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EFFECTS OF COLUMN BASE FLEXIBILITY ON THE SEISMIC RESPONSE OF R C MOMENT RESISTANT FRAMES

Jinsa Johnson, P. G. Student, Universal Engineering College, Vallivattom, jinsa555@gmail.com
Mohammed Aslam, Assistant Professor, Universal Engineering College, Vallivattom, pcaslam4@gmail.com

ABSTRACT: Base restraint can have a significant effect on the behavior of a moment frame. This paper examines analytically different column base restraint conditions and makes an effort to evaluate the effect of soil–structure interaction on seismic response of buildings with isolated footing. Six storey buildings with different column base flexibility conditions such as building with fixed base, hinged base, building with plinth beams extended to adjacent moment frame column bases, building on loose sand and on soft clay were considered. Effect of soil flexibility is incorporated by considering equivalent springs with 6 DOF as per Gazetas. Pushover analysis of frame building is carried out using ETABS 2013 software. Providing a plinth beam between ground storey column helps in controlling the seismic demands in RC frame buildings and also soil structure interaction has considerable effect on the overall performance of structural system.

Key words: Storey shear force, displacement, inter-storey drift, plinth beam, soil structure interaction, pushover analysis

INTRODUCTION

In most of the designs of rigid structural frames, the analysis is carried out by assuming fixity at base, which means that the building is idealized to rest on hard rock. ASCE 7 - 12.7.1 (Foundation Modeling) states "for purposes of determining seismic loads, it is permitted to consider the structure to be fixed at the base. Alternatively, where foundation flexibility is considered, it shall be in accordance with Section 12.13.3 or Chapter 19." Figure 1 illustrates four types of base restraint conditions that may be considered.

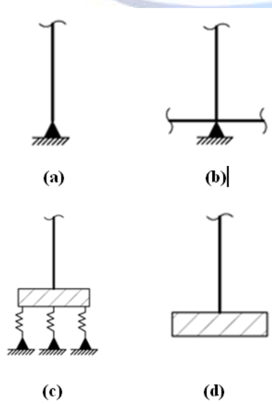

Fig. 1 Column base rotational restraint conditions: (a) hinged base, (b) hinged base, with grade beams extended to adjacent columns, (c) fixed base, and (d) partial restraint to simulate foundation flexibility [Adapted from: Moehle et al, 2008]

Conventional structural design methods neglect the SSI effects. Neglecting SSI is reasonable for light structures in relatively stiff soil such as low rise buildings and simple rigid retaining walls. The effect of SSI, however, becomes prominent for heavy structures resting on relatively soft soils for example nuclear power plants, high-rise buildings and elevated-highways on soft soil. It has conventionally been considered that soil-structure interaction has a beneficial effect on the seismic response of a structure. Considering soil-structure interaction makes a structure more flexible and thus, increasing the natural period of the structure compared to the corresponding rigidly supported structure. Moreover, considering the SSI effect increases the effective damping ratio of the system. In fact, the SSI can have a detrimental effect on the structural response, and neglecting SSI in the analysis may lead to unsafe design for both the superstructure and the foundation.

The importance of evaluating the natural period of a structural frame system by considering the effect of soil flexibility was discussed by Prasad and Srikanta (2010). Spring coefficients for soil flexibility were considered and fundamental natural periods of bare rigid structural frame resting on soil springs were evaluated. Mathew et al. (2014) investigated the effect of earthquake motions on the response of a three dimensional nine storey reinforced concrete structure with and without considering soil-structure

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interaction. Ismail (2014) focused to bring out the effect of flexible foundation soil on the performance of 2D and 3D frame-foundation systems and their overall seismic performance of steel moment resisting frames (MRFs) with flexible column base connections were summarized by Maan and Osman (2002). The frames were modeled with rotational springs having variable stiffness to represent the semirigid effect of base connection. Halkude et al. (2014) investigated the Soil Structure Interaction (SSI) effect on various dynamic properties of R.C. frame such as natural time period, base shear, beam moment, column moment, etc. Effect of various soil and structural parameters are also studied to identify their effect on seismic performance of building frames. Sunitha et al. (2015) performed non linear static pushover analyses using SAP 2000 on buildings with three levels of column base restraints namely, hinged base with taller ground storey, hinged base with plinth beams and equal storey height above plinth and fixed base with taller ground storey.

Non linear static pushover analyses are performed on five building models with different column base restraint condition to assess the influence of rotational restraint at column bases on seismic behaviour of RC moment resistant frames. It also aimed to evaluate the effects of soil structure interaction during seismic analysis. Effect of soil flexibility is incorporated by considering equivalent springs with 6 DOF as per Gazetas.

METHODOLOGY

Buildings with different column base restraint conditions examined analytically by using ETABS 2013. The buildings considered with different column base conditions are as follows

- Building with hinged base
- Building with hinged base and plinth beam
- Building with fixed base
- Building on loose sand
- Building on soft clay

dynamic behavior from pushover analysis, a static non-linear analysis. the results of a parametric study that is conducted to evaluate the

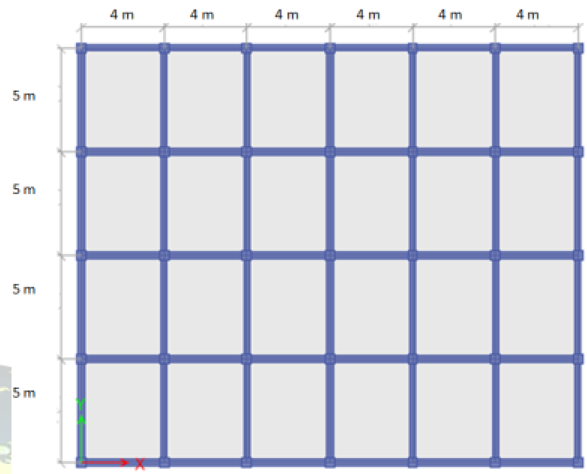

Fig. 2 Plan of the building

All three buildings are 6-storey tall with: 24m×20m plan, 4m typical bay length, 3.5m typical storey height and 5m ground storey height. Plinth beams are provided at1.5m above foundation level on building model with hinged base and plinth beam. Live load considered is of 4kN/m^2 at typical floor and 1.5kN/m^2 on terrace. Dead load includes that due to 200 mm thick URM exterior infill walls (with 20% openings) and 100 mm thick interior URM infill walls. Beam dimensions: 0.3m x0.45m. Column dimensions used are 0.45m x 0.45m for all models. Slabs are of 150mm thickness. Fe415 grade steel and M30 grade concrete are considered in design. 0.8% steel was provided for columns in accordance with IS 456:2000.

Soil spring stiffness for shallow foundation

The movement of the foundation is generally considered in two perpendicular horizontal directions and in vertical direction. The rotations of the same about these three directions should also be considered as shown in figure 3. For buildings with isolated footing, below each column, three translational springs along three directions and three rotational springs about those mutually perpendicular axes should be put together to simulate the effect of soil-flexibility, as suggested in well accepted literature (Gazetas, 1991).

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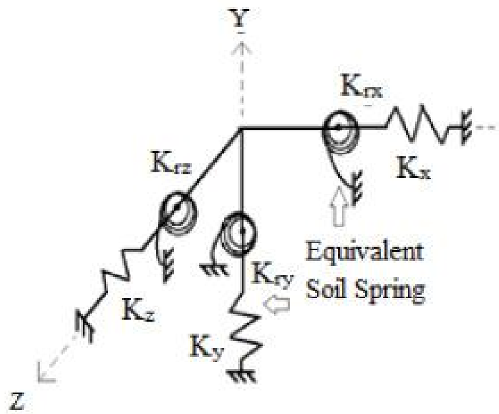

Fig. 3 Equivalent soil spring stiffness along 6 degrees of freedom

Kx, Ky, Kz = Stiffness of equivalent soil springs along the translational DOF along X,Y and Z axis.
Krx, Kry, Krz = Stiffness of equivalent rotational soil springs along the rotational DOF along X,Y and Z axis.

A complete set of algebraic formulae and dimensionless charts for readily computing the dynamic stiffness and damping coefficient of foundations harmonically oscillating on/in a homogeneous half-space is available by Gazetas. Table 1 presents the surface stiffness of rigid plate in different degrees of freedom.

Table 1 Spring Stiffness Equations

Degrees of freedom	**Stiffness of equivalent soil spring**
Vertical	$[2GL/(1-v)](0.73+1.54\chi^{0.75})$ with $\chi = Ab/4L^2$
Horizontal (lateral direction)	$[2GL/(2-v)](2+2.50\chi^{0.85})$ with $\chi = Ab/4L^2$
Horizontal (longitudinal direction)	$[2/(2-v)](2+2.50\chi^{0.85})$-$[0.2/(0.75-v)]\, GL[1-(B/L)]$ with $\chi = Ab/4L^2$
Rocking (about longitudinal)	$[G/(1-v)]Ibx^{0.75}(L/B)^{0.25}[2.4+0.5(B/L)]$
Rocking (about lateral)	$[G/(1-v)]Iby^{0.75}(L/B)^{0.15}$
Torsion	$3.5G\, Ibz^{0.75}(B/L)^{0.4}(Ibz/B^4)^{0.2}$

A_b = Area of the foundation considered
B and *L* = Half-width and half-length of a rectangular foundation
I_{bx}, I_{by}, and I_{bz} = Moment of inertia of the foundation area with respect to longitudinal, lateral and vertical axes, respectively
Two types of soil, Loose sand and soft clay were used for the study. Soil properties are given in table 2.

Table 2 Soil properties

Property	Loose sand	Soft clay
Modulus of elasticity(kN/m^2)	25x10^3	5x10^3
Poissson's ratio	0.3	0.3
Safe bearing Capacity (kN/m²)	245	100

Shear modulus of soil obtained from the relation, $G = E/2(1+\mu)$. Area of individual square footings calculated from column axial loads. Thickness of footing slab determined based on shear. Footings designed for one-way shear and Two-way shear. For different column loads different footing sizes were adopted.

For building on loose sand
Footing 1 - 1.8m x 1.8m x 0.34m
Footing 2 - 2.2m x 2.2m x 0.42m
Footing 3 - 2.6m x 2.6m x 0.52m

For building on soft clay
Footing 1 - 2.8m x 2.8m x 0.35m
Footing 2 - 3.4m x 3.4m x 0.45m
Footing 3 - 3.9m x 3.9m x 0.54m

The stiffness along six DOF for footings were calculated and are shown in table 3 and 4, and the buildings modeled with different column base restraint conditions are shown in figures 4, 5, 6, 7, 8 and 9.

Table 3 Stiffness of equivalent soil spring (loose sand)

DOF	Footing - 1	Footing - 2	Footing – 3
Horizontal (longitudinal direction) (kN/m)	45,814.45	55,995.448	66,176.43
Horizontal (lateral direction) (kN/m)	45,814.45	55,995.448	66,176.43
Vertical (kN/m)	56,126.346	68,598.86	81,071.389
Rotation about the	846.94	1,584.678	2,904.45

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longitudinal axis (KNm/rad)			
Rotation about the lateral axis(KNm/rad)	292.026	546.44	1,001.534
Rotation about vertical axis (KNm/rad)	6,610.742	12,206.778	21,063.008

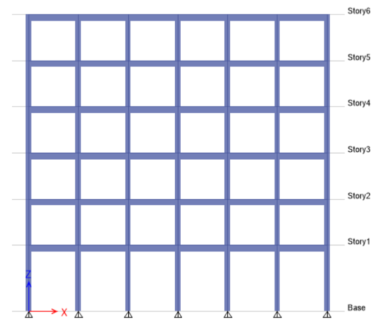

Figure 5 Building with hinged base

Table 4 Stiffness of equivalent soil spring (soft clay)

DOF	Footing - 2	Footing - 2	Footing - 3
Horizontal (longitudinal direction) (kN/m)	14,253.38	17,307.684	20,361.98
Horizontal (lateral direction) (kN/m)	14,253.38	17,307.684	20,361.98
Vertical (kN/m)	17,461.53	21,203.286	24,945.04297
Rotation about the longitudinal axis (KNm/rad)	251.939	512.87	873.80
Rotation about the lateral axis(KNm/rad)	86.875	176.85	301.31
Rotation about vertical axis (KNm/rad)	3,365.37	6364.29	10,559.98

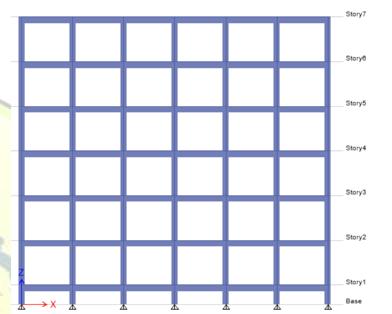

Figure 6 Building with hinged base and plinth beam

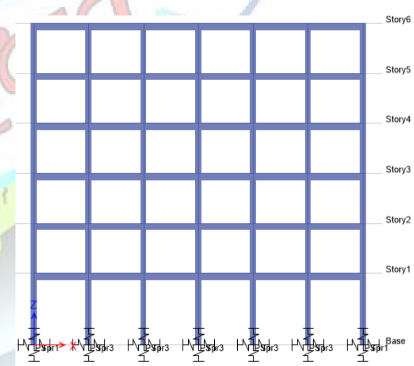

Figure 7 Building on soft clay

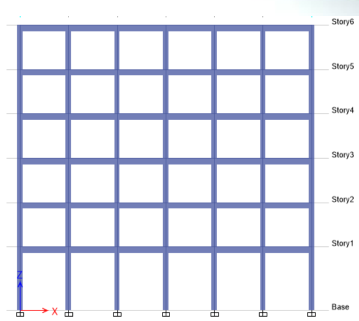

Figure 4 Building with fixed base

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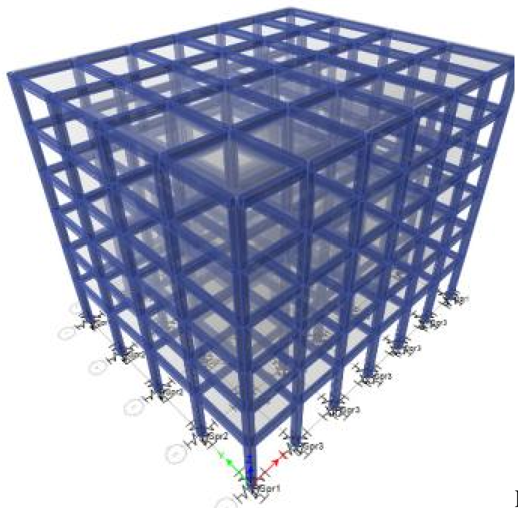

Figure 8 3D view of building on loose sand

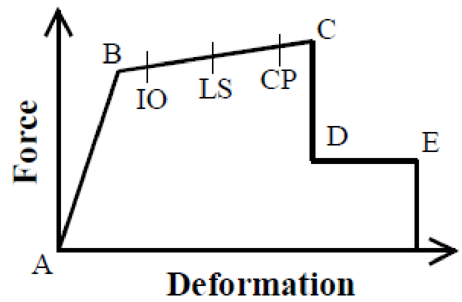

Fig. 9 Force-deformation for pushover hinge

NON-LINEAR STATIC PUSH-OVER ANALYSIS

The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out upto failure, thus it enables determination of collapse load and ductility capacity. On a building frame, and plastic rotation is monitored, and lateral inelastic forces versus displacement response for the complete structure is analytically computed. This type of analysis enables weakness in the structure to be identified. Static pushover analysis is an attempt by the structural engineering profession to evaluate the real strength of the structure and it promises to be a useful and effective tool for performance based design.

The ATC-40 and FEMA-356 documents have developed modeling procedures, acceptance criteria and analysis procedures for pushover analysis. These documents define force deformation criteria for hinges used in pushover analysis. As shown in Figure 1, five points labeled A, B, C, D, and E are used to define the force deflection behavior of the hinge and three points labeled IO, LS and CP are used to define the acceptance criteria for the hinge. (IO, LS and CP stand for Immediate Occupancy, Life Safety and Collapse Prevention respectively.) The values assigned to each of these points vary depending on the type of member as well as many other parameters defined in the ATC-40 and FEMA-356 documents.

Pre-defined non-linear hinge properties corresponding to FEMA 356 hinge model were assigned to columns and beams of the building models and pushover analyses were performed. Nonlinear hinges assigned to beams and columns at relative distances 0.1 and 0.9 from the ends. Load Application is displacement control.

RESULTS AND DISCUSSION

Figure 10 shows the pushover response curve of buildings with different column base restraints. Plinth beams increases the shear force demand in ground storey columns. It is also observed that shear force is smaller for building on soft clay. Soil structure interaction has significant effects on the seismic response of R C frames. There is a large variation in base shear for buildinds on loose sand and soft clay.

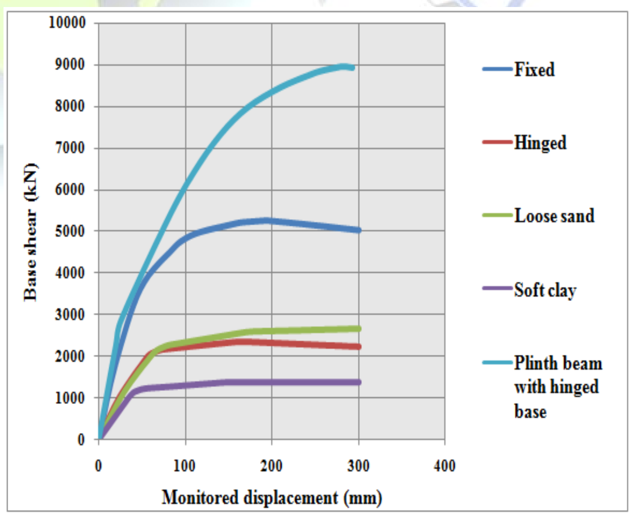

Fig. 10 Pushover response curve

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Variation in the storey displacements are shown in figure 11. As increases the soil flexibility, the displacement of the bottom stories increses.

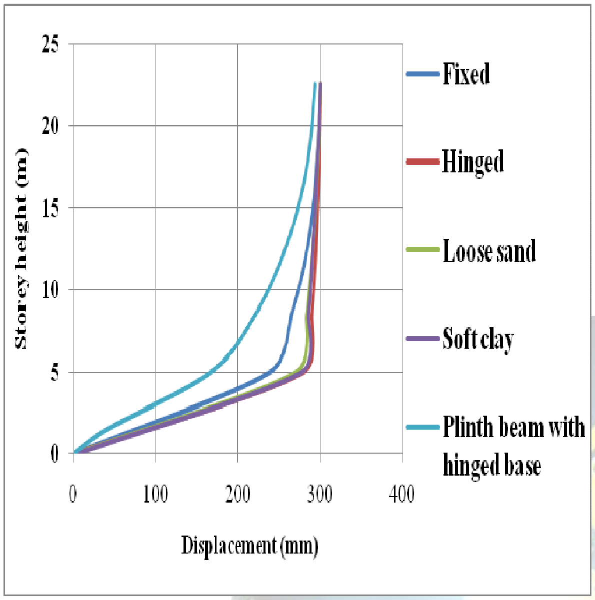

Fig. 11 Storey-displacement curve

CONCLUSION

According to the results of the analytical study on buildings with different column base restraint conditions such as building with fixed base, hinged base, building with plinth beams extended to adjacent moment frame column bases, building on loose sand and on soft clay it is observed that considering plinth beams in the analytical model of the building improves the shear force demand and reduces the bottom storey displacement. The present study also makes an effort to evaluate the effect of soil–structure interaction on the characteristics of buildings with isolated footing. According to the results, soil structure interaction has greater influence on the seismic behaviour of the R C framed buildings.

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