Dynamic Response of an Elevated Water Tank

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***Abstract*—Elevated Water tanks are one of the important and vital structures at times of earthquake and especially after the earthquake. For this reason, Dynamic behavior of storage tanks has attracted attention of many researchers. But the soil surrounding the tank affects behavior of structure in Dynamic analysis of Elevated Water tanks. For this reason, it is necessary to for designers of Elevated Water tanks to understand interaction of soil and structure in dynamic analysis of tanks. In the present study attempt have been made to study the effect of soil structure interaction (SSI) on the performance of water tank. The results obtained for water tank considering SSI are compared with water tank without SSI. Cohesive type of soil has been considered. Three dimensional FEA is carried out using Abaqus software.**

***Keywords*— Finite Element Analysis, Soil Structure Interaction.**

I.INTRODUCTION

Elevated concrete water tanks are mainly used for water supply and fire protection. One of the major problems that may lead to failure of these structures is earthquakes. Therefore the analysis of elevated tank must be carefully performed, so that safety can be assured when earthquake occurs and the tanks remain functional even after earthquake. The irregular shape of the elevated water tanks for which most of the mass confluent in the upper part of the tank makes it more sensitive to any dynamic load, especially due to an earthquake. Structural dynamics deals with methods to determine the stresses and displacements of a structure subjected to dynamic loads. The dimensions of the structure are finite. It is thus rather straightforward to determine a dynamic model with a finite number of degrees of freedom. The corresponding dynamic equations of motion of the discretized structure are then formulated, and highly developed methods for solving them are readily available. In general, however, the structure will interact with the surrounding soil. It is thus not permissible to analyze only the structure. It must also be considered that in many important cases the loading is applied to the soil region around the structure; this means that the former has to be modeled anyway. The soil is a semi-infinite medium, an unbounded domain. For dynamic loading, this procedure cannot be used. The fictitious boundary would reflect waves originating from the vibrating structure back into the discretized soil region instead of letting them pass through and propagate toward infinity. This need to model the unbounded foundation medium properly distinguishes soil dynamics from structural dynamics.

Theory of Soil-Structure Interaction

A structure interacts with its surrounding soil and this causes changes in effect of seismic waves. In seismic analysis, interaction of structure and soil should be considered. Dynamic response of soil-structure system is a function of three factors, dynamic parameters of site, forces and excitations and dynamic model of the system when it is affected by a dynamic loading. Dynamic parameters of the site include soil modulus of elasticity, soil Poisson coefficient, and damping in soil. Damping is also divided into two classes of internal and radiation damping. Internal damping is caused by passage of vibration waves through soil and can be regarded as factor of energy loss due to residue in soil but radiation damping causes energy loss due to emission of waves from foundation of the structure to half-space and for this reason, such geometric distribution of elastic waves is called geometrical damping. Proper analysis of dynamic reaction of soil-structure interaction system requires recognition of different components of the system and excitations which include determination of free field motion i.e. earth motion without presence of structure and calculation of scattering of earthquake waves due to soil and structure interaction. According to principle of superposition, excitations resulting from free field and interaction with each other are added and dynamic model of the system includes dynamic model relation of the foundation environment. Many models are available for consideration and analysis of interaction. Soil and structure interaction is generally classified into two direct and sub-structure methods and each is elaborated separately.

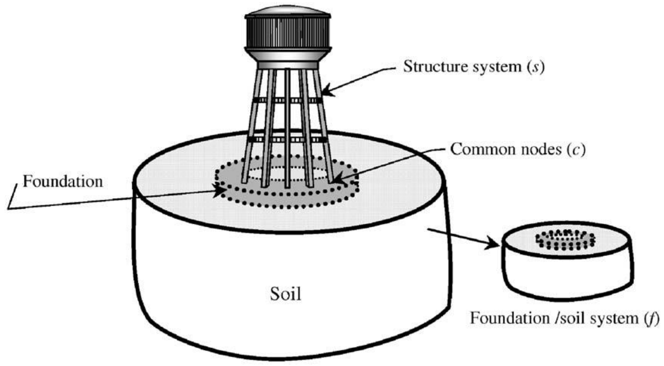

Figure 1.1 Considered structure–foundation/soil interaction model.

Of course, it is worth noting that a method called Hybrid Method was created for analysis of soil-structure interaction recently. In this method, structure and area close to soil and the area far from soil are modeled in the next stage and effect of the distant area is considered. In Direct Method, structure, foundation and soil are modeled altogether and analysis is done in one step. In this case, because principle of superposition is not necessary, it is possible to do nonlinear analyses. In this method, structure and main parts of the soil are generally modeled with finite elements method and are analyzed with each other and motion of free field of soil is applied in boundaries. One of the important issues in modelling soil and structure interaction is to use a model which simulates nonlinear behaviour of the soil. The most general method for modelling surrounding soils a elastoplastic model considering interaction of soil and structure and emission of waves in the soil and one can consider yield criterion for soil based on yield surface in stress-strain surface. The actual problem determines to what extent boundaries become necessary. In this case, the structures under consideration are situated close to the free surface and the soft soil layers at the surface bounded by hard rocks at the bottom. So we can take advantage of real elementary boundaries, a zero displacement boundary at the bottom.

II. PROBLEM FOR ANALYSIS

The elevated tank resting on a pile foundation is considered for the parametric study. It has a capacity of 250 m3 with the top of water level at about 17.8 m above ground. The tank is spherical in shape, 8.6 m in diameter and 7.85 m in height at its centre. The support consists of 6 vertical circular columns and the columns are connected by the circumferential beams at regular intervals, at 4,8,12 and 16 m.

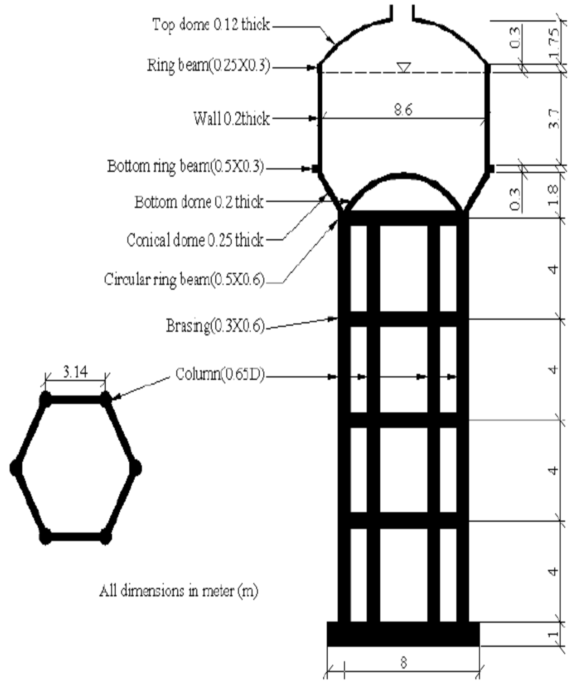

Figure 2.1 Details of tank geometry

III.MODELLING OF TANK AND SOIL

Modelling the contact surface of soil and tank is one of the important parts of soil-tank interaction modelling. Generally, contact surface between tank and soil is modeled in two ways: complete cohesion or friction contact surface in which there is soil and tank slip and segregation between them. In this research, contact elements have been used for modelling contact surface of soil and tank. In Abaqus program, mechanical contacts between two objects are possible in two ways: Surface to surface contact and surface to node contact which are more accurate than the first state. In this research, two contacts between interfaces have been considered: friction contact and vertical contact. In friction contact, penalty formulation with friction coefficient of 0.7 has been used. In vertical contact, penalty formulation has been used.It is possible to select Rayleigh damping in Abaqus program in specifications of materials. Critical damping coefficients have been assumed 5% for this research which are in line with studies. Radiation damping play very important role in modelling of soil and dynamic issues especially issues of soil-structure interaction. In this research, infinite elements and dampers have been used for modelling the soil-tank interaction. Using infinite elements, one can be release from effect of undesirable phenomenon of packing in modelling. Cubic three-dimensional elements with 8 nodes which have three degrees of freedom in each node have been used for modelling soil and tank system.

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A. MODELLING IN ABAQUS

Preprocessing-
It comprises all the steps to create the model with Abaqus/CAE.The following steps are taken equentially:

-Creating a part /defining the model geomet
-Defining the material and section properties
-Creating an assembly
-Configuring the analysis
-Assigning interaction properties
-Applying boundary conditions and applied loads
-Designing the mesh
-Creating, running, and monitoring a job

Postprocessing-
The Visualization module provides graphical display of finite element models and results. It obtains model and result information from the output database; it is controlled what information is written to the output database by modifying output requests in the Step module.

B. Creating a part /defining the model geometry

The first step in creating the model is to define its geometry. The model is created with a three-dimensional, deformable body with a solid, extruded circular base feature. The following dimensions are used:

Table -1.Properties of Solid Part

Modeling Space		3D	3D	3D
Type		Deformable	Deformable	Deformable
Base Feature	Shape	Solid	Wire	Shell
	Type	Extruded	Planar	Revolution
Elements/Sections		Soil ,Pile,Pile Cap	Column, Hexagonal Bracings	Circular tank

The analysis is executed for pile group make comparisons. In case of the pile group, the piles are spaced 3.14 m. At this stage, it is important to decide what system of units to use in the model as Abaqus has no built-in system of units. Thus, the SI system of units is used.

C. Defining the material and section properties

The next step in creating the model involves defining and assigning material and section properties to the part. Each region of a deformable body must refer to a section property, which includes the material definition. In this model linear elastic materials are created for both concrete pile and soil.

1) Grade of concrete for beam, column = M20
2) Grade of concrete for pile = M40

Table -2. Section, Material and Profile.

Sr. No.	Section Created	Material Assigned
1	Beam	M-20
2	Column	M-20
3	Pile	M-40
4	Pile Cap	M-20
5	Soil	Soil
6	Circular Tank	M-20

Table -3.Properties of concrete pile.

Young’s Modulus	Mass Density	Poisson’s Ratio
EC=$0.3605*10^8$ kpa	2504	0.15

Table -4 Properties of beam, column ,circular tank and pile cap

Young’s Modulus	Mass Density	Poisson’s Ratio
EC =$0.25491*10^8$ kpa	2452	0.15

Table -5: Properties of Soil.

Young’s Modulus	Mass Density	Poisson’s Ratio
EC =20000 kpa	2000	0.2

D. Creating an assembly

Each part created is oriented in its own coordinate system and is independent of the other parts in the model. Although a model may contain many parts, it contains only one assembly. The geometry of the assembly is defined by creating instances of a part and then positioning the instances relative to each other in a global coordinate system. Thus, the soil and piles are assembled together.

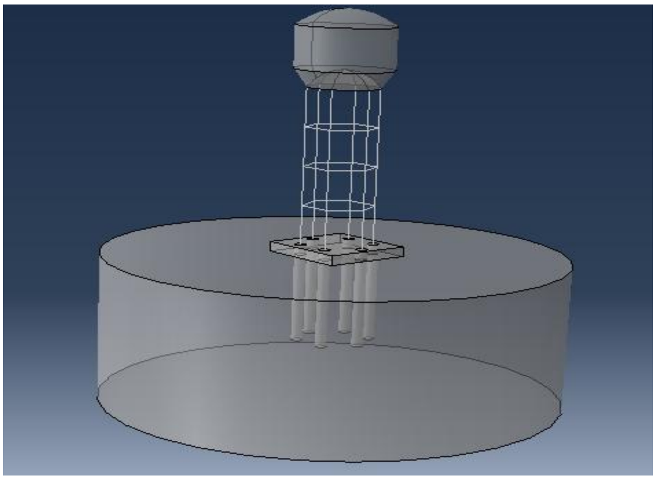

Figure 3.1 Water Tank With Soil

E. Configuring the analysis

Analysis steps can be broadly categorized as an initial step and analysis steps. They are dealt subsequently.

1)-The initial step

Abaqus/CAE creates a special initial step at the beginning of the model's step sequence and names it Initial. It allows defining boundary conditions, predefined fields, and interactions that are applicable at the very beginning of the analysis.

2)-Analysis steps

The initial step is followed by one or more analysis steps. Each analysis step is associated with a specific procedure that defines the type of analysis to be performed during the step. There are two kinds of analysis steps in Abaqus: general analysis steps, which can be used to analyze linear or nonlinear response, and linear perturbation steps, which can be used only to analyze linear problems. In this case, a static linear perturbation step is defined. Specifically, Direct-solution steady-state dynamic analysis step is used because it is used to calculate the steady-state dynamic linearized response of a system to harmonic excitation. Multiple frequency ranges or multiple single frequency points can be requested for a direct-solution steady-state dynamic step.

3)-Requesting data output

Finite element analyses can create very large amounts of output. Abaqus allows controlling and managing this output so that only data required to interpret the results of the simulation are produced. Thus the analysis is limited to give such a relevant output as displacement.

IV.RESULTS

In this section comparison of different parameters of soil structure interaction for An Elevated water tank without soil and with soil is done and analysis validation for tank is done by using substitute frame method.

A. Results discussion for Elevated Water tank

For comparison purpose after analysis all junction points from bracings are considered from elevated water tank frame with soil and without soil. All six columns and bracing joints at each height of base frame are considered as level 1,2,3,4 and 5 respectively.

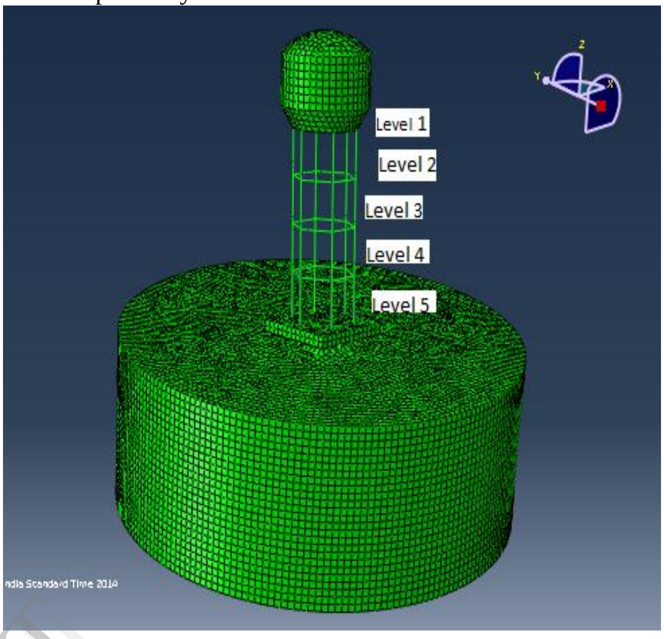

Figure 4.1Different levels of Bracing

B.Description of first five Mode and frequency

Following figures Figure 4.2 & Figure 4.2 shows first five modes & corresponding frequencies for water tank without soil and with soil respectively.

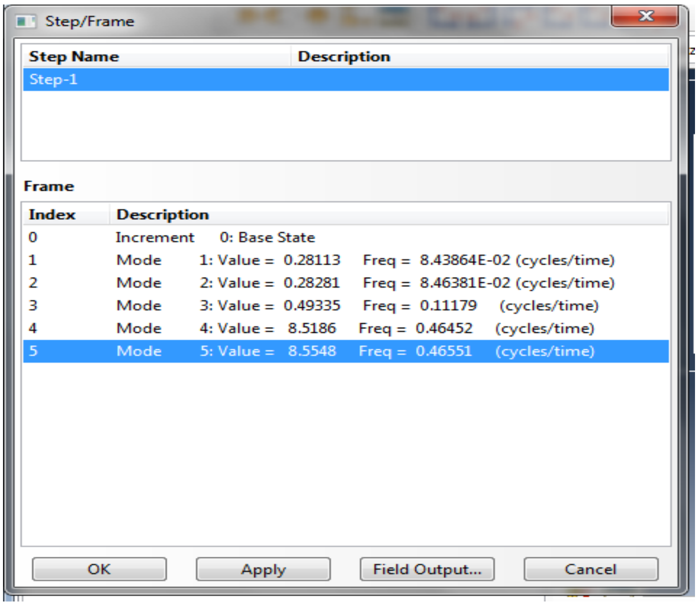

Figure 4.2 First Five modes and Frequency for water tank without soil

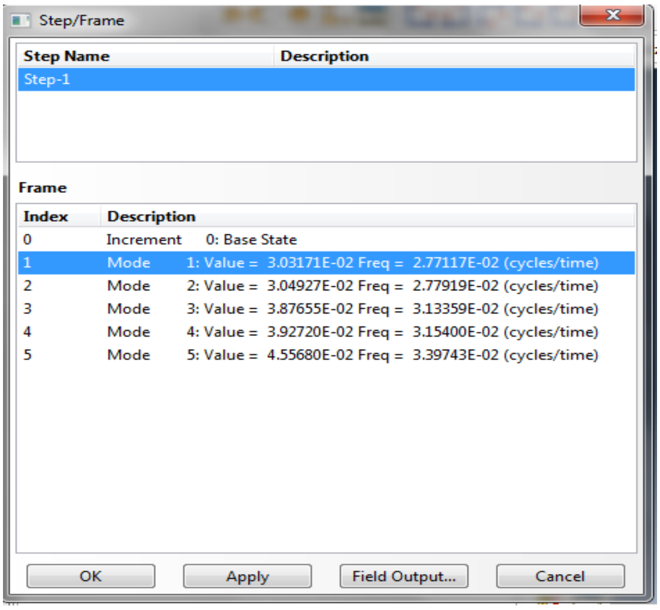

Figure 4.3 First Five modes and Frequency for water tank with soil

C. *Displacement water tank with soil and without soil in first five Modes*

By keeping other parameters constant, the natural frequencies increases with the increase in the mode number of tank. The effect of damping on dynamic response of liquid storage tanks can be studied. In this study, only a constant value for damping was assumed.

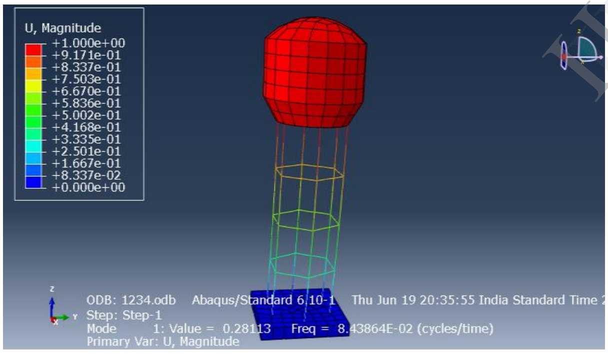

Figure 4.3 Mode 1 for tank without soil

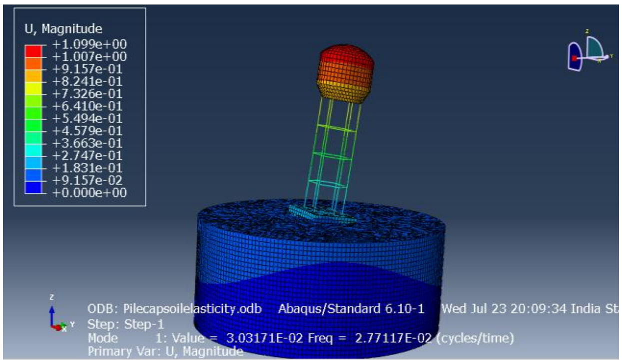

Figure 4.4 Mode 1 for tank with soil

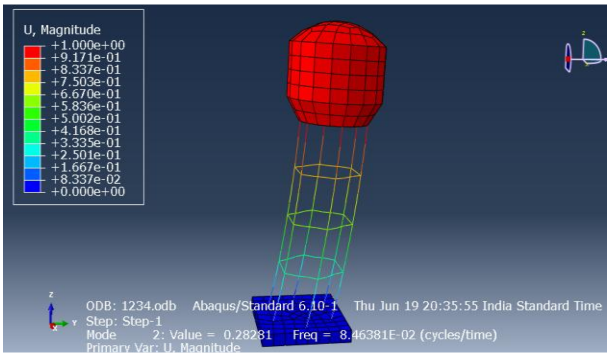

Figure 4.5 Mode 2 for tank without soil

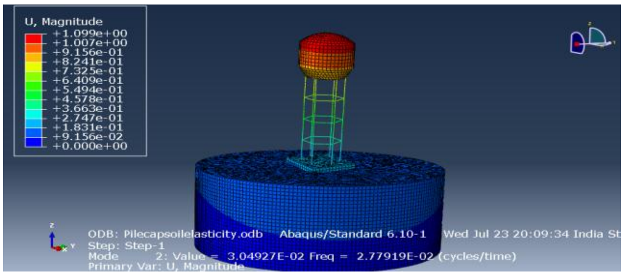

Figure 4.6 Mode 2 for water tank with soil.

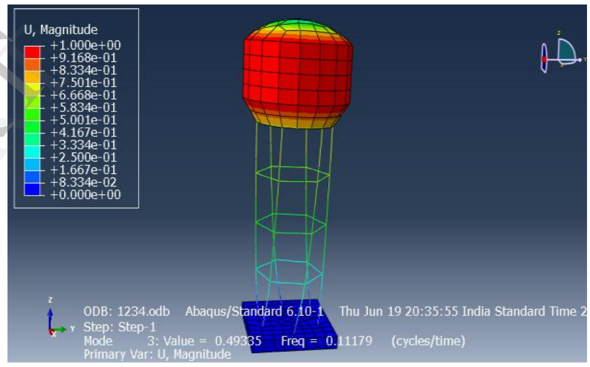

Figure 4.7 Mode 3 for water tank without soil.

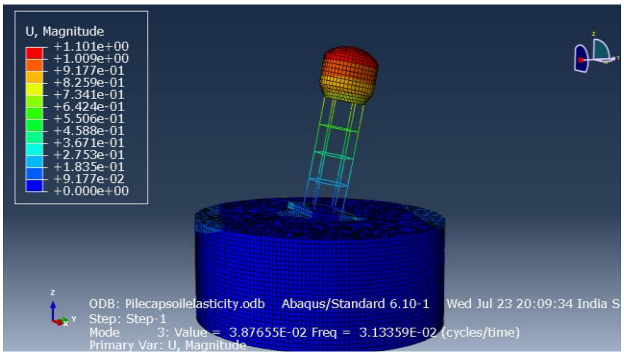

Figure 4.8 Mode 3 for water tank with soil.

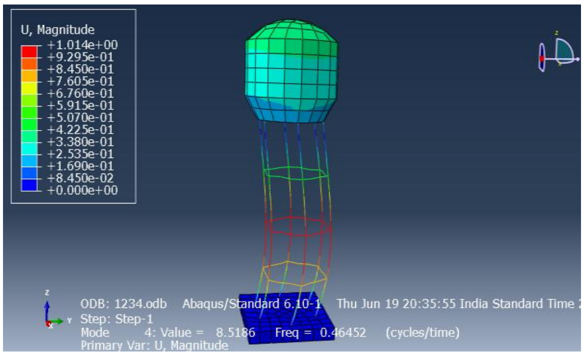

Figure 4.9 Mode 4 for water tank without soil.

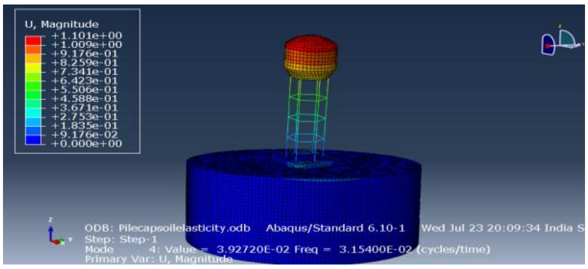

Figure 4.10 Mode 4 for water tank with soil.

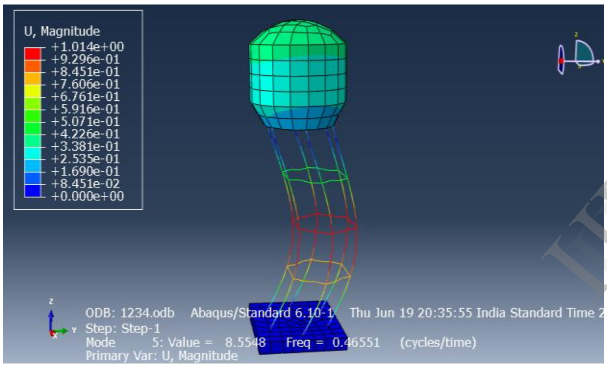

Figure 4.11 Mode 5 for water tank without soil.

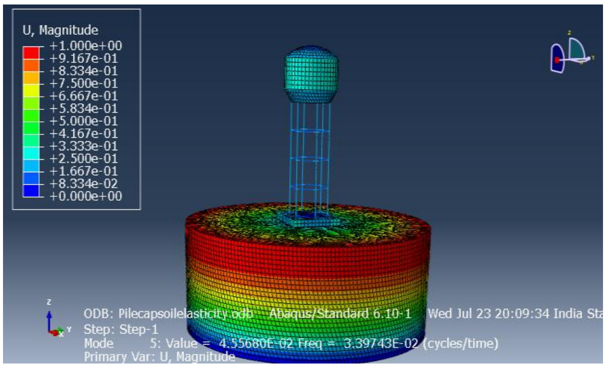

Figure 4.12 Mode 5 for water tank with soil.

Following graphs shows displacement v/s mode number plot for elevated water tank without soil and with soil, at each level 1 for all columns

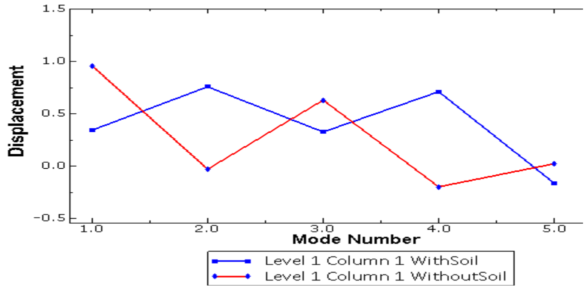

Figure 4.13 Graph of Displacement vs Mode Number for Level 1,Column 1

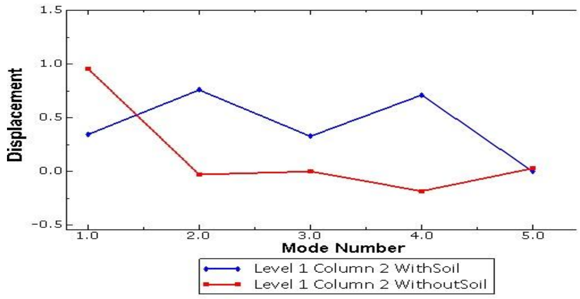

Figure 4.14 Graph of Displacement vs Mode Number for Level 1,Column 2

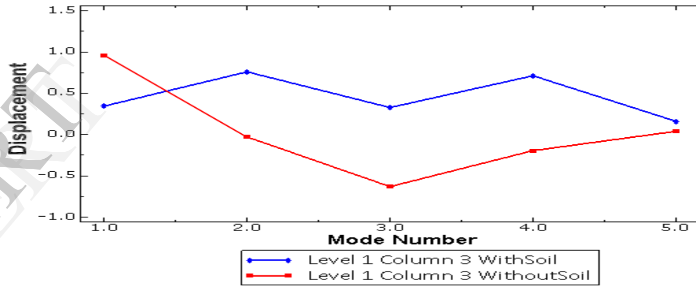

Figure 4.15 Graph of Displacement vs Mode Number for Level 1,Column 3

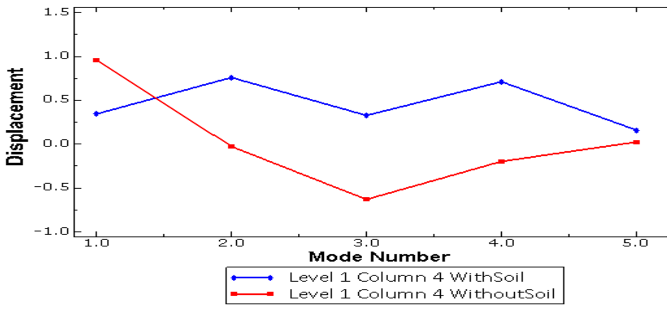

Figure 4.16 Graph of Displacement vs Mode Number for Level 1, Column 4

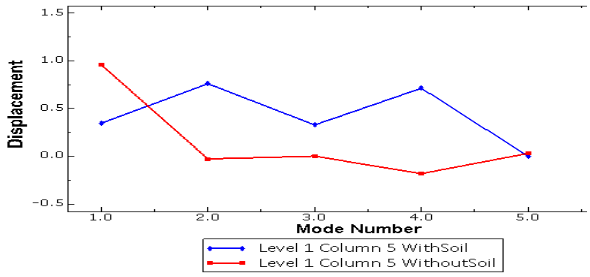

Figure 4.17 Graph of Displacement vs Mode Number for Level 1, Column 5

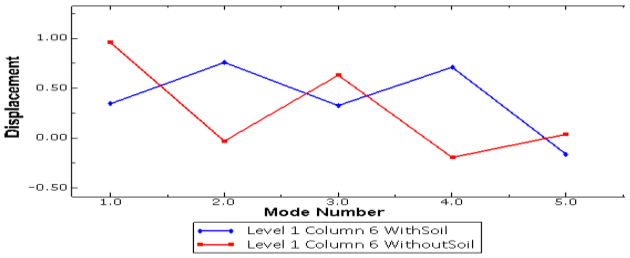

Figure 4.18 Graph of Displacement vs Mode Number for Level 1, Column 6

So on we can comapare the dipalcement of all levels in all modes

V.CONCLUSION

- It can be seen that for respective levels almost all columns shows same displacement for corresponding modes.
- Abaqus software has various capabilities to analyse the structure with SSI.
- Considerable variation in displacement is observed in the structure with and without SSI.
- For mode no 1 displacement of structure without SSI is more as compare to displacement with soil.
- For mode no 2 and 4 displacements of structure with SSI are almost same.
- Displacement of structure without SSI is decreasing from mode 1 to mode 2 and in case of with SSI it is increasing.
- From the obtained results it may be concluded that for relatively heavy structures on soft oil SSI analysis must be carried out.
- ABAQUS software can be used efficiently to investigate the effect of SSI on the structures, further different soil and structural models can be incorporated to improve the accuracy.
- Conclusions drawn from present study will be beneficial in understanding the effect of dynamic SSI on the structure.

FUTURE SCOPE OF THE STUDY

- Present study can be extended to study the seismic behavior.
- Tank fill conditions i.e. half filed,full filled and empty can be incorporated.
- Present study can be extended to study effect of layered soil with different damping co-efficient.

REFERENCES

[1] John p. Wolf, "*Dynamic Soil-Structure Interaction*", Electrowatt Engineering Services Ltd.

[2] Sanaz Mahmoudpour, Reza Attarnejad, and Cambyse Behnia, "*Dynamic Analysis of Partially Embedded Structures Considering Soil-Structure Interaction in Time Domain*", Hindawi *Publishing* Corporation Mathematical Problems in Engineering Volume 2011, Article ID 534968.

[3] Alexander Tyapin, *"Soil-Structure Interaction",* chapter 6 from book Earthquake Engineering. Choon-Gyo Seo, Chung-Bang Yun, Jae-Min Kim, C.-G. Seo "Three-dimensional frequency-dependent infinite elements for soil–structure interaction", et al. / Engineering Structures 29 (2007).

[4] Wen s. Tseng, "*Seismic instrumentation for soil-structure interaction assessment*",International Civil Engineering Consultants, Inc.

[5] Lin Jiahao, Gao Qiang Zhong Wanxie, W.P. Howson, F.W.Williams.,*"Isotropic layered soil-structure interaction caused by stationary random excitations*",

[6] J. L. Wegner, M. M. Yao and S. K. Bhullar, "*Dynamic wave soil structure interaction analysis of a two way asymmetric building system DSSIA-3D*", Journal of Engineering and Technology Research Vol.1 (2), pp.026-038, May 2009.

[7] Professor T.D. O'Rourke, *"Soil-Structure Interaction under Extreme Loading Conditions*", the Thirteenth Spencer J. Buchanan Lecture.

[8] Lou Menglin and Wu Jingning, "*Effects of soil-structure interaction on structural Vibration control*", Developments in Geotechnical Engineering.

[9] Farhang Ostadan, Nan Deng, Orhan Gurbuz and Sanjeev Malushte, "*seismic soil-structure interaction analysis including ground motion incoherency effects*", The 14th World Conference on Earthquake Engineering October 12-17, 2008.

[10] R. M. Jenifer Priyanka, N. Anand, Dr. S. Justin, "Studies *on Soil Structure Interaction of Multi Storeyed Buildings with Rigid and Flexible Foundation*", International Journal of Emerging Technology and Advanced Engineering.

[11] H. Zolghadr Jahromi, B.A. Izzuddin and L. Zdravkovic, "*Partitioned analysis of nonlinear soil-structure interaction using iterative coupling*", Interaction and Multiscale Mechanics, Vol. 1, No. 1 (2007) 33.51.

[12] ACS SASSI Version 2.3.0 (2009) *"An Advanced Computational Software for 3D Dynamic Analysis Including Soil Structure Interaction*", User Manuals, Ghiocel Predictive Technologies, Inc., Rochester, New York, USA, June 15 (http://www.ghiocel-tech.com/engineeringTools.html)