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Effect of Soil-Structure Interaction on High Rise RC Building

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Abstract : *Most of the civil engineering structures involve some type of structural element with direct contact with ground. When the external forces, such as earthquakes, act on these systems, neither the structural displacements nor the ground displacements, are independent of each other. The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as soil-structure interaction (SSI). In this paper, the interaction between the super-structure and sub-structure is investigated by modelling the soil as simple as possible to capture the overall response of the system. As new analytical hysteresis rules and more advanced tools of analysis have been developed in recent years, first the nonlinear response of a single-degree-of freedom system which can be representative of a broad range of newly designed structures, is investigated while allowing for flexibility of the soil-foundation system and SSI effects. This non-linear frame model is high rise residential building of G+42 storeys located at MUMBAI and time history of ELCENTRO is used to study the response of the model in ETABS.*

The simple soil model with pile-raft foundation is then employed in MIDAS GTX NX to this nonlinear frame models to quantify the effect of SSI on the overall response of actual structures. The use of flexible base in the analysis can lead to reduction in the structural response and damage consequences in joints and infills.

Keywords *: Soil-Structure Interaction, soil conditions, settlements, reactions, solid stresses.*

I. Introduction

According to the advanced numerical analysis, the interaction between a raft, soil and the structure is considered. The response of any system comprising more than one component is always interdependent. For instance, a beam supported by three columns with isolated footing may be considered (Fig.1). Due to the higher concentration of the load over the central support, soil below it tends to settle more. On the other hand, the framing action induced by the beam will cause a load transfer to the end column as soon as the central column tends to settle more. Hence, the force quantities and the settlement at the finally adjusted condition can only be obtained through interactive analysis of the soil–structure– foundation system. This explains the importance of considering soil–structure interaction. The three dimensional frame in superstructure, its foundation and the soil, on which it rests, together constitute a complete system. With the differential settlement among various parts of the structure, both the axial forces and the moments in the structural members may change. The amount of redistribution of loads depends upon the rigidity of the structure and the load-settlement characteristics of soil. Generally, it may be intuitively expected that the use of a rigorous model representing the real system more closely from the viewpoint of mechanics will lead to better results. But the uncertainty in the determination of the input parameters involved with such systems may sometimes reverse such anticipation. In the present study, an attempt has been made to scrutinize the various approaches of modeling the soil–structure–foundation system. In most of the civil engineering analysis, structure is assumed to be fixed at the base. Thus, the flexibility of foundation and the compressibility of the supporting soil medium are neglected. Consequently, the effect of uneven foundation settlements on redistribution of forces and moments in the superstructure is also neglected. Conventional structural design methods neglect the SSI effects. Neglecting SSI is reasonable for light structures in relatively stiff soil such as low rise buildings and simple rigid retaining walls. The effect of SSI, however, becomes prominent for heavy structures resting on relatively soft soils for example nuclear power plants, high-rise buildings and elevated-highways on soft soil. Hence, the attempt has been made to study the actual behavior of a multi-storied building with soft soil. The building frame is considered under the gravity loading, earthquake load and wind load. Pile length configurations are modeled and analyzed along with the building to study the optimum forces and moments in the building. Finally, different conclusions are drawn by studying the soil structure interaction.

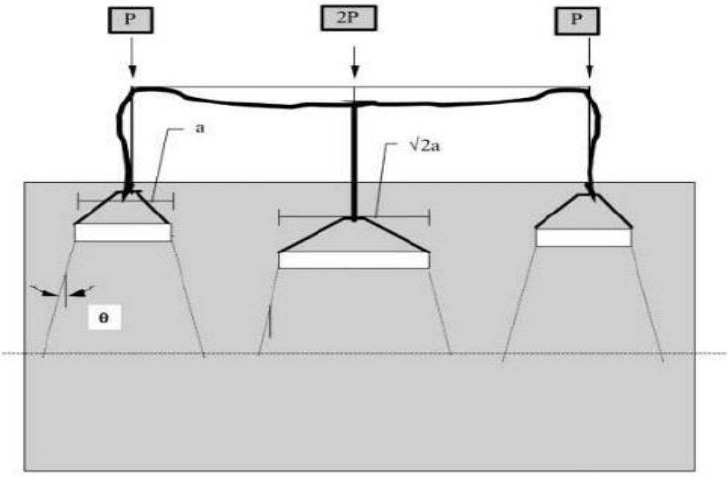


Fig1: Redistribution of loads in a frame due to soil–structure interaction.

Ssi Overview

The dynamic interaction between superstructure and substructure can be divided into two components: inertial interaction and kinematic interaction. Early SSI development was motivated by the seismic design of nuclear power plants. Kinematic interaction is referred to the deviation of ground motion due to presence of a stiff foundation with/without mass and inertial interaction is a consequent deformation of foundation soil due to induced base shear and moments from the superstructure. The relative importance of these two components depends on the foundation characteristics and nature of incoming wave field. Since usually mass of the soil excavated to construct the foundation is similar to the structure mass, kinematic interaction can be ignored unless the replaced foundation is very stiff. Therefore, kinematic component of SSI analyses are usually of concern in designing nuclear power plants or off-shore structures and oil industries. In addition, for motions that are not rich in high frequencies the input motion can approximately be considered equal with that of the free field. Kinematic interaction effects are usually far more difficult to evaluate rigorously than inertial interaction effects.

Kinematic interaction effects are negligible for shallow foundations in a seismic environment consisting exclusively of vertically propagating shear waves or dilatational waves. Kinematic interaction or base averaging effects typically filters out high frequencies. In-situ soil properties are notoriously variable and difficult to determine with any degree of accuracy.

Therefore, a soil model that is easy to implement and computationally efficient is desirable as it enables the user to conduct sensitivity studies and determine the effect of a range of subsurface conditions on the seismic response of the structure that is being modelled. Introducing springs (impedance problem) and dashpots in the base of the structure is the simplest way to take into account the flexible boundary condition for evaluating seismic demands. The results for a uniform half-space are quite amenable. Modelling the foundation soil and base mat with finite elements gives more realistic results but it is too complicated for everyday engineering applications. Seismic codes suggest cases in which SSI should be considered. NEHRP Commentary Studies of the interaction effects in structure-soil systems have shown that within the common ranges of parameters for structures subjected to earthquakes, the results are insensitive to the period and that it is sufficiently accurate for practical purposes to use the static stiffness.

Stiffness properties of soil are less significant than the stiffness and mass properties of super -structure on response. Soil-structure interaction (SSI) can be significant for stiff structures founded on soft soils. The rocking component of SSI effects in general, tend to be most significant for laterally stiff structure such as buildings with shear walls particularly those located on soft soils. In this case the effects of frequency dependence are not usually large because the frequency of this mode of vibration is usually low, and not in the range where the effects are important.

Interactions effects for higher vibration modes are small. Inertial interaction is most important for fundamental model because it has high participation in base shear and base moment. Fundamental period of the flexible-base structures is longer than fixed-base structures as well as effective damping which is higher for the soil-structure system than for the structure alone.

Total displacements of the structure are larger in flexibly based structure and can be quite important for pounding of buildings; on the hand, drifts and damage to structural components are smaller than those of fixed-base structures. The response of soil-structure system is very sensitive to intensity of the input motion. A strong earthquake can bring the soil foundation into the inelastic range reducing the stiffness and increasing the damping while during a small earthquake the soil remains relatively stiff and damping is low. Under some site condition and ground motion properties, SSI can induce detrimental effect on some moderately flexible structures. Similar to the response of structures to far-field earthquakes, the effect of SSI on the seismic performance of structures subjected to near-field earthquake is more pronounced in soft soil types, and has less and negligible effects in stiff and rock soil types, respectively.

System Considered

1. Geometry

The system geometry consists of G+42 Storeys located in Mumbai with plan dimension of 42.2m X 16m. The building will be used for residence. The lateral and vertical load resisting systems are reinforced concrete frames. The frames are composed of columns, shear walls, primary beams and secondary beams.

2. Geological Site Condition

The site condition consists of Yellowish stiff Clay for 3m and Greyish Moderately Weathered Rock beneath.

3. Material and Geometric Properties

Table 1: Material and Geometric Properties of Beams, Shear walls, Raft and Piles.

SR. NO	STRUCTURE	COMPONENT	DETAIL
1.	Frame	a.Storey Height b.Beam Size c.Shear Wall Thickness	Varying (3-3.5m) Varying Varying(0.23-0.45m)
2.	Pile	a.Diameter b.Length	1m 12m
3.	Concrete	a.For shear wall b.For Beamsand Slabs c.For pile andraft	M40 M30 M20
4.	Clay	a.Young'sModulus b.Unit weight	50000kN/sq.m 20kN/cu.m
5.	Sand	a.Young'sModulus b.Unit weight	500000kN/sq.m 20kN/cu.m
6.	Raft	a.Size	

4. Seismic conditions and parameters:

Table 2: List of Seismic parameters

CATEGORY	PARAMETER
Zone	3
Zone Factor	0.16
Importance Factor	1
Response Reduction Factor	5
Vertical irregularity ingeometry	Yes
Soil Type	Soft
Time history	Elcentro City

5. Wind/Gust Category and Parameters

Table 3:List of wind/gust parameters

CATEGORY	PARAMETER
Wind Speed	44m/s
Terrain	3
Structure Class	B
Risk Coefficient(k1)	1
Topography(k3)	1
Windward Co-efficient	0.72
Leeward Co-efficient	0.48
Gust Factor in X-direction	2.28
Gust Factor in Y-direction	2.47

5. Loading Considered

Table 4: Loading considered for slab (kN/sq.m)\

USE	SDL	LL
Parking	1.5	5
Residency Floors	1	2
Staircases	3	3
Lobby	1	3
Balcony	3	2

6. Load combinations

As per IS: 456-2000, following load combinations are applied to the modal:-

1. 1.5(DL + LL)
2. 1.5(DL +/- Wx/Wy)
3. 1.2(DL + LL +/- Wx/Wy)
4. 0.9DL +/- 1.5(Wx/Wy)
5. 1.5(DL +/- Spec1/Spec2)
6. 1.2(DL + LL +/- Spec1/Spec2)
7. 0.9DL +/- 1.5(Spec1/Spec2)

II. Modelling

1. ETABS model:

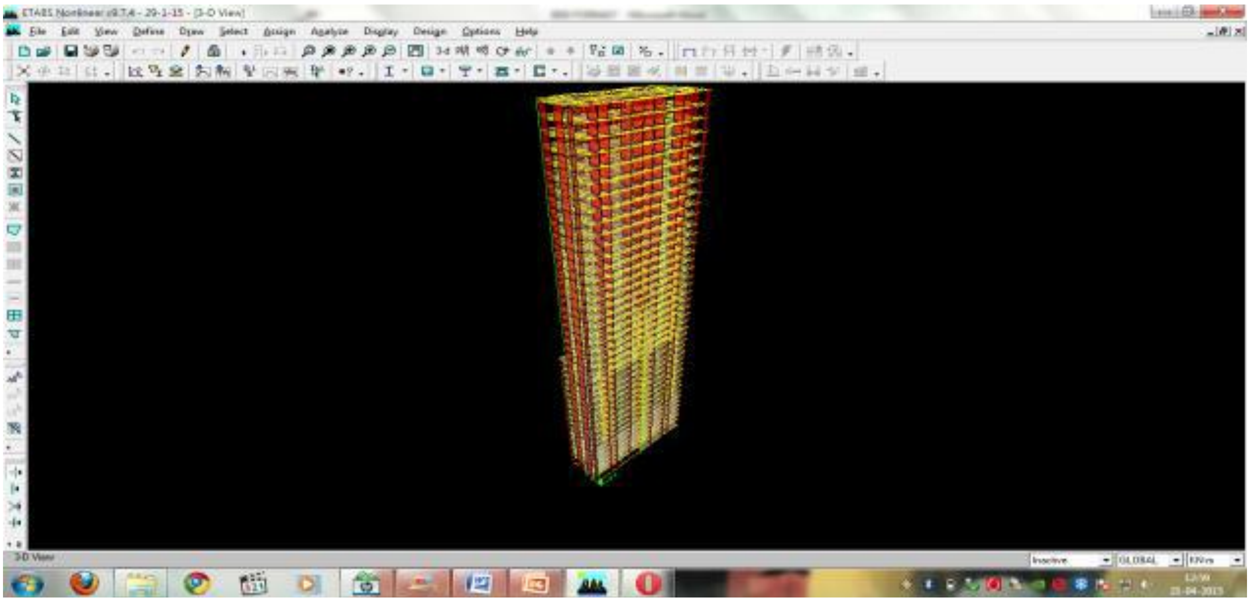
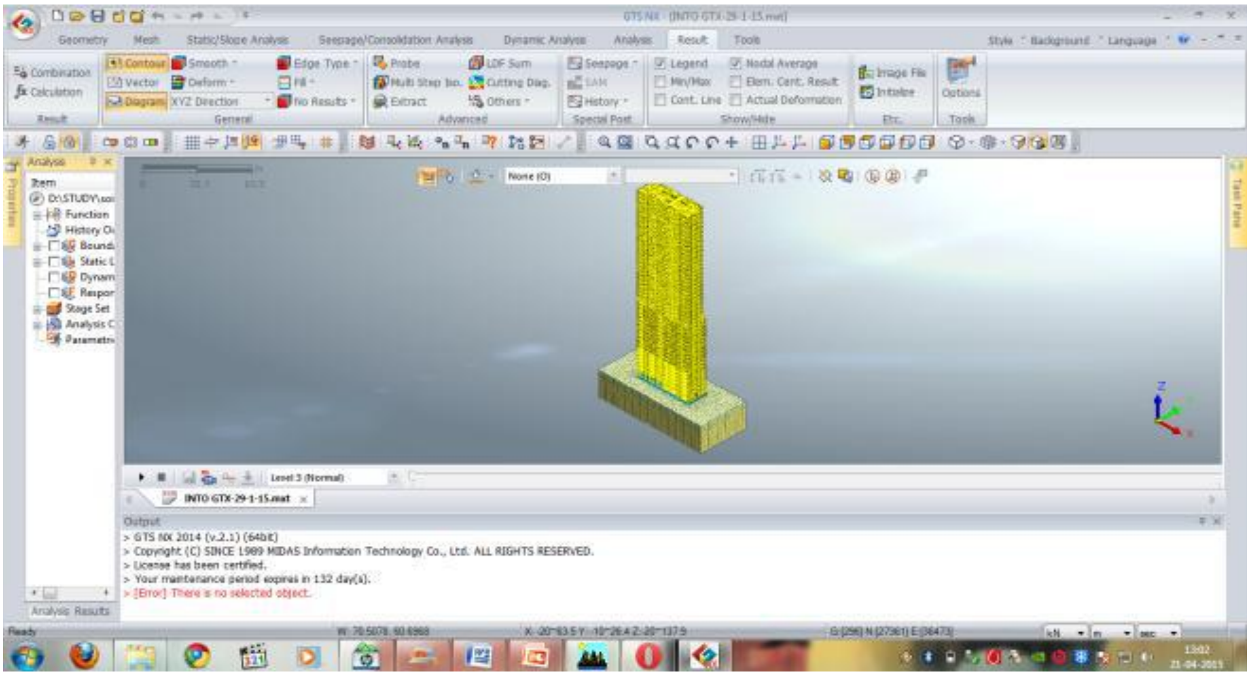


Fig 2: ETABS model

2. Midas soil model with structure:



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> GTS NX 2014 (v.2.1) (64bit)
> Copyright (C) SINCE 1989 MIDAS Information Technology Co., Ltd. ALL RIGHTS RESERVED.
> License has been certified.
> Your maintenance period expires in 132 day(s).
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Fig 3: Soil model in MIDAS GTX NX

III. Results

1. Settlements:

Table 5: Settlement in pile-raft foundation

Step Value	Node: 216 (mm)	Node: 411 (mm)	Node: 635 (mm)	Node: 17100 (mm)	Node: 18007 (mm)	Node: 18296 (mm)	Node: 18363 (mm)
1	0.665053551	0.665053551	0.665053551	0.3020539	0.665053551	0.665053551	0.66505355
1	-1.052440493	-0.909952098	-1.225842629	-0.43410165	-1.21403893	-0.958247983	-0.95191429
1	-13.32722697	-3.601019504	-12.85713352	0.03053371	-10.3427954	-3.71848559	-2.67247646

Table 6: Settlement in raft foundation

No	Step	Step Valu	Node: 216 (m)	Node: 411 (m)	Node: 635 (m)	Node: 18296 (m)	Node: 18363 (m)
1	Constructi	1	0.000845	0.000845	0.000845	0.000845	0.000845
2	Constructi	1	0.001054	0.000912	0.001226	0.00096	0.000955
3	Construct	1	0.013428	0.003742	0.012871	0.004068	0.003034

2. Maximum Reactions:

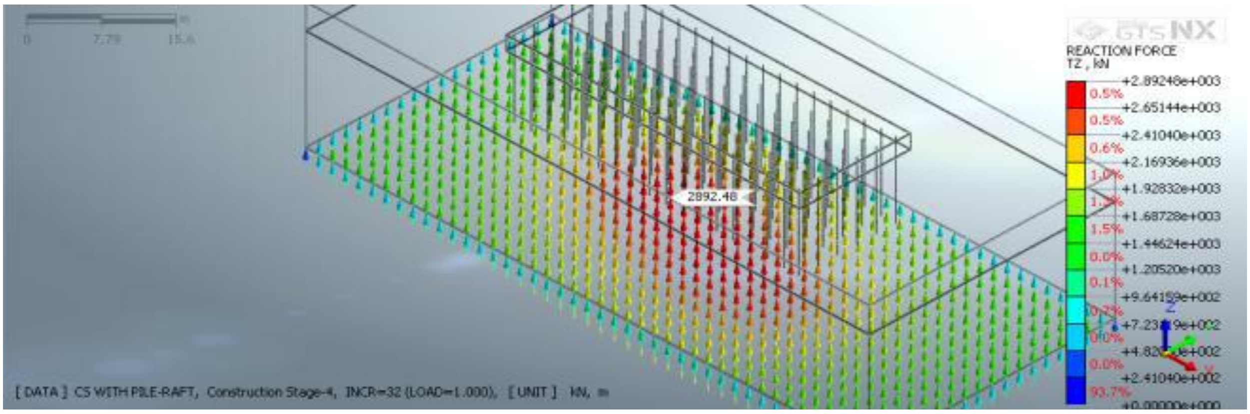

Fig 4: Reaction of pile-raft foundation

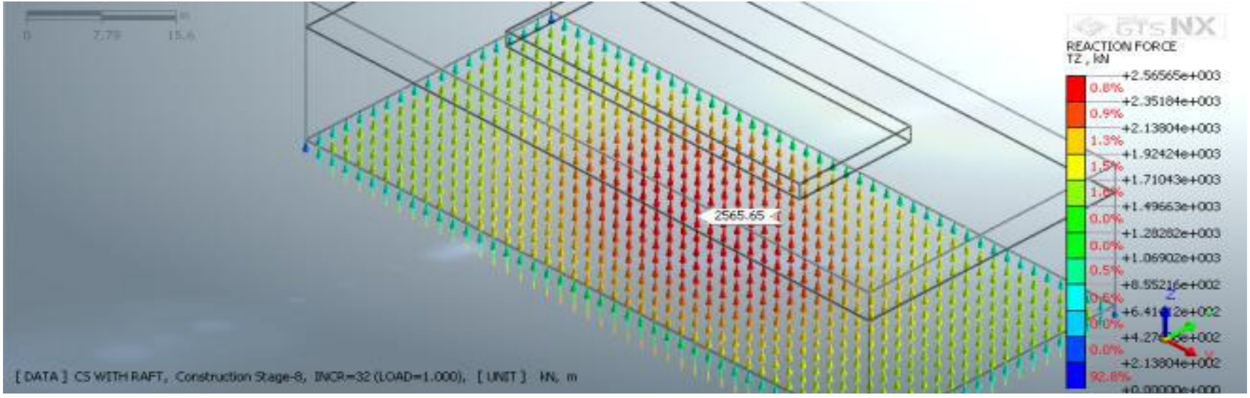

Fig 5: Reaction of raft foundation

3. Solid Stress:

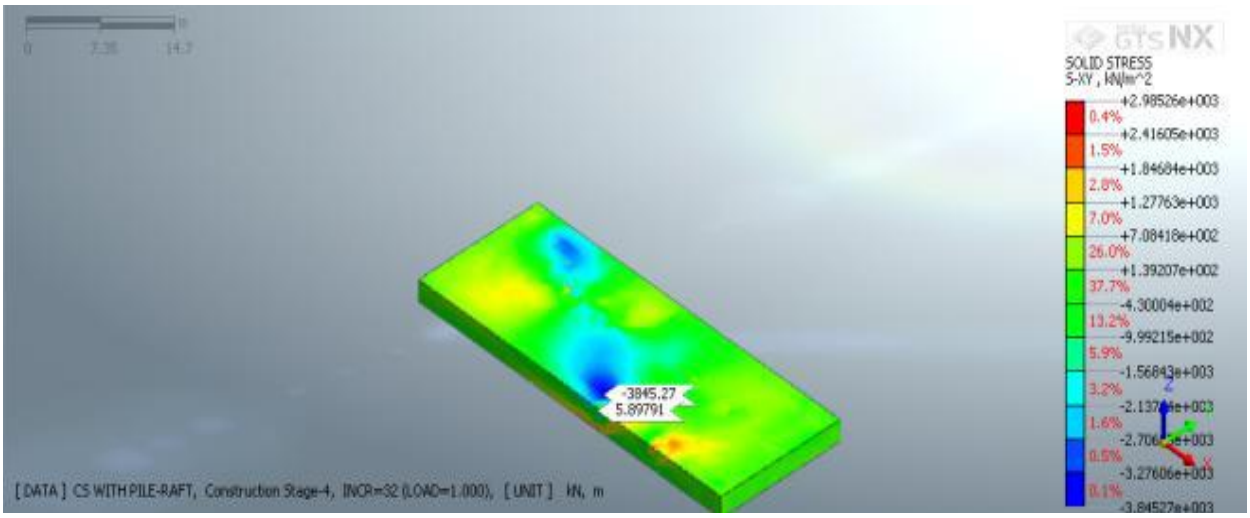

Fig 6: Solid stresses in pile-raft foundation

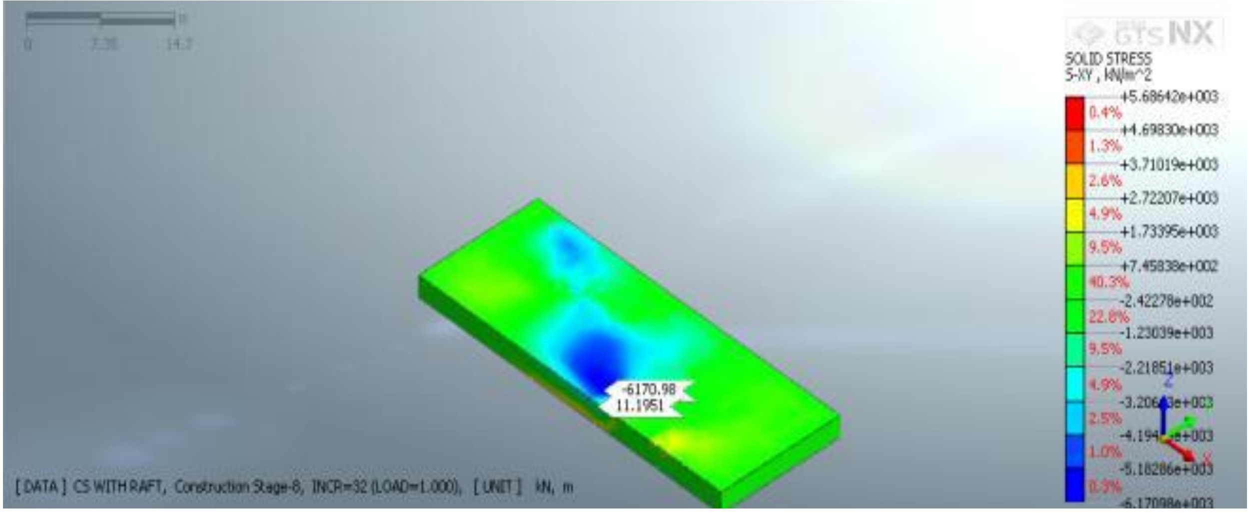

Fig 7: Solid stresses in raft foundation

IV. Conclusion

1. At the very beginning one should estimate the importance of SSI and decide whether it should be considered at all. The answer depends on the soil data (wave velocities in the soil, first of all), base mat size/embedment and inertia of the structure. For civil structures most often SSI can be omitted.
2. If SSI is to be considered, one should examine whether some simple assumptions can be applied. Main assumptions: homogeneous half-space or a layer underlain by rigid rock as a soil model, surface base mat, rigid base mat. General recommendation is as follows. One should start with the simplest model allowed by standards. Only if the results seem over conservative, one should try to go to more sophisticated models, accounting to various specific SSI effects.
3. SSI effects are frequency-dependent. Most of effects are valid in a certain frequency range. Out of this range they may lead to the opposite changes.
4. If direct approach is used, special attention should be paid to the boundaries. Preliminary analysis of test examples (e.g., initial soil without structure with the same boundaries and excitation) is strongly recommended.
5. Wave nature of SSI effects requires special attention when FEM is used: element size for the soil and time step must be compared with frequency ranges of interest. Otherwise, the most significant effects may be missed.
6. Non-linearity of different kinds is to be treated properly. Primary non-linearity of the soil is handled by SHAKE. Contact non-linearity is treated approximately as described above. If a structure it is considerably non-linear, usually one has to omit wave SSI at all.

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