Dynamic Behaviour of Concrete Cylindrical Shells Under Free Vibration

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Abstract- *Shell elements are adopted for several structural elements due to their versatile application. In particular cylindrical shell elements are used commonly for many purposes whose predominant stress will be membrane stress. The properties of the concrete cylindrical shell can be improved by introducing a brass coated steel fiber in concrete. This paper concentrates on a parametric study of free vibration analysis of concrete, brass coated steel fiber reinforced concrete and sandwich-type cylindrical shell. The natural frequency creates resonance when it combines with earthquake frequency. The change in base frequency can be achieved by changes in material properties. Modification of properties can reduce the resonance effect. Vibration analysis is carried out to determine the natural frequency of the shell element using finite element software ANSYS workbench'18.*

Keywords- Resonance effect, sandwich-type cylindrical shell, Vibration analysis

I. INTRODUCTION

The most common application of cylindrical shell element is a pipeline that is used for transporting oil, gas, water and even for disposal of industrial waste and sewage. Pipelines are subjected to vibration both by manmade and natural causes. One of the main causes of pipeline damage is earthquake hazard. Pipelines which are buried in earthquake-prone zone face problems when subjected to vibration.Earthquake occurs in some places like Sumatra, Gujarat, Chamoli and Bihar which causes damage in liquid pipelines. Therefore it is important to concentrate on designing a pipe which should reduce the resonance effect.

A.Shell Element

Shell elements are mostly preferred when small sections need to undertake more loads. A shell is a type of structural element which is characterized by its geometry. A three-dimensional solid whose thickness is very small when compared with other dimensions. The most commonly used shell element is cylindrical. These are generally used for transportation of fluids such as water, sewer, oils, etc.,These cylindrical shells are commonly used as pipelines. In structural terms, the stress resultants calculated in the middle plane displaying components which are both coplanar and normal to the surface. Essentially, a shell can be categorized into two means by the middle surface as a singly or doubly curved surface.

The structural behavior of the cylindrical thin concrete shell is similar to a longitudinal beam along the generator directions and therefore, the materials have to resist both compression and tension stresses. This factor takes advantage of the fibre and reinforced concrete, because these elements can be placed where corresponding tension forces and tension forces. The span (l) to thickness (t) Ratios plays an important role in the strength of the section. By varying, l/t ratio base frequency can be altered.

B. Sandwich structure

Sandwich type of concrete pipe is one of the optimum designs for overcoming the disadvantage due to the resonance effect. This type of pipe consists of two layers made of concrete and brass coated steel fiber reinforced concrete (BSFRC). As the outer end is provided with BSFRC layer while the normal concrete is used at the inner side. Thicknessof BSFRC (ts) to thickness of concrete (t) ratio is varied and hence by varying ts/t ratio also base frequency can be altered.

C. Free Vibration Analysis

The inherent part of a body is mass and due to elasticity inherent mass will cause relative motion. When a body particle is displaced by the application of external force, the internal force in the form of elastic energy will try to bring it to its original position. Thus, any motion which repeats itself for a certain interval of time is called vibration.

Free vibration is the vibration of a system after an initial impact. It is vibration due to its internal forces (free of external impact forces). This initiates an initial deviation (an energy input) of the system from its static equilibrium position. Once the initial impact is suddenly withdrawn, the strain energy stored in the structure tends to return to its original, static equilibrium configuration. Due to the inertia of the system, the system will not return to the equilibrium configuration linearly. Instead, it will oscillate about this position to wear off the Strain energy i.e., free vibration.

The Frequency produced during these vibrations is known as the Natural Frequency. When natural frequency matches the external frequency of the forces, it leads to a resonance effect. The resonance effect leads to an increase in the frequency of the structure vibration leading to an exponential increase of the damage.

II. MATERIAL PROPERTIES

A. Brass coated steel fibers

Steel fibers are generally used in concrete for increasing the tensile properties of concrete. But the main disadvantage of using steel fiber in concrete is corrosion. When it gets exposed to the environment it will get oxidized easily. Hence to overcome this drawback brass coated steel fibers (BSF) areused as shown in Fig1. They are in micro-steel fiber form and their specifications are listed below in Table I.

This fiber has undergone an X-ray diffraction test for analyzing its compounds. It is used to study the crystal structure. By identifying the crystal phases present in the material their chemical composition can be found. By comparing the acquired data with reference data base identification of phases are made.The compound name and the crystal systems are listed in the below Table II and the X-ray diffraction graph is shown in Fig 2.

Fig 1: Brass coated micro steel fibers

Table I Specification for micro steel fiber

Length	Diameter	Aspect ratio	Tensile strength	Density
13mm	0.2mm	65	2850MPa	7890kg/m^3

Table II X ray diffraction result

S.no	Compound name	Chemical Formula	Crystal system
1	Iron Carbide (7/3)	C_3Fe_7	Hexagonal
2	Manganese Nickel Silicide (0.5/0.5/1)	$Mn_{0.5}Ni_{0.5}Si_1$	Cubic

Major compound present in BSF are Iron carbide and Manganese nickel silicide. Manganese nickel silicide is used in this material for improving the resistance to oxidation, corrosion and the effect for heat .It is also responsible for great toughness and high strength to both high and low temperature.

B. Mechanical properties of concrete and BSFRC

Mechanical Properties of Concrete and Brass coated steel fiber reinforced concrete are found experimentally. To carry out finite element analysis some of the mechanical properties like density and isotropic properties like Poisson’s ratio and Young’s modulus are required.

In the experimental investigation OPC 53 grade of cement is used for the production of concrete, manufactured sand is used as fine aggregate satisfying zone II, and as the thickness of the sandwich layer, is varied with an increment of 10mm the aggregate should be within this layer. So the natural coarse aggregate of size 6mm is used in concrete. Silica fumes to enhance the later strength of concrete.

Table III Compressive strength test

S.no	Days	M35 grade concrete (N/mm^2)	BSFRC (N/mm^2)
1	7th day	25.0	27.6
2	14th day	30.0	35.0
3	28th day	37.6	40.2

Table IV Isometric properties

S.no	Mechanical properties	M35 grade concrete	BSFRC
1	Density (kg/m3)	2352	2598
2	Poisson's ratio	0.182	0.191
3	Young's modulus (kN/m2)	28.7	30.2

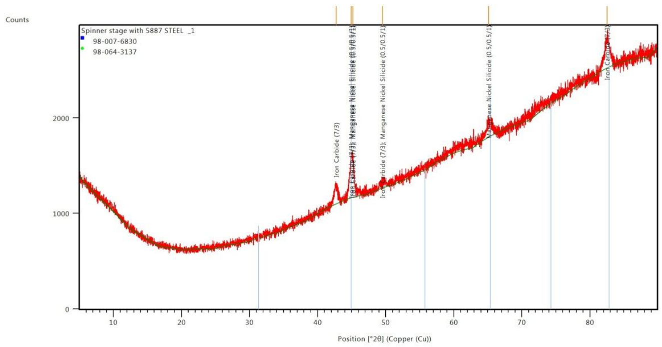

Fig 2: X-ray diffraction graph

M35 grade of concrete is considered for preparing test samples two types of samples were created one with M35 grade concrete and other with M35 grade brass coated steel fiber reinforced concrete. Cubes of size 100mm x 100mm x 100mm are cast for each sample for ensuring the characteristic compressive strength of concrete and Cylinders of size 300mm x 150mm are for finding the isotropic properties like Poisson's ratio and Young's modulus of concrete.

For cubes,the Compressive strength test is carried out. Both onthe 7th day and 28th day. As both the concrete sample show lower early strength value as it is due to usage of pozzolanic material i.e. silica fume in concrete but after 28 days it has achieved the target strength. The compressive strength results of both the samples are listed in Table III.By testing cylinders isometric properties are found for both the samples which are listed in Table IV.

III. ANALYTICAL STUDY ON SANDWICH STRUCTURE

A.Variation of thickness ratio in sandwich-type cylindrical shell:

Sandwich type cylindrical shell element is manufactured by two types of material. BSFRC used at the outer side of the shell element and Normal concrete is used in the inner side of the shell element. By varying thickness ratio that is Thickness of the brass coated steel fiber reinforced concrete (ts) to thickness of normal M35 grade of concrete (t) ratio is varied. Six trials are made by varying the ts / t ratio. The thickness ratio trials are shownin Fig 3. The six trials are listed in Table V.

Table V Thickness ratio trials

Trial No	Thickness details
1	100% of thickness is Normal concrete
2	20% of thickness is BSFRC and remaining 80% of thickness is normal concrete
3	40% of thickness is BSFRC and remaining 60% of thickness is normal concrete
4	60% of thickness is BSFRC and remaining 40% of thickness is normal concrete
5	80% of thickness is BSFRC and remaining 20% of thickness is normal concrete
6	100% of thickness is BSFRC

A. Modeling of the cylindrical shell using ANSYS

a) Material assigning: The physical properties like modulus of elasticity, Poisson ratio and density of the particular material is given based on Experimental investigation. The modeling is quite complicated in ANSYS software due to its layer and so then it is done with the help of ACP pre model. Material properties are assigned. The materials mainly used are normal concrete and BSFRC.

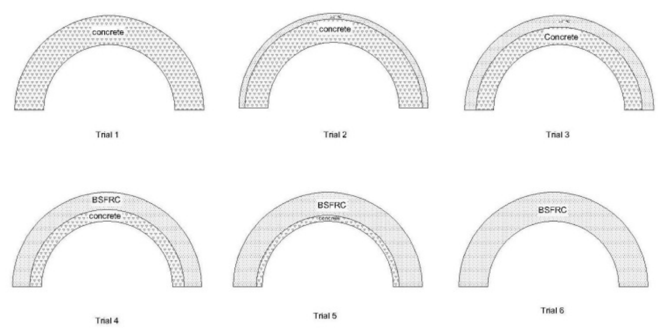

Fig 3: Six thickness ratio trials

b) Geometry:The Geometry of the cylindrical shell is created by giving dimensions as input. Internal diameter, thickness and length are the dimensions given as input. This creates the geometry of the pipe. The tube thickness should be kept zero so that layers can be developed by keeping this surface as a base. Now the shell element is ready for meshing.The meshing is done on the cylindrical to increase the accuracy of the results and the meshing type is hexahedral. Hexahedral meshes are followed because it is economical in the number of elements that is the number of degree of freedom for one hexahedral element is equal to six tetrahedral element. So hexahedral meshing is preferred over the tetrahedral meshing and element size is 25 mm.

c) ANSYS composite pre/post modeling (ACP):ANSYS composite Prep Post differentiates between four material classes: Materials, Fabrics, Stackups and sub laminates. The material class is the material database in ACP and the Fabric class is where the materials can be associated with a ply of a set thickness draping coefficient that can be added as well as unit price properties. The named selections defined in the ANSYS mechanical application or the component in the ANSYS mechanical APDL are imported into ANSYS composite pre/post. These selections are imported with the same names. The faces (Element components in ANSYS Mechanical APDL) are imported as Element Sets and the edges (Node components in ANSYS Mechanical APDL) as Edge Sets. Rosettes are coordinate systems that used to set the reference direction of orientation element sets i.e. Rosettes define the 00 direction for the composite layup. Cylindrical rosettes are based on the cylindrical coordinate system in this the reference direction is either radially inward or outward. The cylindrical rosette runs around the Z- direction.The orientation element set will give reference to the orientation of each layer.In the section Modeling ply Group, the desired composite lay-up can be defined. By specifying an orientation element set and the material data created earlier. Further, the created ply will be displayed as a green reference line. In solid modeling, the created reference ply is now formed into a solid model by ensuring the orientation of layers.

d) *Modal Analysis:*Numerous precast pipe sections may be combined to form the entire network of a pipeline. The sections are assembled in a continuous way such that the junction of two sections acts as a fixed end. This ensures the continuity and monolithic behaviour of the pipeline. Support conditions given to the cylindrical shell for the analysis are assumed as fixed at both faces along where the pipe junctions. Vibrational analysis is carried out for 10 mode shapes.

IV. ANALYTICAL RESULT

A. Length to thickness ratio:

There are different models are created in ANSYS Workbench by varying the Length to radius ratio and modal analysis is carried out for these different models. By analyzing, Natural frequency is obtained for each mode shape. 10 Mode shapes are selected because most of the earthquake frequency matches with the first 10 mode shapes. The length to thickness ratio is obtained by varying lengths of the cylindrical shell. Length is varied from 1000mm to 3000mm. By varying length, eleven sets of length to radius ratios .Fig 4shows the variation of natural frequency for each mode shapes. Increase in mode shape results in an increase in natural frequency. But natural frequency will be decreased gradually by increasing the Length to radius ratio. Thus by increasing the ratio natural frequency can be reduced, which will be effective for reducing the resonance effect.

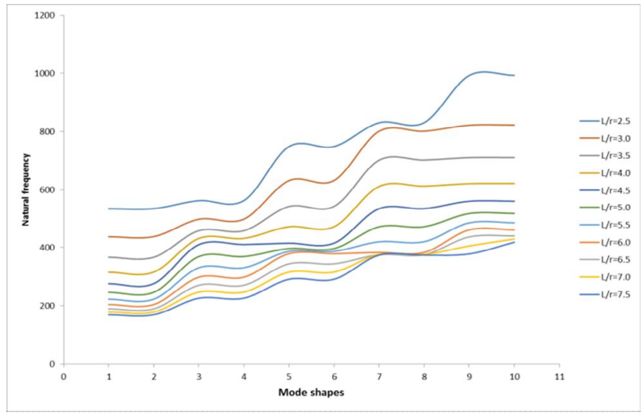

Fig 4: Variation of natural frequency for different length to thickness ratio

B. t / T ratio:

Similarly, different models are created in ANSYS workbench by varying thickness of BSFRC to thickness of concrete ratio and modal analysis is carried out for these different models. By analyzing,the natural frequency is obtained for 10 mode shapes. t / T ratio is obtained by varying the thickness of the shell element to its total thickness. Six set of variation are made in this thickness ratio i.e. 0, 0.2, 0.4, 0.6, 0.8 and 1.0. In addition to this length is also varied from 1000mm to 3000mm for each ratio. In total 66 set natural frequency data, were taken for each of the 10 mode shapes.Fig 5a- Fig 5bshows the variation of natural frequency for each mode shapes for different diameters of pipes. Increase in mode shape results in an increase in natural frequency. But natural frequency will be decreased gradually by increasing thet / T ratio. Thus by increasing the ratio natural frequency can be reduced, which will be effective for vibration resistance.

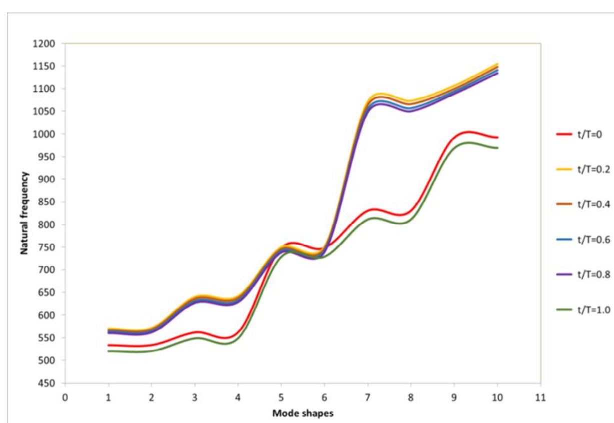

Fig 5a: For 1000mm dia pipe

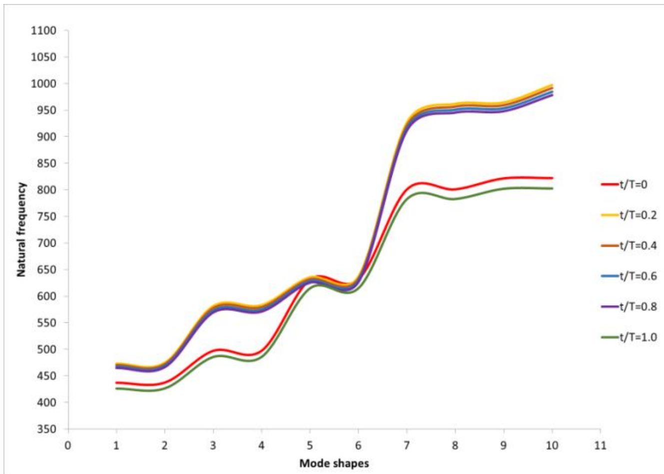

Fig 5b: For 1200mm dia pipe

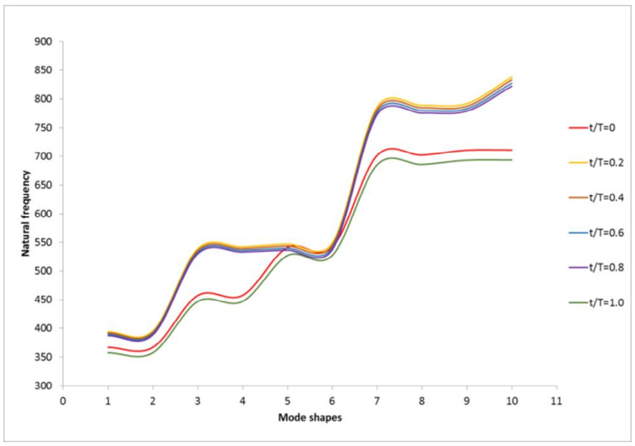

Fig 5c: For 1400mm dia pipe

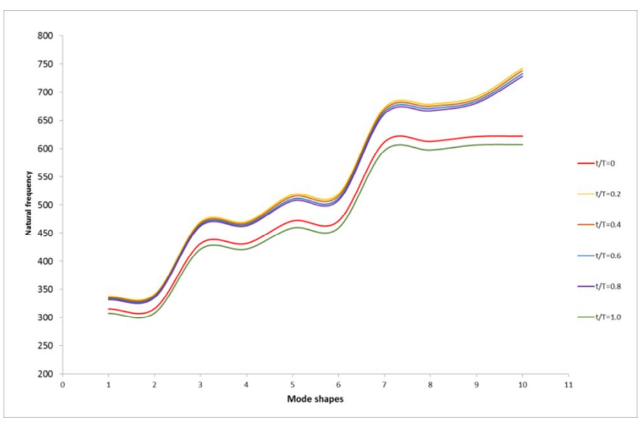

Fig 5d: For 1600mm dia pipe

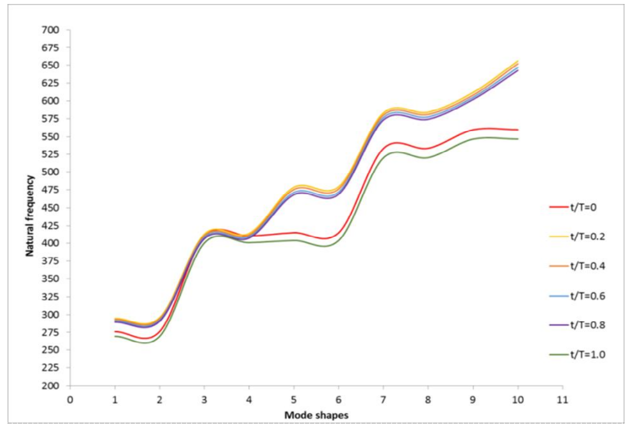

Fig 5e: For 1800mm dia pipe

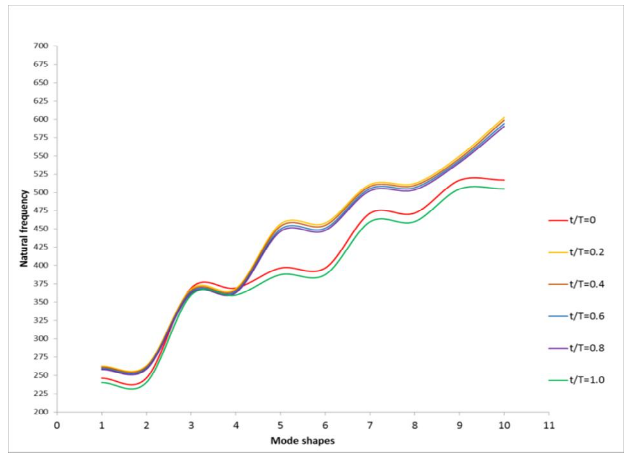

Fig 5f: For 2000mm dia pipe

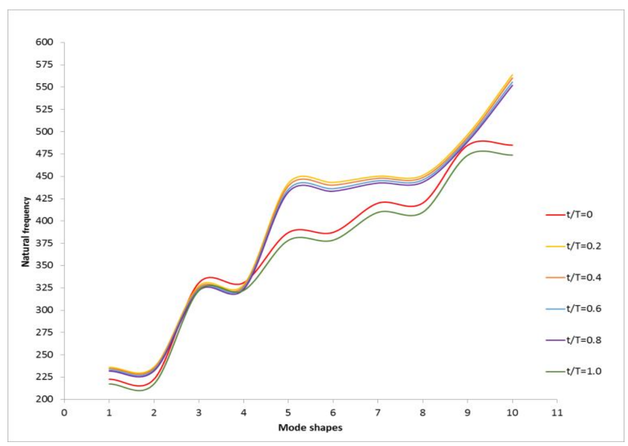

Fig 5g: For 2200mm dia pipe

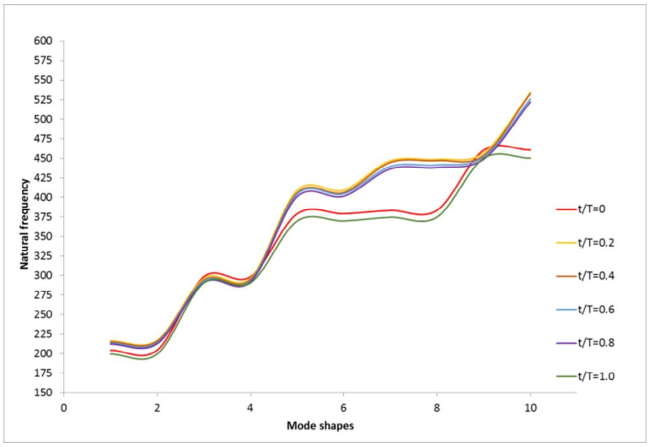

Fig 5h: For 2400mm dia pipe

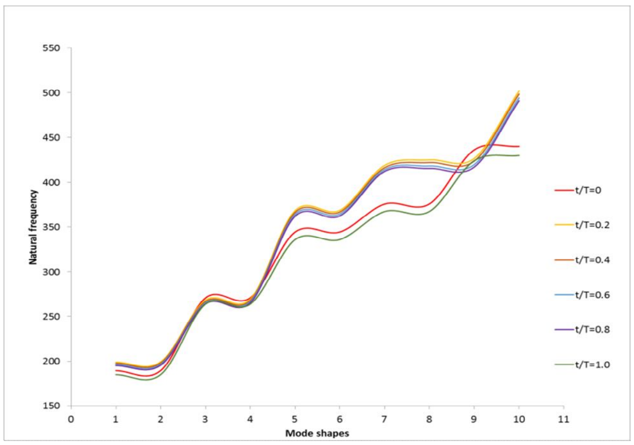

Fig 5i: For 2600mm dia pipe

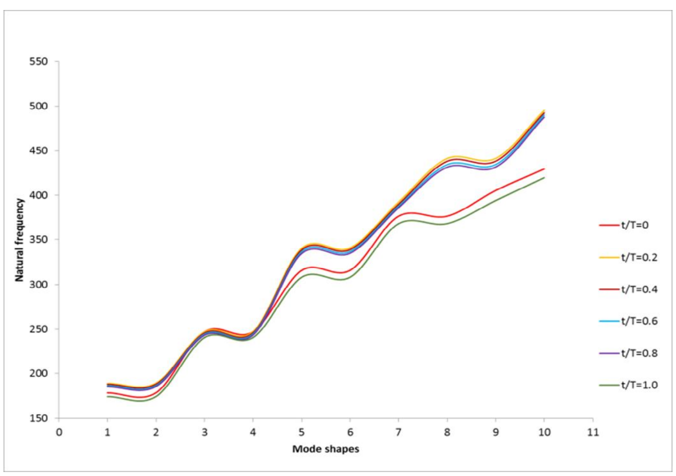

Fig 5j: For 2800mm dia pipe

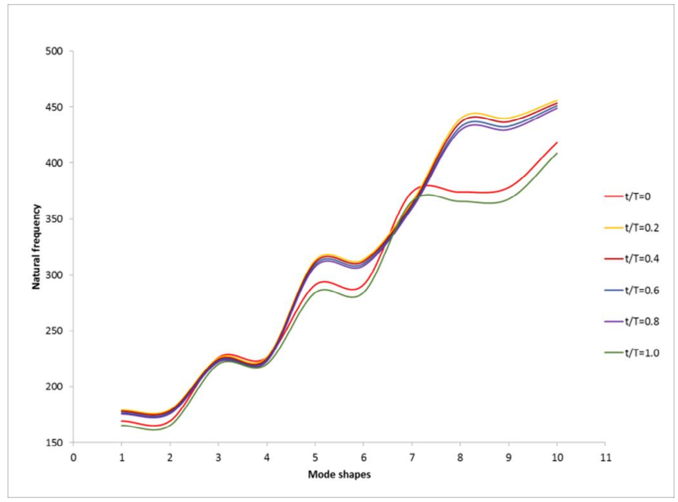

Fig 5k: For 3000mm dia pipe

V. CONCLUSION

Conventionalconcrete, BSFRC and four sets of sandwich-type cylindrical shells by varying ts/t ratio 0.2, 0.4, 0.6 and 0.8 were analyzed. In addition to this Length to thickness ratio(l/t) is varied and analysis is made using ANSYS workbench 18'and the following conclusions arrived.

a) The natural frequency decreases with an increase in length to thickness ratio of Normal concrete cylindrical shell and BSFRC cylindrical shell.
b) l/r ratio has greater influence in the base frequency. The initial modes are varied from (20 to 60)This shows the significant effect on base frequency modification.
c) Similarly, Natural frequency decreases with an increase in length to thickness ratio of four sets of sandwich-type cylindrical shells.
d) As the ts/t ratio of sandwich-type cylindrical shell element increases with a decrease in natural frequency.
e) But while comparing homogeneous and sandwich-type cylindrical shell elements, sandwich-type show slighter variation, which can use for changing the base frequency.
f) From the above investigation, it is found that the resonance effect can be controlled by changing the base frequency of the cylindrical shell element.

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