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3 Dimensional Analysis of Linear Vibrations of the Rubber Dam

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Abstract: In this study, dynamic characteristics of a rubber dam, such as vibration frequencies and the corresponding mode shapes are computed by using finite element software produced by ANSYS, Inc. A three-dimensional model is utilized to compute the vibration modes and the frequencies of a double-anchor rubber dam both in presence and the absence of external water and the results are compared with other results which have been obtained previously. Natural frequencies of the vibrations of a single-anchor rubber dams in the cases without external pressure, with external water pressure and with parallel flow pressure are considered. A computer simulated model of these structures is analyzed and then the effect of the internal pressure, external water head and parallel flow velocity on the vibrations of the rubber dam is studied the results are compared with the case that the dam is not impounding water and finally after comparing these results with the previous analytical and numerical results, the reasons of some little differences have been expressed.

Key words: Rubber dam, vibration, frequency, mode shape, external parallel flow, computer model

INTRODUCTION

Rubber dams are cylindrical membrane structures which are attached to a rigid foundation along two of their generators and are inflated with water, air, or a combination of water and air (Zhang *et al*., 2002). They are basically simple and portable barriers made of rubberized material and are used for various purposes such as irrigation, control flood, tidal defense, water supply and recreational purposes (Watson *et al*., 1999). This type of structure is considered as more economical compared with the rigid type of control structures constructed from concrete, masonry and steel (Tam, 1998). Some studies of their cross-sectional static profiles have been carried out in the past, both for cases when the dam impounds water and when overflow occurs (Hsieh and Plaut, 1990; Wu and Plaut, 1996). After obtaining the equilibrium configurations, Small vibrations have been observed on actual dams and on the physical models about this configuration (Plaut and Leeuwrik, 1988; Mysore *et al*., 1998; Ergin and Temared, 2002; Plaut and Cotton, 2005). To analyze the static and dynamic behaviors of such structure, using the numerical methods such as finite element method and handling the computer analysis procedures based on these methods is enough suitable (Tou and Wong, 1987; Mackerle, 2000). ANSYS uses Newton-Raphson's method as a numerical technique for solving the nonlinear equilibrium equations. The basic idea is to reduce the set of nonlinear equations into a set of linear equations to solve equilibrium equations at small increments, the size of which depends on nonlinearity of the problem (Bathe, 1996). In present study, the finite element package ANSYS is used to perform dynamic analysis of the linear vibration of these dams when impounding hydrostatic and parallel flowing water and without external water.

From viewpoint of anchored system, rubber dams are categorized to single-anchor rubber dams and double-anchor rubber dams (Dakshina Moorthy *et al*., 1995). Although most recently-built rubber dams utilize the single-anchor system which have fin at two attached ends of rubber sheets to facilitate smooth overflow (Chanson, 1997), but for the dams with high height due to more stability of double-anchor rubber dams against different loads, in this study in addition to studying the effect of various parameters in dynamic nonlinear behaviors of a single-anchor dam in various conditions the results which are obtained from analyzing a computer model of double-anchor dam are presented and compared with the research of Dakshina Moorthy *et al.* (1995) and the reasons of the percentage changes of the results in two compared research have been mentioned but because of the little difference between results due to increasing accuracy of modeling of the problem, it is concluded that ANSYS Software can be used to analyze the dynamic behavior of the structures such as inflatable flexible rubber dams.

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VIBRATIONS OF THE DOUBLE- ANCHOR RUBBER DAM

In this study, to study the linear vibrations, the rubber dam is modeled as an elastic shell inflated with air. The internal pressure is increased slowly until it reaches the desired value. The natural frequencies of the model of the double-anchor rubber dam have been computed by using ANSYS software. The assumed model of the rubber dam includes one rubber sheet attached to concrete slab along two edges of sheet longitudinally. The dimensions of the structure and the rubber properties of the rubber dam are selected as the modeled rubber dam in the research of Dakshina Moorthy *et al.* (1995), but the size and the type of meshing of the model is different. Figure 1 shows the model information of the inflatable rubber dam. So, in this 3D model, the rubber sheet is meshed to smaller elements by shell element, SHELL63, 4 nodes element of ANSYS is selected to apply the analysis. Each nodes of element includes 6 degrees freedom that indicates 24 degrees freedom for each element. The applied element is enlarged in Fig. 2.

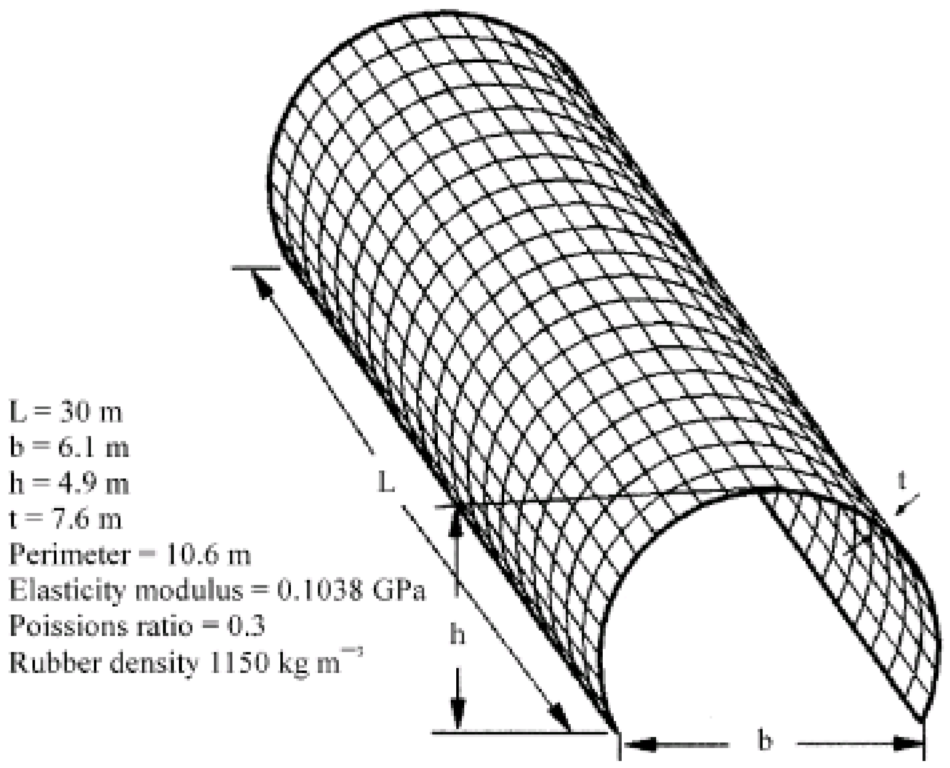

Fig. 1: Dimensions and properties of rubber in the model of the double-anchor rubber dam

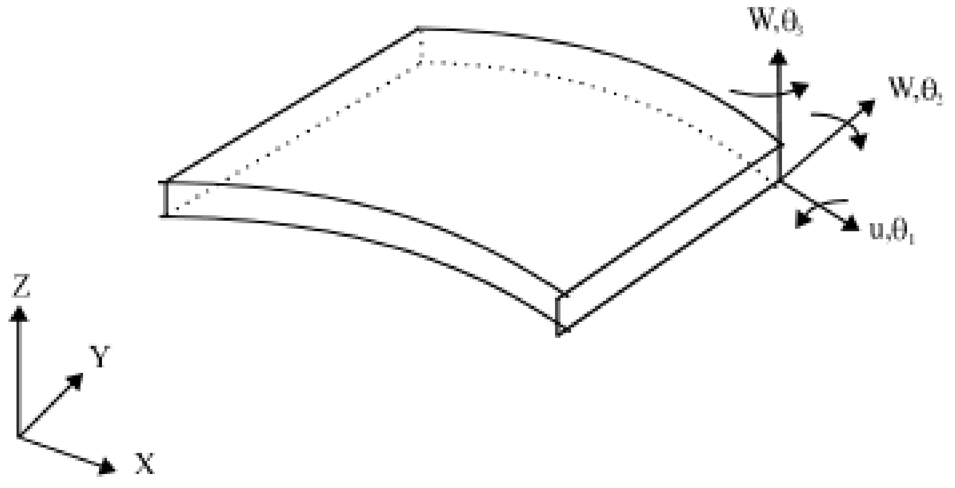

Fig. 2: Element of shell63 in ANSYS

RESULTS OF THE VIBRATION ANALYSIS OF THE DOUBLE-ANCHOR RUBBER DAM

By comparing the results of both models, it is concluded that the obtained vibration frequencies of the structure with presence and absence of external water are in close agreement with those obtained by Dakshina Moorthy *et al.* (1995). The Maximum difference in the first five frequencies is 9.4% without considering external water and 10.2% with the presence of the external water. The difference in frequencies can be attributed to the size of the considered mesh (960 elements in present study and 200 in previous Research) and the type of the selected element in present case and 9-node element in Dakshina Moorthy *et al.* (1995). The frequencies were found to be reduced in presence of external water as were found by Dakshina Moorthy. Figure 3 is clustered column that compare the values of the natural frequencies of a double-anchor rubber dam across five modes.

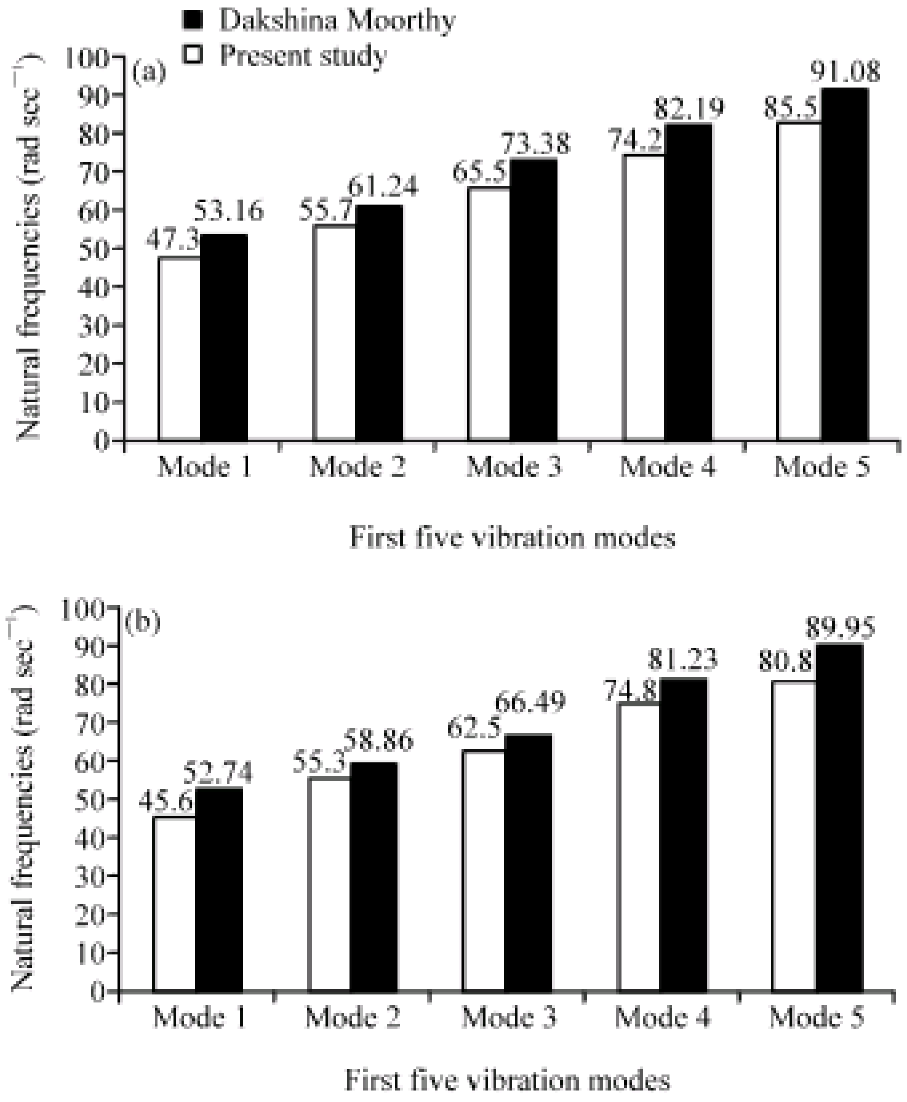

Fig. 3: Natural frequencies of a double-anchor rubber dam when (a) the dam is not impounding water (b) when the dam is impounding water on one side in first five vibration modes via Dakshina Moorthy *et al.* (1995) research and present study

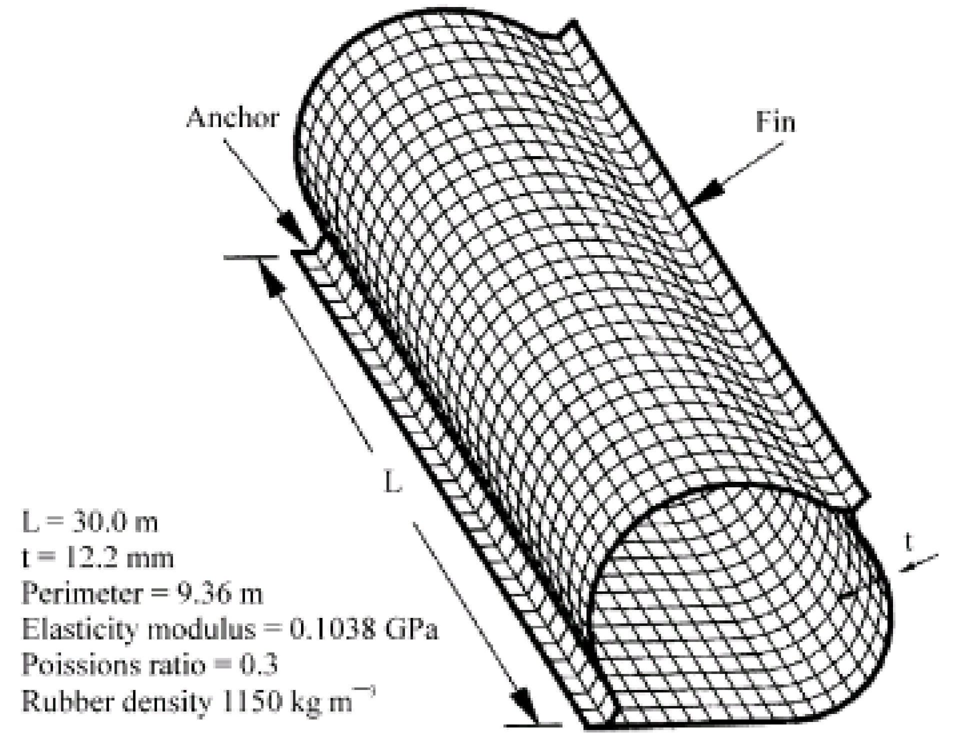

Fig. 4: The model information of a single-anchor rubber dam

VIBRATIONS OF THE SINGLE-ANCHOR RUBBER DAM

The rubber dam with the single-anchor system is modeled as two sheets of rubber, on lying on the top of the other and attaches together at the ends, from one side is anchored to a rigid slab and from the other side makes fins for preventing from severe impact of overflow to backside of the dam. The model of the structure is meshed to 1500 elements of SHELL63 which is introduced earlier. Figure 4 shows the information of the assumed model of the single-anchor rubber dam.

The single-anchor rubber dam is modeled to be analyzed. After running the program, the results of the linear vibration of the membrane of the structure is obtained to prevent from probable damages to the structural system of the rubber dam due to these vibrations. To achieve this purpose, the natural frequencies of the vibration and the mode shapes are established in three various cases without external water, in presence of external water and with parallel flowing of water.

RESULTS OF THE VIBRATION ANALYSIS OF THE SINGLE-ANCHOR RUBBER DAM

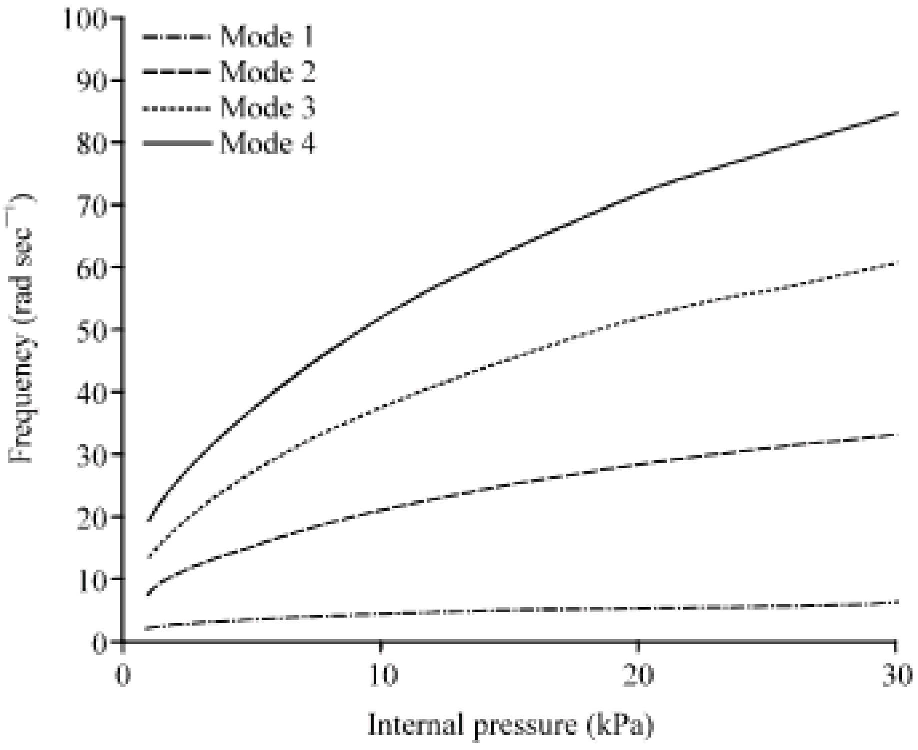

Fig. 5: Variation of vibration frequencies against internal pressure from 0 to 30 kPa, without water

Table 1: Natural frequencies (rad sec^{-1}) of the rubber dam in $P_{int} = 1$ kPa and $P_{int} = 30$ kPa for three cases without water, with hydrostatic water and with water

	$P_{int} = 1$ kPa			$P_{int} = 30$ kPa		
Mode No.	Without water	With hydrostatic water	With water	Without water	With hydrostatic water	With water
1	2.164	2.508	2.103	6.305	7.146	5.939
2	7.769	8.779	7.401	33.310	38.570	30.860
3	13.480	14.700	12.410	60.660	67.260	53.810
4	19.130	20.900	17.420	84.900	92.640	74.100

Without external water: For the vibration analysis, the rubber dam that is not impounding water is clamped at the ends while the equilibrium shape is obtained, then small three-dimensional vibrations are considered about the equilibrium configuration. The first four vibration frequencies and mode shapes are computed. Figure 5 shows the variation of the frequencies against internal pressure for the first four vibration modes and Table 1 shows the corresponding frequencies for $P_{int} = 1$ kPa and $P_{int} = 30$ kPa.

As shown in Fig. 5, the slopes of the curves of the first four vibration modes decrease as the internal pressure increases. Also the slope of the curve in mode 4 is more than the slope of mode 3. So, this relation exists for mode 3 than mode 2 and mode 2 than mode 1. The vibration frequencies increase with the internal pressure as one would expect. The squares of the frequencies vary almost linearly with the internal pressure. Figure 6 and 7 image the first four vibration mode shapes for internal pressures of 1 and 30 kPa, respectively. The first and second modes are symmetric and the third and fourth modes are non-symmetric longitudinally. Also the corresponding profiles of the central cross section for these modes (solid curves) and the cross sections at the distance of one-quarter length from each end (dashed curves) are shown in Fig. 6 and 7 for internal pressures of 1 and 30 kPa, respectively. For the modes that are symmetric longitudinally, the two dashed curves are identical.

With external water: For the case of the dam impounding water on one side, the dam is anchored along the

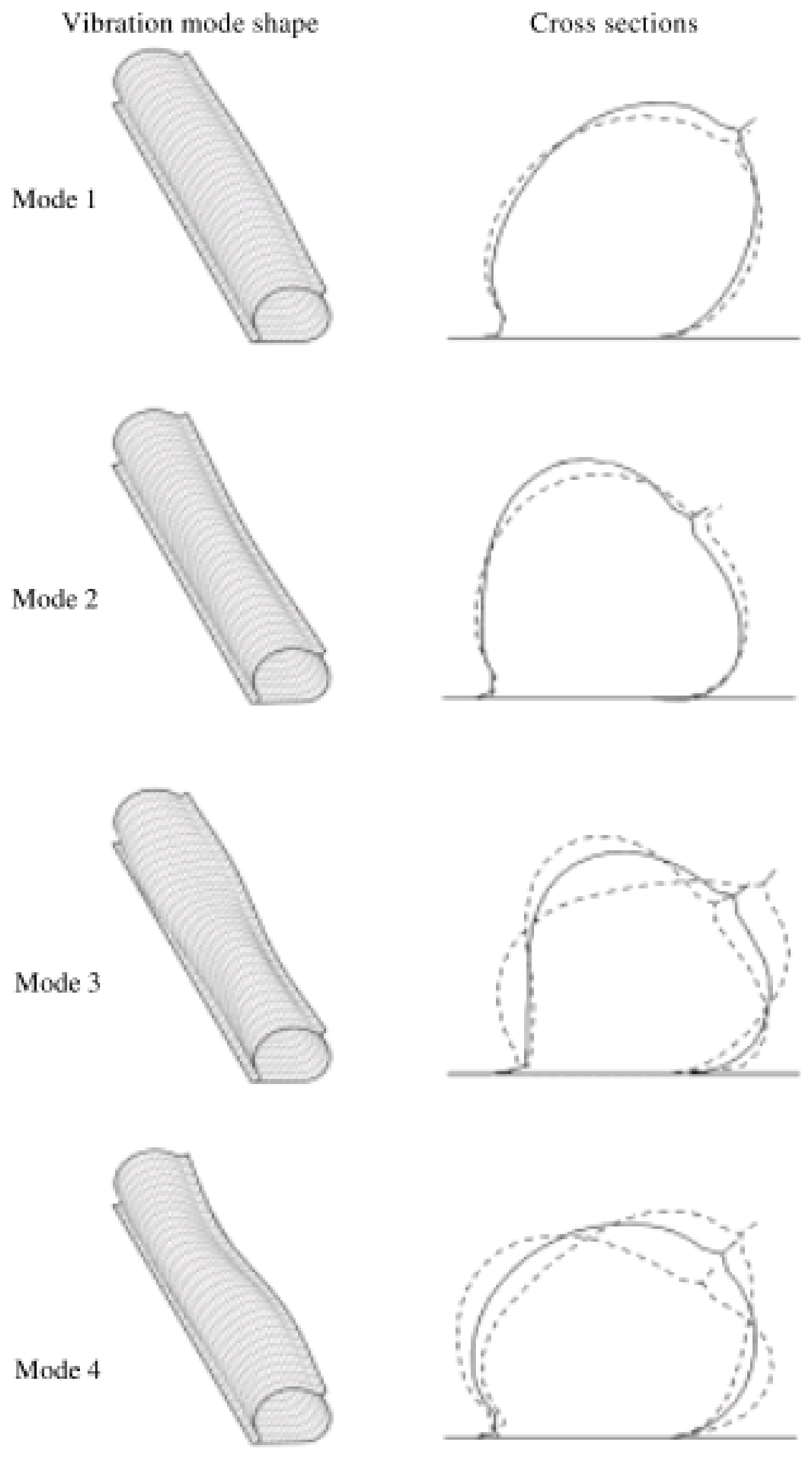

Fig. 6: First four vibration modes shapes and Cross sections of modes at the center (solid curve) and at the quarter-lengths from the ends (dashed curve) in case of without external water, for P_{int}= 1 kPa

equilibrium cross sections at its two ends and then water is applied on the anchored side with a height less than the dry equilibrium height. The new equilibrium configuration is obtained and small vibrations of the dam about this equilibrium shape are analyzed. Figure 8 represents the vibration of the first four frequencies with the external water head, for internal pressure of 30 kPa.

In Fig. 8, the frequencies at first tend to decrease and then increase slightly as the external water head increases. At the first of the curves, the value of decrease in Mode 4 is more than the other vibration modes. The frequencies for the higher modes (modes 3 and 4) show more variation compared to those for the lower modes (modes 1 and 2). The frequencies are high enough to justify the infinite frequency limit assumption used to

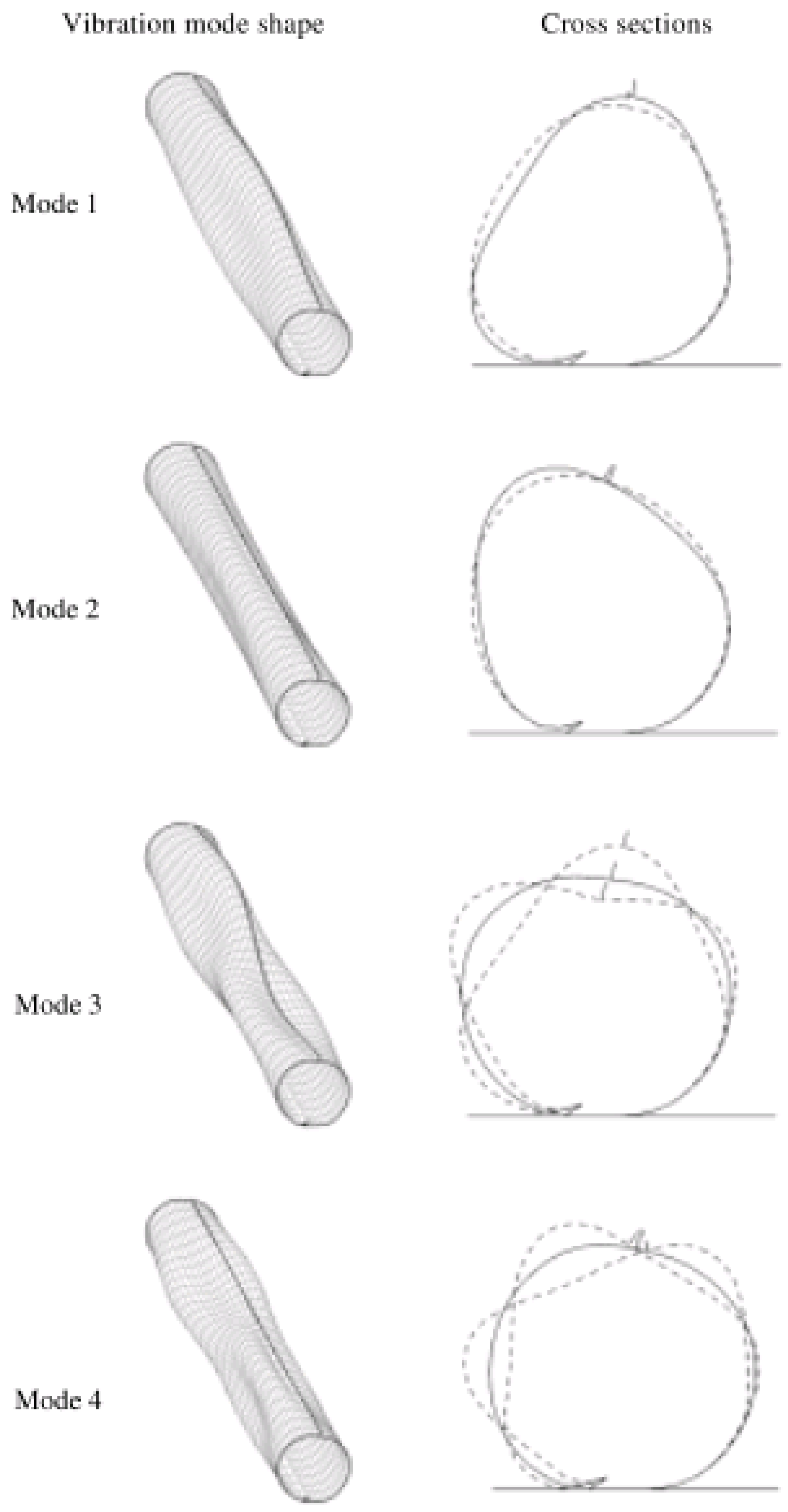

Fig. 7: First four vibration modes shapes and Cross sections of modes at the center (solid curve) and at the quarter-lengths from the ends (dashed curve) in case of without external water, for P_{int}= 30 kPa

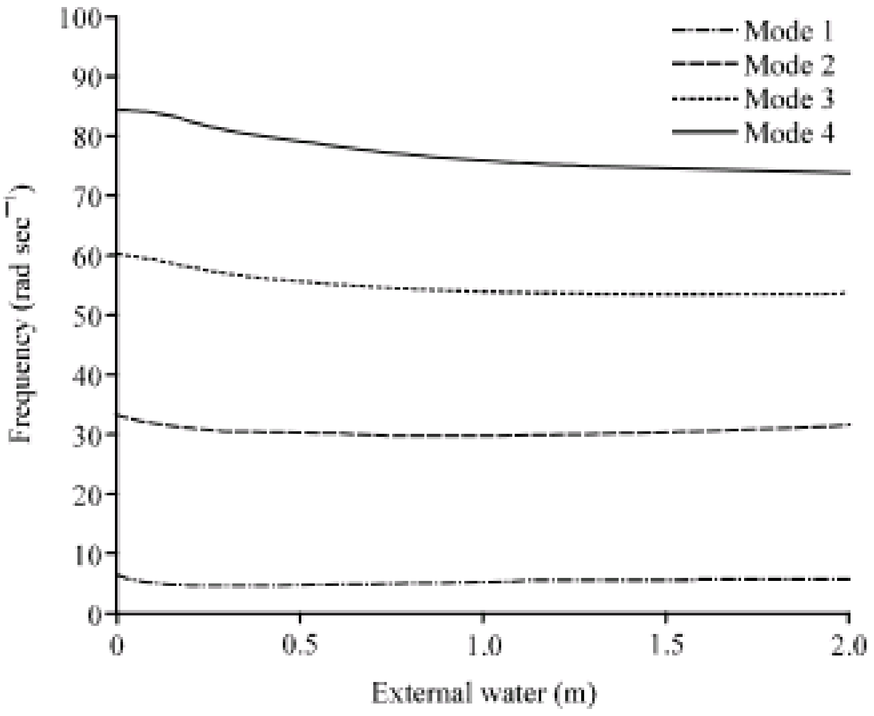

Fig. 8: Variation of vibration frequencies with external water (P_{int} = 30 kPa)

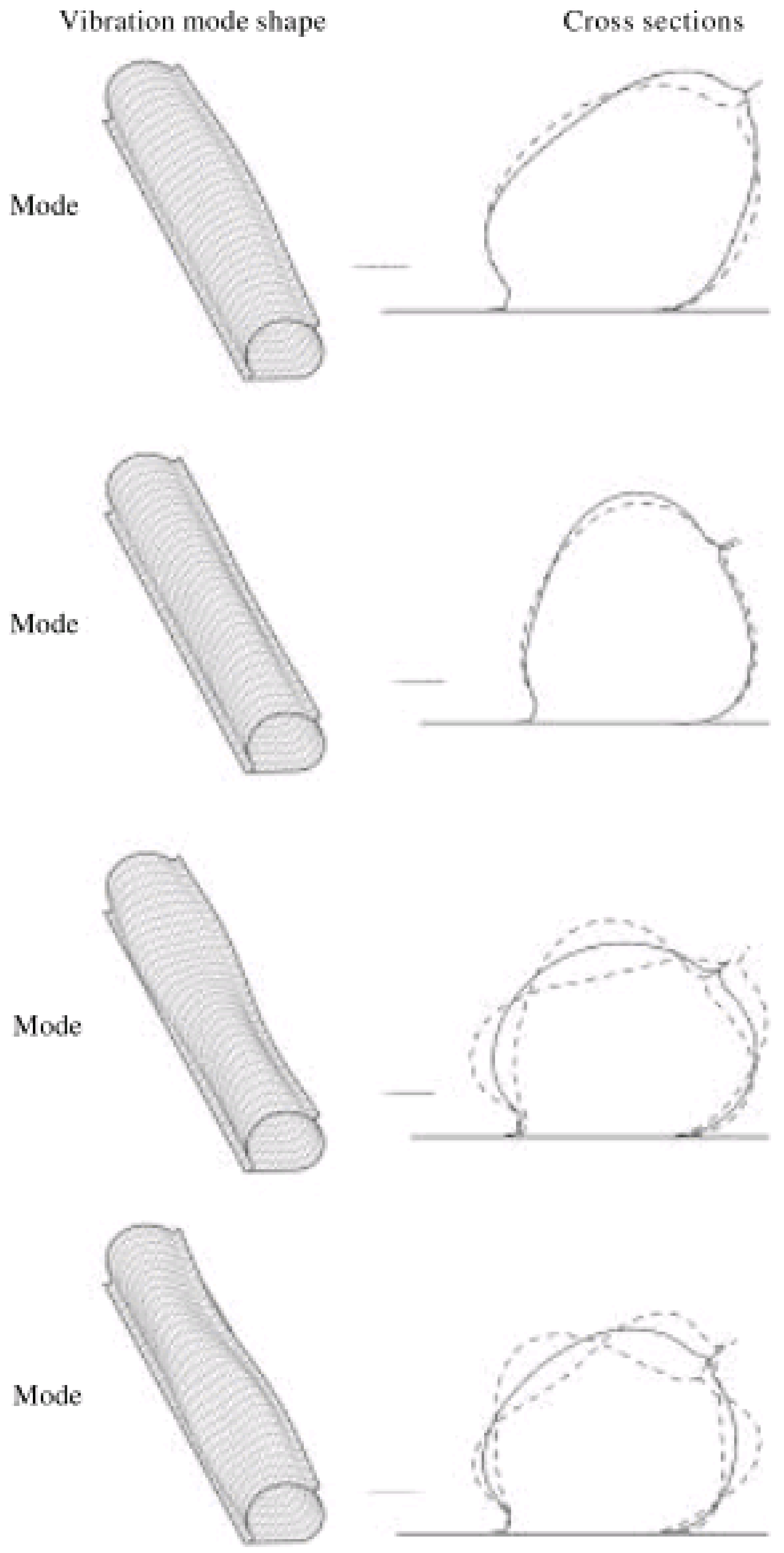

Fig. 9: First four vibration modes shapes and cross sections of modes at the center (solid curve) and at the quarter-lengths from the ends (dashed curve) in case of the presence of external water, for P_{int}= 1 kPa

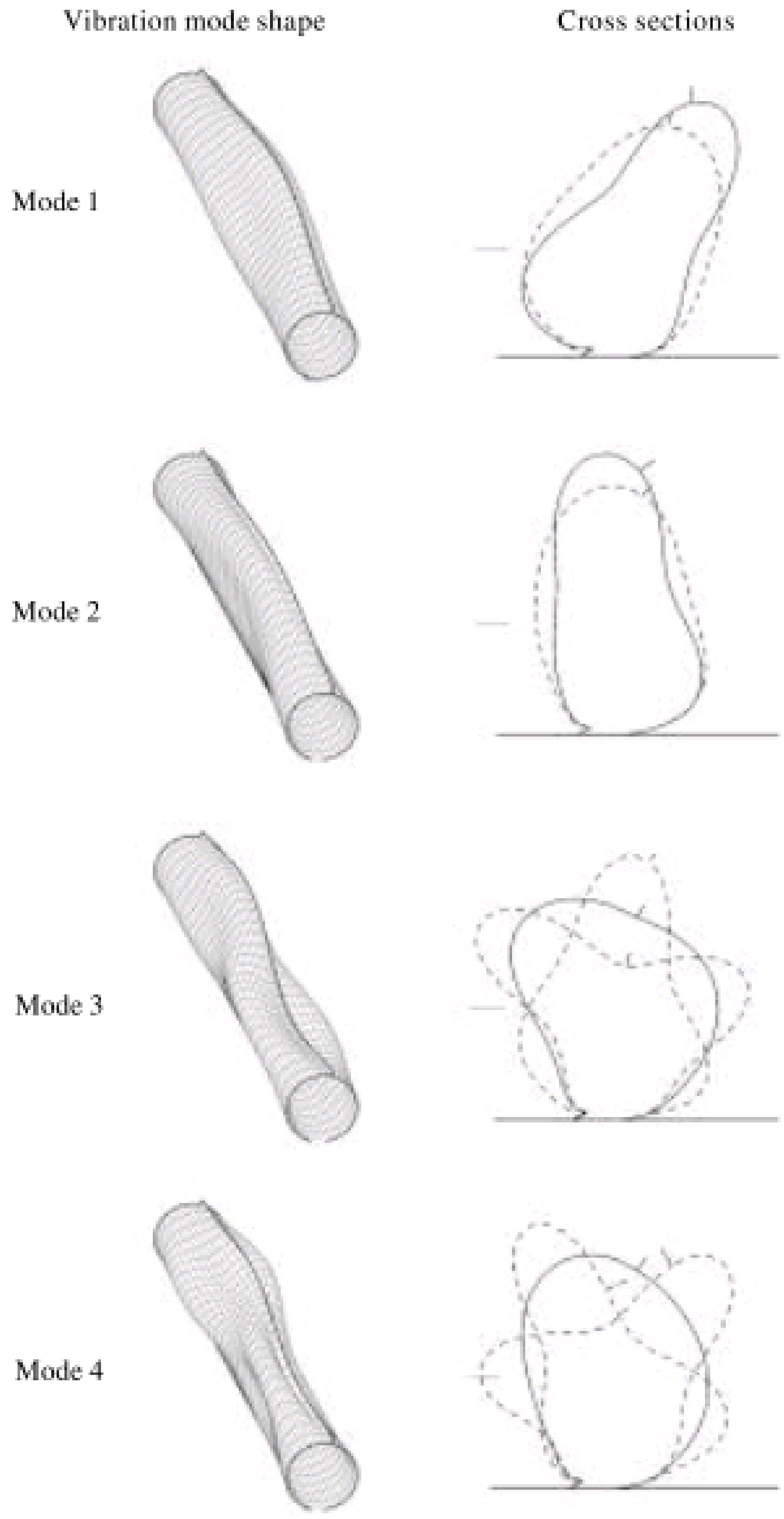

Fig. 10: First four vibration modes shapes and cross sections of modes at the center (solid curve) and at the quarter-lengths from the ends (dashed curve) in case of the presence of external water, for P_{int} = 30 kPa

define the boundary condition on the free surface. Table 1 compares the vibration frequencies of the dam with no external water to those for the dam in presence of external hydrostatic pressure (with no added mass effect), for P_{int} =1 kPa and P_{int} = 30 kPa. The external head is 0.5 and 1.5 m, respectively. Also the frequencies of the structure in the presence of water are lower than those in absence of water by a maximum of 12.7% and the frequencies of the structure absence of water are lower than those in presence of external hydrostatic pressure by a maximum of 8.4% in Table 1. The first and second modes are symmetric and the third and fourth modes are non-symmetric longitudinally. The corresponding first four modes are shown in Fig. 9 and 10. Also these figures show the cross sectional behavior of the modes at the half-length (solid curves) and quarter-length (dashed curves) from each end of the dam for internal pressures of 1 and 30 kPa, respectively. So the horizontal line at the left of the dam indicates the water height. For the first two modes, the two dashed curves are identical. The cross sectional behavior of the structure in the presence of external water, at half-length and quarter-length from the ends, is similar to that of the dam in absence of water for both the internal pressures.

With parallel flow: The case of the rubber dam impounding water flowing parallel to the dam is considered. This situation may occur for the dam installed along a river. In this case, the inflatable rubber dam is restrained along the equilibrium cross sections at its ends

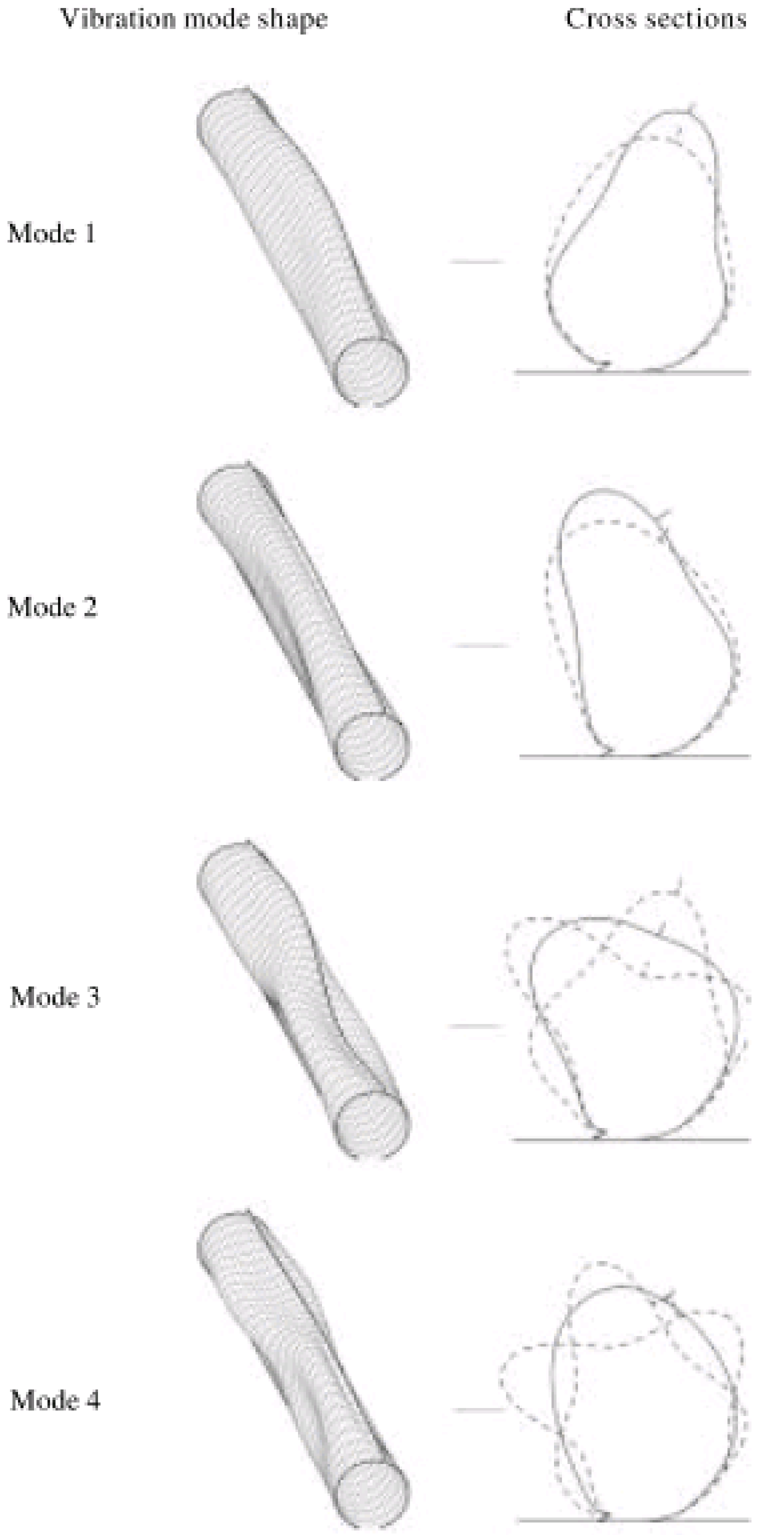

Fig. 11: First four vibration modes shapes and cross sections of modes at the center (solid curve) and at the quarter-lengths from the ends (dashed curve) in case of the presence of parallel flow of 1 m sec^{-1}, for P_{int} = 30 kPa

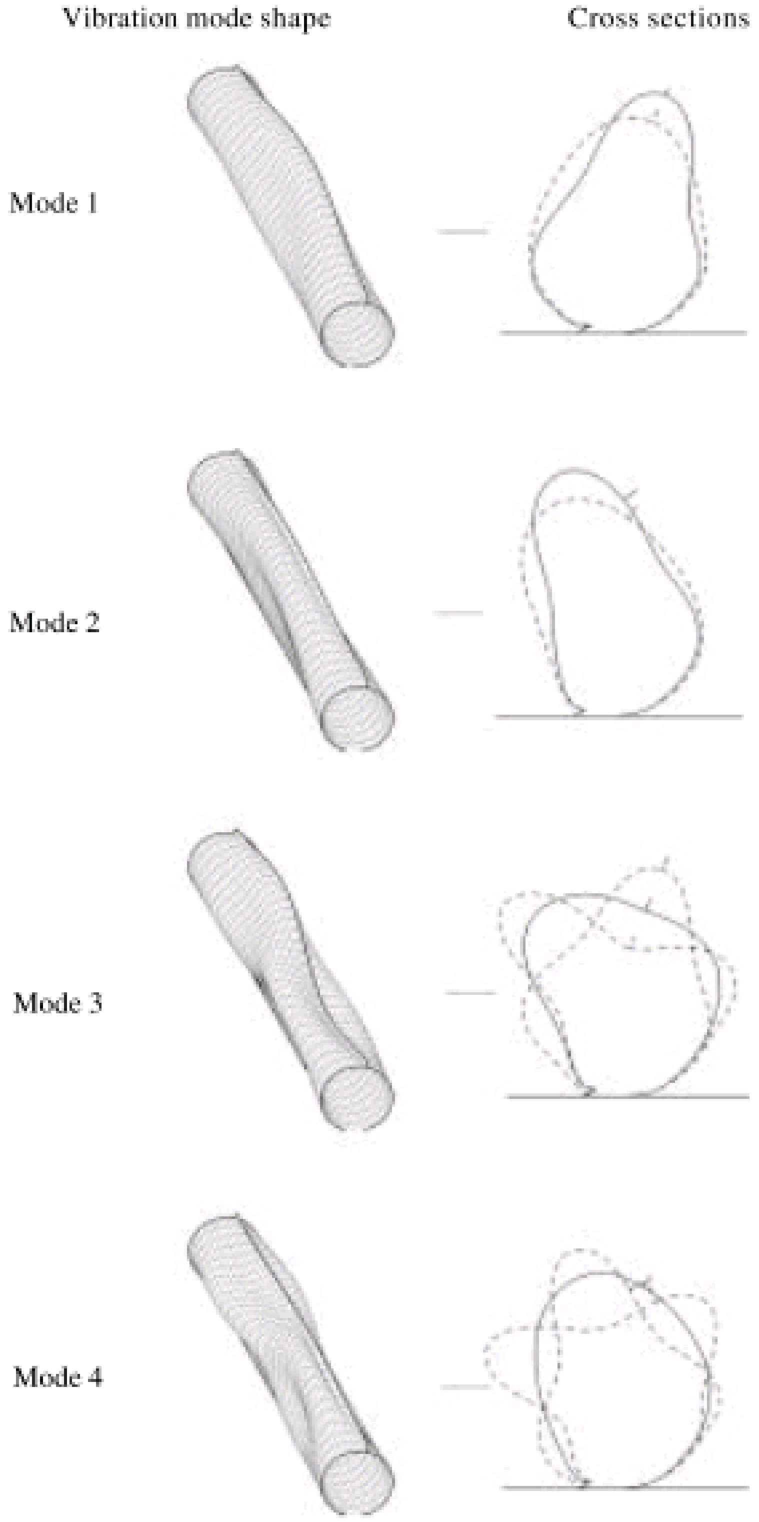

Fig. 12: First four vibration modes shapes and Cross sections of modes at the center (solid curve) and at the quarter-lengths from the ends (dashed curve) in case of the presence of parallel flow of 5 m sec^{-1}, for P_{int} = 30 kPa

Table 2: Natural frequencies (rad sec^{-1}) of the rubber dam with parallel flow, for P_{int}= 1 kPa

Mode No.	Without water	With water	U = 1.0 (m sec^{-1})	U = 5.0 (m sec^{-1})
1	2.164	2.103	2.009	1.993
2	7.769	7.401	7.104	6.954
3	13.480	12.410	11.980	11.540
4	19.130	17.420	16.460	16.020

and then parallel flowing water is applied on the anchored side with the same height as that in the case of hydrostatic water. Small vibrations of the structure about this equilibrium shape are analyzed. The flow introduces hydrodynamic pressure and thus the boundary conditions on the structure change due to the fluid-structure interaction. As the earlier cases, the vibration analysis was performed for internal pressures of 1 and 30 kPa. Flow velocities of 1 and 5 m sec^{-1} were considered.

As seen in Table 2 and 3, the natural frequencies of rubber dam when the dam is impounding water flowing parallel to the dam is lower than that in the presence of water without parallel flow for internal pressure of 30 KPa by maximum of 8% when velocity flow equals to 1 m sec^{-1} and 5.1% when velocity flow equals to 5 m sec^{-1}.

Figure 11 and 12 show the effect of the parallel flow on the vibration behavior of the rubber dam. The direction of the flow is from nearer end to the farther end along the length of the dam in these figures. Also in this case the first and second modes are symmetric and the third and fourth modes are non-symmetric longitudinally as other

Table 3: Natural frequencies (rad sec^{-1}) of the rubber dam with parallel flow, for $P_{int} = 30$ kPa

Mode No.	Without water	With water	U = 1.0 (m sec^{-1})	U = 5.0 (m sec^{-1})
1	6.305	5.939	6.237	6182.00
2	33.310	30.860	29.970	29.55
3	60.660	53.810	52.600	51.97
4	84.900	74.100	72.810	70.30

cases. The cross sectional behavior of the three model of the rubber dam in the presence of external parallel flow, at half-length and quarter-length from the ends is similar to that of the dam in the absence of water.

CONCLUSIONS

In the present study, the dynamic behaviors of linear vibrations of the single-anchor and the double-anchor air rubber dams have been studied by applying engineering ANSYS software. The double-anchor rubber dams have been modeled and analyzed by ANSYS and then the results obtained from this dynamic analysis are compared with the results given by Dakshina Moorthy *et al.* (1995). By this comparison it is found that the outputs of ANSYS model are in agreement with previous researches which have used other softwares but the results of this research is more accurate due to type of meshing and type and size of selected elements. So ANSYS is too capable to perform the dynamic analysis of vibrations of the rubber dam behaviors. The natural frequencies and the corresponding mode shapes of the single-anchor dam for three cases of the dam without external water, with external water and with parallel flow have been computed and then compared. The vibration analysis of the structure makes use of equilibrium configurations which obtained after performing the static analysis. The effects of external water head and internal pressure are studied. When external hydrostatic pressure (with no added mass effect) is applied to the body of dam, the frequency of vibration of single-anchor rubber dam is more than the other cases and in the case of the presence of water impounded by rubber dam, the frequency is less than the others. Also by increasing internal pressure while the ultimate pressure (30 kPa) is achieved, the value of natural frequencies increase too much in mode 1 and this progressive increase in mode 3 and 4 is more than the other modes. Meanwhile by increasing the velocity of parallel water, the variation frequency slightly decreases. So in case of stationary water backside of the dam this amount of decrease is more than the other ones. In first four modes the amount and the form of deformations of cross-section is different together, but in different cross-section, these variations of the mode shapes in mode 3 and 4 is observed more than mode 1 and 2. The presence of the external hydrostatic water tends to reduce the natural vibration frequencies of the rubber dam. The variations of frequency depend on the internal pressure and the external water head. The relation between the frequency and internal pressure for the case of without external pressure is nonlinear and straight and the charts of function of frequency-internal pressure for the first four modes are ascendant with reducer slope. Also in the case of the presence of external water the charts of function of frequency-external water for internal pressure of 30 kPa are descent with reducer slopes and gradually tend to be steady. The effect of external water on the frequency essentially is observed in the low pressure. Finally the case of the rubber dam impounding water flowing parallel to the dam has been considered. The hydrodynamic pressure due to the external parallel flow results in added inertia (i.e., added mass) which reduces the vibration frequencies of the structure. This reduction depends on the internal pressure, the external water head and flow velocity. Overall, it can be concluded that a computer finite element model can be applied to study the dynamic vibration of behavior of a hydraulic structure such as rubber dam which is resulted due to different loads applied to the dam.

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