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Review Article

STUDY OF EFFECTS OF INTERACTION BETWEEN SOIL AND STRUCTURE IN IRREGULAR STEEL STRUCTURES BY CONSIDERATION OF P-Δ

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ABSTRACT
This paper reviews the effects of interaction between soil and structure in both regular and irregular structures with effect of P-Δ by changing the angles of internal friction of soil; and increase of soil height up to bedrock over different parameters include normal period, base shear and anchor on the center of beams. The studied model includes a 10-storey steel regular structure and a 10-storey steel irregular structure at height with bending frame system and bays of 5, 6 and 5m and height of each floor is 3 meters and also cross-section of beams and columns is IPE270. If soil of structure with the internal friction angle and with different soil depth and length are placed on bedrock, by consideration of P- Δ and Naghan earthquake records the results could be investigated. The results show that soil type and effect of interaction between soil and structure can influence on the responses of a high structure in comparison with effects of P–Δ. ABAQUS Software was used for this research. The results shows that by increase of internal friction angle of the soil, the natural period of regular structures is larger than irregular structures; and base shear and anchor on the center of beams in irregular structure is larger than regular structures. Also, by increasing the height of soil to the bedrock we can see that the normal period, base shear and anchor on the beams in irregular structure is larger than regular structures.

Keywords: *Irregular Structure, Consideration of P-Δ, Regular Structure*

INTRODUCTION
One of the most important factors affecting on seismic efficiency of structure is its irregularities in the plan and the height. Seismic efficiency of structures includes irregularity in mass, stiffness, resistance and structural form.

Consideration of interaction between soil and structure shows a real behavior of soil and structure. Destructive effects of earthquakes have indicated the importance of the impact of the dynamic properties of soil.

Earthquake occurrence shows that stone-bed movement can be accelerated at the foundation and then response of structure will be changed significantly. The subject of influence of foundation flexibility on behavior of structures has been studied by many researchers in the past decades.

In general, interaction between soil and structure can increase the period of construction, reduction of base shear, reduction of stories shear and relative lateral displacement that has increased in some stories and decreased in others.

The effect of P-Δ can influence on severity of anchor, beams shear, increase of maximum relative lateral displacement and totally behavior of structure.

The effect of irregularity can increase relative displacement and also can decrease the level of structural efficiency.

It may be possible occur P-Δ in irregular structures. In order to consider the effects, steel bending frames on the concrete foundation should be used. In order to analyze the effect on the soil structure should be used to achieve the intended results. Thus, through interaction between soil and structure, effect of P-Δ and form of structure should be examined on the structural parameters including period of structure, base shear and anchor on the beams.

Background

Rostami (2007) has studied a paper titled “effect of soil layering on the dynamic response of vibrated foundations by the use of dynamic limited-unlimited couple elements. The results show that limited-unlimited couple elements have presented acceptable and logical results as compared with the other methods and are consistent with experimental results.

In a study by Ghanad and Ahmadnia (2006), only parametric study of interaction between soil and structure in inflexible (rigid) behavior of structures has been carried out.

By these studies, soil based on a conical model and structure based on a single-scale has been reviewed through double-line behavior of soil and structure.

Various analyses have been carried out and showed that dimensionless parameters in direction of effect of interaction with structure can be effective in different ductility by record of Center SCT. The results show that interaction between flexible and inflexible forces is created.

But high structures with low periods, maybe inflexible force needed in the structure in soft bed is larger than rigid bed.

A study by Tavakoli *et al.*, (2011) examined the effects of interaction between soil and structure on seismic behavior of steel frames by steel spring method. The study included two 7-storey building with steel bending frames and a convergence bracing.

In their study, each frame has been reviewed by assuming of the rigid and non-rigid on the ground with type 1 and type 4 according to Regulations of 2800 of Iran by acceleration recorder of Tabas and Elcentro earthquake.

Important parameters evaluated in the study include base shear, storey shear and relative displacement of stories. The results of the analysis showed that interaction between soil and structure and flexibility of the infrastructure soil caused the increase of period of structure, reduction of base shear, reduction of storeys shear and relative lateral displacement of storeys which has increased in some storeys and decreased in others.

Model

The studied model includes a 10-story steel regular structure and a 10-story steel irregular structure at height with bending frame system and bays of 5, 6 and 5m and height of each floor is 3m and also cross-section of beams and columns is IPE270. Table 1 shows properties of modeling materials.

Table 1: Properties of sample materials

Poason coefficient υ	E **elasticity module** (pa)	**density** (kg/m^3)	**Materials**
0.3	2.1×10^{11}	7850	Steel
0.2	2.059×10^{10}	2400	Concrete
0.35	2×10^{8}	1500	Limited soil
0.35	2×10^{8}	1500	Unlimited soil

Various dimensions of soil under the structure have been considered in order to have the most appropriate width and depth for such modeling under foundation of structure. Different values of the width and depth of soil mass has been presented by Table 2. In the above table above, B=17 m and equal to the length of foundations with height of 1m.

The soil structure consists of two parts of soil with limited elements, low adhesion and dilation angle of Ψ 3° with different lengths and heights; and also soil with unlimited elements and dimensions proportional to the soil with limited elements. For each of the 9 different soil conditions, the internal friction angle has values of 30° ،33° ،35° and 38°, and according to regular and irregular geometries, 72 models have been made and analyzed.

Table 2: Different modeling modes

Height of soil (H)	Length of soil (S)	Type of structure
$H=B$	$S=2B$	Regular
$H=2B$		
$H=3B$		
$H=B$	$S=3B$	
$H=2B$		
$H=3B$		
$H=2B$	$S=4B$	
$H=3B$		
$H=3B$	$S=5B$	
$H=B$	$S=2B$	Irregular
$H=2B$		
$H=3B$		
$H=B$	$S=3B$	
$H=2B$		
$H=3B$		
$H=2B$	$S=4B$	
$H=3B$		
$H=3B$	$S=5B$	

Terms of Modeling

The boundaries of the model are considered as semi-infinite. The open border or unlimited place can be covered by expansion of mesh grid to far distances; thus impacts of the surrounding place on the case place would be so low that could be ignored, but it causes to have a heavy model and its analysis time will be very long.

Because of these problems, by the use of advanced software such as ABAQUS it possible is to use semi-infinite elements in these cases. The elements can reduce the size of model while can show the effects of deleted section and absorption properties of energy.

Modeling of Couple Limited-Unlimited Dynamic Elements

The dynamic equation for the system intended as follows:

$$[M_t]\{\ddot{u}\}+[C_t]\{\dot{u}\}+[K_t]\{u\}=\{P\}$$

In which matrix of $[M_t]$, $[C_t]$, $[K_t]$, are matrix of mass, damping and stiffness respectively. The proposed model, the soil-structure system is divided into two areas of near and far domains that these areas shall be modeled by normal limited elements and dynamic unlimited elements respectively. So above matrixes could be separated for two areas:

$$[M_t]=[M_n]+[M_f]$$

$$[C_t]=[C_n]+[C_f]$$

$$[K_t]=[K_n]+[K_f]$$

In equations (2) subtitle of (t) represents the entire matrix; (f) and (n) also indicate matrix of far and near domains respectively.

The near domain includes the structure, and the soil under the bed, while the far domain includes the rest of bed to infinity.

Since the analysis of interaction by the way of proposed structure or underneath of structure, it is necessary to determine the dynamic impedance of far domain and then spring-dampers, so the dynamic motion equation should be considered separately. So the dynamic motion for this segment should be calculated separately. Therefore, according to equations (1) and (2) can be written:

$$\lfloor M_f \rfloor\{\ddot{u}_f\}+\lfloor C_f \rfloor\{\dot{u}_f\}+\lfloor K_f \rfloor\{u_f\}=\{p_f\} \tag{3}$$

While formulation of dynamic unlimited elements depends on seismic frequency, and because the analysis of interaction by the way of underneath of structure should be carried out in frequency area and according to the Interaction-Principle; so the equation will be changed and equal to equation (4) in conditions of frequency area and harmonic motion:

$$\lfloor -\omega^2[M_f]+i.\omega.[C_f]+[K_f]\rfloor\{u_f\}=\{p_f(\omega)\} \tag{4}$$

$$\left[\overline{K_f(\omega)}\right]\{u_f(\omega)\}=\{p_f(\omega)\} \tag{5}$$

$$\{u_f(\omega)\}=u_1+i.u_2 \quad \text{و} \qquad \{p_f(\omega)\}=p_1+i.p_2 \tag{6}$$

Given that solutions are applied in the frequency are force and displacement will be mixed as follow.

$$\left[\overline{K_f(\omega)}\right]=\left[K_1(\omega)\right]+.i.\left[K_2(\omega)\right]=\frac{\{p_f(\omega)\}}{\{u_f(\omega)\}} \tag{7}$$

For each harmonic, dynamic impedance could be achieved by load-displacement relation therefore according to equation (4) can be written:

$$\left[\overline{K_f(\omega)}\right]\{u_f(\omega)\}=\{p_f(\omega)\} \tag{8}$$

In which $\lfloor \overline{K_f(\omega)} \rfloor$ dynamic impedance matrix (far domain) is the observed; in this relation matrixes of $[K_1]$ & $[K_2]$ are both a function of seismic frequency of (ω) and matrix $[K_1]$ is dynamic stiffness matrix in far domain which represents stiffness of soil of support and matrix $[K_2]$ also shows the damping coefficient (damper equivalent) for the far domain.

If new matrixes of $[K_f]_e$ and $[C_f]_e$ are equivalent springs and dampers respectively, so:

$$\lfloor K_f \rfloor_e=\left[K_1(\omega)\right]$$
$$\lfloor C_f \rfloor_e=1/\omega\left[K_2(\omega)\right] \tag{9}$$

In equations (4) to (9), parameter of ω is a specific seismic frequency with stiffness and damping properties of the system. So according to matrixes of equivalent spring and dampers; theses matrixes could be mixed by matrixes of mass, stiffness and damping in the near domain (or in the structure) and displacement equation of the system could be written as follow:

$$[M_n]\left\{\ddot{u}\right\}+\left([C_n]+\lfloor C_f \rfloor_e\right)\left\{\dot{u}\right\}+\left([K_n]+\lfloor K_f \rfloor_e\right)\{u\}=\{P\} \tag{10}$$

In fact, the form of the last equation is the changed form of equation (1) in which matrixes of spring and dampers without the mass were replaced by matrixes of stiffness and damping in the far domain of the first system respectively.

Software ABAQUS, for the limited soil near to foundations, the elements of CPE4R have been selected because they are continuous plane strain quadrilateral 4-node elements and use reduced Integration Method; for the semi-infinite section, the elements of CINPE4 have been used because they are continuous linear 4-node elements and use Full Integration Method and have 2-point Gaussian Integration at infinity.

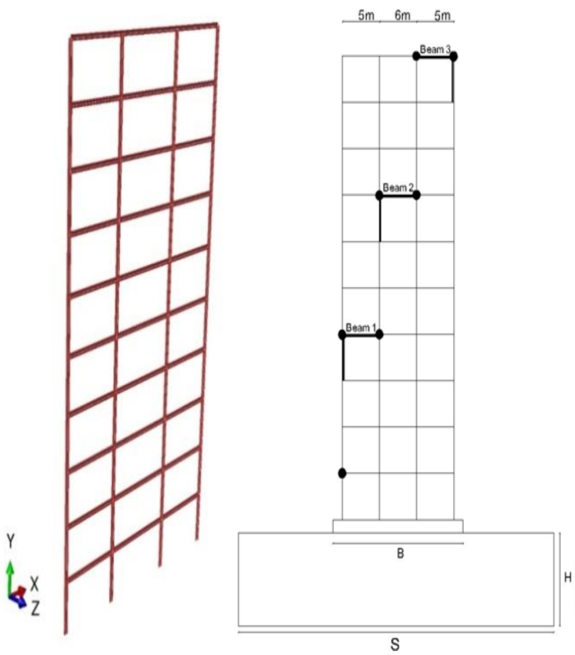
Interaction between soil and foundation, so that their normal behavior is Hard Contact and their tangential behavior is Penalty, means considering the friction coefficient equal to 0.4329.

The second part of the model is the connection between columns and foundation that for this connection, the Constraint of Tie has been used. It means a setting connection established between the foundation and the columns. Figures (1) and (2) presented regular and irregular geometry.

In this study, we have two-dimensional frames with constant beams and columns elements; and foundation, limited and unlimited soil in mode of Homogeneous.

Also we observe both static and dynamic loading that static loading includes gravity loads which applied to the beams linearly; so it is load applied into the soil.

As well as dynamic loading could be defined as the loading history of horizontal and vertical acceleration recorders for earthquake of Naghan; figures (5-3) and (6-3) showed a boundary condition at the lowest soil surface (bedrock) in horizontal and vertical directions as Amplitude. In the study, Boundary Condition as setting at the lowest level of soil could be end to the bedrock and unlimited elements of soil are shown on both sides.



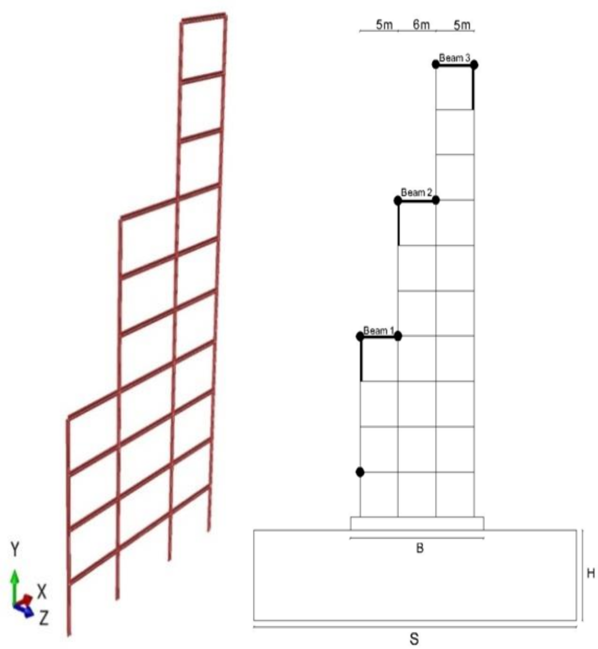


Figure 1: The regular geometry of building
Figure 2: the irregular geometry of building

Analysis of Sensitivity

Effect of Height of Soil Up to Bedrock on the Natural Periods in Regular and Irregular Structures

Effect of height of soil up to bedrock on the natural periods in regular and irregular structures and comparison of them will be studied here. Chart 1 shows the case of S=2B and the angle of friction of 30° and could be seen when the height of soil under the structures is changed; natural period could be increased if the height of the soil is increased up to the bedrock in both regular and irregular structures. It was seen that natural periods in regular structures are larger than irregular structures; and its value is more significant in heights less than H = 2B as compared with higher heights more than H = 2B. For example, the natural period of regular structure has been decreased about 1.2 percent as compared with irregular structures at height of H = 2B.

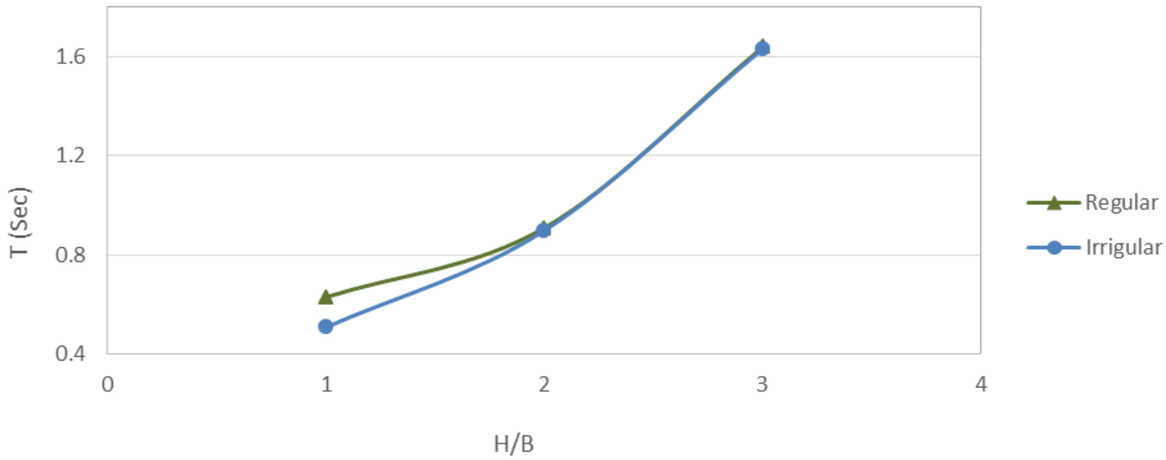


Chart 1: Height of soil to bedrock of the normal period in regular and irregular structures

Effect of Height of Soil Up to Bedrock on the Base Shear in Regular and Irregular Structures

Effect of height of soil up to bedrock on the base shear in regular and irregular structures and comparison of them will be studied here. Chart 2 shows the case of S=2B and the angle of friction of 30° and could be seen when the height of soil under the structures is changed; base shear could be decreased if the height of the soil is increased up to the bedrock in regular structure and this value will be increased in irregular structures at first and then it will be decreased. It was seen that base shear in irregular structures are larger than regular structures; and base shear in regular structures could be increased to 1265 percent as compared with irregular structures in height of H=3B.

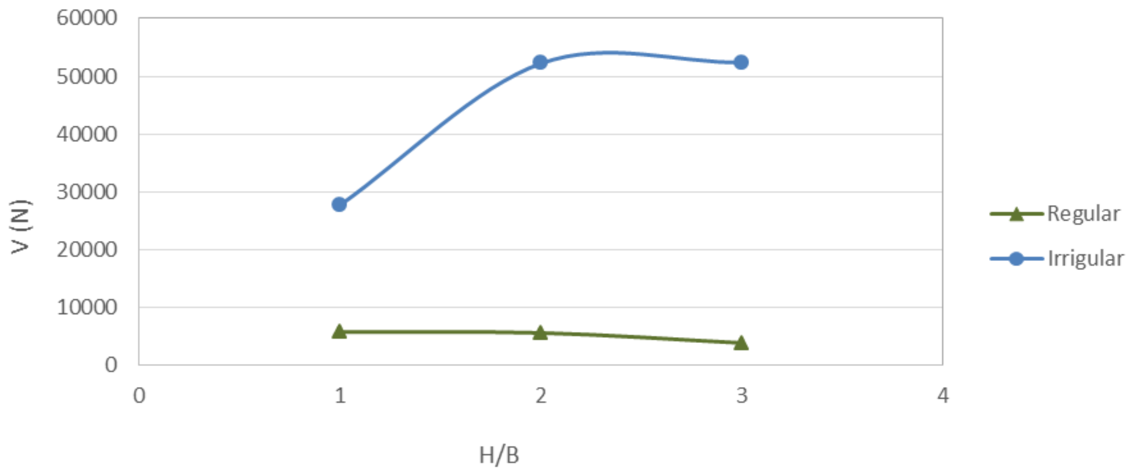


Chart 2: Height of soil to the bedrock on base shear in regular and irregular structures

Effect of Height of Soil Up to Bedrock on the Anchor on the Center of Beams in Regular and Irregular Structures

Effect of height of soil up to bedrock on the anchor on the beam in regular and irregular structures and comparison of them will be studied here. Chart 3 shows the case of S=2B and the angle of friction of 30° and could be seen when the height of soil under the structures is changed; anchor on the beam no. 1 could be decreased if the height of the soil is increased up to the bedrock in regular and then it will be increased in irregular structures. It was seen that anchor on the beam no.1 in irregular structures is larger than regular structures; and for example anchor on the beam no. 1 in regular structure in height of H=2B as compared with irregular structures could be increased about 9.31 percent.

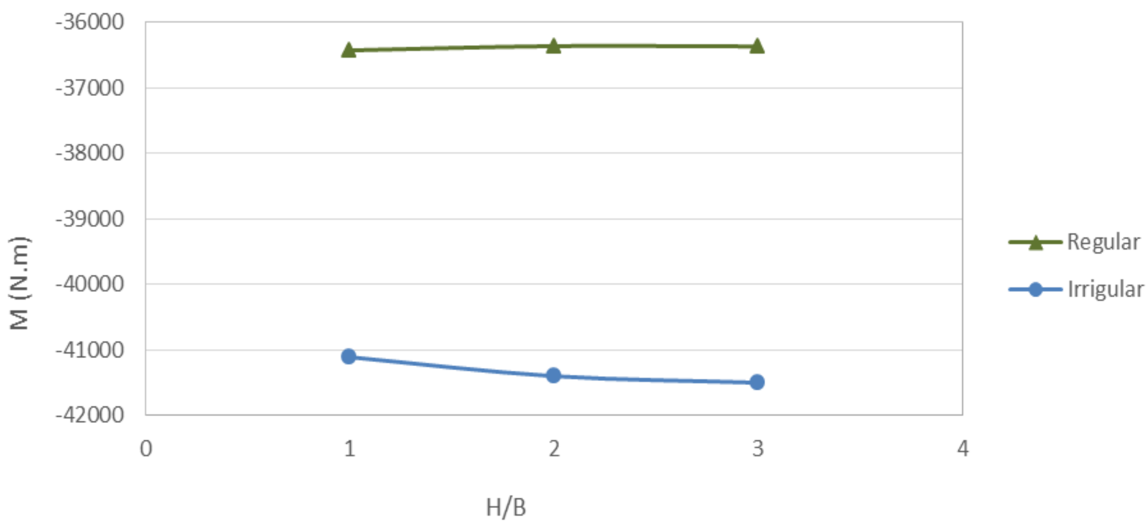


Chart 3: Height of soil up to the bedrock on anchor on the beam no. 1 in regular and irregular structures

CONCLUSION

Interaction between soil and structure has effects on seismic behavior of structures from different aspects. That it can be noted to reduction of the natural frequency of system, and reduction of base shear. The effect of different parameters such as natural period (T), base shear (V) and anchor on the beams (M) in regular and irregular structures in height has been reviewed; and by consideration of the angle of internal friction and different dimensions of soil and also comparing both regular and irregular modes on response of structures the following results have been achieved:

- Increase of internal friction angle of soil causes to have period of regular structure (especially in depth H=B) is larger than the irregular structure.
- By increasing the height of soil up to the bedrock, the natural period of irregular structures (especially in depth H=B) is larger than regular structures.
- By increasing the width of soil, the natural period of irregular structures in depth H=B is larger than regular structures but in other depths in regular structure it is larger irregular structures.
- By increasing the angle of internal friction of soil materials, base shear of irregular structures is larger than regular structures.
- Increasing the height of soil to the bedrock, base shear of irregular structure is larger than regular structure.
- Increased internal friction angle of soil materials, anchor on the beams in irregular structure is larger than regular structure.
- By increasing the height of soil to the bedrock, anchor on the beams in irregular structure is larger than regular structure.

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