Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2016, 3(2):132-139**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Simulation of soil structure interaction problems considering material properties

Aleksandra Bogdanovic, Kemal Edip, Marta Stojmanovska

University "Ss. Cyril and Methodius" Institute of Earthquake Engineering and Engineering Seismology-IZIIS

Abstract In numerical simulation of soil structure interaction problems the issue of presence of dampers in the frame is considered. In this work, problems of dynamic conditions considering the frame materials are considered. 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 using it must be paid more attention when considering the structures with and without damper elements.

Keywords Dampers, soil structure interaction

1. Introduction

In simulation of frame structures considering the seismic input as time dependent acceleration there have been significant advances in softwares. A missing point however has been the treatment of soil structure interaction SSI effects on both the strong motions transmitted to the structure and the structural response to these motions. Moreover, 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. The presence of damper elements is of great importance since structural elements are concerned as real elements. This paper deals with both damper and soil effects in the SSI problem of a three storey frame. In order to make a complete analysis the frame structure is considered both as concrete and as a steel structure. The results show promising point 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.*, [1] and since then have been developed in frequency and time domain. In the work of Häggblad *et al.*, [2] 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.

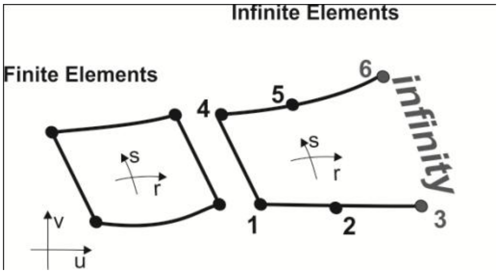

Figure 1: Coupling of Finite and Infinite elements

The element displacement in u and v direction is interpolated with the usual shape functions N_1, N_2, N_4 and N_5:

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

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

$$N_1 = -(1-s)r(1-r)/4$$
$$N_2 = (1/2)(1-r^2)(1-s)$$
$$N_4 = -(1+s)r(1-r)/4 \qquad (2)$$
$$N_5 = (1/2)(1-r^2)(1+s)$$

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

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

where

$$M_1 = -\frac{(1-s)r}{1-r}$$
$$M_2 = -\frac{1}{2}\frac{(1-s)(1+r)}{1-r}$$
$$M_4 = -\frac{(1+s)r}{1-r} \qquad (4)$$
$$M_5 = -\frac{1}{2}\frac{(1+s)(1+r)}{1-r}$$

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 [3]. The new coordinate interpolation functions are taken into consideration in the Jacobian matrix as described in

Bettess [4]. The approximation for the element integrals is done by Gauss qaudrature formulas. For the absorbing layer of the infinite element Lysmer-Kuhlmeyer approach [5] 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:

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

Where, c_p and c_s 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*., [6] are used as multipliers for better numerical results. Transformation from local to global coordinates is done automatically by the software ANSYS [7] 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 modelling of PDDs was done using combin14 element (Figure 2).

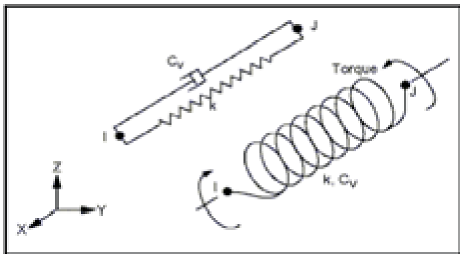

Figure 2: Analytical Model for damper device (PDD)

Mass of the damper, 60 kg, was added by using the appropriate mass element mass 21.The element works based on Kelvin Vought model and is defined by two nodes, a spring constant (k) and damping coefficients CV_1 and CV_2. The damping portion of the element contributes only damping coefficients to the structural damping matrix.

The damping force (F) is computed with equitation given bellow:

$$Fx = -Cv\frac{dUx}{dt} \quad (1)$$

Where CV=CV1+CV2**v** is damping coefficient and **v** is a velocity calculated in the previous step. Because the PDDs were pre-stressed with a force of 30 KN (same as the experimental tested PDDs) a preload in the spring as a compression is specified through an initial force (IFORCE) input in the combin14 element. In the process of optimization for the PDDs the following characteristics have been used: stiffness of the spring K=1000kN/m, CV=35 kNs/m and pre-stress force F=30kN. This type of dampers achieves 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 the dampers in material selection considering soil structure interaction problems, a comparison of boundary cases in the soil structure interaction problem are performed. In this direct time-domain method, the soil medium is modelled 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 behaviour of the frame structure is supposed to be elastic and has been modelled by using two parameters, the modulus of elasticity $E=3.15x10^7$ 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. Three different materials namely, concrete, steel and wood frames are taken into consideration. For all frames, the beam and column sections, the floor masses and the number of bays are considered to be of concrete, steel and wood . The structures are modeled as three-storey frames. The soil medium is presented as a two dimensional model composed of four layers resting on bedrock. In Table 2, 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	4	17	355
2	6	18	435
3	6	18.5	525
4	14	19	720

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 modelling of the coupled soil-structure system is performed by use of the software ANSYS [7] , 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 0.25g. 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.

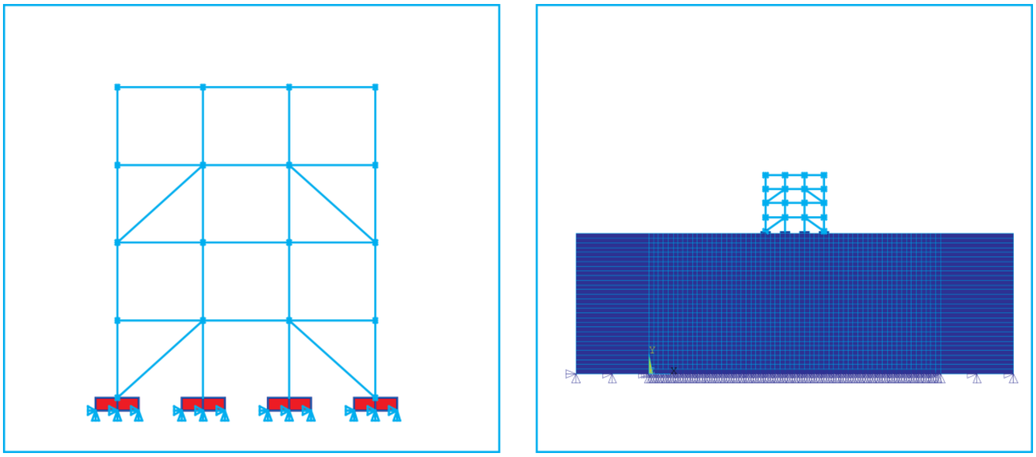

Figure 3: Three storey system with fixed foundation and soil layers

In Figure 3 the coupled system of the soil-structure system is shown. The side boundaries are presented as fixed, viscous and infinite element boundaries. In the case of infinite element boundary, the soil domain is discretized by less elements (two thirds) compared with the analysis of fixed and viscous boundaries.

In Table 3 below, the difference in the structural response is given.

Table 3: Variation of Structural response quantities without dampers

Foundation	Frame structure	Max. acceleration at top of Str. (m/s^2)	Max. displacement at top of Str. (cm)	Max. moment at top of Str. (kNm)
Fixed	Steel	8.28	0.995	127.1
	Concrete	5.46	1.71	49.2
	Wood	2.61	0.52	0.11
Soil layers	Steel	7.22	1.73	187.2
	Concrete	5.63	1.48	95.88
	Wood	2.60	0.56	0.21

Table 4: Variation of Structural response quantities with dampers

Foundation	Frame structure	Max. acceleration at top of Str. (m/s^2)	Max. displacement at top of Str. (cm)	Max. moment at top of Str. (kNm)
Fixed	Steel	8.28	0.995	127.1
	Concrete	5.46	1.71	49.2
	Wood	2.61	0.55	0.01
Soil layers	Steel	7.22	1.73	187.2
	Concrete	5.63	1.48	95.88
	Wood	5.76	0.56	0.17

Comparisons of time history responses for acceleration and displacement for steel, wood and concrete structure with and without pdd for two different conditions are given bellow (fig.5-fig7). The same tendency is confirmed for fixed case and case with soil layers previously commented in the tables above.

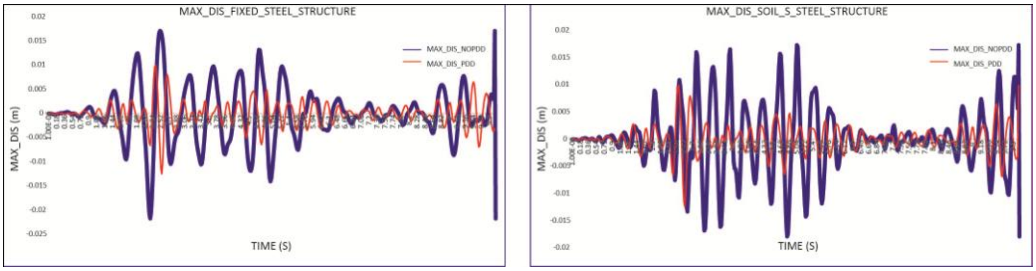

Figure 4: Comparisons of time history responses for displacement for fixed and soil layers for steel structure with and without pdd dampers

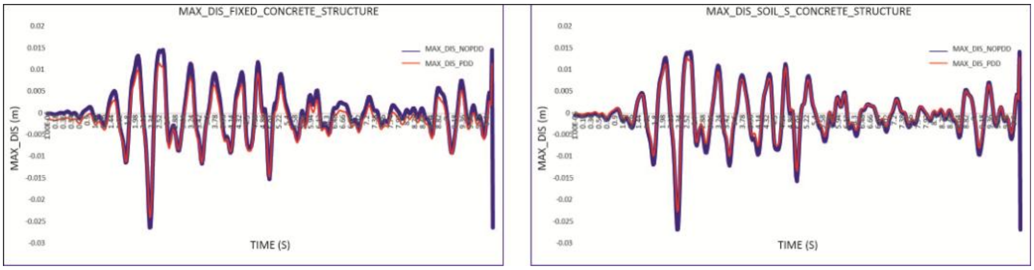

Figure 5: Comparisons of time history responses for displacement for fixed and soil layers for concrete structure with and without pdd dampers

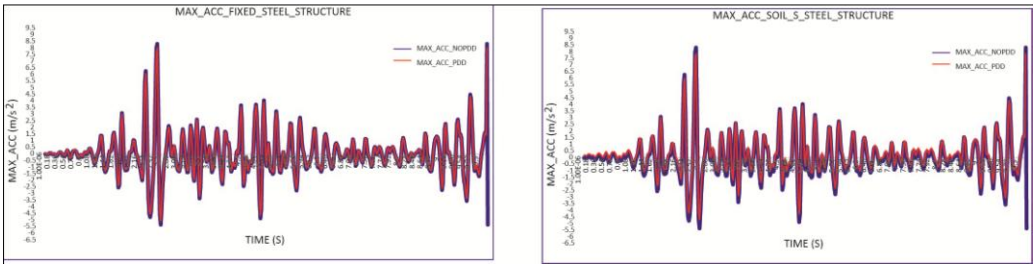

Figure 6: Comparisons of time history responses for acceleration for fixed and soil layers for steel structure with and without pdd dampers

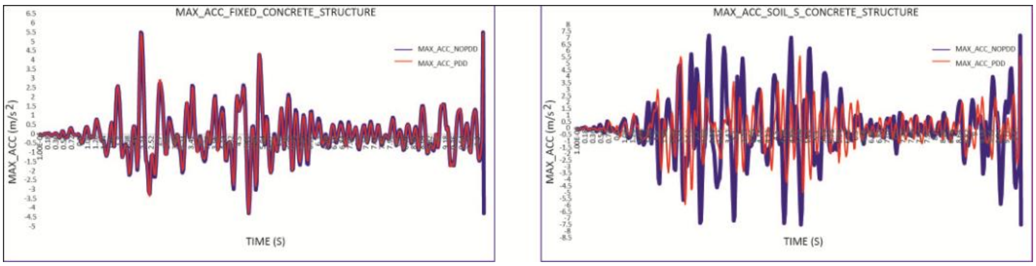

Figure 7: Comparisons of time history responses for acceleration for fixed and soil layers for steel structure with and without pdd dampers

According to the acceleration values in Table 3, the maximum acceleration at the top of the structure is considerably increased when using fixed boundaries. On the other hand, when using viscous and infinite element boundaries, the results of acceleration, displacement and moment at the top frame elements show similar values. The main difference is that, when using the coupled finite-infinite elements, the number of finite elements is decreased considerably, saving extra work and time. When comparing the soil stiffness, it is clearly seen that, in the case of soft soil the difference in structural moment values between the fixed and the infinite element boundaries is nearly two times. This fact reveals that, in the case of massive structure founded on soft soils, the interaction effects are expressed greatly. The number of stories affects the results in such a way that the higher storeys exhibit a bigger displacement (which is also expected) that should be considered in the element analysis, separately. To sum up, the usage of the proposed infinite elements in soil-structure interaction problems decreases the number of finite elements without affecting the correctness of the final results. Thus, the usage of coupled finite infinite elements is advised particularly in complex geometries of soil media.

4. Conclusion

In this work the coupled computational method of finite and infinite elements has been presented in selected geotechnical problems. For the numerical simulation of geotechnical problems 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. The obtained numerical results are reliable and further application of coupled finite and infinite elements can be considered in the field of soil structure interaction (Edip et al., 2011). Since the programmed infinite elements are in time domain non-linearity of materials can be also simulated in the finite element region.

References

[1]. Zienkiewicz, O. C., Emson, C., & Bettess, P. (1983). A novel boundary infinite element. *International Journal for Numerical Methods in Engineering*, *19*(3), 393-404.

[2]. Häggblad, B., & Nordgren, G. (1987). Modelling nonlinear soil-structure interaction using interface elements, elastic-plastic soil elements and absorbing infinite elements. *Computers & Structures*, *26*(1-2), 307-324.

[3]. Klaus-J 鏴 rgen· Bathe. (1982). *Finite element procedures in engineering analysis*. Prentice-Hall.

[4]. Bettess, P. (1992). *Infinite elements*. Penshaw Press.

[5]. Lysmer, J., & Kuhlemeyer, R. L. (1969). Finite dynamic model for infinite media. *Journal of the Engineering Mechanics Division*, *95*(4), 859-878.

[6]. White, W., Lee, I. K., & Valliappan, S. (1977). Unified boundary for finite dynamic models. *Journal of the Engineering Mechanics Division*, *103*(5), 949-964.

[7]. ANSYS, 2007, www.ansys.com, FEM-Software, ANSYS Inc.,Version 11.0

[8]. Edip, K., Garevski, M., Sesov, V., Gjorgjiev, I., & Cvetanovska, J. (2011). Boundary effects on seismic analysis of multistorey frames in soil structure interaction problems *14th International Symposium of Macedonian Association of Structural Engineers (MASE)* 28 September – 01 October, 2011 Struga, Macedonia.

[9]. Abdel-Fattah, T. T., Hodhod, H. A., & Akl, A. Y. (2000). A novel formulation of infinite elements for static analysis. *Computers & Structures*, *77*(4), 371-379.

[10]. Rakicevic, Z., Bogdanovic, A., & Jurukovski, D. (2009). Shaking table effectiveness testing of GERB PDD (prestressed damping device) control system. *IZIIS Report*, *40*.

[11]. Rakicevic, Z., Bogdanovic, A., Jurukovski, D., Kammerer, H., & Nawrotzki, P. (2010). "Shaking Table Testing of a Steel Frame Structure Without and With GERB Prestressed Damping Devices", *5th World Conference on Structural Control and Monitoring*, *12-14 July 2010, Tokyo, Japan*, Session E-8, Paper No 226.

[12]. Ohrid, R., Macedonia Lago, A., Sullivan, T.J., & Calvi, G.M. (2012). "Analytical Estimation of the Effectiveness of Prestressed Damping Devices Using Shaking Table Experiments, *14Europian Conference on Earthquake Engineering, 29-3 September.*

[13]. Bogdanovic, A., Rakicevic, Z., Filipovski, D., & Markovski, I., (2013). "Seismic Design of Structures with Passive Energy Dissipation Systems", *IUSS Report, In press.*