THE EFFECTS OF SOIL TYPES ON STRUCTURAL RESPONSE OF BUILDINGS UNDER EARTHQUAKE LOADING

Kerem PEKER
ERDEMLI Engineering & Consulting Co. Ltd.
Istanbul, Turkey

Keywords : Soil-Structure Interaction

Abstract : The design made by the assumption that the foundations are rigid is almost perfect on condition that the foundations are settled on strong rocky ground. If the foundations are settled on soft layers of ground, then the ground must also be designed as a structure, to transfer the loads to stronger layers that can be assumed to be rigid. The aim of this set of analyses is to present the influence of soil on structural behavior.

1. INTRODUCTION

The aim of design in structural engineering is transferring any load, given in space, by any structural element, safely to ground level to the foundations where the structure is supposed to have completed its duty, maintaining the deformation limit conditions defined in the relevant codes and specifications.

In cases where the soft layers need to be considered on the load path to the strong layers, soil profile under the structure should also be considered in the analysis carried out.

The design procedure for taking the ground levels into consideration is usually very complex and requires very strong computational effort. The engineer should well analyze the possible benefits of modeling soil and structure together. Detailed study should be done as the behavior depends on some site-specific parameters and experience dependent structural assumptions.

In this paper, a group of analyses will be carried out related with steel frames, to have an idea about the effects of soil and structure interaction on steel structures.

2. METHOD OF ANALYSIS

The analyses will be based on 3 types of soil models and will contain three different structural storey-heights together with four separate soil depths utilized for each.

2.1 Ground Motion:

A linear time-history analysis is carried out using the real ground motion EW direction records from the 13.March, 1994 Erzincan earthquake of magnitude 6.8 with a duration of 21seconds. The damping is assumed to be 7%, which is a composite damping of steel structure and the soil model together.

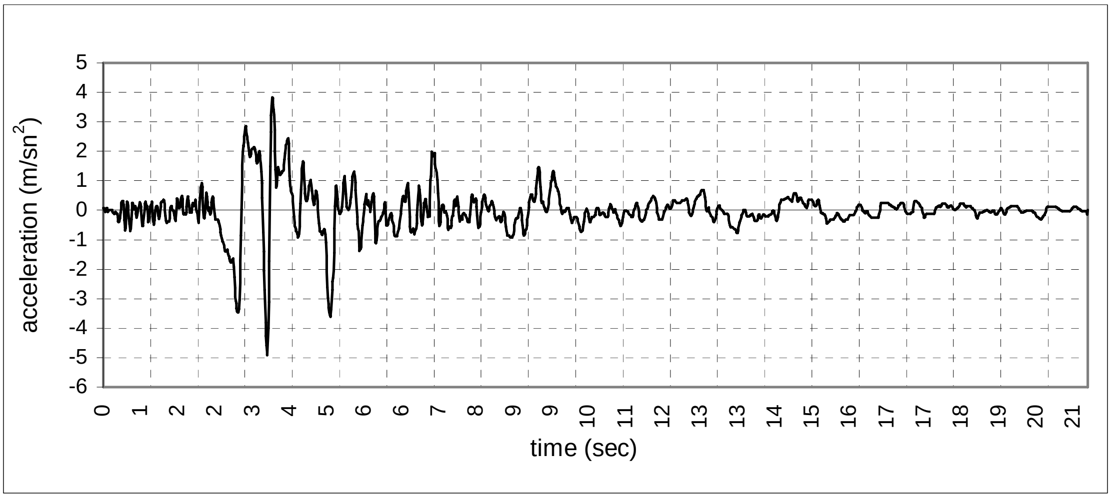

Figure 1. Erzincan earthquake, EW horizontal acceleration component.

2.2 Soil Properties:

A finite element mesh, composed of 1m.x1m finite elements, models the soil under the structure. The depths of the soil layers are variable and 3 profiles are selected for analysis, which are 25m. , 15m. and 5m. deep respectively. The mesh width is assumed as 100m. taking into account that the boundary conditions should satisfy the free field behavior of the analyzed soil profile.

The analysis are carried out for 3 soil profiles of single layer with the given depth, with average shear-wave velocities Vs, of 200 m/sec, 400 m/sec and 800 m/sec respectively. Mechanical properties of the soil types are calculated using the formula,

$$Vs = \sqrt{\frac{G}{\rho}} \qquad (1)$$

$$G = \frac{E}{2*(1+v)} \qquad (2)$$

where , G is the elastic shear modulus, ν is the poisson ratio and ρ is the mass density.

ν = 0.333
ρ = 1.900 t/m^3

The shear modulus to be used in the analyses of soil structure interaction should be reduced in order to maintain closer behavior of soil, as it has a non-linear dynamic behavior under cyclic loading. The reduction depends on loading conditions, as shear modulus decrease with the increasing shear strain. There are many methods to obtain the reduced shear modulus in codes. In the analyses carried out for this paper the reduced shear modulus Go is assumed to be 50% of G calculated by (1) & (2). If we modify (2) formula to be used becomes,

$$G = \frac{E}{(1+v)} \qquad (3)$$

2.3 Structural Properties:

The frames analyzed in each group are supposed to be the middle frame of a three bay, in plan symmetric structure with no irregularity according to the earthquake provisions. The first group considers a middle frame of a single storey building with bay widths of 7m-6m-7m in each direction and a storey height of 4m. The second group considers a middle frame of 5 storey building with bay widths of 7m-6m-7m in each direction and a storey height of 4m. This group is supposed to simulate low rise buildings. The third group considers a middle frame of 10 storey building with bay widths of 7m-6m-7m in each direction and a storey height of 4m. This group is supposed to simulate high rise buildings.

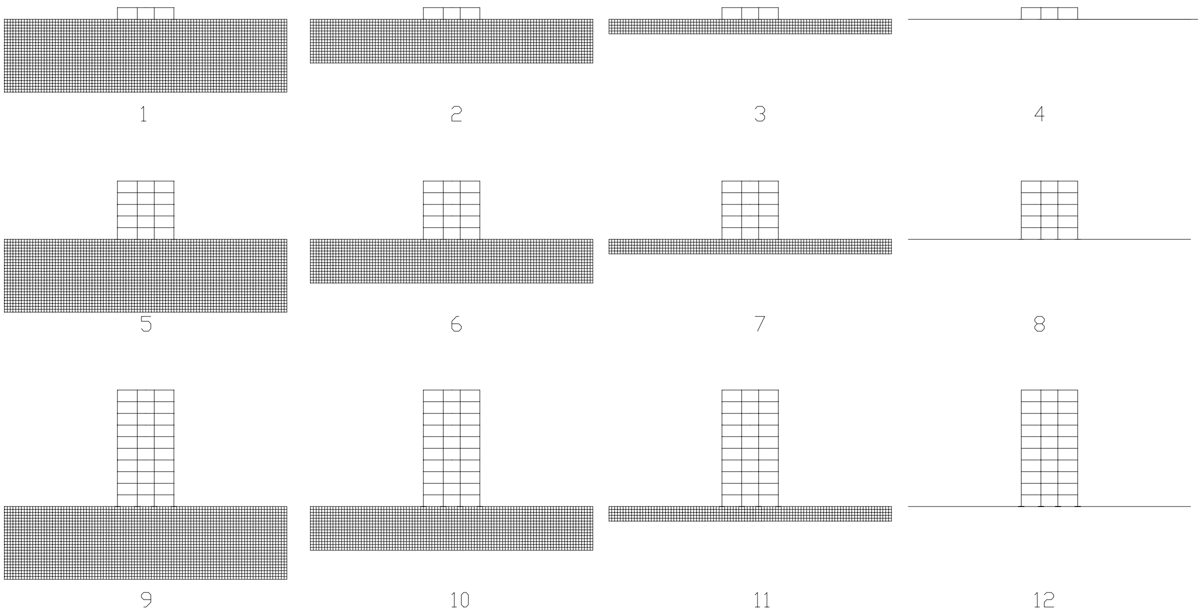

Figure 2. Series of data used in analyses.

3. ANALYSES & RESULTS

The base shear and overturning moments created by the inertial forces are the main parameters to be checked in order to understand how the soil-structure interaction works. Both of these parameters are the functions of the first free vibration mode of the structure. The contribution of higher modes may be negligible for most of the engineering structures.

During the analysis procedure taking the above-mentioned points into account the fundamental period of the structures are selected as indicators of understanding soil-structure interaction and are listed in Table 1 below.

Table 1. First vibration mode periods (T) from the analyses carried out.

Shear Wave Velocity	Soil Depth	First Vibration Mode Period T (sec)			
		Free Field	Single Storey	5 Storey	10 Storey
S1 Vs = 800 m/sec	Fixed base	-	0.1766	0.7945	1.7156
	5m	0.0243	0.1770	0.8313	1.7186
	15m	0.0663	0.1839	0.8371	1.7518
	25m	0.0953	0.1864	0.8401	1.7582
S2 Vs = 400 m/sec	Fixed base	-	0.1766	0.7945	1.7156
	5m	0.0486	0.1910	0.8506	1.7881
	15m	0.1308	0.2101	0.8730	1.8423
	25m	0.1855	0.2312	0.8840	1.8661
S3 Vs = 200 m/sec	Fixed base	-	0.1766	0.7945	1.7156
	5m	0.0972	0.2326	0.9216	1.9701
	15m	0.2607	0.3261	1.0039	2.1569
	25m	0.3683	0.4116	1.0443	2.2346

Results for soil profile S3 is considered to best present the roof joint-foundation displacement relations for 25m soil profile and the rigid foundation.

The Time-History / Absolute Displacement figures are printed below to easily observe the differences between fixed based structure and the effects of soil profile depth to the soil-structure interaction.

The results are discussed in the conclusions.

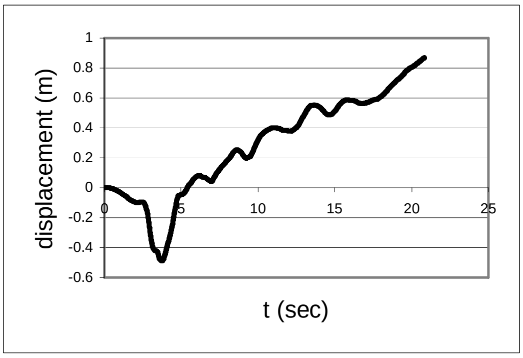

Figure 3
T-H displacement for single storey-rigid foundation

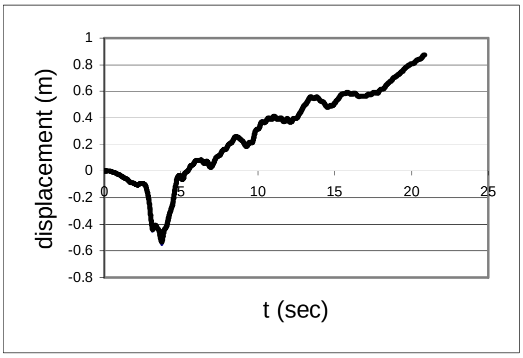

Figure 4
T-H displacement for single storey-25m soil profile

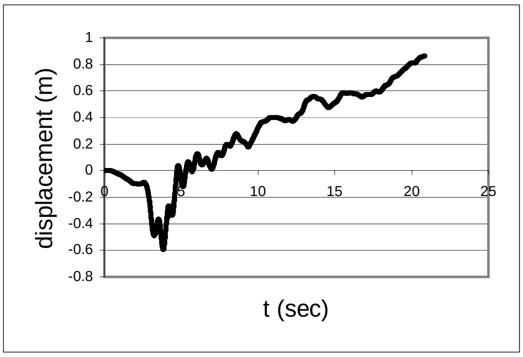

Figure 5
T-H displacement for 5 storey-rigid foundation

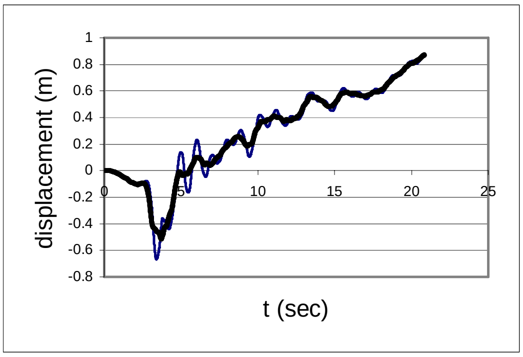

Figure 6
T-H displacement for 5 story-25m soil profile

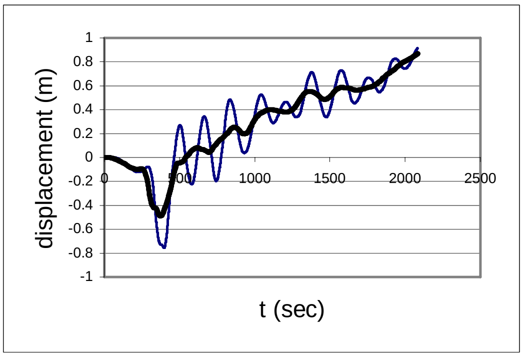

Figure 7
T-H displacement for 10 storey-rigid foundation

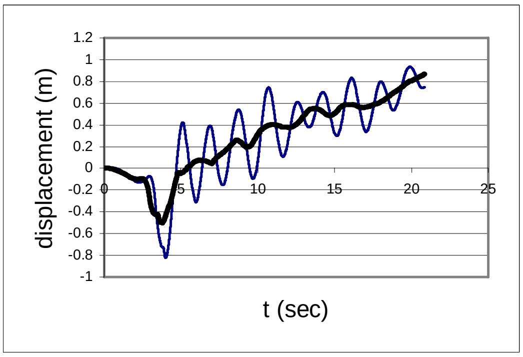

Figure 8
T-H displacement for 10 story-25m soil profile

4. CONCLUSIONS

The natural first mode free vibration period of the free field is altered by the structure above the soil profiles.

Steel structures may be analyzed with a damping ratio of 4-5%. When the structure is modeled together with the soil underneath it, the damping ratio may be assumed to be higher. The composite system with higher damping must be checked in order to define the real behavior of the structure.

The elastic base shear increases as the shear wave velocities of the soil underneath the structure decrease, however the lower the shear wave velocity is, the larger the first vibration mode period comes out as the result of analyses carried out and listed in Table.1. Which means the soil structure interaction needs to be considered, where there are low shear wave velocities or tall structures, as taking the interaction into account may decrease the base shear.

The displacements at roof level of a steel structure are strongly affected by foundation displacements and rotations. So the soil-structure interaction turns out to be significant where the second order effects are important as. Steel structures usually have high deformation capacity, but this capacity is limited because of service requirements. To have more realistic approach to the limit displacements through the structure soil-structure interaction should be checked.

REFERENCES

[1] ANSAL, A " Lecture Notes On Soil Dynamics "

[2] KRAMER, S.L. "Earthquake Geotechnical Engineering " (1996)

[3] KAPTAN, A " Interaction of Soil and Multi-storey R-C Frames " Msc.Thesis (1999)