Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 52(1) (2020) 71-74
DOI: 10.22060/ceej.2018.14671.5713

An investigating into the effect of various modeling parameters on the behavior of special steel moment frames

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ABSTRACT: In this paper, the effect of various modeling parameters such as beam-column connections, soil and shallow foundation types are studied to assess the seismic response of steel moment frames. For this purpose, five-story special steel moment frames with two different soil types (II and IV) were considered. The footing and strip shallow foundations were designed for these buildings, with a safety factor of three. Prequalified bolted flange plate connections were used in these buildings. The finite element models were developed using OpenSees software considering soil – foundation – structure interaction. The seismic performance of SMFs was evaluated using nonlinear time history analyses, through seven far–fault ground motions. Nonlinear behavior of soil was modeled by nonlinear Winkler springs. The numerical results showed that in the models that considered beam-column connections, SFSI and soil type IV, the maximum inter-story drift was more, compared to models without connections and with fixed based conditions. The maximum base-shear force of structures in the mentioned models was reduced. In models, that structures rested on soil type II, maximum values of these two parameters were diminished. The effect of foundation type in models resting on the soil type IV was more than models with soil type II. Generally, connections, foundation type and soil-foundation-structure interactions have a great influence on the nonlinear responses of steel moment frames.

Review History:

Received: 6/28/2018
Revised: 7/26/2018
Accepted: 8/5/2018
Available Online: 8/14/2018

Keywords:

Special steel moment frame
Soil – foundation – structure interaction
Fixed connections
Soil and foundation type
Time history dynamic analysis

1. INTRODUCTION

Accurate structural analysis against the dynamic loads, especially earthquake, has significant importance. The nonlinear behavior of ground, in soft or relativity soft soils, produces structure responses completely different from the structures with fixed-based or free-field motion. The term "free-field" represents the movements that they are not affected by the structural vibration or waves scatting around the foundation. So, the process, in which the response of soil is influenced by the structure responses and the dynamic response of structures is also affected by the deformation in the soil of sub-layers, is known as soil-structure interaction. Two kinematic and inertial interactions are considered in the dynamic soil-structure interactions. Kinematic interaction results from the presence of stiff foundation elements on or in soil, which causes motions at the foundation to deviate from free-field motions. The inertial interaction is the result of the mass of the structure and movement of them during the vibrations. Inertial interaction produces base shear, moment and torsion forces at the structures [1].

In majorities of recent researches, the simultaneous effect of beam-column connections, shallow foundations and soil types on the structural responses have not been investigated. The procedures regulated in some codes do not elaborate on different types of foundations, Moreover, an equivalent linear behavior for the subsoil has also been adopted in these codes without directly capturing any soil nonlinearity. So, in this study, the impact of beam-column connections, the variation of soil and foundation types, and also considered soil–foundation–structure interaction, are studied to assess the seismic behaviors of special steel moment-resisting frame buildings. For this purpose, the five-stories steel moment-resisting frame was modeled in six various conditions with two different soil types; as follows:

- Fixed-based and without beam-column connections effect.
- Fixed-based and with beam-column connections effect.
- Flexible base with footing foundation and considering beam-column connections.
- Flexible base with footing foundation and without considering beam-column connections.
- Flexible base with strip foundation and considering beam-column connections.
- Flexible base with strip foundation and without considering beam-column connections.

The nonlinear dynamic time-history analyses using seven far–fault ground motions were performed.

2. DETAILS OF MODELS

In this study, five-stories buildings located on the soil types II and IV [2] were considered for evaluating the effect of

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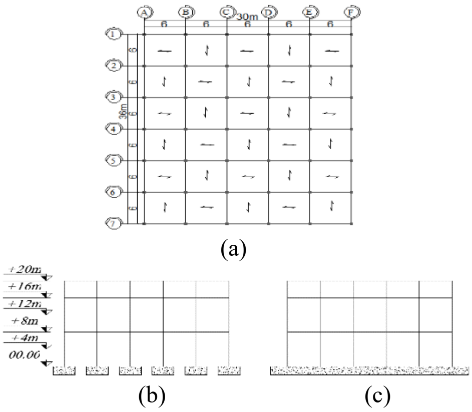

Fig. 1. (a) Plan, (b) sections of building with footing and (c) strip foundations

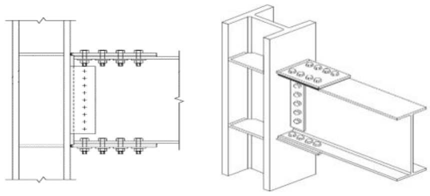

Fig. 2. Bolted flange plate moment connection [3]

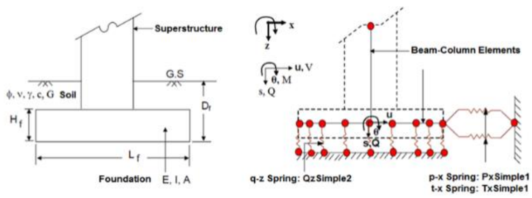

Fig. 3. Schematic diagram of the BNWF model [6].

soil and foundations on the seismic behavior of special steel moment-resisting frames. Plan and the view of the assumed buildings are shown in Figure 1. The buildings were designed according to the Iranian National Building Code [3] and all seismic provisions were included. BFP prequalified moment connections were designed to connect the beams and columns based on the mentioned code (Figure 2). The structures were assumed to be rested on square isolated footing and strip foundations with a safety factor of 3. The ultimate bearing capacity of shallow foundations, located on the soil types IV and II, have been calculated by Meyerhof equations and SPT [4] results, respectively.

3. NUMERICAL MODELING WITH OPENSEES

In this study, the numerical modeling of structures was performed using OpenSees software. The structural members are modeled to behave nonlinearly. The beams and columns were modeled as nonlinear beam-column elements, with Steel01 materials. The impact of rigid beam-column connections has been included in the modeling of frames. Separate nodes were introduced to model connections at the end of beams and columns. Then, two nodes with the same coordinates have been joined with ZeroLength element as a RotSpring2D. Uniaxial hysteretic material was used for the connections. At this study, moment rotation relationship of connections with flange plates has been utilized to define hysteretic behavior of connection's material as [5]:

$$M = \frac{k\varphi}{[1+(k\varphi/M_p)^{5.5}]^{1/5.5}} \quad (1)$$

In which the value of k and M_p is obtained as follows [5]:

$$k = 0.5\,Ebth^2 / l \quad (2)$$

$$M_p = bth\sigma_s \quad (3)$$

Beam on nonlinear Winkler foundation (BNWF) model was used for modeling of nonlinear behavior of soil. In the BNWF model, the two-dimensional shallow foundation model is modeled as a flexible, elastic beam-column element with three degree-of-freedom per node (Figure 3). These elements were supported by a number of discrete, nonlinear Winkler springs that leads to forces and deformations in horizontal, vertical, and rotational directions. Each nonlinear Winkler spring was independent of other springs and was considered as one-dimensional ZeroLength element in the framework of OpenSees. The q-x springs are used to simulate the vertical and rotational resistance of the footing, while two springs, namely p–x and t–x, are placed horizontally to capture the passive and sliding resistance of the footing, respectively [6]. Horizontal and vertical stiffness specifications of springs are calculated using Gazetas [7] equations.

4. RESULTS AND DISCUSSION

Nonlinear time history analysis was performed using seven ground motion records; therefore, the PEER's database of strong ground motions was used for choosing them. The selected ground motions are far-fault records, their central distance from the station was more than 20 km and they were recorded on bedrock. An overall assessment of structural damages showed that ground condition had significant effects on the distribution of destruction; furthermore, it is one of the influential factors in variation of input earthquake parameters such as frequency and intensity. In this study, NERA [8] software was used for investigating the mentioned effects in the models with soil.

The results of these analyses are shown as maximum inter-story drift and maximum story-shear forces diagrams for five-stories models with footing and strip foundations resting on the soil types IV and II in Figures 4 to 7. Four conditions were assumed for evaluating the seismic behavior of this frame including (a): fixed-based without connections, (b): fixed-based with connections, (c): flexible base with connections and (d): flexible base without connections influences, that they are discussed in this section.

As it was observed from the given data in Figures 4 and 5, the maximum inter-story drift of frames with fixed-based and

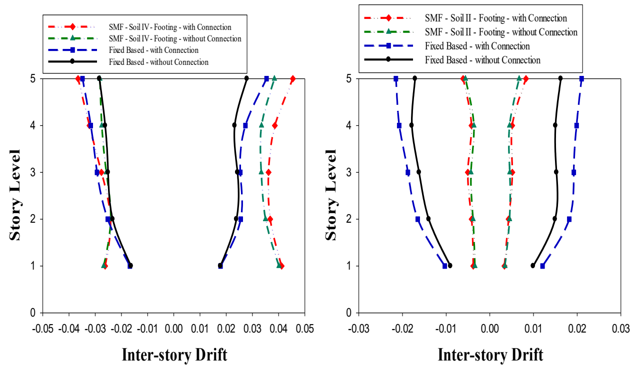

Fig. 4. The maximum inter-story drift with footing foundation resting on the soil types IV and II

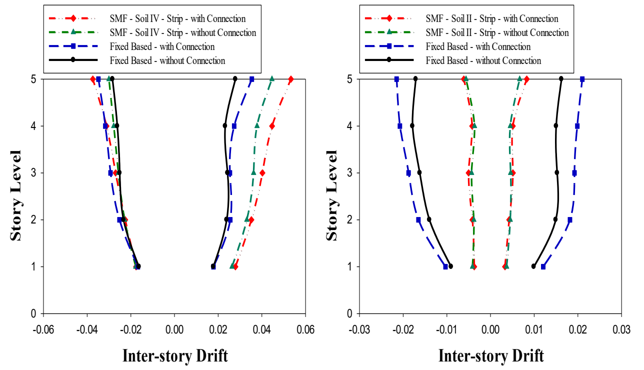

Fig. 5. The maximum inter-story drift with strip foundation resting on the soil types IV and II

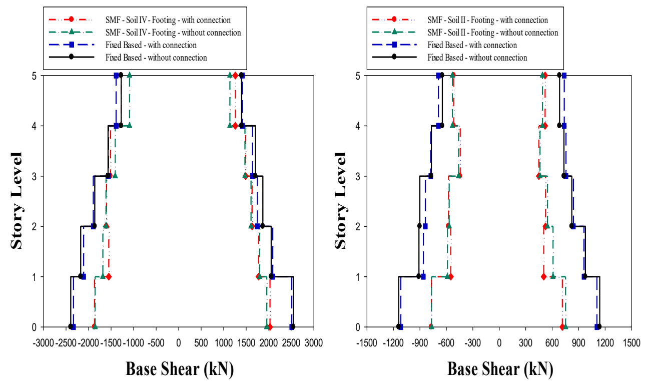

Fig. 6. The maximum story-shear forces with footing foundation resting on the soil types IV and II

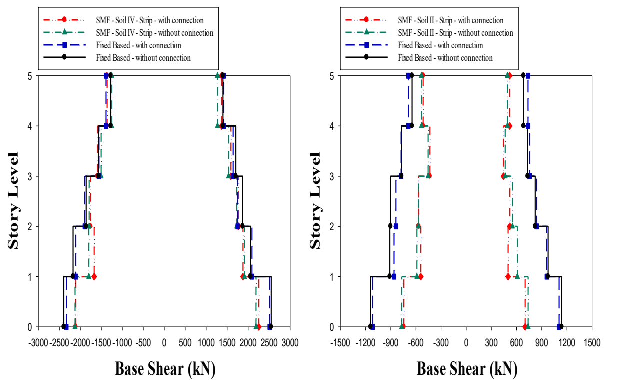

Fig. 7. The maximum story-shear forces with strip foundation resting on the soil types IV and II

with connection, resting on the soil type IV and II, increased by 24.67% and 20.40% compared to models without the impacts of connections and with fixed-based, respectively. The maximum inter-story drift in the models with footing and strip foundation and without connections which were located on the soil type IV, enhance by 41.34% and 57.16% compared to models with fixed-based, respectively. But, this parameter decreases 63% in models resting on the soil type II. It can be also seen that, when the connections and flexible base are considered, the maximum inter-story drift of structures with footing and strip foundations located on the soil type IV enhanced up to 60.01% and 87.85% to models without considering effects of them, respectively. In contrast, in models rested on the soil type II, this parameter was decreased as much as 54%.

According to Figures 6 and 7, the maximum story-shear forces of models with fixed-based and with connection, resting on the soil type IV and II, diminished 1.49% and 2.86% relative to models without connections. The maximum base shear in the models with footing and strip foundation and without connections resting on the soil type IV, decreased by 23.23% and 14.23% compare to models with fixed-based, respectively. But, this parameter decreased by 32% in the models resting on the soil type II. As well as, when the connections and flexible

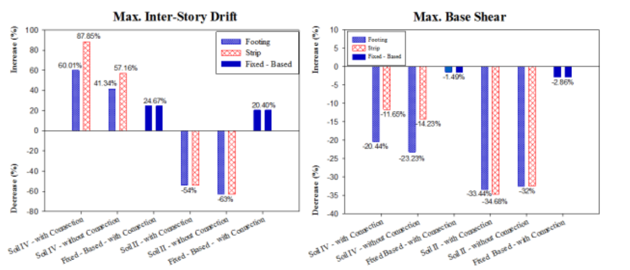

Fig. 8. The percentage of variations at the maximum inter-story drift and maximum story-shear forces

base are considered, the maximum story-shear forces of models with footing and strip foundations situated on the soil type IV decreased as much as 20.44% and 11.65% compared to models without considering effects of them, respectively. Furthermore, in models with structures rested on the soil type II, this parameter was decreased as much as 33.4% and 34.68%, respectively.

The percentage of maximum inter-story drift and maximum story-shear forces variations are illustrated in Figure 8 for models including connections and soil-foundation-structure interaction, models with one component like soil or connections to models without them. The maximum story-shear forces of models resting on the soil type IV with footing foundation had the most reduction percentage, and the maximum inter-story drift of models with strip foundation resting on the soil type IV has the most enhanced. But, considering these effects leads to the same decrease in the models situated on soil type II.

5. CONCLUSIONS

In this paper, the influence of two prominent parameters such as beam-column connections and soil-foundation-structure interaction on the seismic behavior of five-stories steel moment-resistance frames with different soil and foundation types was investigated. The following specific findings of this research were obtained:

1- Modeling of connections in frames with fixed-based led to the enhancement of maximum inter-story drift and reduction maximum story-shear forces.

2- In models with footing and strip foundation, rested on the soil type IV, the maximum inter-story drift was observed to increase, but the maximum story-shear force is decreased when connections and flexible base were considered, compared to models with fixed-based conditions and without connections. But, in models rested on the soil type II, considering the above parameters caused reduction at structure responses.

3- The foundation type had a significant impact on the maximum inter-story drift and maximum story-shear forces of structures located on the soil type IV, but it did not have any influence on responses of structures located on the soil type II.

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HOW TO CITE THIS ARTICLE

M. Zare Aghblagha, H.R. Shokrgozar, An investigating into the effect of various modeling parameters on the behavior of special steel moment frames, Amirkabir J. Civil Eng., 52(1) (2020) 71-74.

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