Seismic Response of Rectangular RC Building with and Without Infill Walls Considering Soil–Structure Interaction

P. S. Bhurse, S. S. Sanghai, and N. Lalitha Kumari

Abstract In the last few years, the tall, proportioned and irregular structure exhibits more risks during earthquakes. For interior wall and exterior walls of structure, infill walls are frequently used to fill up the space between beam and column frame. In this study, the influence of the response of infill walls on the seismic performance of the reinforced concrete building prone to lateral seismic loads is investigated. The exact modeling of the structure reflects on many structural aspects like strength and stiffness of the structure to resist the lateral earthquake load initiated by the earthquake. A comparative and parametric study is carried out with the help of joint displacement, axial force, maximum bending moment, shear force, time period, etc.

Keywords Infill walls · Soil–structure interaction · Time history analysis · Equivalent diagonal strut method

1 Introduction

The masonry infill wall has the main influence on the structural reaction of reinforced concrete (RC) structures when exposed to seismic activity. Infill wall is mostly used to increase initial stiffness and strength of reinforced concrete building construction. The arrangement of infill strut panel and reinforced concrete edge is mostly used in the structure, where the section is predisposed to seismic movement. Infill wall is normally used as a partition element because of many suitable components like lighter in load, openness in structure, excellent visible view, defending fabric goods, etc.,

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even so in the structural investigation, solely the impact of mass is measured and its structural physical appearance such as strength and stiffness is usually neglected. Still it provides significant lateral stiffness to the bare framed structures, these existed not measured in the preceding edition of Indian standard code of seismic activity resilient project is IS 1893:2002(Part 1) [1]. But, in the new publication of Indian standard for a seismic activity resilient plan IS 1893:2016(Part 1), [2] many provisions for infill walls are specified. The condition is that unreinforced infill wall can be modeled as an equivalent sloping strut, which if not considered results in unequal structure. The ends of the equivalent strut treated as pin joint are connected to the RC frame and influence the opening on a width of the equivalent diagonal strut also stated. Infill wall is unknown, although the mutual masonry wall, brick wall, etc. For the study, we must measure the structural strength, stiffness of infill walls. As per statement 7.9 p.n. 25 IS 1893:2016(Part 1), [1]

$$W_{ds} = 0.175 \propto_h^{-0.4} L_{ds} \tag{1}$$

where

$$\propto_h = h \left\{ \sqrt[4]{\frac{E_m.t.\sin 2\theta}{4.E_f.I_c.h}} \right\} \tag{2}$$

E_m = Modulus of resistance of the material of the unreinforced brickwork infill
E_f = Modulus of resistance of the material of the RC moment resisting structure
I_C = Moment of inertia of the adjacent column
t = Width of masonry infill walls
θ = The angle of the diagonal strut with the parallel
h = Height of URM infill walls
W_{ds} = Breadth of equivalent diagonal strut
L_{ds} = Sloping distance of infill strut panel (Fig. 1). It is well known fact that,
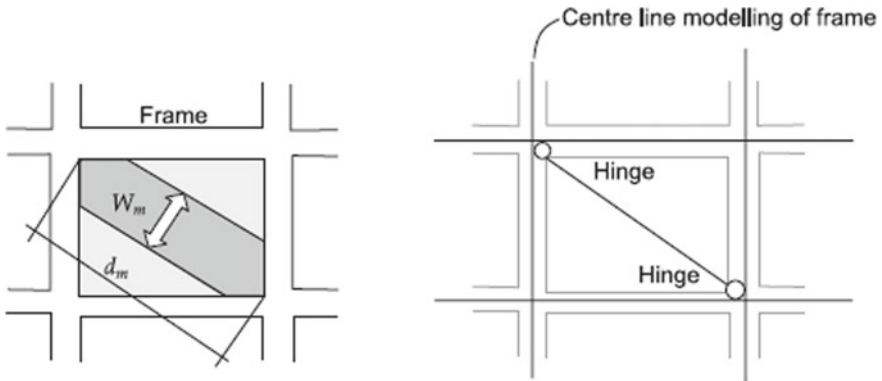
Fig. 1 Diagonal strut action of the infill [3]

characteristics of earthquake motion depends upon local site conditions. If the soil strata is very soft, then it alters the characteristics of earthquake motion. Hence, soil-structure interaction plays important role in response calculation of building. Neglecting the stiffness of infill strut and overestimating the stiffness of soil strata may lead to conservative approach in response calculation. Hence, this study is done to calculate the seismic response by considering the stiffness of infill panels for rectangular building resting on nonlinear soil-foundation system.

2 Finite Element Modeling

The structure models are modeled, while 3D structural solids with element category are allocated by FEA software, ANSYS 15. Mesh convergence study was prepared for structure and intended for soil a coarser mesh used. The ANSYS framed framework is model with 2-node beam element BEAM188, and it has six degrees of freedom at each node. Slab surface used SHELL181 also has six DOF at each node. And foundation with SOLID 186, interface with the element is CONTA174 and TARGE170; SURF154 is used for various loads and surface effect application in 3D analysis of structure. The soil is modeled with SOLID65, and Drucker–Prager model is used for nonlinear material of soil activities.

3 Material Models Used

The soil volume dimension is modeled as the solid section with dimensions as length and breadth as five times the equivalent dimension of the structure and depth of soil should be at least three times elevation of structure [4]. In this paper, soil volume is modeled by using the direct method. Dead load and live load is given as per IS875 (Part 1) and (Part 2) 1987 [5, 6], respectively. The dead load includes self-weight and wall loads (Table 1).

Table 1 Material property of concrete and soil [7, 8]

Properties	Structure	Soil		
Material	Concrete (M25)	Hard	Medium	Soft
Young's modulus E (N/m^2)	2.5×10^{10}	8.40×10^9	4.46×10^8	1.03×10^8
Poisson's ratio	0.25	0.3	0.35	0.4
Density, P (kN/m^3)	25	22	18	16
Cohesion, C (kN/m^2)	–	20	30	23
Internal friction angle (°)	–	30	0	23

4   Geometry of Building

The design is similar for G+3 and G+7 story structures shown in Figs. 2 and 3. Usual floor-to-floor altitude is taken as 3.1 m for both the story. The dimension of
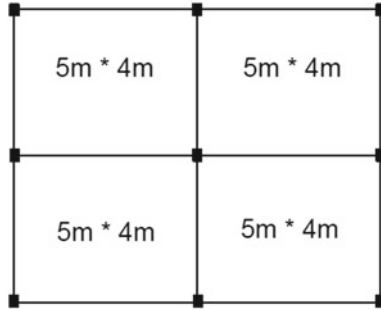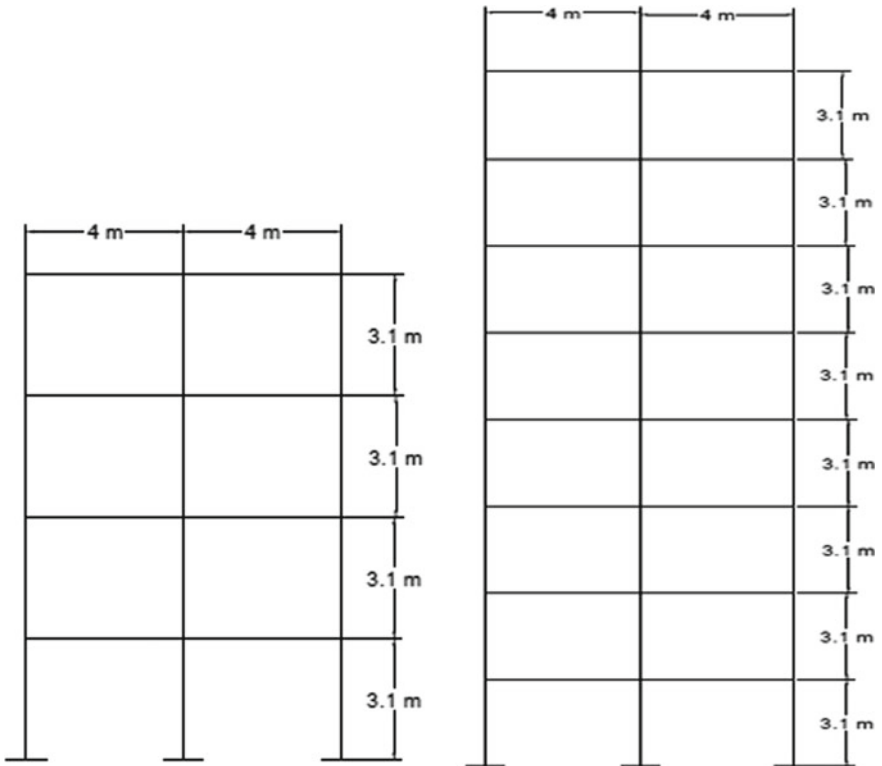

Fig. 2 Plan of structure

Fig. 3 Elevation of structure

Table 2 Geometric details of G+3 and G+7 story building

Parameters	Rectangle (m)
Plan dimension	10 × 8
Height of story	3.1
Depth of foundation	1.2
Size of diagonal strut	0.440 × 0.345
Thickness of slab	0.15

Table 3 Acceleration time history records

Earthquake	Peak ground acceleration (PGA)			Duration (s)
	Hard soil (g)	Stiff soil (g)	Soft soil (g)	
El-Centro	0.0922	0.1042	0.08919	40
Uttarkashi	0.3708	0.5042	0.6229	36.16
Dharamshala	1.3734	1.8639	2.29554	16.18
Kocaeli	0.1004	0.10449	0.0995	34.96
Parkfield	0.01226	0.04179	0.01226	30.33

the building is shown in Table 2. The framed structure is modeled in finite element program ANSYS 15.

The plan and elevation of all three categories of structure are given below:

Following are the acceleration time history records which are used for analysis (Table 3).

5   Demonstration with a Study on MDOF System

The finite element modeling is done for building along with the foundation system using FEM software ANSYS 15.0. The soil physical properties are applied from the material reference library in ANSYS for different linear or nonlinear soil model and structure.

In the present estimation, the analysis of loam modeled by using ANSYS 15.0.

Following models are studied.

Table 4 Results of G+3 and G+7 story structure

|		G+3 square		G+7 square	
		fundamental time period (s)	Top floor displacement (mm)	fundamental time period (s)	Top floor displacement (mm)
Bare frame	Model 1:Bare frame (BF)	0.323	64.6	0.816	128.25
	Model 2:BF with SSI hard soil	0.650	82.8	1.054	146.32
	Model 3:BF with SSI stiff soil	0.857	87.80	2.133	164.6
	Model 4:BF with SSI soft soil	0.923	145.79	2.915	233.14
Strut frame	Model 5:Strut frame (SF)	0.257	0.079	0.768	39.20
	Model 6:SF with SSI hard soil	0.116	2.23	0.302	42.4
	Model 7:SF with SSI stiff soil	0.131	2.42	0.416	43
	Model 8:SF with SSI soft soil	0.340	2.78	0.431	44.4

Fig. 4 Bare frame
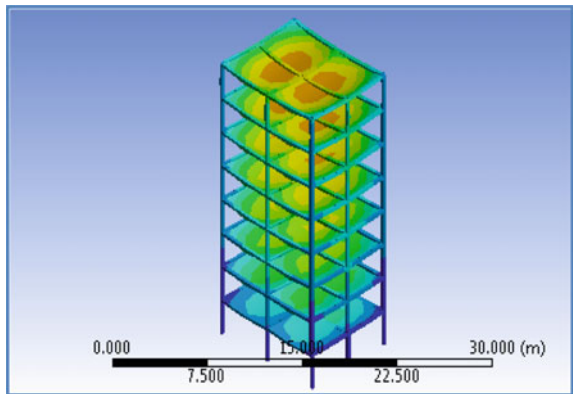
Fig. 5 Strut frame
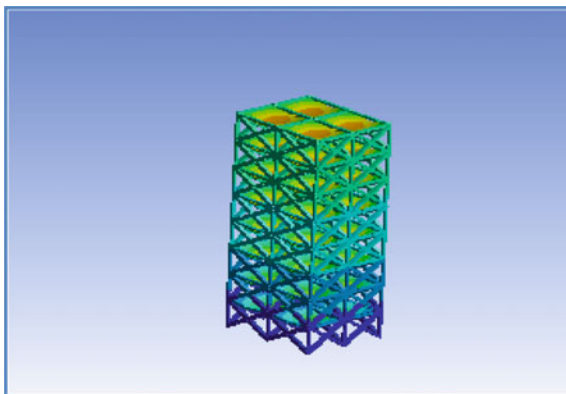
Fig. 6 Bare frame with SSI
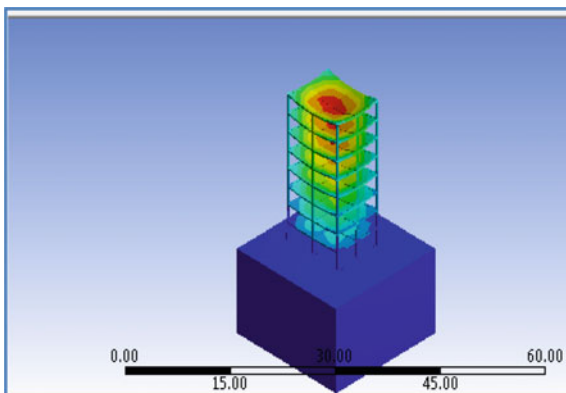
Fig. 7 Strut frame with SSI
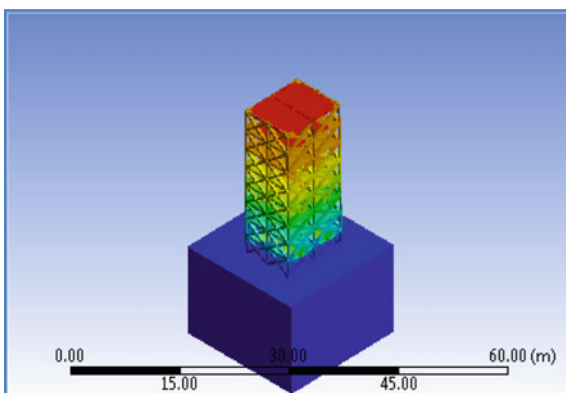
6   Results and Discussion

Displacement in X-direction is calculated for dynamic loading at every point for top of model is shown in Table 4 (Figs. 4, 5, 6 and 7).

From Table 4, it is clear that in all four types of building time period increase with consideration of the effect of SSI, while time period decreases with consideration of stiffness of infill strut panel. Since the soil is becoming softer, the time period increases consequently. And also shows that joint displacement of the structure decreases with consideration of strut frame up to 86.83% as consideration of bare frame. The maximum deformation in strut frame with SSI is decreases to 90.81% as compared to the bare frame with SSI. The bare frame with SSI increases to 30.88% as compared with the bare frame as the effect of SSI specified to the structure. However, from the results, it is clear that due to the effect of SSI, consideration of infill strut panel gives better results.

7   Maximum Axial Force for G+3 and G+7 Story Building

Maximum axial force for all models for G+3 and G+7 story rectangle building is shown in the following figures.

From Figs. 8 and 9 suggests the graph of maximum axial force in rectangle-shaped building; it is clear that the maximum quantity of axial force decreases to 76.67% due to infill strut panel. Considering the strut frame with SSI, axial force decreases to 83.92% as compared to the bare frame with SSI. The bare frame with SSI decreases to 69.14% as compared with the bare frame. The effect of SSI indicates that the axial force decreases due to the fact soil turn into softer due to expand in a time period. For high story building, SSI and infill strut play a vital role and gives better results.

8   Maximum Bending Moment for G+3 and G+7 Story Building
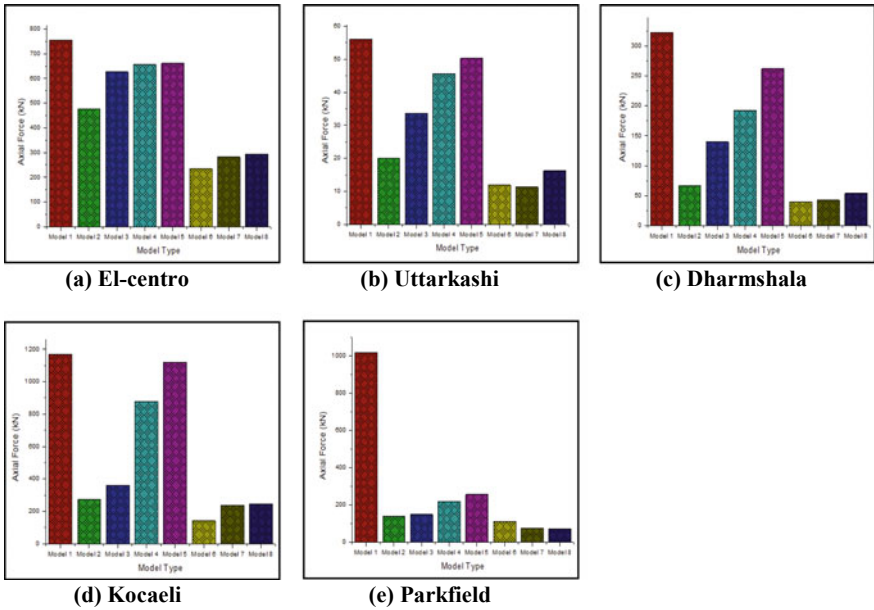
Maximum bending moment for G+3 and G+7 building with consideration of different soil is shown in the following figures.

From Figs. 10 and 11, it is clear that maximum bending moment changes drastically while considering infill and SSI. When only infill struts are modelled, it was observed that, bending moment decreases by 98.60% as compared to the bare frame. But when SSI effects are considered along with infill struts, bending moment decreases by 88.68%. This changes will ultimately change the design of main structural members.
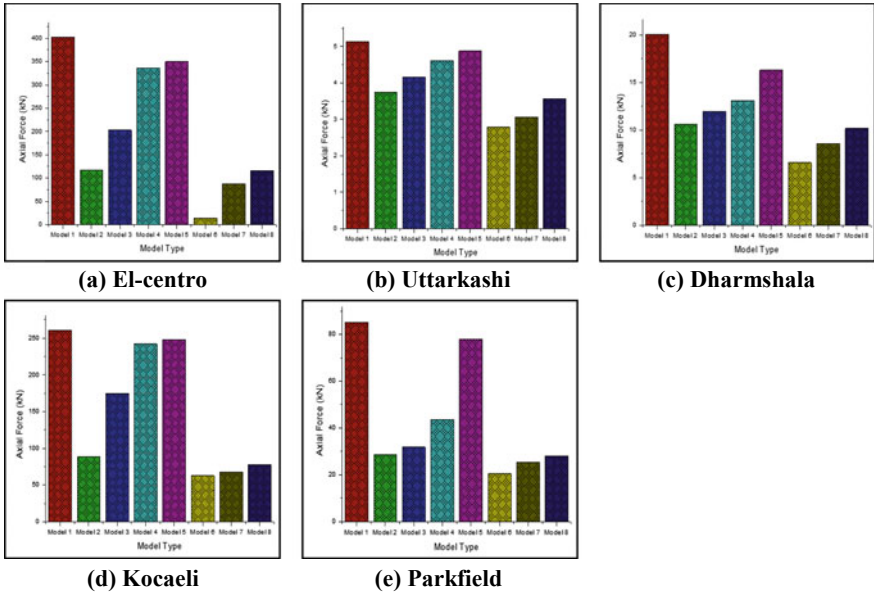
Fig. 8 Maximum axial force for G+3 story rectangle building for earthquake. **a** El-centro, **b** Uttarkashi, **c** Dharamshala, **d** Kocaeli, **e** Parkfield

Fig. 9 Maximum axial force for G+7 story rectangle building for earthquake. **a** El-centro, **b** Uttarkashi, **c** Dharamshala, **d** Kocaeli, **e** Parkfield
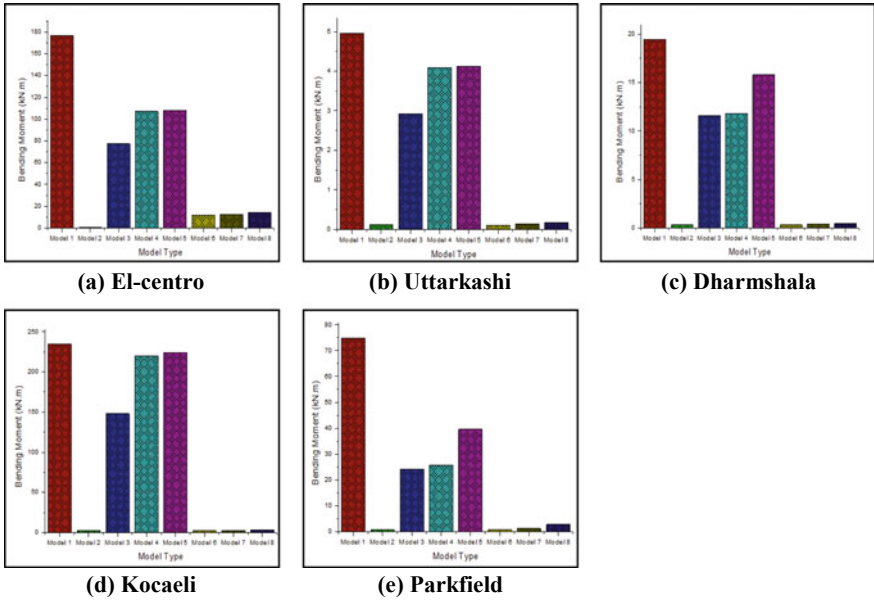
Fig. 10 Maximum bending moment for G+3 story rectangle building for earthquake. **a** El-centro, **b** Uttarkashi, **c** Dharamshala, **d** Kocaeli, **e** Parkfield
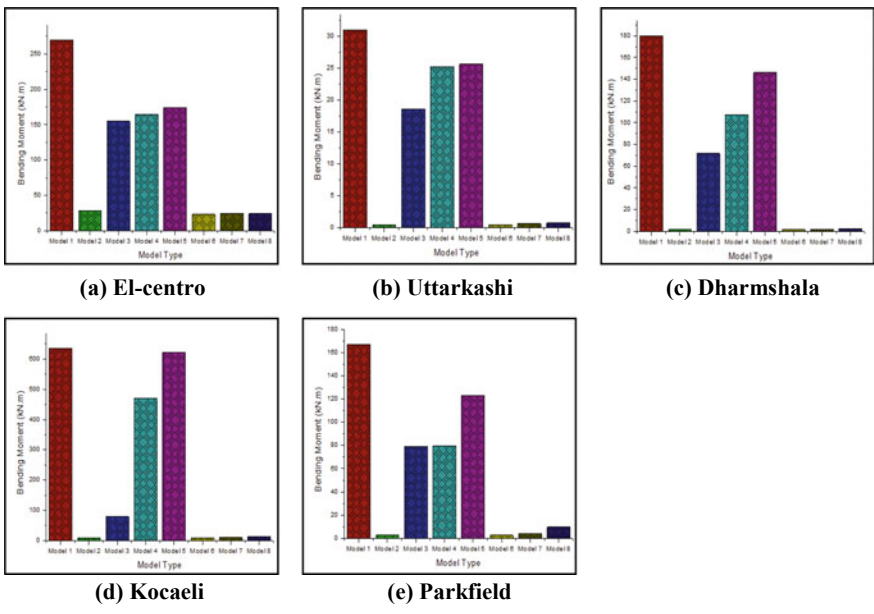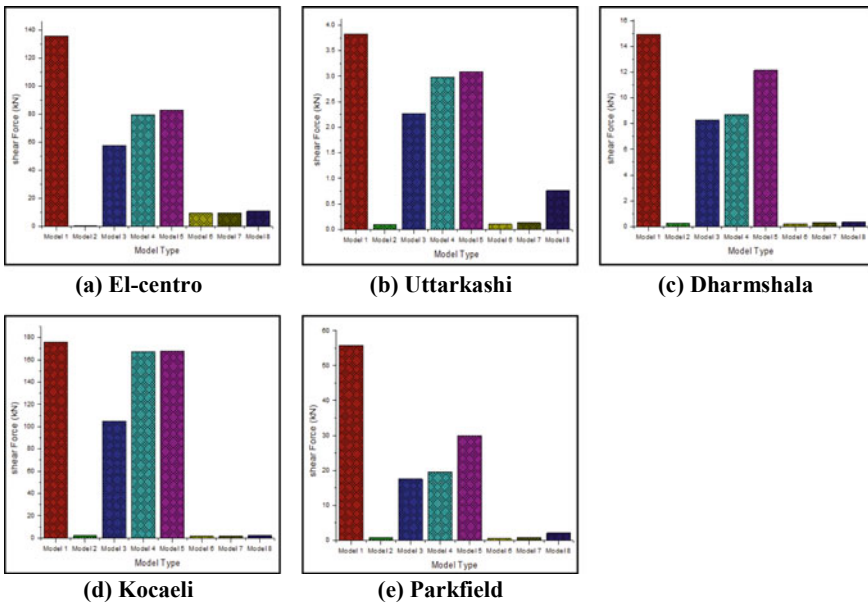

Fig. 11 Maximum bending moment for G+7 story rectangle building for earthquake. **a** El-centro, **b** Uttarkashi, **c** Dharamshala, **d** Kocaeli, **e** Parkfield
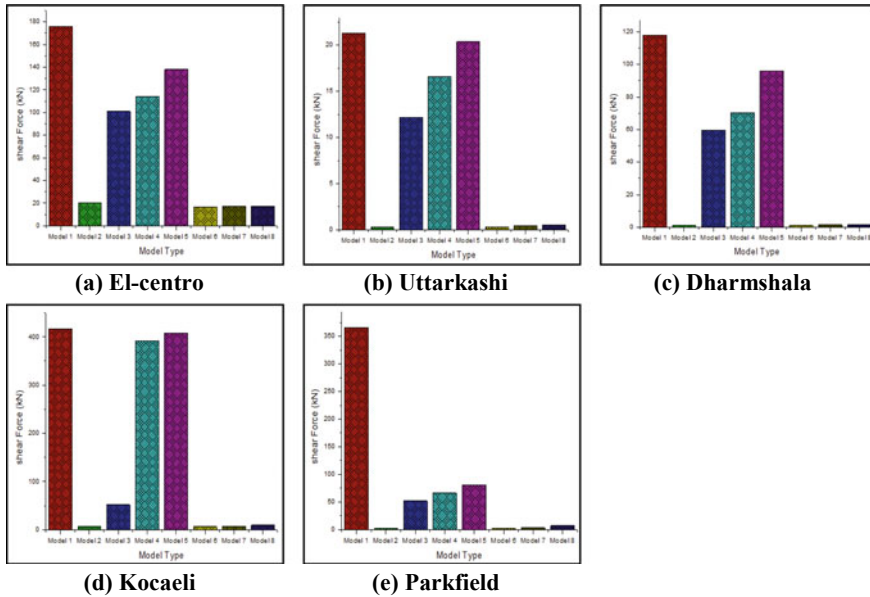
9 Maximum Shear Force for G+3 and G+7 Story Building

The maximum shear force for G+3 and G+7 story building with consideration of soil effect is shown in figures.

From Figs. 12 and 13, it shows that the once installation of infill walls to the structure is reduced up to 98.46% as compared with the bare frame. Similarly in strut frame with SSI, the axial force the shear force is also decreasing to 87.47% as compared with a bare frame with SSI. The bare frame with SSI decreases to 87.50% as compared with the bare frame. Therefore, consideration both infill and SSI effect provide better results.

Fig. 12 Maximum shear force for G+3 story rectangle building for earthquake. **a** El-centro, **b** Uttarkashi, **c** Dharamshala, **d** Kocaeli, **e** Parkfield

Fig. 13 Maximum shear force for G+7 story rectangle building for earthquake. **a** El-centro, **b** Uttarkashi, **c** Dharamshala, **d** Kocaeli, **e** Parkfield

10 Conclusions

In this research, the diverse effect of soil–structure interaction on infill strut panel is considered. RC structure with regarding to the loading of 3.1 m floor-to-floor height with base measurement 10 m × 8 m is examined for the impact of soil–structure interface by utilizing *Drucker–Prager* model nonlinear in ANSYS 15 with and without infill strut panel. From above results, it can be concluded that

1. Time period influence the earthquake reaction of the structure, since time period increases with consideration of SSI where as time period decreases with consideration of infill strut panel.
2. Deformation besides increases with consideration of SSI whereas reducing consideration of infill strut panel.
3. From ratio between bare frame and strut frame, it has been observed that maximum axial force, bending moment; shear force decreases after introducing infill strut panel.
4. From ratio between bare frame with SSI and strut frame with SSI, it has been observed that maximum axial force, bending moment; shear force increases due to effect of SSI. For as much as strut frame with SSI decreases the axial force, shear force; bending moment.
5. From above consequences, it is concluded that the strut frame results more as balance to a bare frame. And bare frame with SSI results more as balance to a

strut frame with SSI. So we can convey that strut frame with SSI results is much more to another model.

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