The Effect of Shear Walls on Seismically Isolated Buildings of Variable Geometric Configurations

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***Abstract*—Multi-story hypothetical reinforced concrete buildings of variable geometric configurations (symmetrical, vertically irregular, horizontally irregular); with and without shear walls; base isolated via high damping rubber bearing and friction pendulum systems, are analyzed using the finite element method under seismic load function (North-South component of the ground motion recorded at a site in El Centro, California in 1940). The bilinear hysteretic model of base isolation system and the Rayleigh damping framework for superstructure are adopted. The results showed that, inclusion of shear walls has minor effects on the total base shear and maximum acceleration responses whereas, a considerable reduction in the maximum relative displacement is reported. The twist values of irregular buildings are affected by the changes in eccentricity values (between centers of mass and rigidity) due to the presence of shear walls, especially for the friction pendulum system.**

Keywords*— Multi-story, vertically irregular, horizontally irregular, isolated building, friction pendulum, high damping rubber bearing, seismic, finite element

I. INTRODUCTION

The concept of passive base isolation has two basic types of isolation systems.

a. The system that uses elastomeric bearings. In this approach, the building is decoupled from the horizontal components of the earthquake ground motion by interposing a layer with low horizontal stiffness between the structure and the foundation.

b. The system that uses sliding. In this approach, the system is limiting the transfer of shear across the isolation interface by using sliders or rollers between the structure and the foundation.

A shear wall is a wall that is designed to resist shear, the lateral force that causes the bulk damage in earthquakes. Many building codes mandate the use of such walls to make the structures more safe and stable.

In this paper, the effect of inclusion of shear walls on the behavior of isolated buildings is studied. Two types of isolation systems are utilized namely, the friction pendulum (FPS) and the high damping rubber bearing (HDRB) systems.

II. MODELING THE ISOLATED BUILDINGS

The buildings are modeled using the finite element method. A directional material model is used for the superstructure elements, in which uncoupled stress-strain behavior is modeled for one or more stress-strain components. When the state of stress or strain reaches critical value, the concrete can start failing by fracturing. The fracture of concrete can occur in two different ways. One is by cracking under tensile type of a stress state, and the other is by crushing under compressive type of a stress state.

The force-deformation behavior of the two systems of isolators is modeled as non-linear hysteretic represented by the bi-linear model as shown in Fig. 1. The isolator is modeled using six springs. The springs for three of the deformations: axial, shear in the x-z plane, and pure bending in the x-z plane are shown in Fig. 2. The hysteretic models for bearings is used to account for all the energy dissipation, and the viscous damping using the Rayleigh damping framework is used for the superstructure.

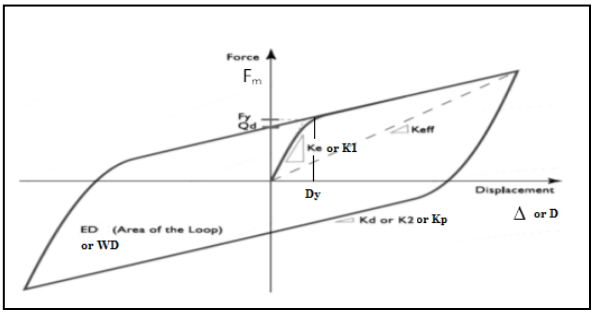


Fig. 1. Parameters of basic hysteresis loop of an isolator for bilinear modeling [1].

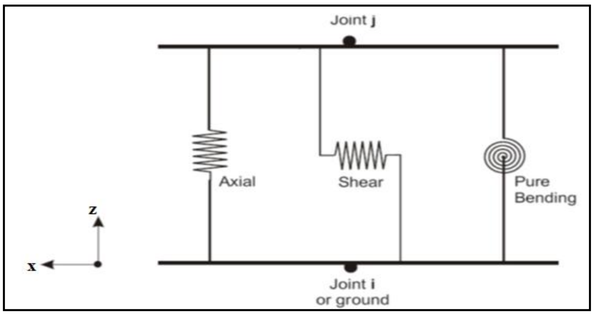
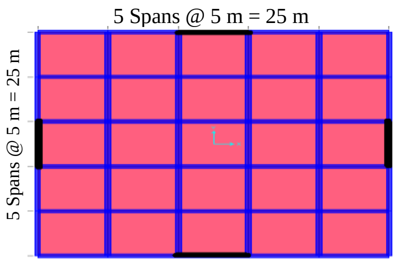
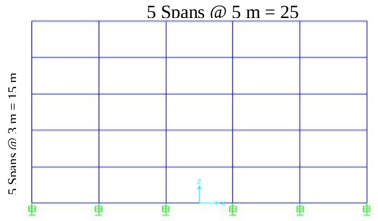


Fig. 2. Three of the six independent springs in a link/support element [2].

The geometric configurations of the superstructures are shown in Fig. 3, 4 and 5. A (150 mm) thick slab and (150 mm) thick shear walls are considered with (400 mm x 600 mm) beam typical sections and column size of (600 mm x 600 mm).

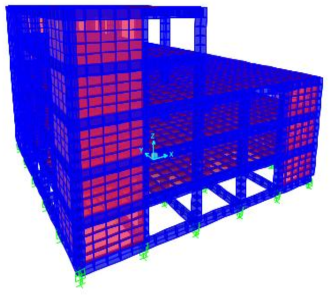


a. Plan

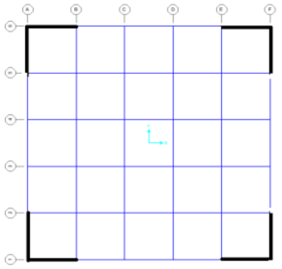


b. section

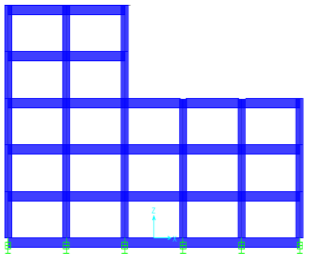
Fig. 3. Symmetrical building



a. 3D view

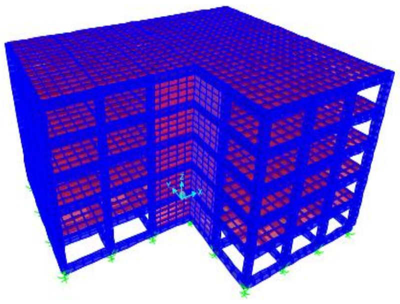


b. Plan

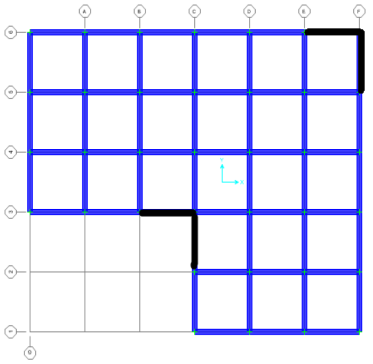


c. Section

Fig. 4. Vertically irregular building



a. 3D view



b. Plan

Fig. 5. Horizontally irregular building

III. APPLIED LOADS

The reinforced concrete buildings are analyzed for dead, live, and earthquake functional loads. The minimum design dead load on each floor consists of loads due to floor slab, beams, columns and portion walls. The floor live load is taken as (3 kN/m²) and the roof live load is taken as (1.5 kN/m²). The North-South component of the ground motion recorded at a site in El Centro, California in 1940, shown in Fig. 6, is applied to the building. All of the dead load and only (25%) of the live load is considered in the seismic analysis [IBC 2012][3].

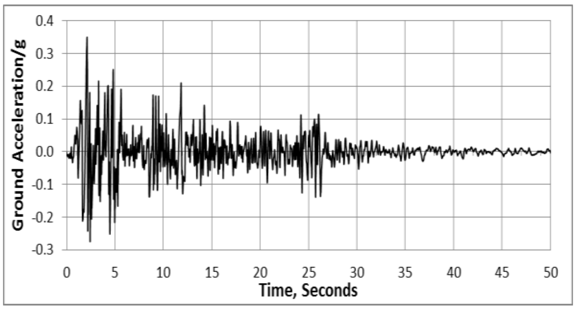
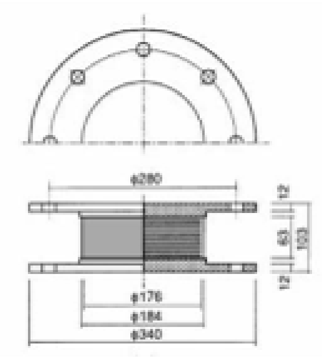


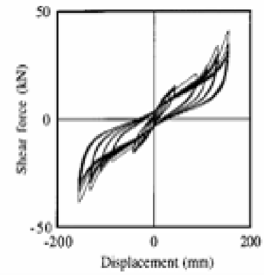
Fig. 6. El Centro, California in 1940 earthquake [4].

IV. DESIGN OF BASE ISOLATORS

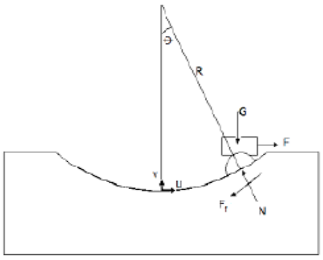
The isolators are designed according to the procedures described in the UBC-97 [5]. The characteristics of high damping rubber bearing system are illustrated in Fig. 7-a,b whereas, the mechanism of friction pendulum system is shown in Fig. 7-c.



a. High damping rubber bearing used in the earthquake simulator tests with dimensions in mm[6].



b. Corresponding force-deformation hysteresis for HDRB [6].



c. Mechanism of the friction pendulum system [7].

Fig. 7. The characteristics of isolation systems.

The characteristics of superstructure materials and the design parameters of the isolation systems are summarized in Tables 1 and 2.

TABLE 1 THE SUPERSTRUCTURE MATERIAL PROPERTIES.

Symbol	description	unit	Value
f'_c	The cylinder ultimate compression strength of concrete	N/mm^2	25
f_y	The yield stress of steel reinforcement	N/mm^2	410
E_c	The modulus of elasticity of concrete	N/mm^2	23000
ρ_c	The concrete density	kg/m^3	2400
ν_c	Poisson's ratio of concrete	---	0.15

TABLE 2 DESIGN PARAMETERS OF ISOLATORS.

data	Parameter and unite	Value for HDRB	Value for FPS	Nomenclature
Input	T (sec)	2.5	2.5	Design period
	β (%)	20	20	Effective damping
	D (mm)	200	200	Design displacement
	W (kN)	2000	2000	maximum vertical load in service condition including seismic action
	μ	----	0.02	friction coefficient
Output	K_{eff} (kN/m)	1500	1370	Effective stiffness
	Q (kN)	88	40	Short term yield force
	K_2 (kN/m)	1200	1150	Inelastic stiffness
	K_1 (kN/m)	12000	115000	Elastic stiffness
	D_y (mm)	8.1	0.4	Yield displacement
	R (mm)	----	1700	radius of curvature

V. NONLINEAR DIRECT INTEGRATION METHOD

All buildings are analyzed using the nonlinear direct integration method.

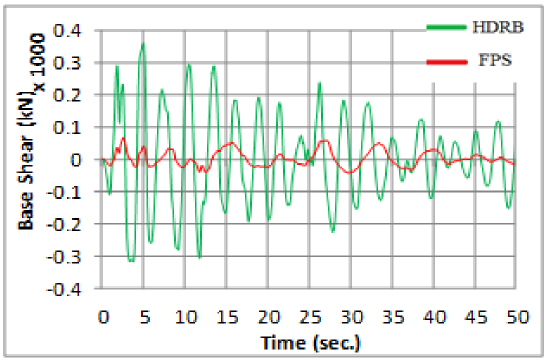
The fundamental modal periods of the free vibration analyses of buildings are shown in Table (3).

TABLE 3 THE FUNDAMENTAL PERIODS OF THE FREE VIBRATION ANALYSES FOR THE TWO ISOLATED BUILDINGS.

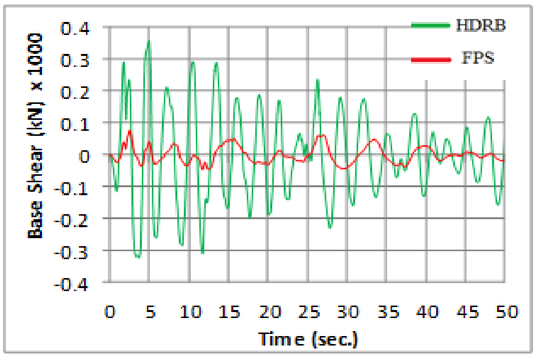
Base condition Case	HDRB		FPS	
	T(Sec) Without shear walls	T(Sec) With shear walls	T(Sec) Without shear walls	T(Sec) With shear walls
Symmetrical	2.44	2.45	2.45	2.49
Vertically Irregular	2.25	2.28	2.25	2.31
Horizontally Irregular	2.42	2.42	2.43	2.48

It is clear that, the fundamental periods of the isolated buildings using both systems are slightly affected due to the presence of shear walls.

The responses of buildings in terms of total base shear are shown in Fig. 8, 9 and 10.

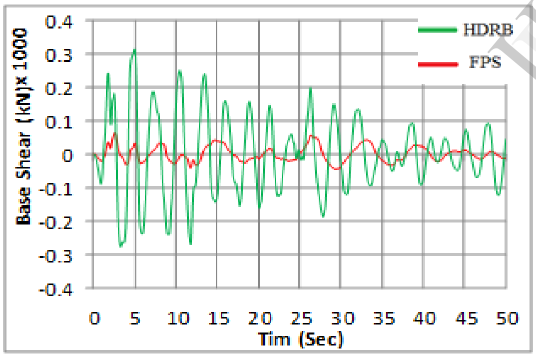


a. Without shear walls

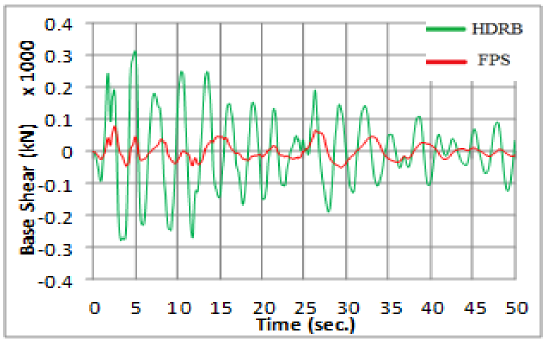


b. with shear walls

Fig. 8. Total base shear for symmetrical building.

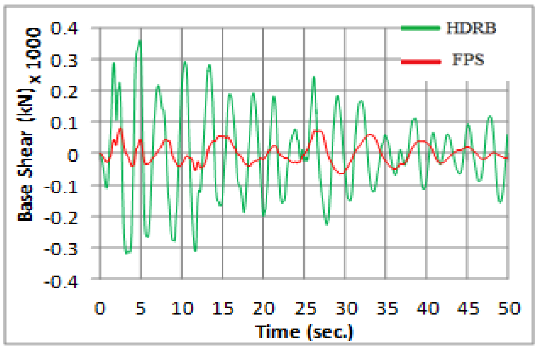


a. Without shear walls

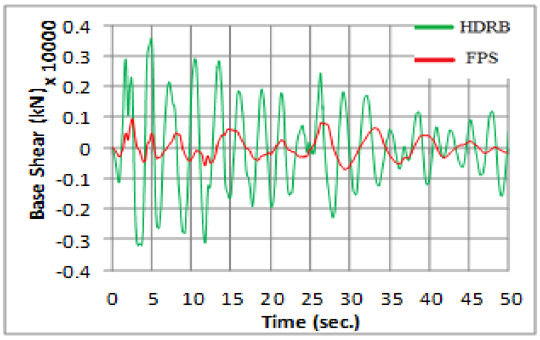


b. with shear walls

Fig. 9. Total base shear for vertically irregularity building.



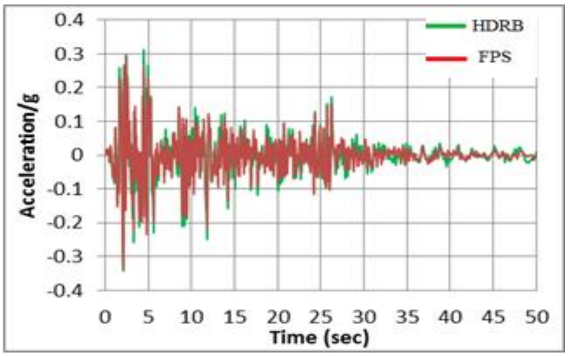
a. Without shear walls



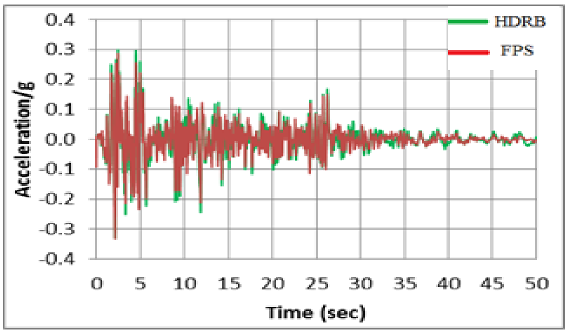
b. with shear walls

Fig. 10. Total base shear for horizontally irregularity building.

The maximum acceleration time histories for the isolated buildings are shown in Fig. 11, 12 and 13.

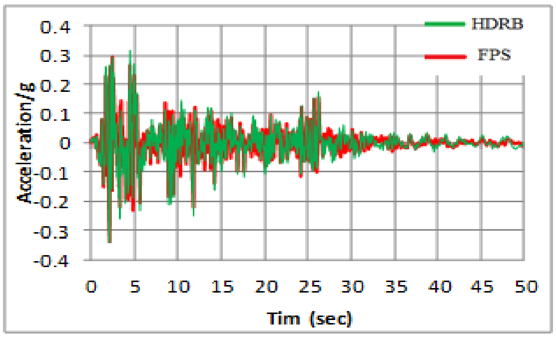


a. Without shear walls

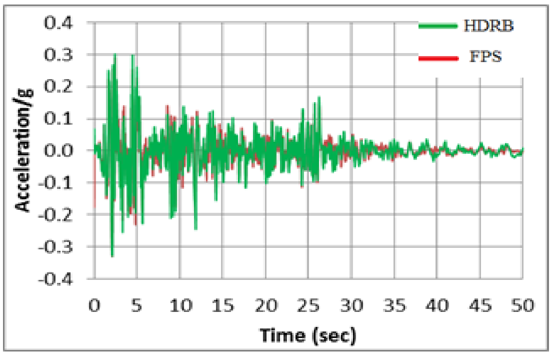


b. with shear walls

Fig. 11. Maximum acceleration for symmetrical building.

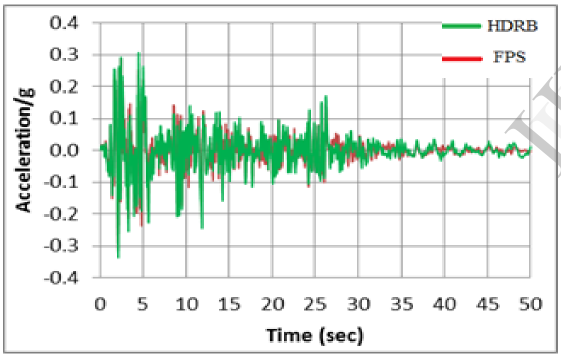


a. Without shear walls

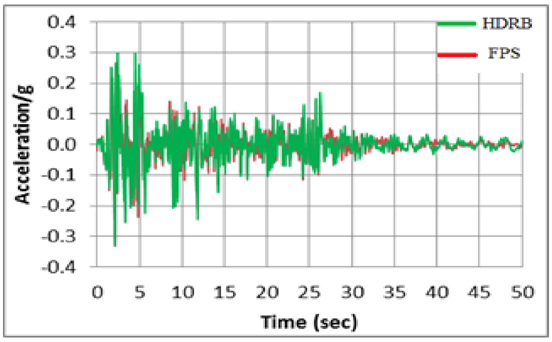


b. with shear walls

Fig. 12. Maximum acceleration for vertically irregularity building.



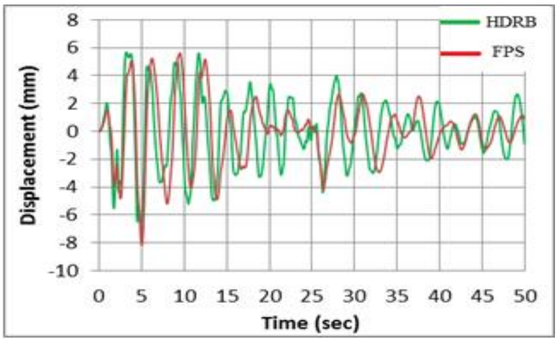
a. Without shear walls



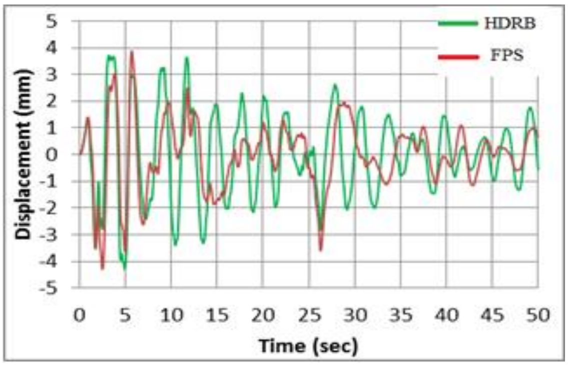
b. with shear walls

Fig. 13. Maximum acceleration for horizontally irregularity building.

The maximum relative displacements (displacement with respect to displacement of base) for the isolated base buildings are shown in Fig. 14, 15 and 16.

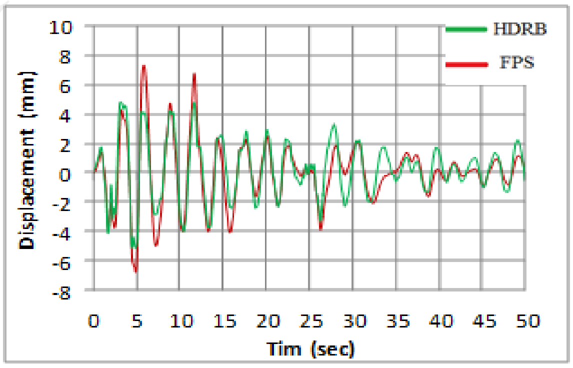


a. Without shear walls

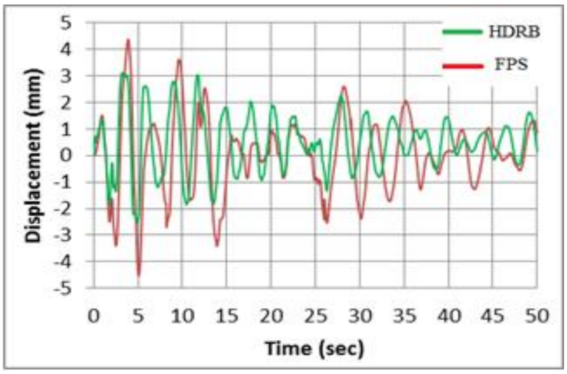


b. with shear walls

Fig. 14. Maximum relative displacement for symmetrical building.

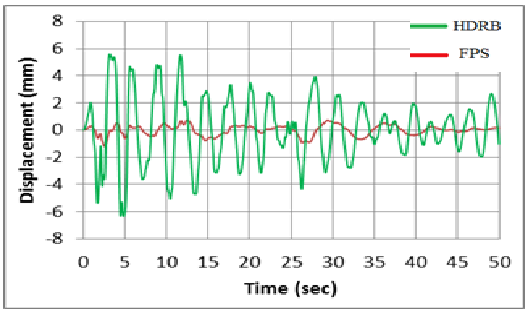


a. Without shear walls

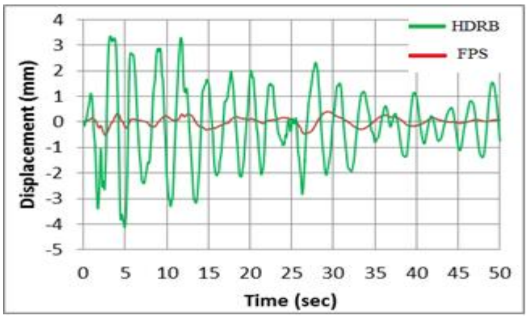


b. with shear walls

Fig. 15. Maximum relative displacement for vertically irregularity building.



a. Without shear walls



b. with shear walls

Fig. 16. Maximum relative displacement for horizontally irregularity building.

It is evident that, adding shear walls has minor effects on the total base shear and the maximum acceleration while, the maximum relative displacement is reduced considerably.

Tables 4 and 5 list the eccentricity values, between center of mass and center of rigidity, for irregular buildings with and without shears walls.

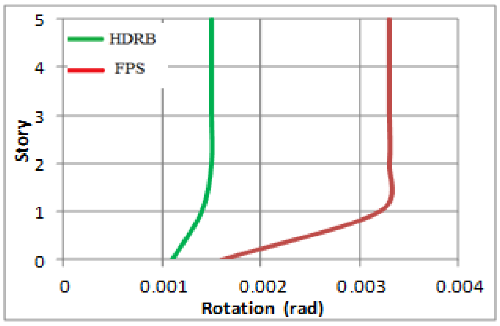
TABLE 4 ECCENTRICITY VALUES FOR THE VERTICALLY IRREGULAR BUILDINGS.

Shear walls	without		with	
Story	e_x (m)	e_y (m)	e_x (m)	e_y (m)
STORY5	2.6	0	1.8	0
STORY4	4.5	0	1.4	0
STORY3	0.3	0	0.2	0
STORY2	0	0	0	0
STORY1	0	0	0	0

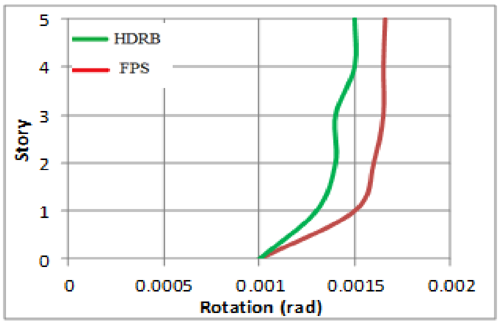
TABLE 5 ECCENTRICITY VALUES FOR THE HORIZONTALLY IRREGULAR BUILDINGS.

Shear walls	without		with	
Story	e_x (m)	e_y (m)	e_x (m)	e_y (m)
STORY5	0.15	0.11	3.16	2.01
STORY4	0.13	0.09	3.43	2.13
STORY3	0.10	0.07	3.71	2.24
STORY2	0.05	0.03	3.88	2.28
STORY1	0.04	0.06	3.61	2.05

Fig. 17 and 18 show the maximum rotation of the center of mass about z- axis in the five stories of isolated buildings.

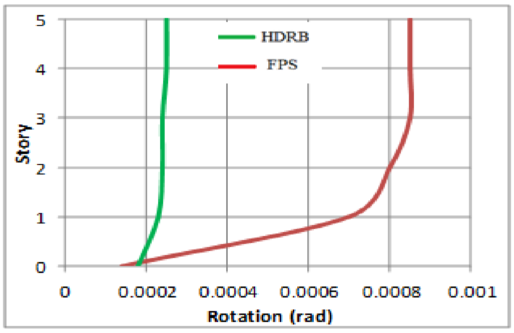


a. Without shear walls

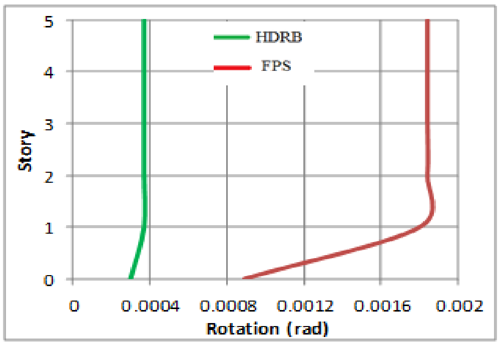


b. with shear walls

Fig. 11. Maximum rotation of the vertically irregular building.



a. Without shear walls



b. with shear walls

Fig. 16. Maximum rotation of the horizontally irregular building.

It is clear that, the influence of shear walls on building rotation depends on their position and effect on the eccentricity at each story.

VI. CONCLUSIONS

a. The inclusion of shear walls has negligible effect on total base shear and maximum acceleration of the isolated buildings.

b. The inclusion of shear walls reduces the maximum relative displacement of the base isolated buildings.

c. The twist of irregular buildings is proportional to the change in eccentricity values, produced by the presence of shear walls.

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