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Influence of Height in Simulation of Soil Structure Interaction Problems with Dampers

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Abstract

In numerical simulation of soil structure interaction problems the presence of dampers in the frame is an advantage yet a special topic to be considered. This paper presents valuable observation on the dynamic soil structure interaction analysis of multi storey frames and considers the effect of height in simulation of soil structure interaction problems. Comparison of these problems has been done by comparing the obtained results from different set up in the software ANSYS. The results of numerical analysis illustrate that it has to be paid more attention when considering the structures not alone but also considering the effect of soil medium.

Key words: dampers, soil structure interaction, infinite elements

1 Introduction

The problems in soil structure interaction arise when computing the structural response to seismic response. The inclusion of the soil structure interaction effects influences the results considerably [1]. In numerical simulation of frame structures considering the earthquake input as time dependent acceleration there have been significant advances in softwares. The missing point however has been the treatment of soil structure interaction SSI effects considering the presence of damper elements. Namely the presence of damper elements changes the response of the structural response although in definite conditions the results might not be promising.
On the other hand, in numerical simulation of soil medium as a wide region the boundaries should be given special concern not to impact the results by reflection of the traveling waves in the soil medium. In dynamic analysis the situation is additionally complicated by the inertia terms such the radiation of the wave should be considered. This paper deals with both damper and soil effects in the SSI problem of several frames consisting of different number of storeys. The results show promising points to be considered.

2 Infinite Elements

The formulation of infinite elements is the same as for the finite elements in addition to the mapping of the domain. Infinite elements are first developed by Zienkiewicz et al. [2] and since then have been developed in frequency and time domain. In the work of Häggblad et al. [3] infinite elements with absorbing properties have been proposed which can be used in time domain. In this work the development of infinite element has followed the techniques considering the time domain in which the infinite element is obtained from a six nodded finite element as shown in Figure 1.

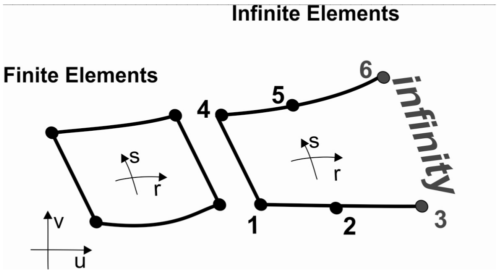

Figure 1: Coupling of Finite and Infinite elements

The element displacement in *u* and *v* direction is interpolated with the usual shape functions N1, N2, N4 and N5:

$$u = [N_1 \quad N_2 \quad 0 \quad N_4 \quad N_5 \quad 0]\mathbf{u}$$
$$v = [N_1 \quad N_2 \quad 0 \quad N_4 \quad N_5 \quad 0]\mathbf{v} \tag{1}$$

In expression (1) *u* and *v* are vectors with nodal point displacements in global coordinates.

$$\begin{aligned} N_1 &= -(1-s)r(1-r)/4 \\ N_2 &= (1/2)(1-r^2)(1-s) \\ N_4 &= -(1+s)r(1-r)/4 \\ N_5 &= (1/2)(1-r^2)(1+s) \end{aligned} \tag{2}$$

For coordinate interpolation in *r*-*s* coordinate system a one-dimensional mapping is applied.

$$r = [M_1 \quad M_2 \quad 0 \quad M_4 \quad M_5 \quad 0]\mathbf{r}$$
$$s = [M_1 \quad M_2 \quad 0 \quad M_4 \quad M_5 \quad 0]\mathbf{s} \tag{3}$$

$$
\begin{aligned}
M_1 &= -\frac{(1-s)r}{1-r} \\
M_2 &= -\frac{1}{2}\frac{(1-s)(1+r)}{1-r} \\
M_4 &= -\frac{(1+s)r}{1-r} \\
M_5 &= -\frac{1}{2}\frac{(1+s)(1+r)}{1-r}
\end{aligned} \tag{4}
$$

In expression (3) *r* and *s* are vectors of nodal point displacements in local coordinates where it is to be mentioned that on the side of infinity (r=1) no mappings have been assigned to the nodes as it is taken that no displacement is possible at infinity. Construction of element matrices is done by using the usual procedures as described in Bathe [4]. The new coordinate interpolation functions are taken into consideration in the Jacobian matrix as described in Bettess [5]. The approximation for the element integrals is done by Gauss quadrature formulas. For the absorbing layer of the infinite element Lysmer-Kuhlmeyer approach [6] is used. In all cases plane strain two dimensional case is studied. For impact of plane waves on element sides normal and tangential stresses are derived as:

$$
\begin{bmatrix} \sigma_n \\ \tau \end{bmatrix} = \begin{bmatrix} a\rho c_p & 0 \\ 0 & b\rho c_s \end{bmatrix} \begin{bmatrix} \dot{u}_n \\ \dot{u}_t \end{bmatrix} \tag{5}
$$

where *cp* and *cs* indicate compression and shear waves, ρ is the density of soil medium. In order to take into account the directions of the incident waves coefficients *a* and *b* as suggested in White et al. [7] are used as multipliers for better numerical results. Transformation from local to global coordinates is done automatically by the software ANSYS such that there is no need of defining transformation matrices. By bringing together the contributions from each element the governing incremental equations for equilibrium in dynamic analysis are obtained. Time derivatives are approximated by Newmark's method and equilibrium iterations are used in each step as given in the Theory reference of ANSYS software.

3 Dampers

Mathematical modeling of dampers was done using combin14 element (Figure 2).

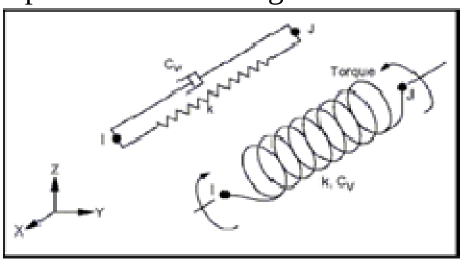

Figure 2: Analytical Model for damper device

Mass of the damper, 60 kg, is added by using the appropriate mass element mass21 in the software ANSYS. The element works based on Kelvin Vought model and is defined by two nodes, a spring constant (k) and damping coefficients C_{V1} and C_{V2}. The damping portion of the element contributes only damping coefficients to the structural damping matrix as given in work of authors [8-11]. The damping force (F) is computed with the following equation:

$$Fx = -Cv\frac{dUx}{dt} \tag{6}$$

where $cv=cv^1+cv^2$ *v* is damping coefficient and *v* is velocity calculated in the previous step. Since the damper elements are pre-stressed with a force of 30 KN a preload in the spring as a compression is specified through an initial force input in the combin 14 element. In the process of optimization for the damper elements the following characteristics have been used: stiffness of the spring K=1000kN/m, c**v**=35 kNs/m and pre-stress force F=30kN. These types of dampers achieve 10% added damping in the structure for reducing the response and improve the performance for earthquake excitation.

4 Coupled soil structure system response

In order to show the influence of storey numbers in frame elements considering soil structure interaction problems, a comparison of different height of structures are performed. In this direct time-domain method, the soil medium is modeled by two dimensional quadrilaterals using the finite element method. Similar soil-structure interaction problems have been studied in the works of other authors. In order to provide a complete insight, the soil side boundary of infinite elements is used. The frame structural elements are idealized as two dimensional elastic beam elements having three degrees of freedom at each node, translations in the nodal x and y directions and rotation about the nodal z axis. The behavior of the frame structure is supposed to be elastic and has been modeled by using two parameters, the modulus of elasticity E=3.15x107 kPa and Poisson's ration n=0.2. The bay length of the frame is taken to be 4.0 m, while the storey height is 3.0 m. The section of beams is 40 x 50 cm while that of the column is 50 x 50cm. For all frames, the beam and column sections, the floor masses and the number of bays are considered to be of concrete. The structures are modeled as one, four and eight-storey frame. The soil medium is presented as a two dimensional model composed of four layers resting on bedrock. In Table 1, the soil layers properties are tabulated in a way that the bottom layers are characterized by better soil characteristics.

Table 1: Soil properties

Number of layer	Thickness (m)	Unit weight (kN/m^3)	Shear velocity (m/s)
1	3	19	330
2	7	19	420
3	8	21	510
4	12	23	690

The soil is assumed to represent a linear-elastic material and is discretized by using eight nodded plane strain elements. The dynamic analysis has been performed by transient analysis using the step by step method. The proportional viscous damping matrix is taken to be proportional to mass and stiffness matrix (Rayleigh damping). Finite element modeling of the coupled soil-structure system is performed by use of the software ANSYS [12], as shown in Figure 3. The effect of soil-structure interaction is carried out by using the acceleration time history of the El Centro earthquake with a scaled peak ground acceleration of 0.30g. The moment transfer capability between the column and the footing is created by using a constraint equation where the rotation of the beam is transferred as force couples to the plane element as given in the ANSYS software manual [12]. In order to simulate the soil medium correctly side boundaries of infinite elements are used such that the wave propagation in the soil domain is simulated correctly.

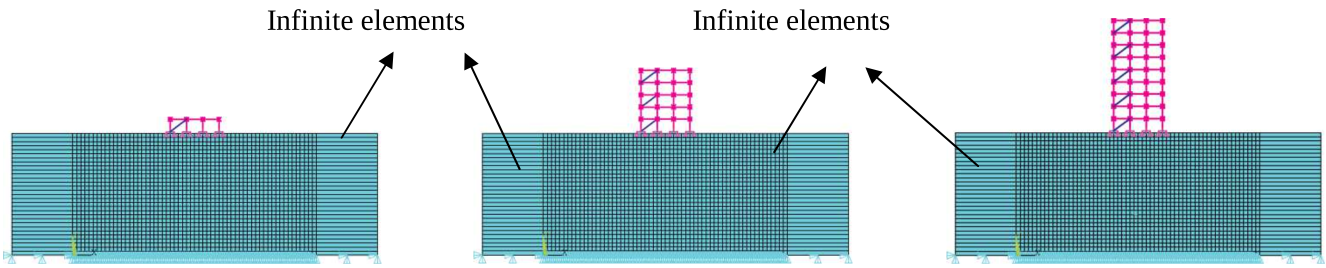

Figure 3: Frame element system with soil layers as foundation

The results obtained show interesting outcomes. First of all the structural moments obtained at the top of the structures are shown in the Figure 4. It is quite interesting to see that the one storey structure has an effect of resonance due to the fact that the soil layers alone have a natural frequency of 10Hz.

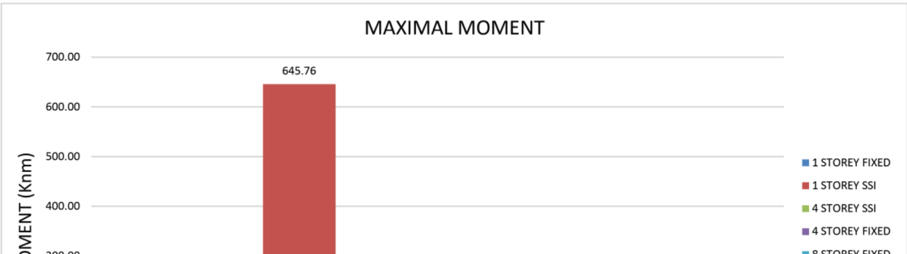

Figure 4: Variation of structural moments at the top of structures

On the other hand, the difference of structural moment results of four and eight storey structures show that the presence of soil layers does make difference in the results. On the other hand the comparison of maximal acceleration as given in Figure 5 clearly shows that the presence of soil layers increases the acceleration at the structural elements. This is a logical result since there is an expected amplification of the acceleration in the soil layers.

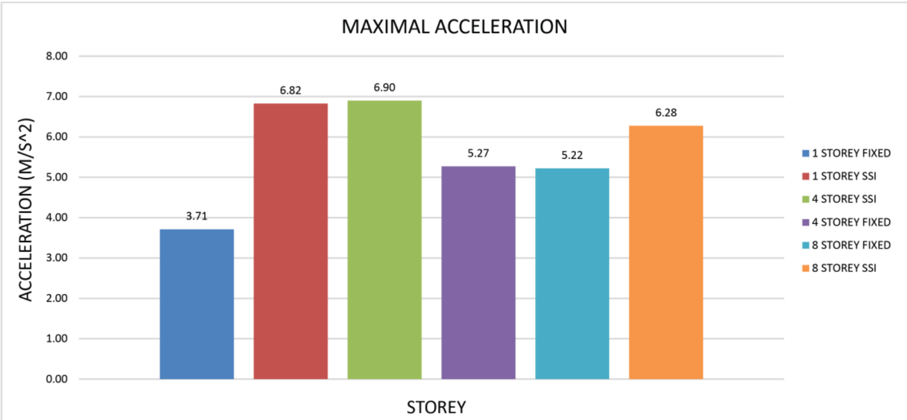

Figure 5: Variation of structural response acceleration

The Figure 5 has an interesting point that the one storey structure has the biggest relative increase in the values. This is reasonal since the effect of resonance has the effects also in maximal acceleration. When considering the maximal displacements as given in Figure 6, it is quite interesting that the displacements are quite smaller when the effect of soil structure interaction is considered.

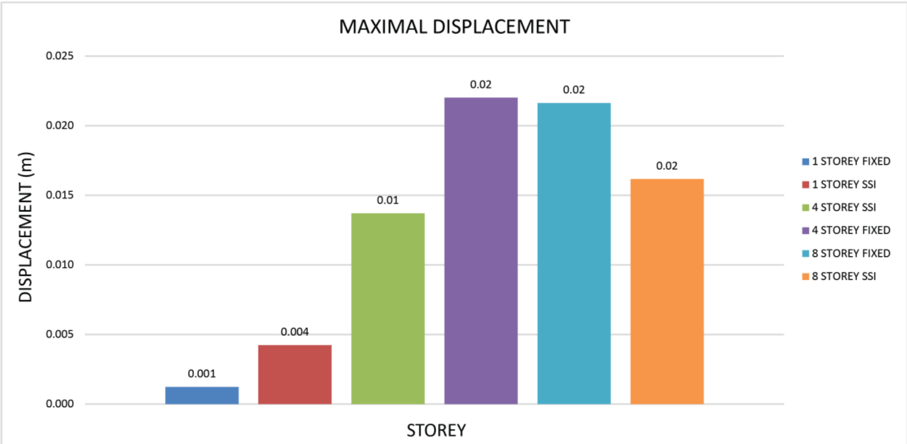

Figure 6: Variation of structural response displacement

Considering the above stated it might be concluded that the soil structure interaction effects have both positive and negative effects on the results. Namely, the structural response of acceleration is increased when considering the SSI effects. On the other hand, the effects of soil layer presence decrease the maximum displacements at the structures. This hold mainly for bigger number of storeys.
Since acceleration and displacement appear to be of importance in SSI problems, next the complete dynamic soil structure interaction time history analyses are performed.

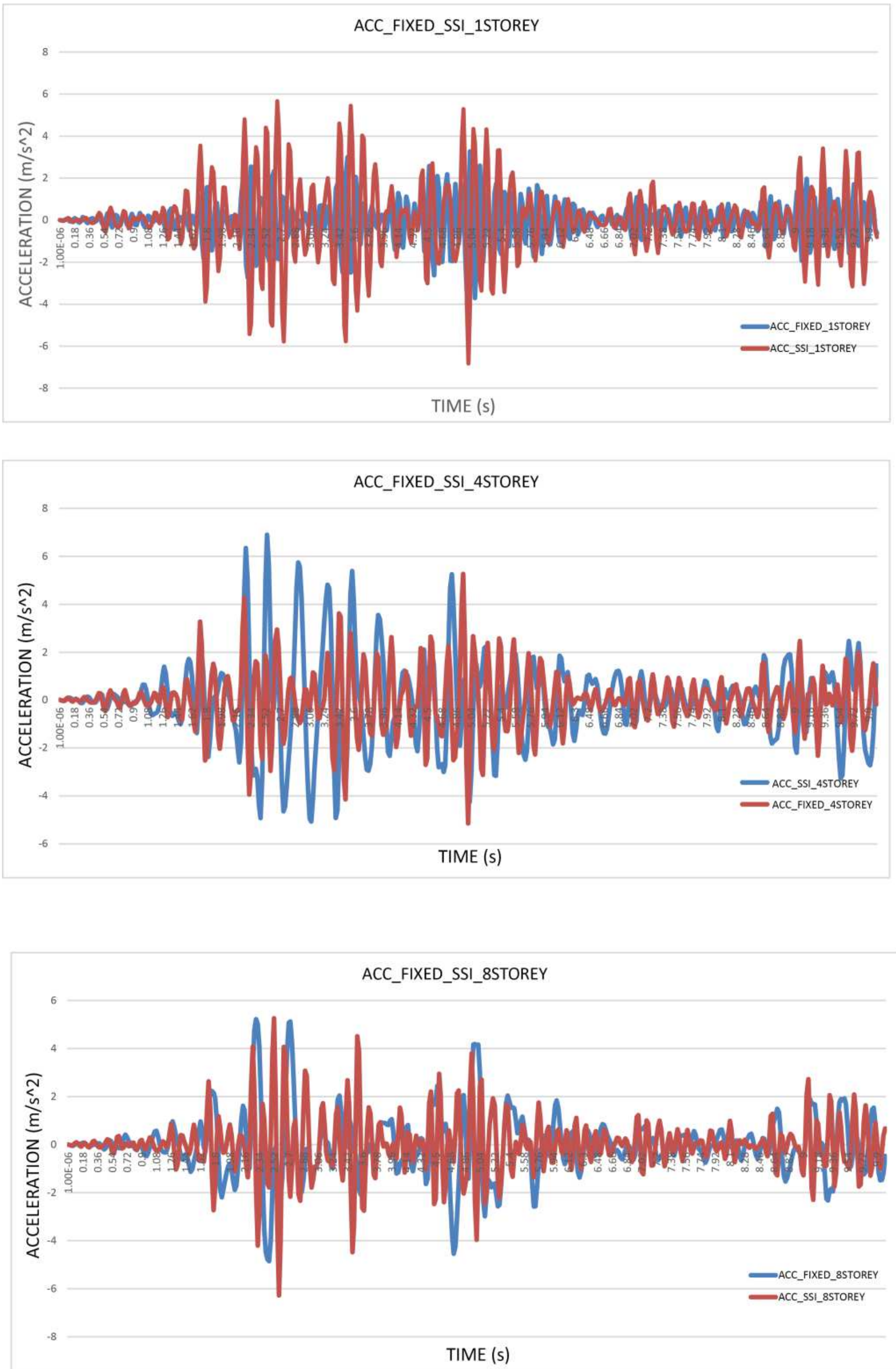

Figure 7: Comparisons of time history responses for acceleration for 1, 4 and 8 storey structure

As can be seen from the Figure 7 the acceleration time history is mostly influenced in eight storey frame structure. The results in Figure 7 show that the red lines which represent the SSI effects are dominant in the figure. This shows that the influence of SSI is crucial.

Next in Figure 8 the displacement time history analysis for one, four and eight storey are given. It is clearly seen that the displacement increase due to soil layer presence is effective through all time of earthquake effect.

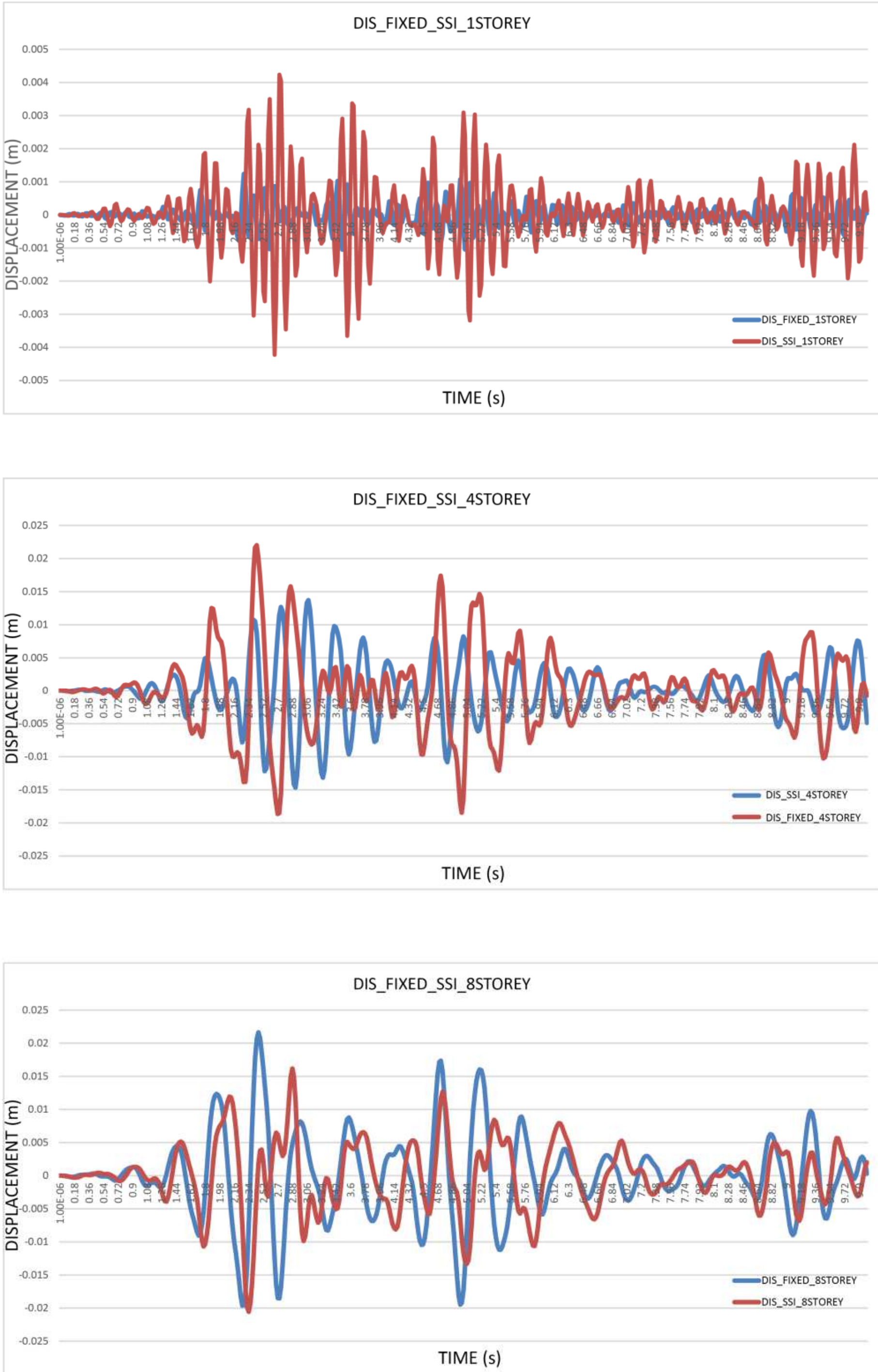

Figure 7: Comparisons of time history responses for displacement for 8 storey structure

Last but not least is to state that the dampers are present in all structural frames and their presence is considered to absorb the seismic energy. The detailed analysis is given elsewhere by the same authors. This fact reveals that, in the case of massive structure founded on soft soils, the interaction effects are expressed greatly. The same effect is seen when the structure has a big height especially when compared with other structures with smaller heights.

5 Conclusion

In this work the coupled computational method of finite and infinite elements has been used in soil structure interaction problems. For the numerical simulation the local region of interest is modeled by finite elements which enable simulation of more complex geometries.
On the other hand the surrounding filed of the domain is considered using the infinite elements which have the capability to simulate the infinite region very well. In numerical simulations ANSYS software is used where using its programmable features it is possible of programming new elements such as the infinite elements.
In order to make the comparison complete, different storey number for frames have been used. Evaluation of numerical analysis shows that one storey frame has small soil structure interaction influence. In contrast, when the storey number increases a more significant soil structure influence was observed.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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