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Simple Pile-Soil Interaction Effect on Seismic Response of Fixed Offshore Platforms

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ABSTRACT: In this paper effect of pile-soil consideration in obtaining seismic response offshore structure is assessed due to earthquake loading. InducedSeismic force is one of the most important excitations for the dynamic response of an offshore structure. According to API, Seismic forces should be accounted in platform design for seismically active regions in order to determine the allowable seismic risk for the type of operation intended. Two model were developed, in the first one, pile-soil interaction was neglected whereas in the second one, pile-soil interaction was considered by using un-grouted pile stubs. The models that were used in this research were consist of two dimensional finite element models with linear behavior. After obtaining dynamic specification of structural system, a linear time history analysis was performed on both models and eventually the response of structure in the form of overall drift and maximum top displacement was compered. Finally it was shown that neglecting consideration of pile soil interaction will not always result in ensuring structural responses.

Keywords: *Offshore structures; Piling system; Seismic loads; Un-grouted*

INTRODUCTION

Fixed offshore platform also known as Jacket platforms are used for offshore oil exploration. These superstructures are under different kind of environmental loading such as wave, earthquake and wind. The lateral stability of these structures are achieved by using piles.In this paper the effect of consideration ofpile-soilinteraction on dynamic response of fixed offshore platform is studied.

Mardfekri et al. Has studiedbehaviorof laterallyloaded monopole foundations both linearly and nonlinearly and assessed the accuracy of different pile soil interaction modelcompared to analytical finite element model (Mardfekri *et al.*, 2013). Cyrus et al. Has conducted feasibility study on utilization of endurance time method on an un-grouted offshore jacket structure (Cyrus *et al.*, 2012). Komachi and Tabeshpour had assessed the requirements for accurate modeling of offshore jacket structures including pile-soil interaction. JIANG and et al. Has summarizes the developments in grouted pile and its performance under different kind load cases (Wang *et al.*, 2010).

One of the major problems encountered in achieving lateral stability of offshore jacket structure foundations is the safe attachment of the structure to the ground and in particular how the loads applied to the structure should safely be transferred to the surrounding soil. An important solution was developed by engineers is the utilization of piling system in order to harness the lateral displacement of these structures. There are two main piling system, grouted and un-grouted. In grouted system the specific adhesion between the grout and steel surfaces can be achieved and transitional movement of pile in the leg will be fixed. Also as indicated in mechanical tests, the presence of grout will improve the fatigue performance of the structural systems as well as its strength (Dedić, 2009).

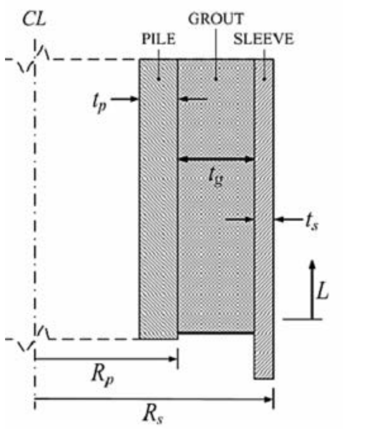

Fig. 1: Profile of lateral grouted piling system[4]

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Fig. 2: a) Pile head of un-grouted piling system b)Wishbone element installed in un-grouted piling system

Another method of piling system is un-grouted piling system.In this methodthe top of the pilewill be fixed to top of the jacket by welding the both member in this way the leg and pile are allowed to have finite axial strain relative to each other but in normal direction they are bound to each other by the aid of wishbone elements.

Due to the cost of calculations often in developing and analyzing offshore structures a simpler model are being used. To simplify Foundation system two method are proposed, equivalent linearized foundation super-element and equivalent pile stubwhich determines yields the same deflections and rotations as the pile-soil system. In static analysis based on sufficient accuracy we can replace the nonlinear pile-soil system with an approximately equivalent linear pile stub whereas in dynamic analysis it is necessary to linearize the foundation system (Engineering Dynamics, 2010).

In general the presence of soil will affect the response of structure in two aspect (Tabeshpour, 2006):

1-The structural system will be more flexible and will attract less seismic force.

2-The piles will experience different frequency and amplitude of seismic loadsin height of the piles due to difference between layers of soil specification.

Modeling pile-soil interaction in the form of pile stub will only take into account the increase of natural vibration frequency of structure whereas it could not consider the resonance effect that may be produced by dynamic specification of soil layers.

Modeling description

A two dimensional finite element model ofjacket structure was developed. In order to achieve a more reliable simulation, the structural inertial mass was calculated based on three dimensional model of the same structure and was installed on the 2Dmodel. The model was consist of jacket structure and un-grouted pile stubs (for the sake of simplicity). The structure is fixed to the bottom.

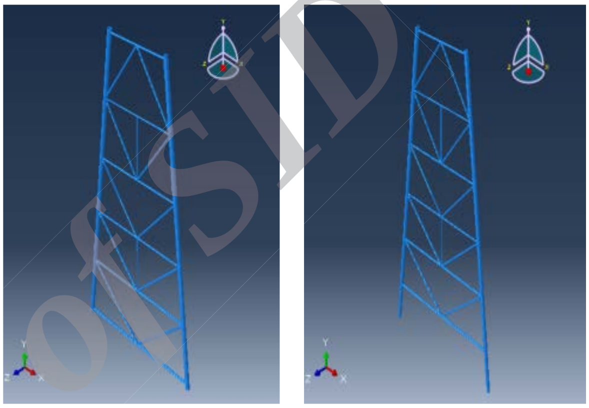


Fig. 2: Finite element model of the case study jacket

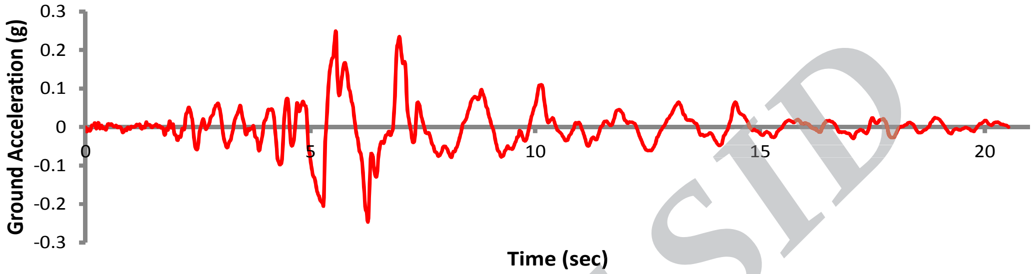
The structural model was subjected to scaled seismic loads in two condition one with inclusion of pile-soil interaction by utilizing un-grouted pile stub system (Barltrop *et al.*, 1991) and the other without pile-soil interaction.

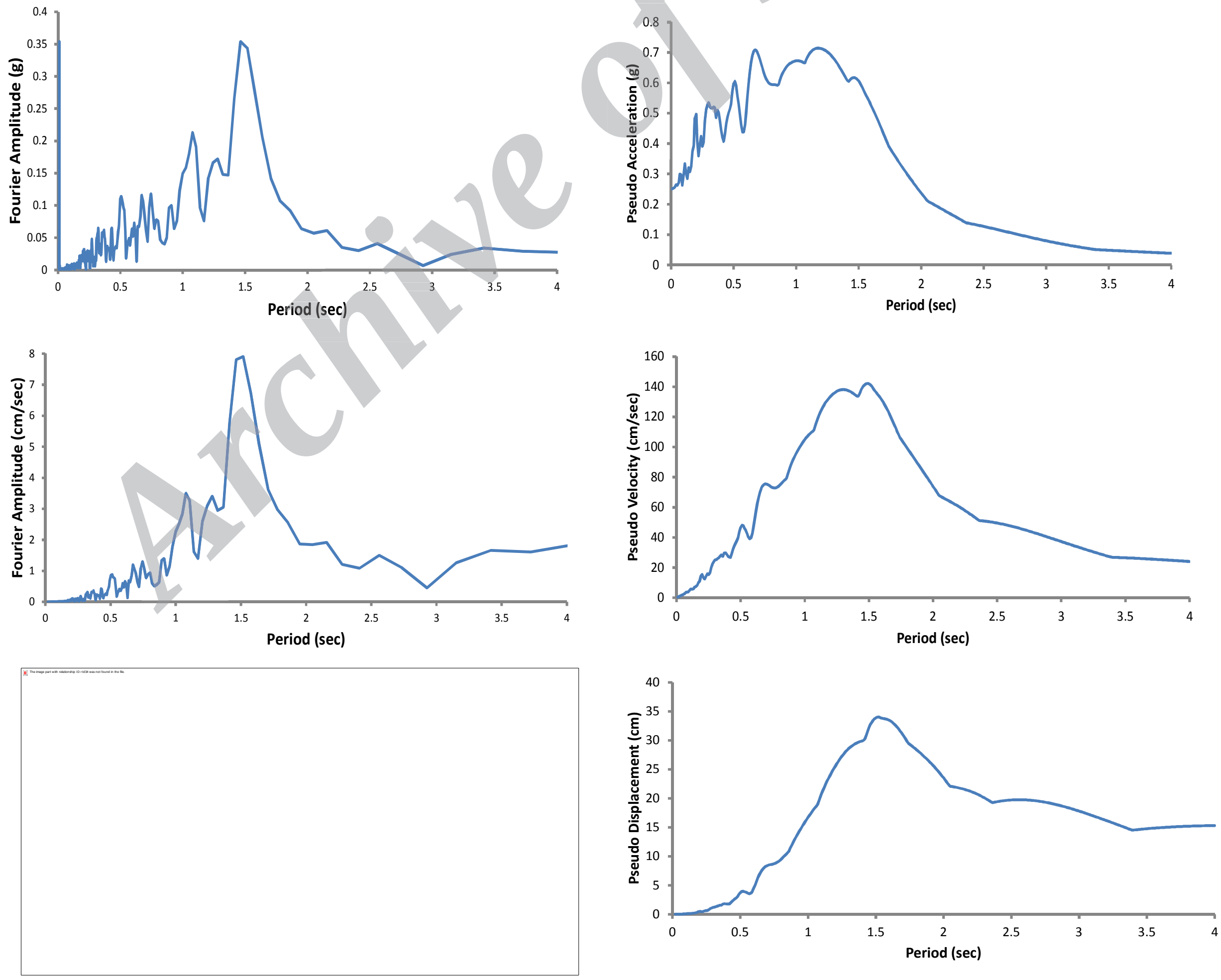
Time history records of response due to seismic loading are very sensitive to specification of earthquake records, because of this reason multiple analysis must be performed in order to obtain reliable responses. In this research the seismic loads was consist of three earthquake acceleration records and was exerted in the base of structure in both condition, the records were scaled to 0.35g (ductility level earthquake) and 0.5g PGA equal 2000 year return period. In fig 3-5 the, time history of acceleration, Fast Fourier Transform of acceleration, velocity and displacement and pseudo acceleration, velocity and displacement is shown.

By looking at the unscaled records (Fig. 3-5), some general difference will be spotted in records specification. These differences are: number of effective cycle, frequency of effective cycle, duration of effective movement, amplitude and combination of low frequencies and dominant frequency of earthquake record. In Emeryville earthquake the dominant period of earthquake is exactly 1.5 sec whereas in Landers and Victoria, Mexico earthquake the dominant period of record is distributed over a range of 1 to 3 seconds.

Table 1: Structural system specification

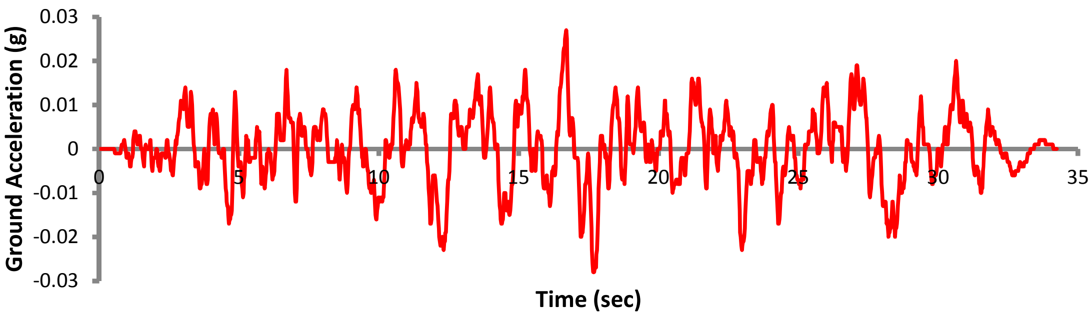
Model Description		Material properties	
Water Depth	67.4 (m)	Steel Mass Density	7850 (kg/m^3)
Jacket Height	72.07 (m)	Young's Modulus	2.1E11
Leg Profile	0.4953X0.012	Poison's Ratio	0.3
Pile profile	0.4572X0.025	Damping parameters (model without pile)	$\alpha = 0.3, \beta = 0.005$
Pile stub Length[1]	10 (m)	Damping parameters (model with pile)	$\alpha = 0.22, \beta = 0.004$





[1] The pile stubs are usually chosen about 9~10 D(the diameter of pile)

Fig. 3: EmeryvilleEarthquake Specification



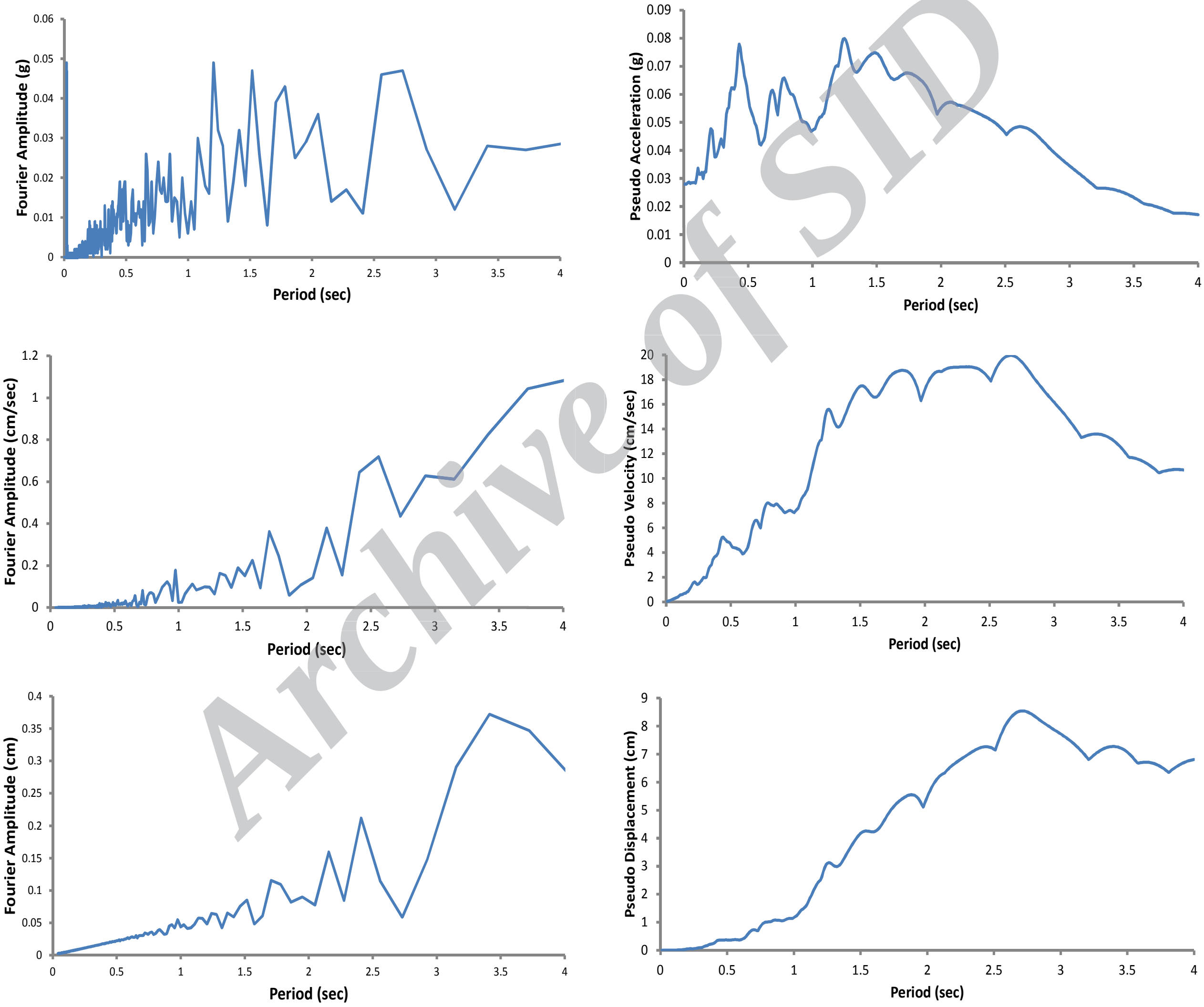


Fig. 4: Fourier Amplitude of Acceleration record for Landers Earthquake

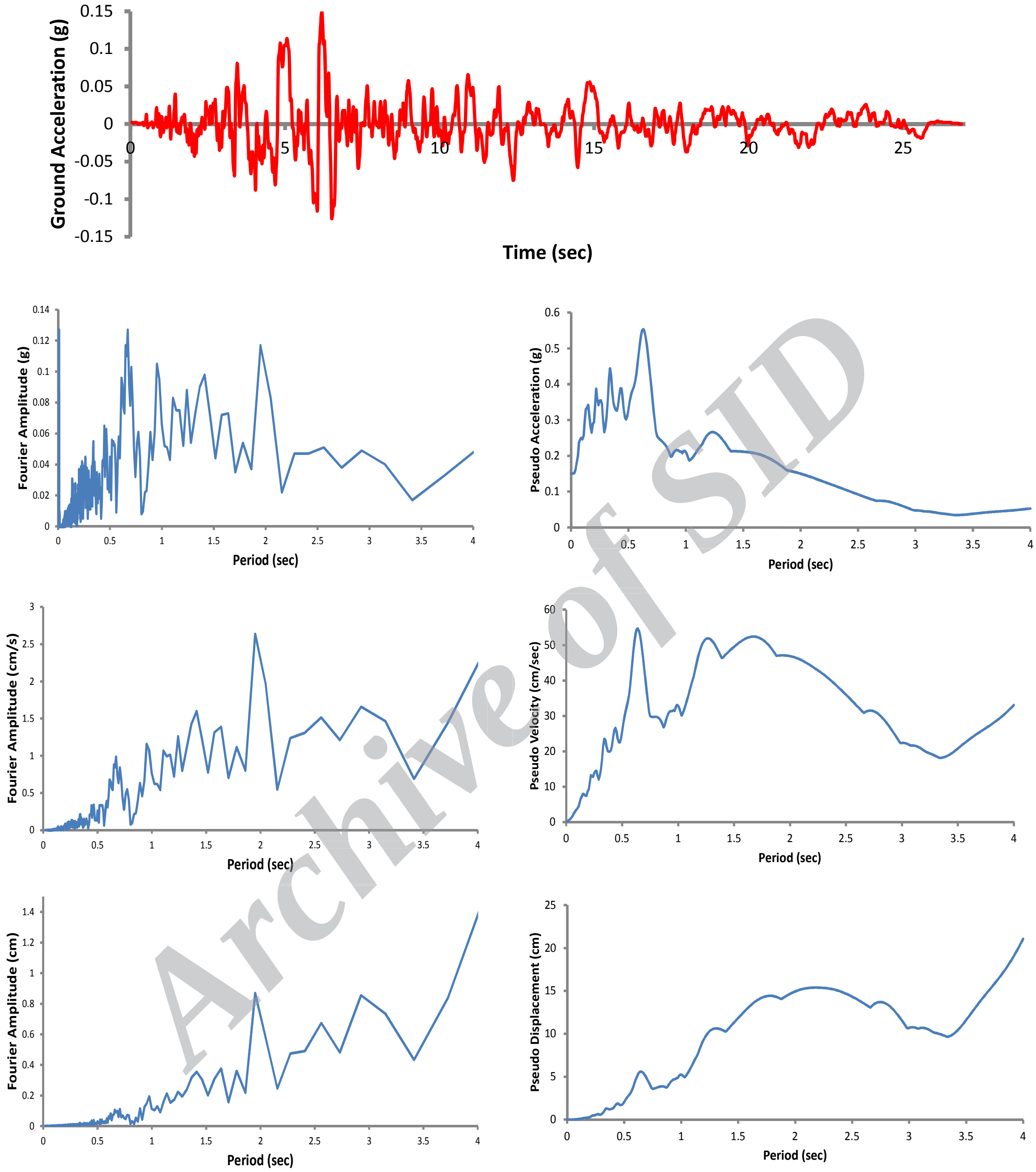


Fig. 5: Fourier Amplitude of Acceleration record for Victoria,Mexico Earthquake

RESULTS AND DISCUSSION

Prior to seismic analysis, a frequency analysis was performed on the model with and without piling system in order to obtain dynamic parameters of structure in both conditions.In fig6 the mode shape difference between two model is shown.

Based on Fourier spectrum of records (Fig. 3-5) and modal information of structure in both condition (Table 2), lower responses are expected for Emeryville earthquake, since consideration of pile-soil interaction will shift away fundamental period of vibration about 0.78 sec from its primitive measures(it will be shift away fromdominant period of earthquake record). In Landers and Victoria, Mexico earthquakeconsideration of pile-soil interaction will not shift away the fundamental period of structure from dominant period of earthquake record since the dominant period in both records is distributed over a range of 1 to 3 seconds. Therefore even though the structural system has become more flexible after considering pile soil interaction, higher structural responses are expected in comparison with model without pile-soil interaction.

Reviewing fig. 7-8 shows that, in the Emeryville earthquake there is 57 percent decrease of top displacement response after considering pile-soil interaction in 0.35g scaled record, this quantity was about 58 for 0.5g record. This result validates primary surmises. Unlike the Emeryville earthquake, the response of the structure in Landers and Victoria, Mexico earthquake was increased 40 and 30 percent for 0.35g records and 100 and 31 percentfor 0.5g after installation of piles in the model.

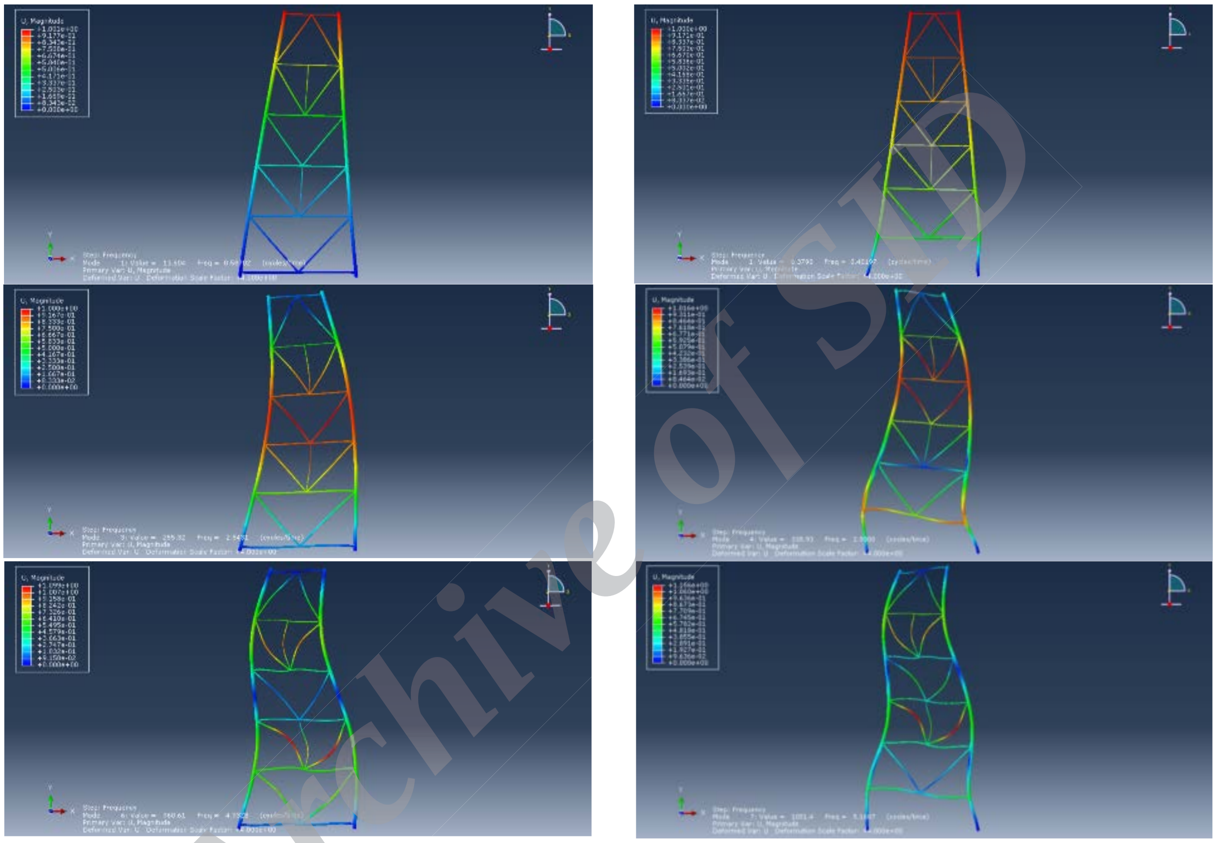
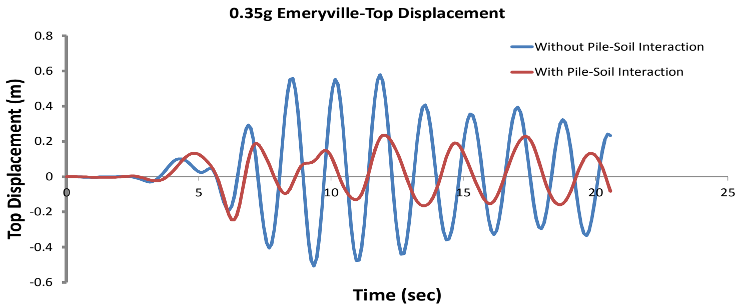


Fig. 6: a) First three mode shape of structure without piling system b)First three mode shape of structure with un-grouted piling system

Table 2: Natural Period of structure

Model	Natural Period of first mode	Natural Period of second mode	Natural Period of third mode
Without Lateral piling system	1.72	0.39	0.2
Un-grouted piling system	2.5	0.33	0.19



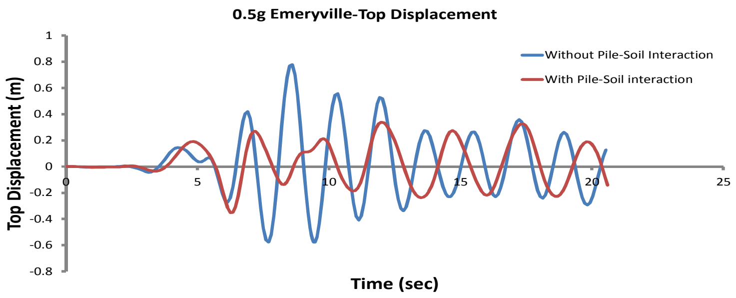


Fig. 7: Time History record of response for Emeryvilleearthquake

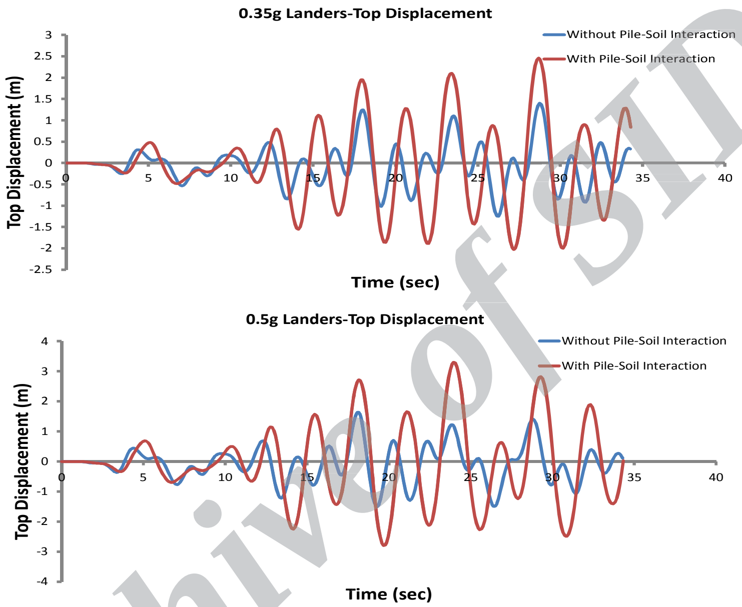


Fig. 8: Time History record of response for Landers earthquake

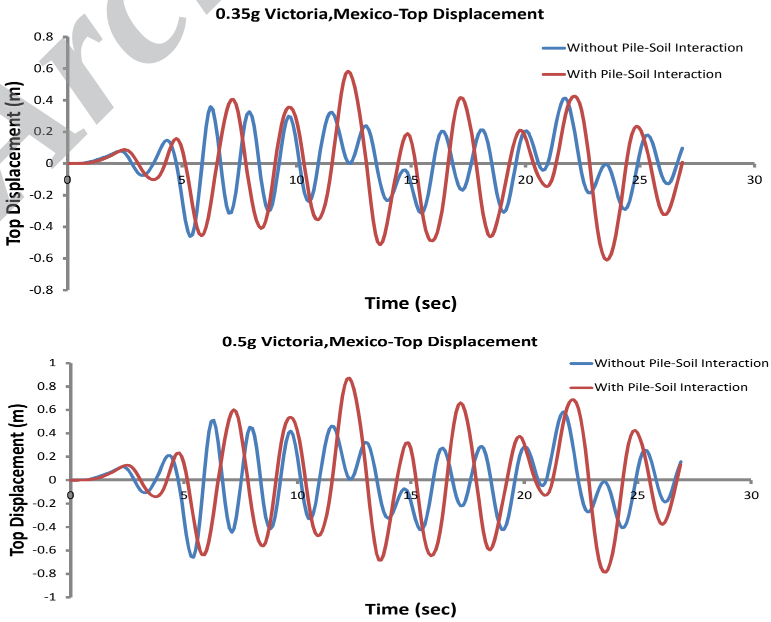


Fig. 9:Time History record of response for Victoria, Mexico earthquake

Table 3: comparison of dynamic response of structure under earthquake scaled to 0.35g

Earthquake Record	Stability	Maximum top displacement (m)	Maximum Displacement at Pile Head (m)	Structural System Drift (%)	Mudline Drift (%)	Maximum Base shear (kN)
Emeryville	Without piling system	0.57	-	0.79	-	4383
	Piling system	0.24	0.16	0.28	0.11	1339
Landers	Without piling system	1.4	-	1.94	-	6665
	Piling system	1.96	1.24	2.34	0.99	8104
Victoria, Mexico	Without piling system	0.46	-	0.63	-	3133
	Piling system	0.6	0.42	0.71	0.24	2170

Table 4: comparison of dynamic response of structure under earthquake scaled to 0.5g

Earthquake Record	Stability	Maximum top displacement (m)	Maximum Displacement at Pile Head (m)	Structural System Drift (%)	Mudline Drift (%)	Maximum Base shear (kN)
Emeryville	Without piling system	0.79	-	1.09	-	5956
	Piling system	0.35	0.22	0.41	0.18	1837
Landers	Without piling system	1.63	-	2.26	-	5815
	Piling system	3.29	1.62	3.94	2.31	10690
Victoria, Mexico	Without piling system	0.66	-	0.91	-	3903
	Piling system	0.87	0.56	1.04	0.43	3229

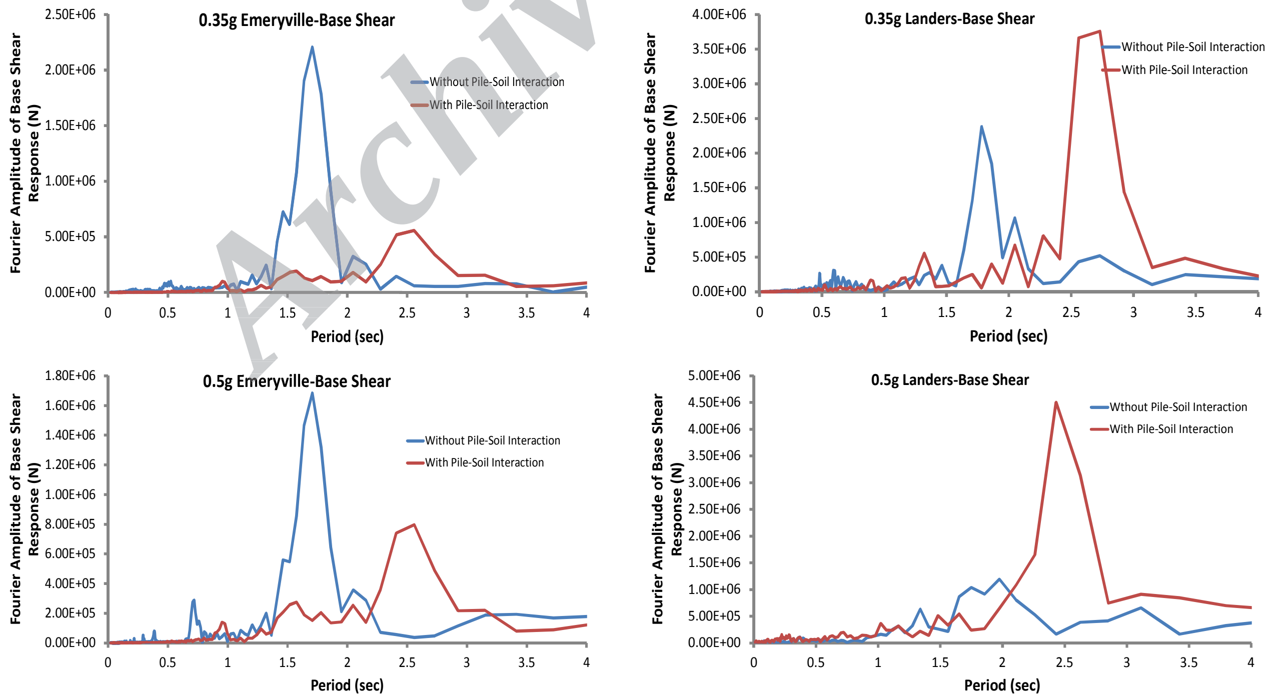


Fig. 10: Comparison of Fourier Transform corresponding to Base Shear Response

As demonstrated in fig10 Fourier amplitude of base shear response in Emeryville earthquake was decreased evidently, due to recede of natural period of structure from its primitive measure whereas in Landers earthquake Fourier amplitude of base shearresponse was increased sensibly.

CONCLUSION

In this paper the dynamic effects, related to consideration of pile-soil interaction was assessed and later was shown that the choice of inclusion of pile-soil interaction in the seismic analysis is highly depend on dynamic specification of input records and expected performance of structure. Inclusion of pile-soil interaction will lead to more realistic modeling but one must keep in mind that it will also change the dynamic specification of system. For future research comparison of dynamic behavior of jacket structure with grouted and un-grouted pile is recommended.

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