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# Effect of Foundation Flexibility on the Capacity of Concrete Moment Frames with Shear Wall

E. Rajabi*

Department of Civil Engineering, Tafresh University, 39518-79611 Tafresh, Iran

**ABSTRACT:** Considering the soil-foundation-structure interaction (SFSI) in the structural modeling procedure can change the seismic structural response. However, the SFSI effects are mostly ignored in the analysis procedure of structures, as a general engineering belief regarding its conservative effects. This conservation is not always the case, although the period and the damping of structures change by considering SFSI effects and consequently, the seismic demand decreases. The aim of this paper is to evaluate the influence of foundation flexibility on the capacity of concrete moment frames with the shear wall. For this purpose, the beam on nonlinear Winkler foundation approach is used, which is a simple and efficient method. First, a collection of 3, 6 and 10 storied reinforced concrete moment resisting frames founded on soft, medium and hard soils are designed based on FEMA450. After the implementation of frames in Opensees software, a set of seismic scenarios are selected. In the following, each frame that has been founded on the soft, medium and hard soil is analyzed for the case of fixed-base and the flexible-base assumption by incremental dynamic analysis (IDA). A comparison is made between the results of each frame in the flexible-base and fixed-base conditions. The results show that the consideration of the SFSI effects can significantly influence the IDA curves and decrease the structural capacity of frames. So that dynamic instability will occur before the expected capacity corresponding to fixed-base assumptions has been achieved. This instability increases with increasing shear wave velocity of soils and height of frames. For example, 3 and 6 storied frames with the flexible base, which have been founded on soft soil, reach ultimate capacity in 52% and 45% of spectral acceleration corresponding to fixed base, respectively.

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## 1- Introduction

The characteristics of the structure change due to the SFSI effect in comparison with the fixed-base assumption because the ground motion input can be significantly modified in the case of soft soil. Moreover, the natural period of a given structure can extend and in turn, the level of seismic input would decrease [1].

In fact, the SFSI effect is a combined phenomenon in which the structure is influenced by the dynamic behavior of the soil and the foundation and vice versa [2]. Despite the evidence in Structural and earthquake engineering literature, most structures are designed without considering the effect of SFSI because of incorrect belief that neglecting the SFSI is conservative. In recent years, the effects of vertical earthquake motion on high-rise RC frame structures are investigated [3] considering SFSI and fixed support condition. However, investigation of SFSI effects seems necessary. For this, the influence of the foundation flexibility on the capacity of concrete moment frames with shear wall is studied in the present paper.

## 2- Methodology

### 2.1. Shear Wall Frames

A set of 2-D concrete moment resisting frames with shear walls containing 3, 6 and 10 story frames are designed based on FEMA450 [4] static linear guidelines on hard, medium and soft soil conditions introduced through site classes B, C and D (Figure 1). As shown in Figure 1, the story height and the bay length are 600 and 350 cm, respectively. The shear wall thickness is 25 cm for the 3 and 6 story frames and equals to 30 cm for the 10 story frames. The geometric and material properties of the designed frames are presented in Tables 1 and 2.

Implementation of frames is performed in the Opensees framework [5]. In this paper, the nonlinear beam element with concentrated hinges is employed for beam modeling. Beams with concentrated plastic hinges and columns of fiber section are employed to simulate the nonlinear flexural behavior of the moment frames. The beam With Hinges element is chosen for the beams.

*Corresponding author's email: rajai@tafreshu.ac.ir

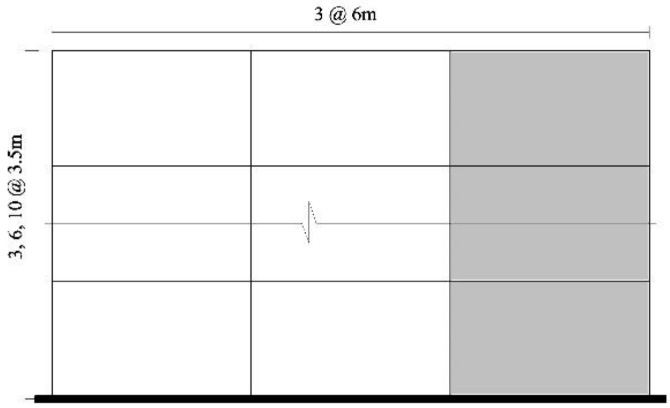


**Fig. 1. The schematic elevation of the studied frames**

**Table 1. Geometric properties of the designed frames**

| Story No. | Level | Column Width (cm) | Column Height (cm) | Beam Width (cm) | Beam Height (cm) |
|---|---|---|---|---|---|
| 3 | 1-2-3 | 45 | 45 | 45 | 45 |
| 6 | 1-2-3-4-5-6 | 45 | 45 | 45 | 45 |
| | 1-2-3 | 55 | 55 | 55 | 40 |
| 10 | 4-5-6-7 | 45 | 45 | 45 | 40 |
| | 8-9-10 | 45 | 45 | 45 | 40 |

**Table 2. Material properties of the designed frames**

| Concrete Compression Strength, ($kg/cm^2$) | Modulus of Elasticity, ($kg/cm^2$) | Yield Stress ($kg/cm^2$) | Shear Modulus ($kg/cm^2$) |
|---|---|---|---|
| 250 | 2.388 e+5 | 4000 | 99500 |

The nonlinear behavior of the plastic hinges was defined in accordance with Haselton et al. [6], who proposed essential relationships in their study based on the calibration of numerous test results in the form of the tri-linear backbone curve suggested by Ibarra [7].

Columns are modeled by the fiber method with the capability of developing distributed plasticity along the element's length. Then, the fiber sections are assigned to the nonlinear Beam Column elements. Each element was also divided into four sub-elements in a story level to provide more robustness. In order to simulate the shear wall element, Flexure-Shear Interaction Displacement-Based Beam-Column element has been selected which developed in the Opensees platform based on the concept of formerly used Multiple Vertical-Line-Element Model (MVLEM). The definition of the boundary elements was also provided in the model.

In this study, the Beam on Nonlinear Winkler Foundation (BNWF), which is capable of simulating the uplift and rocking motions (geometrical nonlinearity) as well as the nonlinear behavior of the soil (material nonlinearity), is employed to model the soil-footing interface. For this, BNWF numerical model has been constructed by assigning nonlinear Beam-Column and zero Length elements to the strip footing and the soil springs, respectively. In order to define the Winkler springs, first, their properties are determined according to different site classes and the corresponding footing dimensions. Second, Qzsimple1 material (in the Opensees) is chosen to represent the soil behavior based on the computed parameters. Moreover, the Gazetas concentrated stiffness has been employed to define the stiffness of the soil springs. Therefore, the distributed stiffness of the Winkler foundation was estimated based on the continuum approaches.

**Table 3. The features of SGMs – Fixed base**

| Story No. | Period (s) | SGM's ID |
|---|---|---|
| 3 | 0.14 | 3-8-14-20-21-24-27-28 |
| 6 | 0.44 | 2-4-10-12-20-21-23-30 |
| 10 | 0.93 | 8-9-12-15-16-22-23-29 |

**Table 4. The features of SGMs – Flexible base**

| Story No. | Soil Type | Period (s) | SGM's ID |
|---|---|---|---|
| | B | 0.15 | 3-8-14-20-21-24-27-28 |
| 3 | C | 0.26 | 3-8-14-20-21-24-27-28 |
| | D | 0.34 | 2-4-10-12-20-21-23-30 |
| 6 | B | 0.45 | 2-4-10-12-20-21-23-30 |

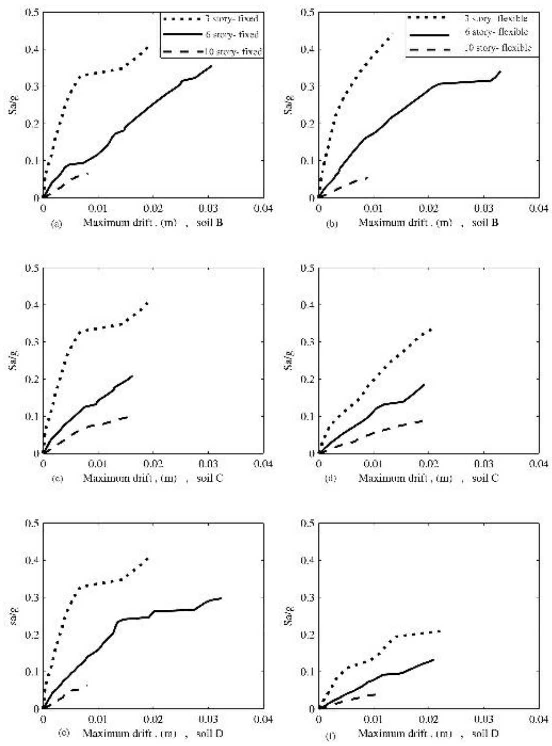

**Fig. 2. The comparison of summarized IDA curves of RC frames with shear wall in fixed and flexible base, a) Soil B, b) Soil C and c) Soil D**

## 2.2. Strong Ground Motions

Strong ground motion (SGM) selection can significantly modify the nonlinear response of structures. The procedure for record selection suggested by Ghafory Ashtiany et al. [8] has been employed in this paper which chooses a few strong ground motion records in order to get approximately the same result as a large set of records. Using the mentioned procedure can decrease the computational time significantly. In this study, the records selected are based on the natural period of each frame and are introduced in Tables 3 and 4.

## 3- 3. Discussion and Results

Incremental dynamic analysis is performed for each frame which has been founded on the soft, medium and hard soil for the case of fixed-base and flexible-base assumption. The summarized IDA curves are shown in Figure 2 for each frame based on soil type. Results show that SFSI is beyond the increasing period of interaction systems. This phenomenon can significantly affect the capacity of frames. So that the endpoints of IDA curves which present the capacity of structures, decrease with considering SFSI. In other words, dynamic instability will occur before the expected capacity corresponding to fixed-base assumptions has been achieved. This instability increases with increasing shear wave velocity of soils and height of frames. For example, 3 and 6 storied frames with the flexible base, which have been founded on soft soil, reach ultimate capacity in 52% and 45% of spectral acceleration corresponding to a fixed base, respectively.

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