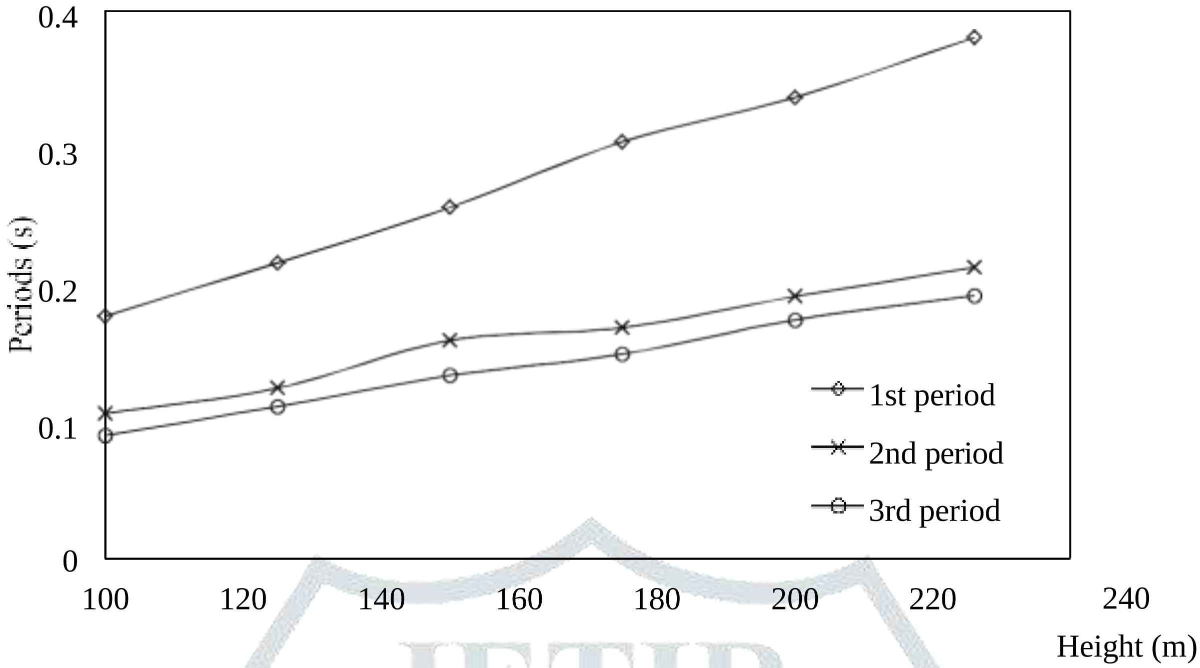


Fig 4.5: Plot between heights vs. period

Relation between the Base Width and Time Period

In the similar manner the relationship between the base width and natural time period is tabulated in Table 4.7. In order to have the relationship a plot between the base width and time period is drawn and presented in Fig. 4.6. It can be clearly seen from the Fig 4.6 that the 1st mode period of the dam decreases with increase in Base Width. The rate of decreasing is decreasing with increase in the base width. But in case of 2nd and 3rd mode period; the base width was found to have no influence. From this it can be conclude that the 1st mode period depends on Base Width but other higher mode periods are independent of base width.

Table 4.7: Relationship between Base Width and Time Period.

Base Width (m)	1st Period (s)	2nd Period (s)	3rd Period (s)
135	0.32	0.17	0.13
180	0.28	0.16	0.13
270	0.26	0.16	0.13

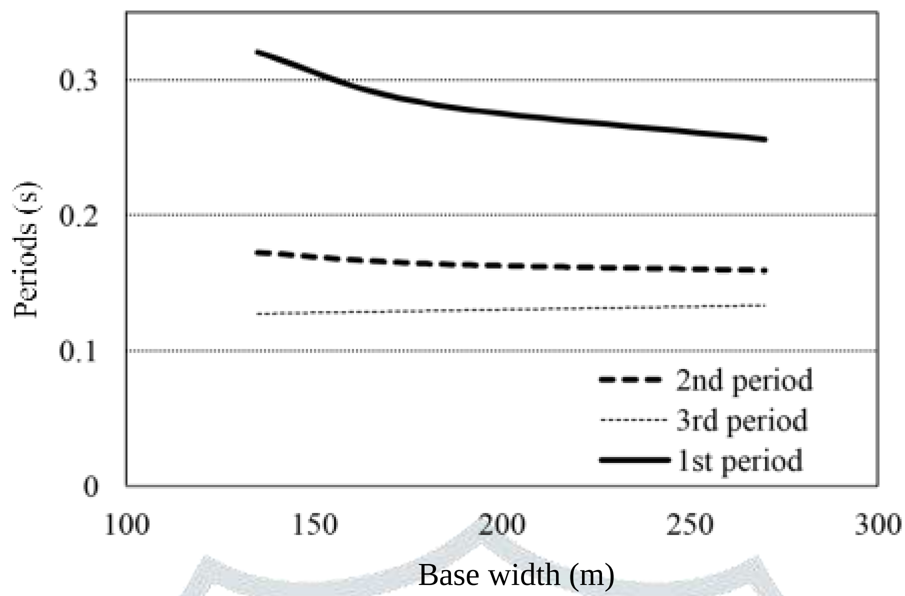


Fig 4.6: Plot between Base Widths vs. Periods

Formulation for Natural Time Period

A regression analysis is carried out on the data obtained from the selected dams. From Table 4.5, it can be seen that the first two periods are more important as its contribution to modal mass ratio is about 75%-95%. Because of that an empirical formula for the first two periods is formulated in this chapter. From Figs. 4.4-4.5, it can be clearly seen that the first natural time period depends on height and base width of the dam. But in case of second natural time period, it depends only on height of the dam. Thus, the formula to calculate the first and second time period of a given dam is given by the Eq. (4.1) and Eq. (4.2) respectively.

$$T1= 0.0028h^{1.3}b^{-0.35} \quad (4.1)$$

$$T_2 = 0.002h^{0.86} \quad (4.2)$$

Where T_1 is the first natural time period of the dam, T_2 is the second natural time period of the dam, h is the height of the dam and b is the base width of the dam.

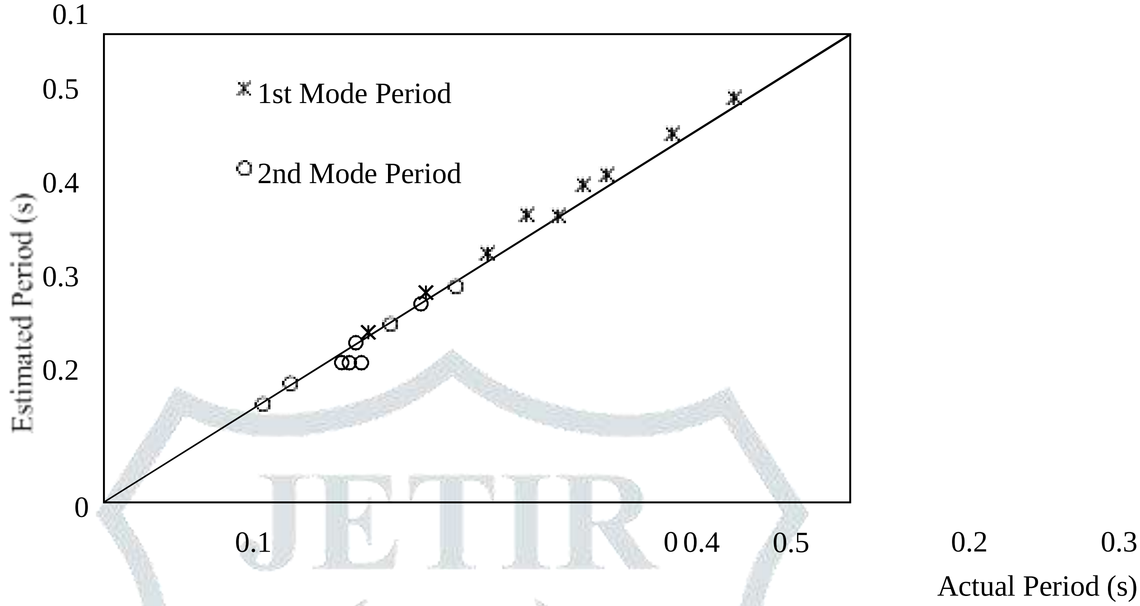


Fig 4.7: Plot between Actual periods vs. Predicted periods

In order to check the accuracy of the Eq. (4.1) and Eq. (4.2), a plot between the actual period and the estimated period is drawn. This plot can be seen in the Fig. 4.7. The actual period and the estimated period are almost lies near to each other when a 45^0 line is drawn in order to compare the deviation. This shows that the formula that has been derived in Eq. (4.1) and Eq. (4.2) give almost good result to real life problems.

CALCULATION OF BASE SHEAR

After having the empirical formula for natural time period, the next big thing is to "How to calculate the base shear?" According to IS 1893 Part-1, the Base Shear is calculated as given in Eq. (4.3).

$$V_B = A_h W \quad (4.3)$$

$$A_h = (Z/2)(I/R)(S_a/g) \quad (4.4)$$

Where V_B is the base shear of the dam, A_h is the horizontal seismic coefficient, W is the total weight of the dam, Z is the Zone Factor given in Table 2 of IS 1893 part 1, I is the Importance Factor given in Table 6 of IS 1893 part 1, R is the Response Reduction Factor and S_a/g is the spectral acceleration coefficient.

The above formula is also applicable for the dam as it is calculated for the single degree of freedom system. Now, the problem is how to calculate the horizontal seismic coefficient. The value of Z and I can be obtained from IS 1893 Part 1. The value of R can be taken as 4 because of the brittle nature of the dam. S_a/g value can be obtained from the Fig 4.8 corresponding to its period. In case of building first natural time period is dominating. So, corresponding to the first period S_a/g value is calculated from Fig. 4.8. But in case of dam both the first and second time period are important. Hence, how to calculate the S_a/g value for the dam is explained in the next section.

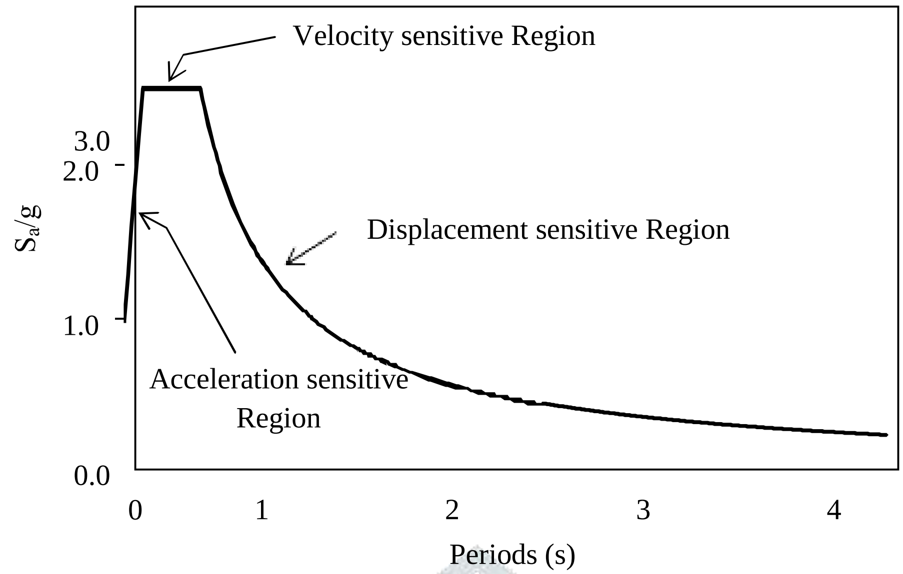


Fig. 4.8 Response Spectra for Rock and Hard Soil Sites for 5 Percent Damping

CONCLUSIONS

The conclusions presented here are limited to the salient contributions made in the present study:

i) A formulation for estimation fundamental period of concrete gravity dam is proposed based on dynamic analysis of a family of concrete gravity dam of varying dimensions.

ii) A procedure is developed to estimate the design base shear of concrete gravity dam that includes the higher mode effect.

iii) A new approach for spatial distribution of base shear along the height of the dam is proposed. This procedure is computationally attractive for the designers.

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