Seismic Response of Non-Structural Elements

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ABSTRACT-Non-structural elements are those which are attached to or housed in building system, but are not part of the main load-resisting structural system of the building. Therefore, these are often neglected from the structural design point of view. Performance in the past earthquake clearly pointed out that in view of the absence of inadequacy of design provisions for non-structural elements and their attachments it has resulted in poor performance of non-structural elements. In this research paper a numerical study has been carried out to investigate the seismic response of non-structural elements. The time history analysis has been performed to obtain the displacement and acceleration of non structural elements which is placed on various floor of three story asymmetric building. It is found that the displacement of non-structural elements is minimum at centre of first floor.

Keywords: Seismic, Non-Structural Elements, Displacement, Acceleration.

I. INTRODUCTION

Non-structural elements of a building are not a part of the main load-resisting system. The damage costs of Non-Structural Elements (NSEs) may account for 65% to 85% of the total construction cost of commercial buildings [1]. In critical facilities like hospitals, the indirect losses due to damaged equipment, lost inventory and records, and revenue can be two to three times greater than the cost of replacing collapsed buildings or structures. Such damages have major social or economic implications, particularly for critical buildings (e.g., hospital) or commercial buildings (e.g., stock exchange) [2].

1.1 Classification of Non-Structural Elements

1) Architectural Components: This category included elevator penthouses, stairways, partitions, parapets, and heliports, cladding systems, signboards, lighting systems and suspended ceilings.
2) Mechanical and Electrical Equipment: This category included storage tanks, pressure vessels, piping systems, ducts, escalators, smokestacks, antennas, cranes, radars and object tracking devices, computer and data acquisition systems, control panels, transformers, switchgears, emergency power systems, fire protection systems, boilers, heat exchangers, chillers, cooling towers and machinery such as pumps, turbines, generators, engines and motors.
3) Building Contents and Inventory: This category included Masonry wall, door, window, stair, lintel, Bookshelves, file cabinets, storage racks, decorative items and any other piece of furniture commonly found in office buildings and warehouses [3]-[4].

It is necessary to design non-structural elements to resist seismic forces or seismic relative displacements along with detailed commentary on the proposed clauses [5]. Full scale shake table tests of suspended ceiling systems were conducted in order to evaluate the response of the systems subjected to earthquake induced excitation [6]. The overturning ratio under one sine pulse analyzes the behaviour of a rigid body. Those review the rocking motion and overturning behaviour of a rigid block subject to sinusoidal pulses [7]. Villaverde (2006) proposed an approximation method to estimate the seismic response of nonlinear non-structural components supported by nonlinear structures. The method was based on the procedure previously developed for analyzing linear non-structural components attached to a linear primary structure. Although, some of the work has been done to investigate the seismic forces in NSE. However, no work has been reported to obtain the optimum location of NSE in asymmetric building.

Hence, the main objective of the present research work is as follows:

i. To perform the time history analysis for various recorded earthquake data and to find the acceleration and displacement for NSEs kept at various locations in building.

ii. To determine the best suitable locations for non structural elements in Asymmetric buildings.

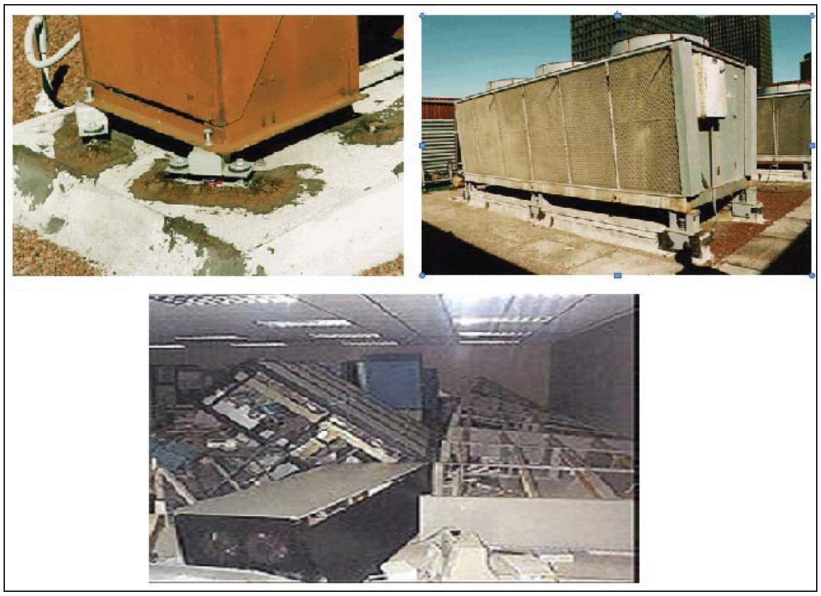

Figure 1.1 Typical damage of Non-Structural Elements. [9]

II. STRUCTURAL MODEL

The system considered is linearly elastic idealized three-story building which consists of a rigid deck supported on columns, as shown in Fig.2.1 The mass of deck is assumed to be uniformly distributed and hence the centre of mass (CM) coincides with the geometrical centre of the deck. The columns are arranged such that it produces the stiffness asymmetry in one direction and, hence, the centre of rigidity (CR) is located at an eccentric distance, ex from CM in x-direction. The system is symmetric in x-direction and, therefore, two degrees-of-freedom are considered for model, namely the lateral displacement in y-direction, u_y, and torsional displacement, u_θ, as represented in the Fig. 2.1. The governing equations of motion of the model with coupled lateral and torsional degrees of freedom are expressed by:

$$M\ddot{u} + C\dot{u} + Ku = -M\Gamma\ddot{u}_g \quad (1)$$

Where M, C, and K are mass, damping, and stiffness matrices of the system, respectively; $u = \{u_y \; u_\theta\}^T$ is the displacement vector; Γ is the influence coefficient vector; $\ddot{u}_g = \{\ddot{u}_{gy} \; 0\}^T$ is the ground acceleration vector; $\ddot{u}_{gy}$ is the ground acceleration in y-direction.

The mass matrix can be expressed as [10]:

$$M = \begin{bmatrix} m & 0 \\ 0 & m r^2 \end{bmatrix} \quad (2)$$

Where *m* represents the lumped mass of the deck; and r is the mass radius of gyration about the vertical axis through CM which is given by, $r = \sqrt{\frac{B^2 + D^2}{12}}$ where B and D are the plan dimensions of the building.

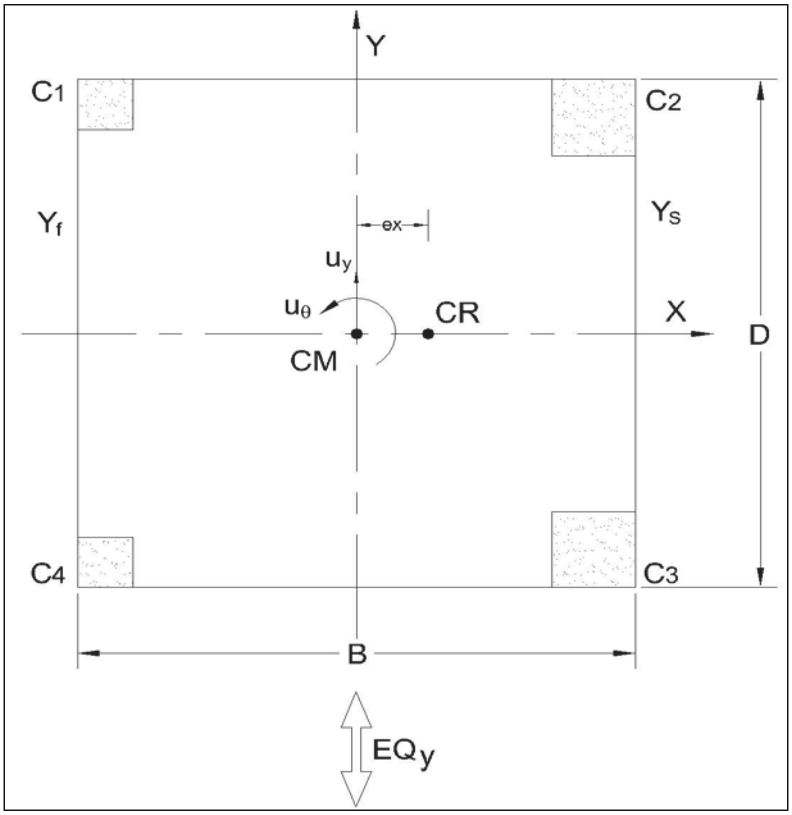

Fig. 2.1 Plan of one-way asymmetric system

The stiffness matrix of the system is obtained as follows [10]:

$$K = K_y \begin{bmatrix} 1 & e_x \\ e_x & (e_x)^2 + r^2 \times (\Omega_\theta)^2 \end{bmatrix} \quad (3)$$

$$e_x = \frac{1}{K_y} \sum_i K_{yi}\, x_i \text{ and } \Omega_\theta = \frac{\omega_\theta}{\omega_y} \quad (4)$$

$$\omega_\theta = \sqrt{\frac{K_{\theta r}}{m r^2}} \text{ and } \omega_y = \sqrt{\frac{K_y}{m}} \quad (5)$$

$$K_{\theta r} = K_{\theta\theta} - (e_x)^2 K_y \quad (6)$$

$$K_{\theta\theta} = \Sigma K_{xi}\,(y_i)^2 + \Sigma K_{yi}\,(x_i)^2 \quad (7)$$

$$K = \begin{bmatrix} K_{yy} & K_{y\theta} \\ K_{\theta y} & K_{\theta\theta} \end{bmatrix} \quad (8)$$

Where K_y denotes the total lateral stiffness of the system in y-direction; e_x is the structural eccentricity between CM and CR of the system; Ω_θ is the ratio of uncoupled torsional to lateral frequency of the system; ω_y is uncoupled lateral frequency of the system; ω_θ is uncoupled torsional frequency of the system; $K_{\theta r}$ and $K_{\theta\theta}$ are the torsional stiffness of the system about a vertical axis at the CR and at the CM, respectively; K_{xi} and K_{yi} indicate the lateral stiffness of i^{th} column in x and y-direction, respectively; and x_i and y_i are the x and y-coordinate distance of i^{th} element with respect to CM respectively.

The damping matrix of the system is not known explicitly and it is constructed from the Rayleigh's damping considering mass and stiffness proportional as,

$$C = \alpha [M] + \beta [K] \quad (9)$$

Where, $\alpha = \frac{2\xi\,\omega_{n1}\,\omega_{n2}}{(\omega_{n1}+\omega_{n2})}$, and $\beta = \frac{2\xi}{(\omega_{n1}+\omega_{n2})}$

In which α and β are the coefficients depends on damping ratio of two vibration modes. For the present study 5% damping is considered for both modes of vibration of system.

2.1 Solution of Governing Equations of Motion

To facilitate Time History Analysis, the equation of motion of the structure is considered in state-space representation as follows [11];

$$\dot{Z}(t) = A\,Z(t) + E\,\ddot{u}_g \quad (10)$$

$$A = \begin{bmatrix} 0 & I \\ -M^{-1}.K & -M^{-1}.C \end{bmatrix}_{2n\times 2n} \quad (11)$$

$$E = -\begin{bmatrix} 0 \\ r \end{bmatrix} \quad (12)$$

$$Z(k+1) = e^{A\Delta t}\,Z(k) + E_d\,\ddot{u}_g(k) \quad (13)$$

$$E_d = A^{-1}(e^{A\Delta t} - I)E \quad (14)$$

$$Z(t) = \begin{bmatrix} X(t) \\ \dot{X}(t) \end{bmatrix}_{2n\times 1} \quad (15)$$

$$\dot{Z}(t) = \begin{bmatrix} \dot{X}(t) \\ \ddot{X}(t) \end{bmatrix}_{2n\times 1} \quad (16)$$

III. NUMERICAL STUDY

The seismic response of linearly elastic, idealized three storey, one-way asymmetric building investigated by numerical simulation study. The response quantities of interest are lateral and torsional displacements of floor mass obtained at the CM (u_y and u_θ), displacements at stiff and flexible edges of building (u_{ys} and u_{yf}), lateral and torsional accelerations of floor mass obtained at the CM ($\ddot{u}_y$ and $\ddot{u}_\theta$), accelerations at stiff and flexible edges of building ($\ddot{u}_{ys}$ and $\ddot{u}_{yf}$). The peak responses are obtained for four considered earthquake ground motions namely, Imperial Valley (1940), Loma Prieta (1989), Northridge (1994) and Kobe (1995) as per the details summarized in Table 3.1. The average values of peak responses from four earthquakes are also obtained and parametric study is carried out based on these average trends such as to have more definite study under the range of seismic ground motions.

Table 3.1 Details of Earthquake Motions Considered for the Numerical Study

Earthquake	**Recording Station**	**Component**	**Duration (Sec)**	**PGA (g)**
Imperial Valley, 19th May, 1940	El Centro (Array # 9)	ELC 180	40	0.31
Loma Prieta, 18th October,1989	Los Gatos Presentation Centre	LGP 000	25	0.96
Northridge, 17th January, 1994	Sylmar Converter Station	SCS 142	40	0.89
Kobe, 16th January,1995	Japan Meteorological Agency	KJM 000	48	0.82

The numerical study has been carried out to investigate the displacement and acceleration of NSE which is placed at various positions of different floors. The time period of NSE is also varied. The following parameters are considered for numerical study.

Plan Dimension of Building, B = 4 m and, D = 4 m.
Column Dimension $C_1 = C_4 = 0.3$ m × 0.3 m and, $C_2 = C_3 = 0.45$ m × 0.45 m.
Story Height = 3.5 m, No. of Floors = 3
Concrete Grade = M 20
Mass of Floor = 190000 kg
Stiffness, K = 5.1219×10^7 N/m

The mass of structure of the system are considered such as to have required time period, $T_y = 1.02$ second. Centre of mass and centre of stiffness are calculated as 2 m and 3.3402 m respectively. So eccentricity (e_x) is 1.3402 m.

Mass of Non-Structural Elements = 1900 kg

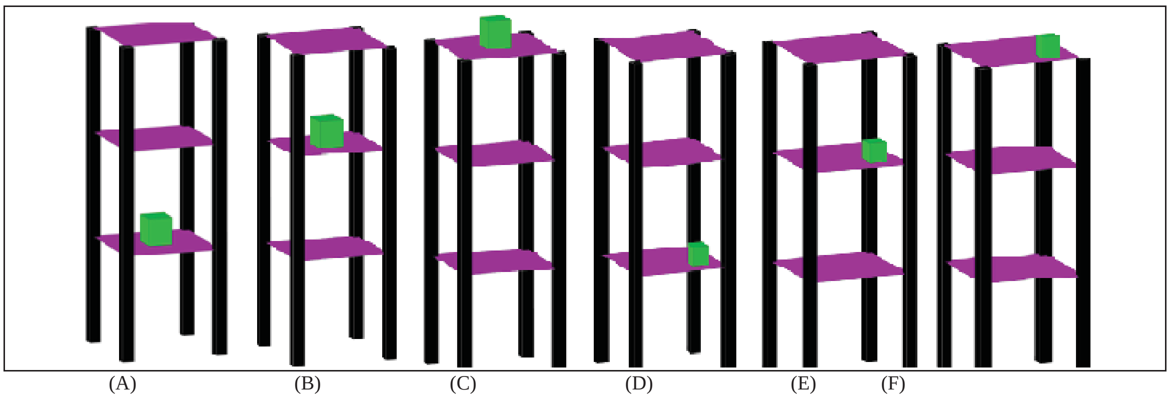

Figure 3.1 Position of Non-Structural Elements at Various Location in Different Floors

Fig. 3.1 shows the placement of NSE at various locations in different floors. For example, fig. 3.1(A) show the NSE placed at centre of first floor and fig. 3.1 (D) stiff edge of first floor.

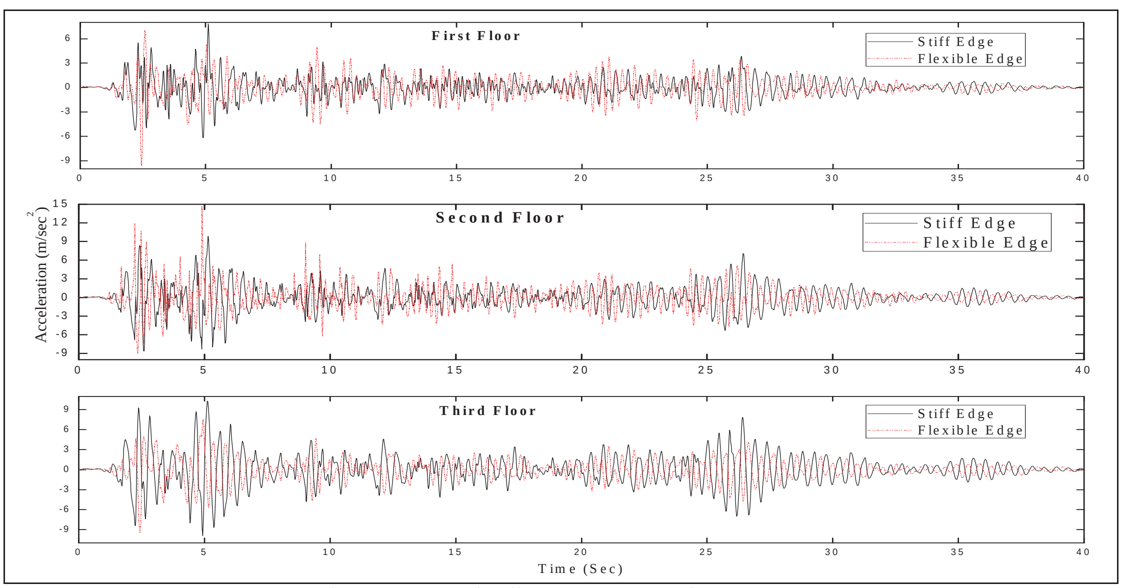

Fig. 3.2 Time histories for Acceleration of Stiff and Flexible Edge of Building under Imperial Valley EQ

The time history analysis has been performed for the building under Imperial Valley EQ and acceleration at various floors centre, flexible edge and stiff edge are obtained and plotted in fig. 3.2 in acceleration at stiff and flexible edge. In this study stiff edge acceleration is greater than flexible edge and increase to lower floors to higher floors.

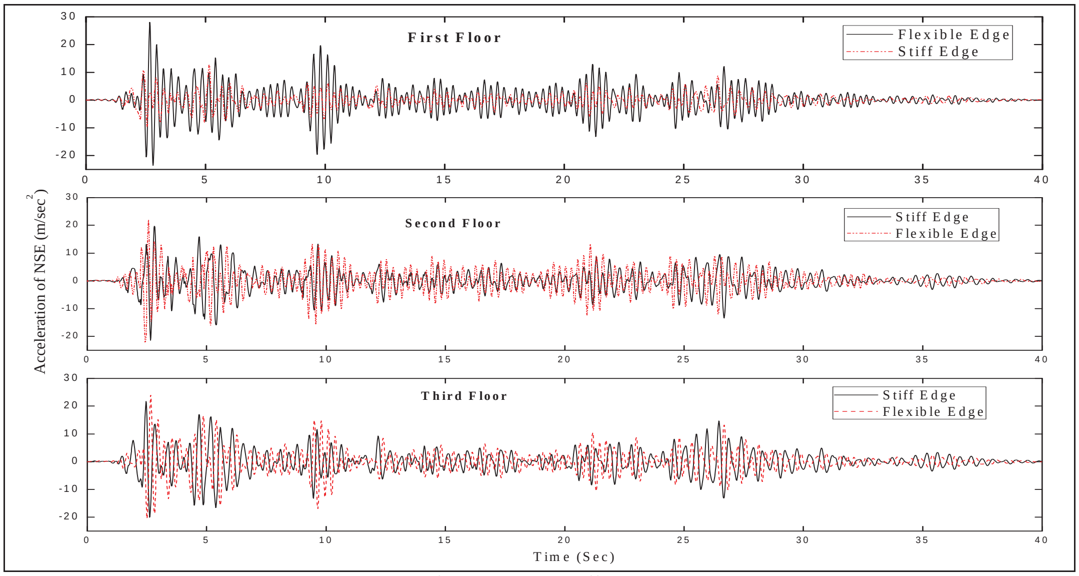

Fig. 3.3 Time histories (Acceleration) of NSE Placed at stiff and Flexible Edge under Imperial Valley EQ

When floor acceleration of building is applied as ground motion to the NSE and the numerical representation of NSE subjected to various floor acceleration is obtained and plotted in fig. 3.3 and 3.4. Fig. 3.3 shows the time history acceleration of NSE at various position on different floor under Imperial Valley EQ. `

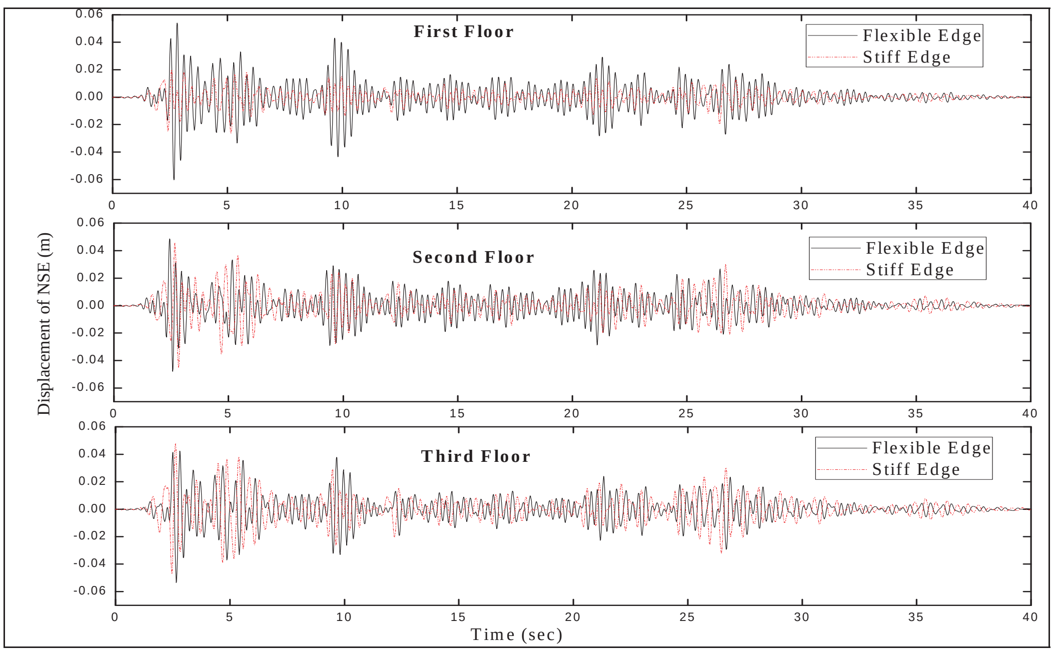

Fig. 3.4 Time histories (Displacement) of NSE Placed at stiff and Flexible Edge under Imperial Valley EQ

Fig. 3.3 shows the time history displacement of NSE at various positions on different floor under Imperial Valley EQ. The time period NSE is also varied from 0.1 to 0.5 second.

Similarly the results are obtained for other earthquake such as Kobe, Loma Prieta and, Northridge and finally the average acceleration and displacement of NSE placed at different location in building.

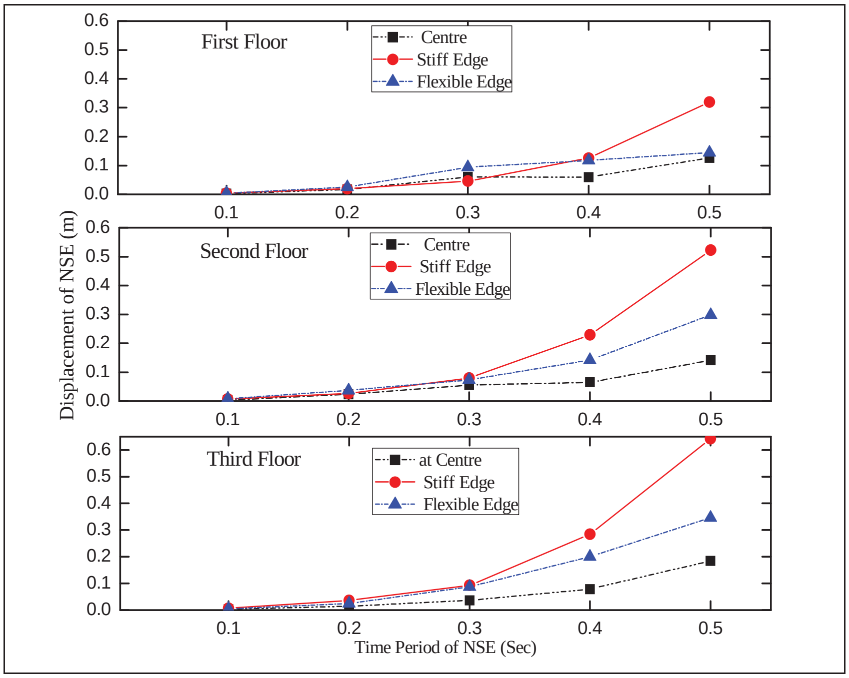

Fig. 3.5 Maximum Average Displacement of NSE Placed at Various Positions on Different Floors

Fig. 3.5 shows the maximum displacement of NSE which is placed at various positions. It is observed that for very stiff NSE the displacement remains same at all positions. Whereas the displacement of NSE is minimum at the centre of floor and it is also less at the first floor.

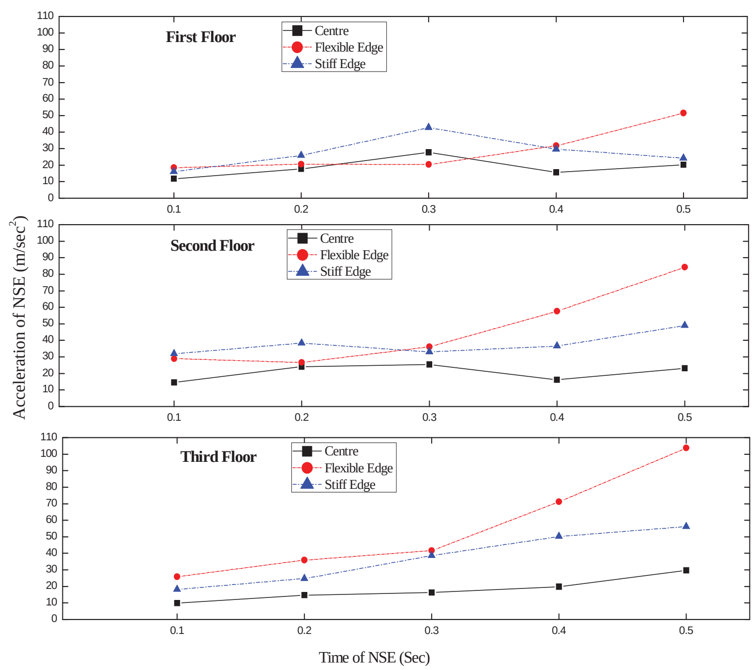

Fig. 3.6 Maximum Average Acceleration of NSE Placed at Various Position on Different Floors

Fig. 3.6 shows the maximum acceleration of NSE which is placed at various positions. It is observed that for very stiff NSE the acceleration remains same at all positions. Whereas the acceleration of NSE is minimum at the centre of floor and it is also less at the first floor.

IV. CONCLUSIONS

Non-structural elements are those which are attached to or housed in building system, but are not part of the main load-resisting structural system of the building. Performance in the past earthquake clearly pointed out that in view of the absence of inadequacy of design provisions for non-structural elements and their attachments it has resulted in poor performance of non-structural elements. In this research paper a numerical study has been carried out to investigate the seismic response of non-structural elements. The time history analysis has been performed to obtain the displacement and acceleration of non structural elements which is placed on various floor of three story asymmetric building. From the present study the following conclusion can be drawn:

(i) The peak displacement of NSE is least at the centre of first floor of asymmetric building subjected to seismic excitations.

(ii) The peak acceleration of NSE is least at the centre of first floor of asymmetric building subjected to seismic excitations.

(iii) It is advisable to place the NSE at the centre of first floor because the displacement and acceleration of NSE is higher at upper floor.

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