STUDYING THE EFFECTS OF SOIL-STRUCTURE INTERACTION ON THE PERFORMANCE POINT CHARACTERESTICS OF HIGHRISE FRAMED TUBE STRUCTURES CONTAINING TRUSS BELTS

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Keywords: Soil-Structure Interaction, Framed Tube Tall Structures, Capacity Spectrum, Modal Pushover Analysis, Pseudo-Acceleration Spectrum

ABSTRACT

Current research is carried out on Steel Framed Tube Tall Structures with Truss Belts, consisting of welded connections. The main goal of this research is to illustrate the effects of soil-structure interaction on the Performance Point of such structures. For this purpose, two dimensional 40, 50 & 60 stories Framed Tube Structures, equipped with belt trusses are modeled, analyzed and designed according to ASCE 7-10 code, based on 3 soil categories of Rock (Vs>800m/s), Dense Soil (500<Vs<800m/s) and Loose Soil (150<Vs<500m/s), taking into account the spectral acceleration level of Sa=0.40g. On the next step, Modal Pushover Analyses are carried out on models according to FEMA 440 guideline, due to which the Capacity Spectrums and Performance Point characteristics are computed for each model, using UBC 97 pseudo-acceleration spectrums. Finally, the Performance Point characterestics are computed once more, taking into account the Soil-Structure Interaction (SSI) for each soil category, due to FEMA 440 guidelines and at last the final results are compared.

INTRODUCTION

Previous experience of earthquakes illustrates that many types of structures behave nonlinearly during a severe earthquake. So a huge amount of input energy is mainly dissipated through the form of damping and hysteresis. According to this, the structures are usually designed for much lower lateral forces than those demanded by aseismic design codes in elastic range. The aseismic behavior analysis and accurate design of structures for severe earthquakes are mainly carried out using Nonlinear Time history Analysis method (NTHA).

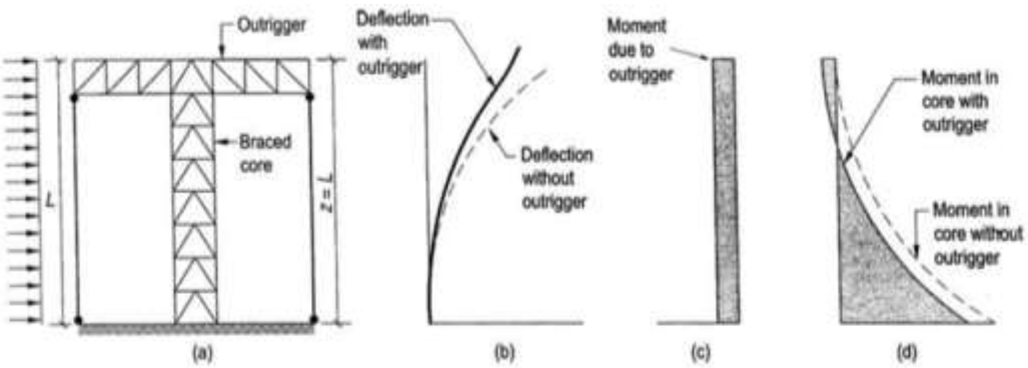

Figure 1. The effect of using truss belts in lateral displacement reduction

Framed tube system is a proper solution for overturning control of tall buildings ranging from 40 to 60 stories high. Meanwhile the system lets to have a wide spread free spaces for architectural purposes. It is also a proper solution to construct a tall building without any additional fee due to height. The technique of additional truss belts is a high efficient one, capable to reduce the lateral deformation as much as 25~30 percent as shown in Figure 1. In this research, the effect of soil categories on the performance point of framed tube structures are computed.

GENERAL STRUCTURAL SEISMIC BEHAVIOR

Both structural and non structural collapses during earthquakes occur due to lateral displacements, so the determination of "Ductility Demand" in Performance based design method is of much importance.

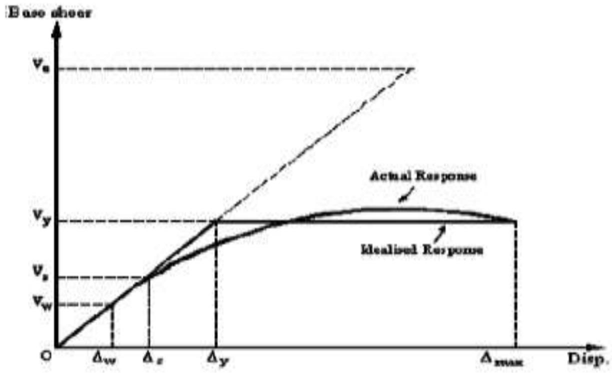

Figure 2. General seismic response of structures

According to the reduced lateral forces, the lateral displacements computed through a linear analysis, should be increased in order to estimate the real displacements during a severe earthquake. In Figure 2, Δmax is the maximum inelastic displacement, Δe is the maximum linear displacement. The real behavior of the structure is replaced by a bilinear elasto-plastic model. In equation 1, μ is the Ductility Factor and is described as follows:

$$\mu = \Delta_{max} / \Delta_y \quad (1)$$

TARGET DISPLACEMENT DETERMINATION BASES

Using the Displacement Coefficient Method, the target displacement can be computed due to equation (2):

$$\delta_t = C_0 C_1 C_2 C_3 S_a.\ g.\ T_e/4\pi^2 \quad (2)$$

C_0 is a modification factor to relate the spectral displacement and likely building roof displacement.The value of C_0 ranges 1.0~1.5 according to number of stories.
C_1 is a modification factor to relate maximum inelastic displacements to displacements calculated for linear elastic response. The values of C_1 would never be taken less than 1.0.
C_2 is a modification factor to represent the effect of hysteresis shape on the maximum displacement response. The values of C_2 depends on the framing type and performance level of the structure and can be taken 1.0~1.5.
C_3 is a modification factor to represent increased displacements due to dynamic P-Delta effects. For buildings with positive post-yield stiffness, C_3 can be set equal to 1.0.
S_a is response spectrum acceleration at the effective fundamental period, T_e and damping ratio for the building in the direction under consideration.

T_e is the fundamental period and is computed according to equation (8):

$$T_e = T_i \sqrt{K_i / K_e} \quad (3)$$

where T_i and K_i are the initial elastic fundamental period in seconds and initial stiffness of the building in the direction under considered.

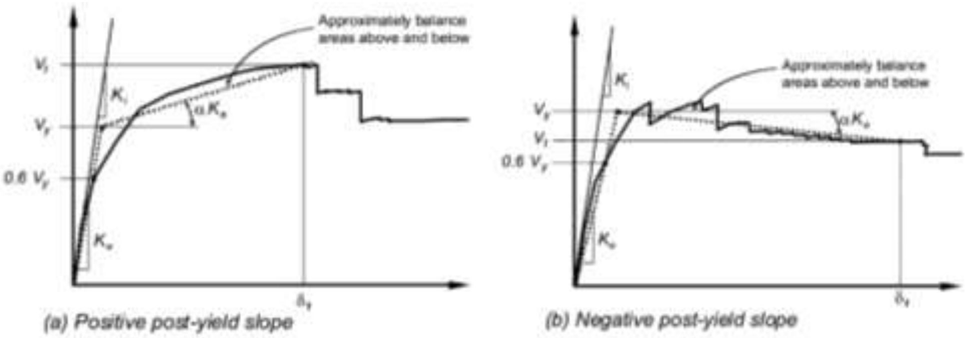

Figure 3. Calculation of target displacement δt

It is obvious that in order to determine the effective fundamental period, Te, and the target displacement, δt, the pushover curve for the building is needed according to Figure 3.

COMPUTATIONAL MODELS AND ANALYSES

According to above mentioned descriptions, 3 two dimensional framed tube structures of 40 to 60 stories high, equipped with Λ type truss belts are modeled as shown in Figure 4. All steel connections are assumed to be welded rigid. Steel used for all structural elements demonstrates a complete elasto-plastic behavior. Slabs are assumed to bear a live load equal with 200kg/m2. In design process, the requirements of lateral displacement and interstory drift limitations due to ASCE 7-10 seismic code are satisfied.

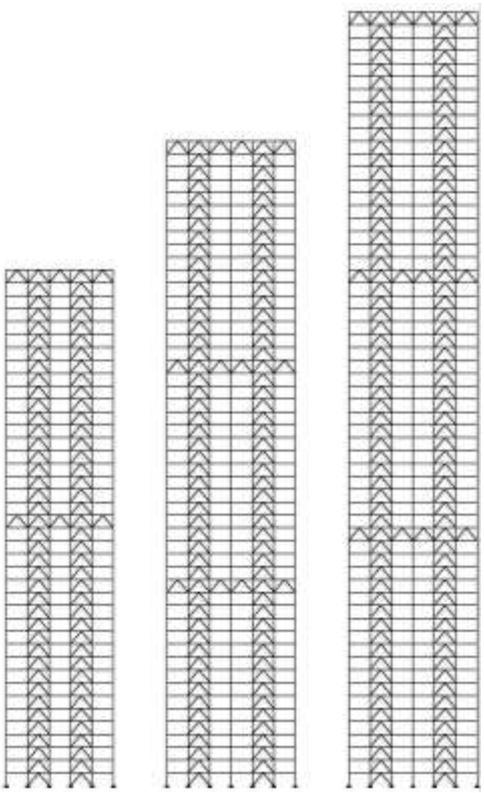

Figure 4. 2D view of finite element computational models

All computational models are analyzed and designed for Sa=0.40g spectral acceleration levels, considering 3 soil types of Rock, Dense Soil and Loose Soil, including P-Δ effects.

ANALYSIS RESULTS

The results from the pushover analyses are summarized in Table 1. All performance point displacements and base shear forces according to soil categories are computed separately.

Table 1. Performance Point results according to FEMA440 guideline.
(V= base shear force (Ton) & D= displacement (cm))*

Soil Type	P.P.	40 Stories		50 Stories		60 Stories	
		w.SSI	w/o SSI	w.SSI	w/o SSI	w.SSI	w/o SSI
Rock	V*	118.9	129.8	162.5	175.9	183.1	197.1
	D*	51.6	56.3	73.2	80.1	90.1	98.5
Dense Soil	V	176.2	187.3	219.9	235.1	257.3	278.1
	D	74.1	80.1	109.0	119.0	134.6	147.1
Loose Soil	V	251.1	268.0	351.8	372.3	440.2	465.3
	D	104.1	113.6	145.3	158.2	179.7	195.8

Finally, Pushover analysis is performed to determine the Performance Points, according to FEMA 440 guidelines. The capacity curves are shown as indicated in Fig. (5) ~ (7):

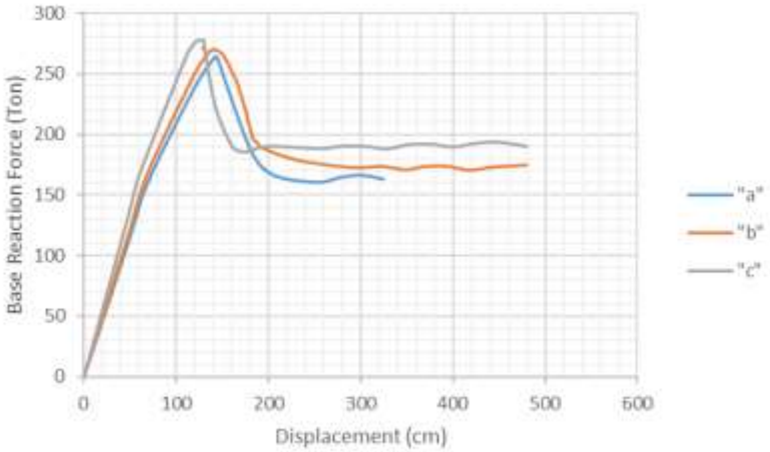

Figure 5. 40 Story Structural model Capacity Curves: a) SI , b) SII , c) SIII

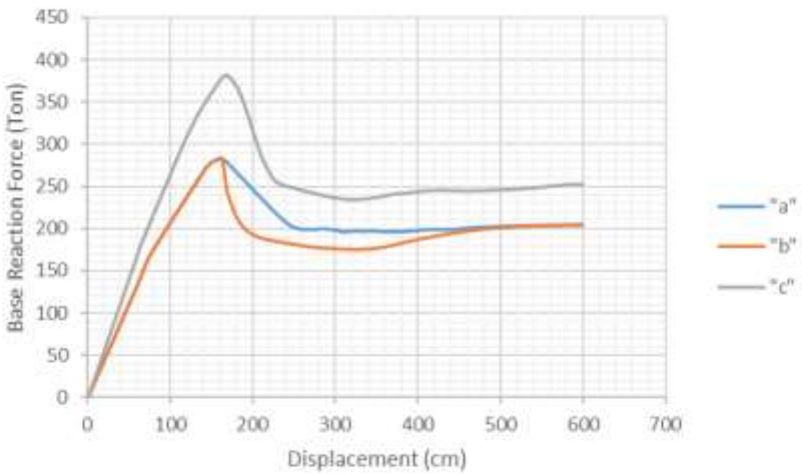

Figure 6. 50 Story Structural model Capacity Curves: a) SI , b) SII , c) SIII

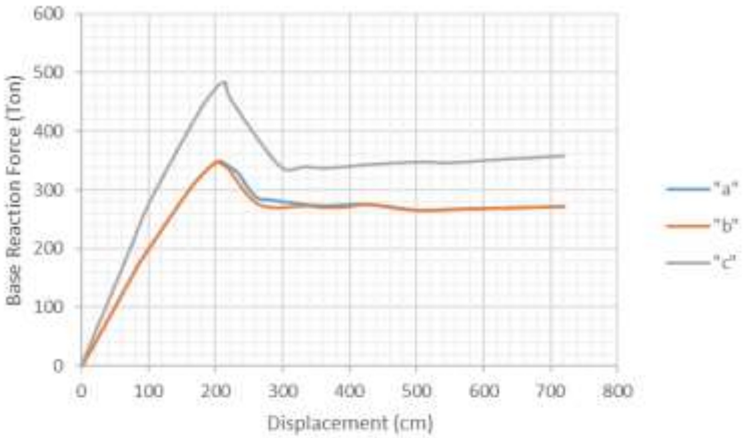

Figure 7. 60 Story Structural model Capacity Curves: a) SI , b) SII , c) SIII

CONCLUSIONS

According to the results in Table 1, the Performance Point Displacement average reduction percent is about 8.3% for all soil categories, when the SSI is taken into account, which shows that the different soil categories have almost the same effect on P.P. displacement reduction. In case of P.P. Base shear Force, one could observe variations in reduction when SSI is taken into account. For Rock category, the P.P. base shear force reduction percent decreases when the height of the structure raised from 40 to 60 stories. This starts from 8.4% for 40 St. to 7.1% for 60 St. structures. The situation is just the opposite for Dense soil category, in which one can observe an amplification from 5.9% for 40 St. to 7.5% for 60 St. structures. For Loose soil category, the situation is again similar to Rock, in which it could be observed a base shear force reduction of 6.3% for 40 St. to 5.4% for 60 St. In general it could be concluded that the P.P. displacement reduction percent mean value is about 8.3% regardless of the soil category. On the other hand, unlike the P.P. displacement reduction percent, the base shear force reduction percent is obeying a variation, which is an amplification based on height for Dense soil, and is a reduction based on height for Rock and Loose soil categories.

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