KINEMATIC INTERACTION OF STRIP EMBEDDED FOUNDATION WITH INCOMPLETE CONTACT BETWEEN SIDEWALL AND SURROUNDING SOIL

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ABSTRACT

In the field of soil-structure interaction (SSI), Kinematic Interaction (KI) can potentially be a source of notable influences on structure dynamic response. Such influences take place through alternation in foundation input motion. In this paper, first the effect of KI on input motion for the case of single rigid strip embedded foundation with incomplete contact between sidewall and nearby soil, under vertical propagation of shear waves is investigated. Then it is discussed that how this input-change would be reflected in response spectrum. Results for different embedment depths and various soil-wall contact lengths of foundation are depicted. In this research, numerical analysis was conducted by ABAQUS, finite element software. It is shown that for high frequencies of excitation, significant intensification of input motion would be expected, as besides horizontal input, a rotational component will be generated because of embedment depth. Also it seems, an optimum sidewall contact length can be found through which, minimum ordinates of input motion would excite soil-structure systems.

INTRODUCTION

Evaluation of dynamic response of structure requires consideration of soil structure interaction. Kinematic interaction, (KI), is one of the prominent topics in the field of Soil-Structure interaction that would alter the seismic input motion. In other words, KI change the free field motion (FFM) of ground due to earthquake loading. This alternation usually modifies the frequency content and even may become a source to generate a set of input motions in new degrees of freedom (Bielak, 1974; Iguchi, 1982). A well-known example of the above phenomena is the reduction in horizontal amplitude and inducing rocking input motion to embedded foundation under vertical propagating shear waves (Mori and Fukuwa, 2012; Pais and Kausel, 1985). According to previous findings, KI would be affected by different parameters like properties of soil, shape of foundation, and depth of embedment. KI is usually quantified by transfer function (TF) which is the ratio of foundation input motion (FIM) components to free field motion in frequency domain. Veletsos and Prasad (1989) reported the effect of incident incoherent wave field on circular massless-foundation response. KI effects on embedded rectangular foundation was formulated and examined by field data (Hoshiya, 1983). Iguchi (1984) estimated dynamic response of cylindrical foundation due to variation of foundation embedment depth and incident wave angle. Gives (2012) demonstrated that the model suggested by ASCE-41 and NIST for considering KI effects were overestimated relative to those from Japanese codes to date.

However most researches in this field are formed based on the assumption of full contact between foundation and surrounding medium. That is while the more realistic case of partial contact with neighbouring medium has rarely been investigated yet (Ahmad and Bharadwaj, 1991). The other notable point is that the influence of KI on the response spectrum has not attracted enough attentions in spite of it's engineering prominence.

Here, the effect of KI on input motion to strip foundations with incomplete soil-wall contact is presented. Then it is illustrated that how this effect alters the structure response spectrum.

State of the problem

As mentioned before, the order of KI effects depends on different parameters. Although Importance of Foundation characteristics especially embedment depth on FIM was discussed widely, one of the notable points, which is the contact length of foundation sidewall to surrounding soil, has not been considered comprehensively, yet. The other significant point is the influence of KI on the response spectrum which has not attracted enough attentions in spite of it's engineering prominence.

In this paper, first the effect of KI on input motion for the case of single strip embedded foundation with incomplete contact between sidewall and nearby soil, under vertical propagation of shear waves is investigated. Then it is discussed that how this input-change would be reflected in response spectrum. The model detail and its parameters are illustrated in Figure1, in which D is embedment depth, d is contact length and a is half wide of the foundation.

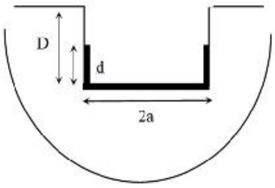


Figure 1. Strip foundation with partial contact of sidewall with the soil

MODELLING AND VALIDATION

Numerical analysis is conducted by ABAQUS, finite element software, to extract the transfer function (TF) components of kinematically induced input motions. This simulation was two dimensional and done for strip foundation subjected to vertical propagating field of shear wave. Figure 2 depicts the sample deformed shape at an arbitrary time and input pulse inserted at the base of the model. Free field columns besides viscoelastic boundaries were utilized as non-reflecting boundary conditions in this model.

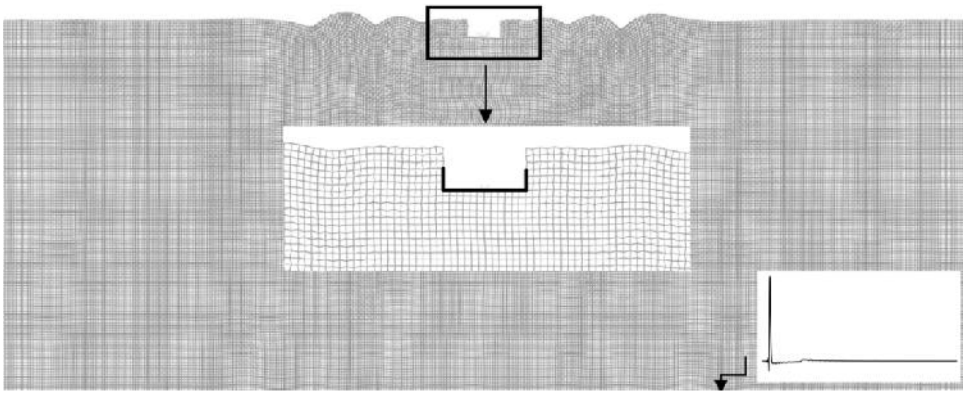
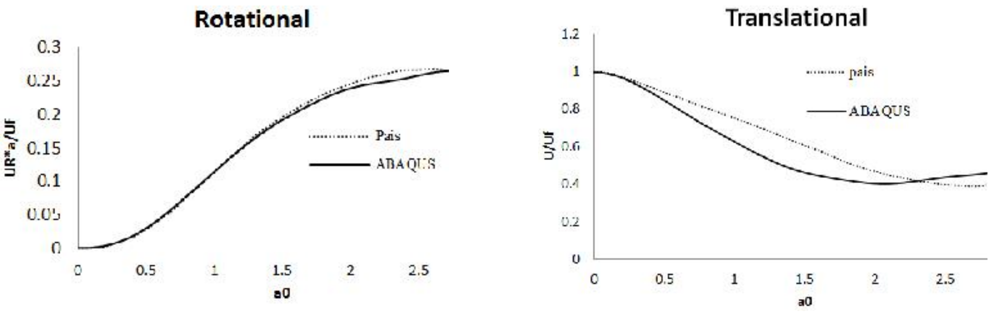


Figure 2. Deformed shape of the model

Validation of the model is an important part of simulation to examine the accuracy of the results. In this regard, as a sample, the KI induce FIM's for the case of full contact state is compared to past findings which are defined as a benchmark in this field (Pais and Kausel, 1985). Figure 3 displays the Horizontal and rotational TF versus non-dimensional frequency of excitation, a0=ω*a/Vs, where ω is frequency of excitation. U and UR are horizontal and rotational components of foundation input motion respectively and Uf is free field motion. These comparing graphs illustrate the same trend that insures that the simulation is appropriate. Table 1 represents the soil properties and foundation dimensions of this validation.

Table 1. Properties of soil and foundation dimensions

Prop.	υ	ρ	Vs	a
	0.3	1.65gr/cm^3	100m/s	3m



(b) (a)

Figure 3.Validation of ABAQUS Model a) Translational Component b) Rotational Component

Following Non-dimensional parameters were utilized in discussing the results in subsequent sections.

- D/a defines as embedment ratio. Here four vales of 0.5, 1, 1.5 and 2 is considered for this parameter.
- d/D defines as partial contact ratio. Three values of 0, 0.5 and 1 are investigated here.

The specific state with D/a=1 and d/D=1 were considered for model validation. It is notable that by interpreting results within the frame work of dimensionless of parameters; the conclusions may cover a class of soil-structure system rather than a specific case.

METHOD OF ANALYSIS

The following procedure was conducted for assessment of KI effects on Foundation input motion and response spectrum. MATLAB codes were utilized for this purpose.

1. Implementing an instant pulse, FFM and FIM time histories are recorded separately.
2. Dividing Fourier transfer of translational and rotational FIM's to FFM's, TF's regarding KI effects are derived.
3. An ensemble of twenty FFM real records is chosen.
4. The above ensemble is converted to frequency domain from time domain.
5. Using product of step 1 and step 4, frequency domain representation of KI induce FIM's from ensemble ground motion is achieved.
6. The frequency domain FIM's are converted to time domain.
7. Response spectra for the whole ensemble mentioned in step 6 are estimated as FIM response spectra.
8. Response spectra ratio of FIM to that of FFM is computed as response correction factors due to KI.

RESULT AND DISCUSSION

Analyses were conducted parametrically and extracted graphs are reported in this section. Figure 4 shows the Translational and rotational TF components of rigid embedded strip foundation with incomplete contact against a0. The figure consist of four rows of TF's belonging to four embedment ratios, i.e. D/a= 0.5, 1, 1.5 and 2. Every row includes two graphs in which the left and right hand side ones depict horizontal and rotational motions respectively. Finally, in each of mentioned graphs three contact length ratios of soil-side wall are investigated that varies between, d/D=0, as a symbol of non-contact sidewall- nearby soil condition, to d/D=1 that is a representative of full contact situation.

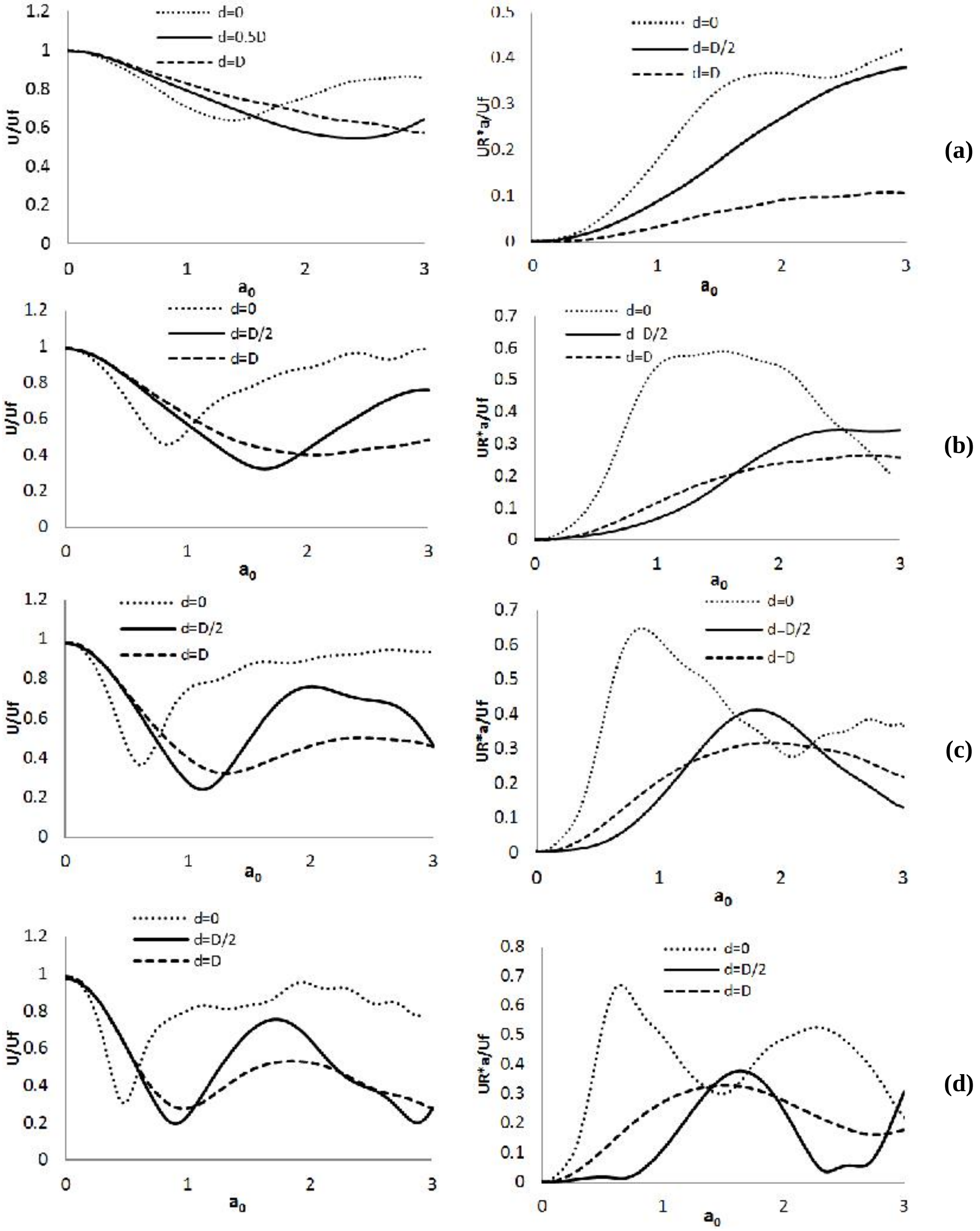


Figure 4. Transfer function components of rigid embedded foundation with incomplete contact for different d/D and D/a. a) D/a=0.5 b) D/a=1 c) D/a=1.5 d) D/a=2

Regarding different characteristics of embedment and contact conditions the following conclusions may be drawn:

- For all horizontal TF's by increasing non-dimensional frequency, starting from zero, a decreasing trend from an initial value of unity is witnessed. After that a non-complete buildup with some fluctuations happens that hardly may cause the ordinate to meet an amount of unity again. Hence, it can be concluded that the KI induced horizontal FIM, scale the amplitude of all components of FFM to a fraction of unity.
- Comparing soil-wall full and partial contact states, show different trends in low and high non-dimensional frequencies. For low values of a_0, before a specific threshold, the state of partial contact reduces amplitudes of horizontal FIM. That's while beyond that limit, a reverse trend takes place in such a way that the ordinates again approaches to unity as the values of a_0 grow up. This tendency intensifies for the state of no soil-wall contact. The mentioned threshold diminishes as the contact length descends and embedment ratio increases.

- Rotational TF's, starting from zero, follows a rising trend as a_0 grows up. Except for the case of D/a=0.5, unexpectedly, for low values of a_0, partial contact of side wall leads to lower rotational ordinates of input motion in comparison with full and non-contact states.

To provide more comprehensive engineering insight, response spectrum representation of the results is included in this research. In this regard, the calculated TF's are implemented to convert a set of FFM records to horizontal and rotational input motions, respectively. The ensemble of ground motions consists of 20 records with the descriptions listed in table 2.

Table 2. Descriptions of real selected records

Station	Geology	Earthquake Date	Magnitude	Epicentral Distance(km)	Component	PGA(g)
El Centro-Irrigation Distinct	Alluvium	Imperial Valley, May 18, 1940	6.3(M_L)	8	S90W, S00E	0.21, 0.31
Taft _ Lincoln School Tunnel	Alluvium	Kern County, July 21, 1952	7.7(M_S)	56	308 , 218	0.15, 0.18
Figueroa _ 445 Figueroa St.	Alluvium	San Fernando, February 9, 1971	6.5(M_L)	41	N52E, S38W	0.14, 0.12
Ave. of the stars _ 1901 Ave. of the Stars	Silt and Sand Layers	San Fernando, February 9, 1971	6.5(M_L)	38	N46W, S44W	0.14, 0.15
Meloland_ Interstate 8 Overpass	Alluvium	Imperial Valley, October 15, 1979	6.6(M_L)	21	360 , 270	0.31, 0.30
Bond Corner _ Heighways 98 and 115	Alluvium	Imperial Valley, October 15, 1979	6.6(M_L)	3	140 , 230	0.51, 0.78
Alhambra _ Freemont School	Alluvium	Whitter_ Narrows, October 1, 1987	6.1(M_L)	7	270 , 180	0.41, 0.30
Altadena _ Eaton Canyon Park	Alluvium	Whitter_ Narrows, October 1, 1987	6.1(M_L)	13	90 , 360	0.15, 0.30
Burbank_ California Fedral Saving Building	Alluvium	Whitter_ Narrows, October 1, 1987	6.1(M_L)	26	250 , 340	0.23, 0.19
Los Angeles _ Baldwin Hills	Alluvium over Shale	Whitter_ Narrows, October 1, 1987	6.1(M_L)	27	90 , 360	0.06, 0.13

The average normalized spectral responses of sway and rocking input motions are summarized in Figure 5. This figure includes four rows, representing the effect of different embedment ratios where the responses are normalized to FFM responses. Every chart includes three graphs belonging to different states of soil-wall contact lengths.

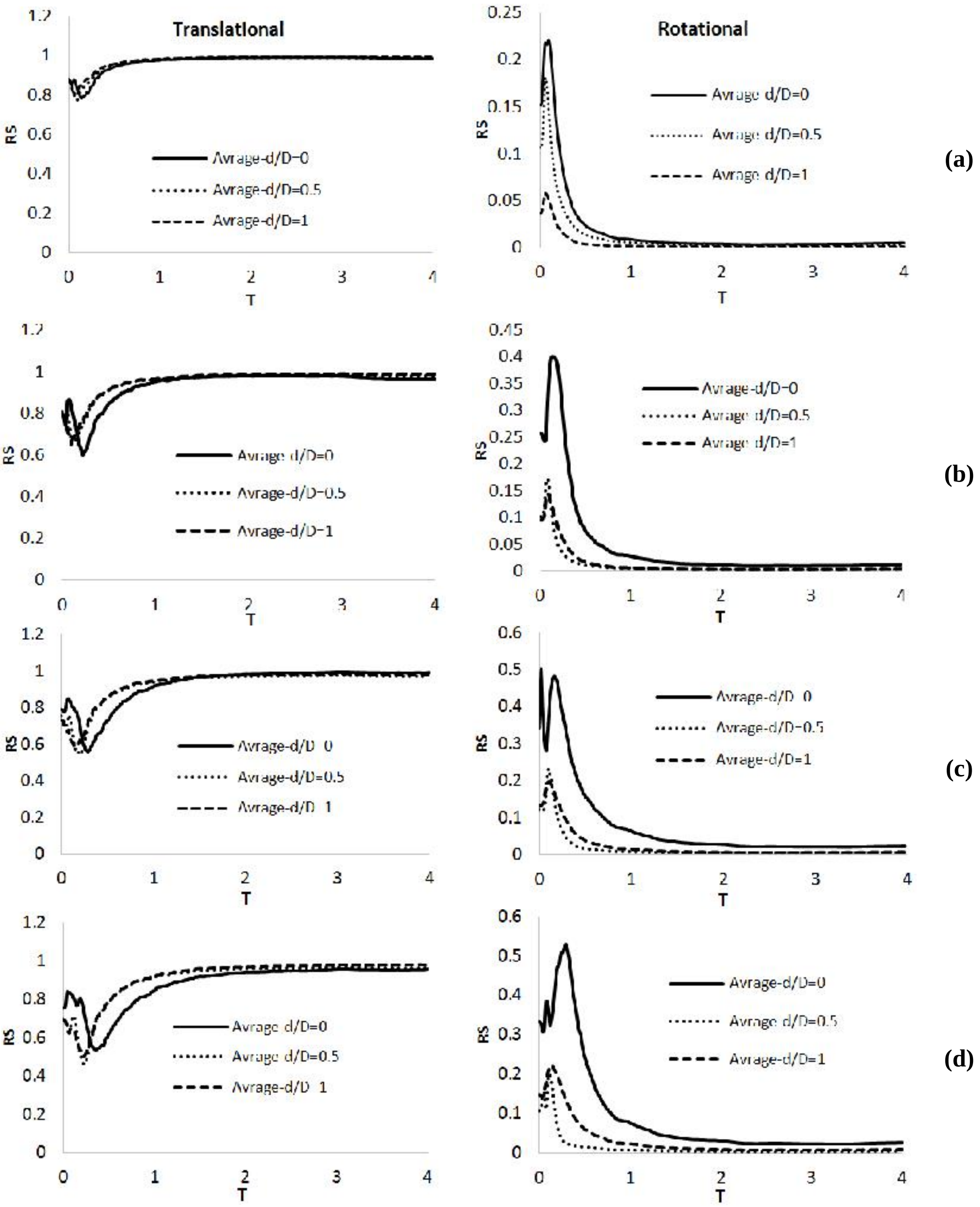


Figure 5. Affected average response spectrum for different d/D and D/a. **a)** D/a=0.5 **b)** D/a=1 **c)** D/a=1.5 **d)** D/a=2

An over view on the variations of responses for low periods, i.e. periods less than one, uncover reverse trends for sway and rocking correction coefficients. The former and later coefficients show reduction and intensification up to 50 percent with respect to FFM spectrum. It should be mentioned that rotational component is scaled by half width of the foundation symbolically. That's while it would be more rational to scale the results by slenderness ratios of the structure to reflect the effect of rotational motion on input acceleration to structural mass. This issue is out of the scope of this paper. Again, an interesting point is that partial contact holds lower values of response correction coefficients in comparison to full and non-contact conditions. This would raise the idea of construction with optimum contact length to minimize the power of input motions.

CONCLUSIONS

A numerical analysis was conducted to investigate the KI effect of rigid embedded strip foundation with incomplete contact to surrounding soil. KI effects were presented as transfer function in frequency domain for both translational and rocking components. Although horizontal TF components of foundation with non and partial contact, i.e. d/D=0 and 0.5, are lower than that of full contact, i.e. d/D=1, in low frequencies, rotational component for incomplete contact state, in contrary, possess higher ordinates. The influence of KI on Response spectrum is considered as well. Twenty selected records were used to observe these effects. As anticipated, response spectra were affected by KI especially in low periods. Increase of foundation embedment depth has markedly influences on altering the horizontal and rocking components of foundation input motion. From both TFs and response spectra correction functions, partial contact between soil and side wall, seems to result in minimum gain from free field motion, either with respect to full or non contact conditions.

REFERENCES

ABAQUS Inc. (2011) ABAQUS V.6.11 user’s manual. Providence, Rhode Island, USA

Ahmad S and Bharadwaj A (1991) Horizontal Impedance of Embedded Strip Foundations in Layered Soil, Journal of Geotechnical Engineering, 117(7), 1021-1041

Bielak J (1974) Dynamic behavior of structures with embedded foundations, Earthquake Engineering and Structural Dynamics, 3, 259-274

Givens MJ and Stewart JP (2012) Assessment of Soil-Structure Interaction Modeling Strategies for Response History Analysis of Buildings, Proceedings of the 15th International Conference on Earthquake Engineering, Lisbon, Portugal

Hoshiya M and Ishii K(1983) Evaluation of kinematic interaction of soil-foundation systems by a stochastic model, Proceedings of the 1th International Conference and Exhibition on Soft Dynamics and Earthquake Engineering, Southampton, UK

Iguchi M (1982) an approximate analysis of input motion for rigid embedded foundation, Transactions of Architectural Institute of Japan, 315, 61–75

Iguchi M (1984) Earthquake response of embedded foundation to SH and SV wave, Proceedings of 8th World Conference on Earthquake Engineering, San Francisco (CA), pp. 1081-1088

MATLAB6.1, The MathWorks Inc., Natick, MA, 2000

Mori M and Fukuwa N (2012) Simplified Evaluation Methods for Impedance and Foundation Input Motion of Embedded Foundation, Proc. of the 15th World Conf. on Earthquake Engineering, Lisbon

Pais A and Kausel E (1985) stochastic response of foundations, Report No. R8506, Massachusetts Institute of Technology, Cam-bridge, MA

SeismoSoft (2004) "SeismoSignal v.3.1.0". www.seismosoft.com

Veletsos AS and Prasad AM (1989). Seismic interaction of structures and soils. JOURNAL OF STRUCTURAL ENGINEERING (ASCE), Vol. 115, No.4, pp.935-956