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Two dimensional Modal behaviour of an Arch dam

[1] Anjali Baby, [2] Glynez Joseph
[1][2] Assistant Professor
[1] baby.anjalibaby@gmail.com, [2] glynezj@gmail.com

***Abstract*-- Reservoir and foundation affect the dynamic characteristics especially modal frequencies and consequently the dynamic response of arch dams. A study is performed in this paper to view the effect of reservoir presence, foundation and fluid-dam interfaces modelling on modal behavior of arch dam using ANSYS. To represent water reservoir, two methods such as added masses approach and finite element method are adopted here.**

***Keywords*-- Ansys, Arch dam, Modal frequency, PLANE 182**

1. INTRODUCTION

Arch dams are one of the important structures for public safety because they retain a large quantity of water. When these arch dams fail there is loss of life and downfall of economy. Therefore arch dams are of strategic and economic importance for countries. The arch dam is generally double curvature in plan and elevation. They have two structural behaviors as cantilever and arch [1]. They transfer water forces to foundation and left-right abutments through cantilever behavior and arch behavior respectively.

The dynamic analysis of an arch dam is a complex problem. The response of a dam subjected to dynamic loading is a combined effect of the interaction among dam, foundation and reservoir systems. The dynamic behavior of a structure can be determined by modal behavior characteristics. Modal behavior of the structure consists of its vibration characteristics such as natural frequencies and mode shapes [5]. The foundation and water reservoir presence affect the structural vibration characteristics.

Many of the existing dams in Kerala are designed several years ago with minimal consideration of extreme earthquake loading conditions. The recent earthquakes points that, due importance should be given for earthquake loading while designing any structure. Hence the modal behavior of dams is to be evaluated critically.

2. ANALYSIS MODEL

A crown cantilever section of an arch dam is used for the present study [7]. Two methods are adopted to model the reservoir, using finite element and a surface element. In order to satisfy the continuity conditions between the fluid and dam at the boundaries, the nodes at the common line of the fluid element and plane elements are constrained to be coupled in the normal direction of the interfaces, while relative movements are allowed to occur in the tangential directions. This is implemented by merging of interface nodes

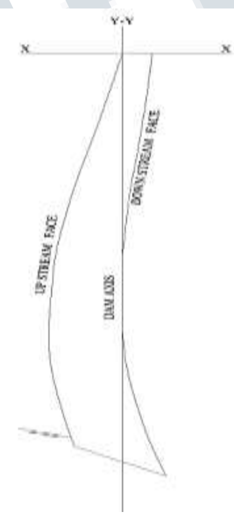

Fig 1. Crown cantilever section of arch dam

The non-overflow monolith of the dam body shown in figure 1 is modelled by using PLANE 183 element [3]. The crown cantilever section is 7 m width at the top, 19m width at the base and height as 169 m. The depth of the reservoir is taken as 135.63 m and the length is taken as 140m. First order acoustic element in ANSYS, FLUID29 is used to model reservoir [4]. The dam is assumed to be rest on a 350x140 m foundation. PLANE 182 is used for modelling the foundation. To stimulate unbounded nature of foundation infinite element boundary conditions are used at the end of the foundation block [8]. The use of infinite elements for the simulation of unbounded nature of the medium has been explained by Zienkiewicz et al. (1983) for static as well as dynamic conditions.SURF153 element is

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used to model reservoir in added masses approach [4].
Parameters of the structure considered are; elastic modulus Ed = 25000 MPa, mass density = 2356 kg/m^3 and Poisson's ratio = 0.2. Then parameters of the reservoir water are; mass density = 1000 kg/m^3, sonic velocity = 1440 m/s and admittance = 0.5. The foundation parameters are elastic modulus Ef = 62054 MPa, mass density = 3300 kg/m^3 and Poisson's ratio = 0.33 [8].Self weight of the structure and the water pressure are the loads considered here.
Two approaches are adopted to investigate the foundation – dam interaction; fixed support foundation and the mass foundation [2]. To investigate the modal behavior of the dam, six different case are taken as follow [6].

- Dam with fixed support, empty reservoir, named "Fixed empty".
- Dam with fixed support, reservoir height at operating water level (2280ft.) and fluid modelled by finite element and interface by merging of interface nodes, named "Fixed coupling".
- Dam with fixed support, reservoir height at operating water level and fluid modelled as added masses, named "Fixed surf".
- Dam with mass foundation, Empty reservoir, named "Mass-empty".
- Dam with mass foundation and reservoir height at operating water level, fluid modelled by finite element and interface by merging of interface nodes, named "Mass coupling".
- Dam with mass foundation, reservoir height at operating water level and fluid modelled as added masses, named "Mass surf".

3. EFFECT OF RESERVOIR AND INTERFACE MODELLING

Case of Fixed support foundation

The Modal analysis is carried out in the above explained models using ANSYS 11.0. The results of fixed empty, fixed coupling and Fixed surf models are given in Table1.

TABLE 1

Mode Number	Frequency (Hz)		
	Fixed empty	***Fixed coupling***	***Fixed surf***
1	2.753	2.3242	3.5536
2	6.0344	5.8856	6.1398
3	6.9298	6.6262	8.3219
4	12.442	8.5108	14.654
5	16.006	10.007	16.033

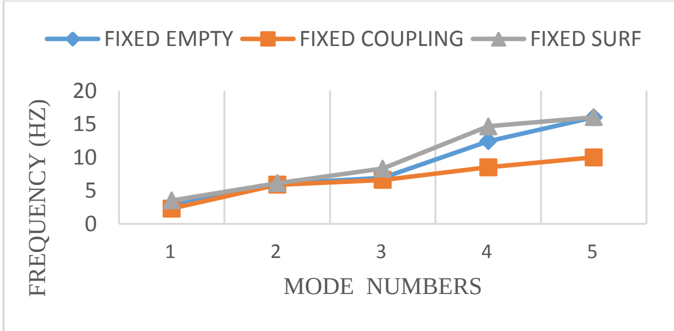

Fig. 1. Effect of reservoir and interface modelling on frequencies

Figure 1 represents for the case of fixed support foundation, the effect of reseroir presence and the interface modelling on modal frequencies of the dam section.

It is clear from the figure that the presence of water leads to decrease of the modal frequencies of the dam and the added mass approach overestimate the frequencies modes value by 43%.The total mass of the system increases by modelling of the reservoir which leads to a decrease of system frequencies.For the two reservoir modelling approaches the same quantity of water is added to the dam-foundation system, but the application manner is different. By fluid finite element , the water effect is transnitted to the dam as displacement. But while modelling the reservoir using surface element, the water effect is applied as uniform masses at the upstream dam face which increases the system stiffness. Due to this reason the frequencies obtained using surf elements are much greater than those obtained using fluid finite elements.

Case of Mass foundation

The modal analysis results of Mass empty, Mass coupling and Mass surf models are tabulated in Table 2.

TABLE 2

Mode Number	Frequency (Hz)		
	Mass empty	***Mass coupling***	***Mass surf***
1	2.6383	1.8539	3.3252
2	3.7564	3.2821	3.7648
3	4.0207	3.4378	4.0298
4	5.4729	3.7578	5.4095
5	5.9482	5.2450	6.0073

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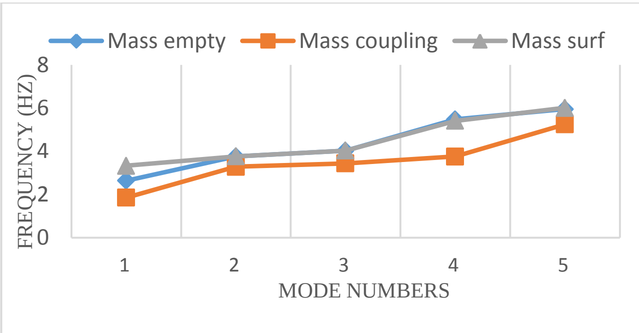

Fig.2. Frequency comparison – dam with foundation

The case of mass empty, mass coupling and mass surf are shown in figure 2.

It is clear that the presence of water leads to a decrease of the modal frequencies of the Dam and added masses approach overestimate the frequencies modes values by 79%. This is due to the fact that the stiffness added by the uniform masses applied at the upstream dam face is increased by taking into account the mass foundation.

4. EFFECT OF FOUNDATION INTERACTION ON DAM

Empty reservoir case

The comparison of frequencies obtained for fixed empty and mass empty cases from modal analysis is tabulated in Table 3.

TABLE 3

Mode Number	Frequency (Hz)	
	Fixed empty	***Mass empty***
1	2.7530	2.6383
2	6.0344	3.7564
3	6.9298	4.0207
4	12.442	5.4729
5	16.006	5.9482

Figure 3 represents the comparison of modal frequencies for Fixed-Empty and Mass-Empty case.

The figure shows that adding foundation to dam in the modelling which means taking into account the foundation structure interaction effect leads to a decrease in the modal frequencies values furthermore for the mass foundation model. Adding foundation to dam structure leads to a decrease in its stiffness and consequently a decrease in frequencies values furthermore when taking into account the mass of the added foundation, because this leads to an increase in the mass system and since this later is situated at the denominator in the frequency formula, the obtained value is smaller.

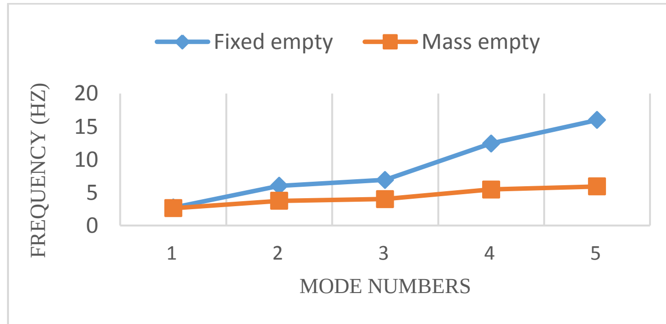

Fig.3. Foundation- structure interaction on dam with empty reservoir

Reservoir height at operating water level case (Reservoir modelled as finite element)

The comparison of frequencies obtained for fixed coupling and mass coupling cases from modal analysis is tabulated in Table 4.

TABLE 4

Mode Number	Frequency (Hz)	
	Fixed coupling	***Mass coupling***
1	2.3242	1.8539
2	5.8826	3.2821
3	6.6262	3.4348
4	8.5108	3.7578
5	10.007	5.2450

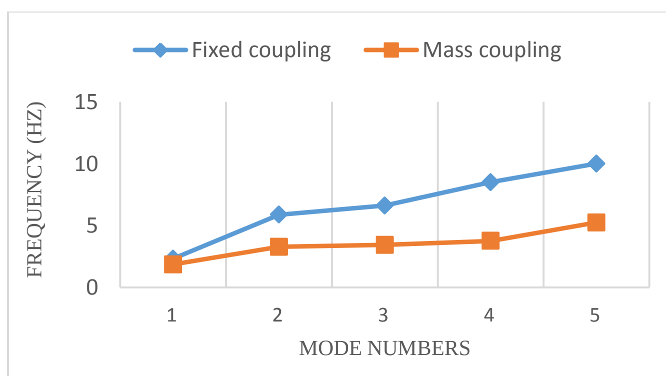

Fig.4. Foundation- structure interaction on dam with full reservoir

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Figure 4 represents the modal frequencies for Fixed-coupling and Mass-coupling cases which represent respectively the case of dam with fixed support and the case of dam with mass foundation where the reservoir is modelled by finite element and interface is modelled by merging of nodes.

Reservoir height at operating water level case(Reservoir modelled as added mass)

The comparison of frequencies obtained for fixed surf and mass surf cases from modal analysis is tabulated in Table 5.

TABLE 5

Mode Number	Frequency (Hz)	
	Fixed surf	***Mass surf***
1	3.5536	3.3252
2	6.1398	3.7648
3	8.3219	4.0298
4	14.654	5.4095
5	16.033	6.0073

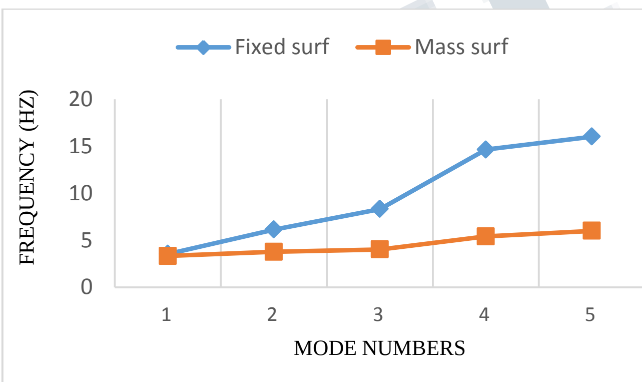

Fig.5. Foundation- structure interaction on dam with full reservoir(added mass)

Figure 5 represents the modal frequencies for fixed surf and Mass surf cases. From Figure 3, Figure 4 and Figure 5, it is clear that foundation structure interaction effect leads to a decrease in the modal frequencies even if the reservoir water is modelled (either by fluid finite element or added masses) or not (Empty case).

5. EFFECT OF RESRVOIR LEVEL

The comparison of frequencies obtained for different reservoir water levels from modal analysis is tabulated in Table 6.

TABLE 6

Mode Number	Frequency (Hz)		
	Hw/Hd = 0	***Hw/Hd = 0.4***	***Hw/Hd = 0.8***
1	2.6383	2.3286	1.8539
2	3.7564	3.4568	3.2821
3	4.0207	4.0060	3.4378
4	5.4729	5.3464	3.7578
5	5.9482	5.5854	5.2450

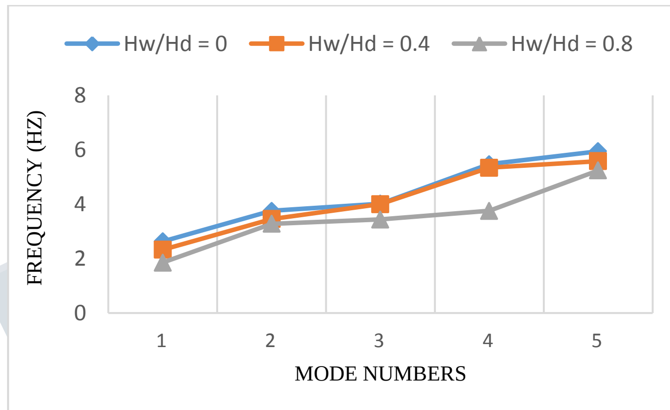

Fig.6. Reservoir water level effect on dam-foundation-reservoir system

"Hw" denotes the water level height, and the "Hd" denote the concrete dam height. Figure show that modal frequencies are inversely proportional with the reservoir water level; which means that frequencies decrease when water level increase and the amount of period grows with arising reservoir water level which is because of increasing total mass of the system.

6. CONCLUSIONS

A study is performed in the present work to investigate the effect of water reservoir presence, foundation and fluid-dam / fluid-foundation interfaces modelling on the two dimensional modal behaviour of a crown cantilever section of an arch dam.

The study shows that foundation modelling, water reservoir presence and the reservoir water level have the same effect on the modal frequencies results which means the modal behaviour of an arch dam. Surface elements available in ANSYS library are a good tool to represent the fluid using the added masses approach. From modal analysis it is observed that;

- Presence of foundation decreases the frequency values due to the increase in mass of the system.
- The water in the reservoir leads to change in the dynamic characteristics of the system such as it increases the time period of vibration of system and it modify the mode shapes.
- The frequency value of a dam-foundation-reservoir system decreases with increase in water level.
- The first mode frequency of a dam – reservoir system with fixed boundary conditions decreases by 15% of the frequency of empty dam with the same boundary conditions.
- While comparing the empty reservoir with a mass foundation and presence of reservoir with mass foundation, it can be concluded that the first mode frequency of the first case decreases by a value of 29 % than a dam case with presence of reservoir and mass foundation.
- There is a difference in the percentage of frequency decrease from 29 % to 15 % in the above mentioned cases. It is due to the change in mass of the system with the presence of mass foundation.
- Surface elements available in ANSYS library are a good tool to represent the fluid using the added masses approach. Added masses approach for fluid modelling overestimate the frequency value as compared to fluid finite element modelling.
- The above mentioned approach overestimate the frequency value by 43 % in the case of dam with fixed support and 79% for the case of dam with mass foundation. This increase is due to the increase in the stiffness of the system.

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