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Seismic Response of Non-Structural Element Placed on Single Story Two-Way Asymmetric Building under Bi-Directional Excitations

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Abstract:
The seismic response of non-structural element placed on single-storey, two-way asymmetric building under bi-directional excitations is investigated. The response is obtained by numerically solving the governing equations of motion. The seismic response of the system and non-structural element is obtained by numerically solving the equations of motion using state-space method under different system parameters. The comparative performance is investigated of non-structural element placed at different places on single story asymmetric building and finding a best place for survival during earthquake. It is found that non-structural element at flexible edge along Y- direction gives less response of displacement and acceleration. So, non-structural element placed at flexible edge along Y- direction on asymmetric SDOF system performs better in earthquake than at other places.

Keywords: Seismic, Bi-Direction Excitation, Non-Structural Elements, Displacement, Acceleration.

I. INTRODUCTION

Non-structural elements (NSEs) of a building are not a part of the main load-resisting system. Murty and Goswami (2005) found that the damage costs of Non-Structural Elements (NSEs) may account for 65% to 85% of the total construction cost of commercial buildings. Vijayanarayanan et al. (2012) found that in critical facilities, building has losses due to damaging equipment and inventory can be two to three times greater than the cost of replacing collapsed buildings or structures.

Classification of Non-Structural Elements

1) Architectural Components: This category includes the elevator penthouses, stairways, partitions, parapets, and heliports, cladding systems, signboards, lighting systems and suspended ceilings.
2) Mechanical and Electrical Equipment: This category includes the 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 includes the masonry wall, door, window, stair, Bookshelves, file cabinets, storage racks, decorative items and any other piece of furniture commonly found in office buildings and warehouses (Mondal and Jain, 2005)

In the past, many researchers investigated and studied about the behaviour of NSEs. Adam and fotiu (1997) investigated numerically the effect of ductile material behaviour on the response of coupled primary-secondary systems by using linear and nonlinear floor response spectra. Villaverde(1997)determined simple way equivalent static lateral forces for the seismic design of NSE attached to primary structure. Mondal and Jain (2005) provide design philosophy and design provision of international seismic code, and recommended design lateral forces. Singh et al.(2006)calculated and compared the seismic design force for flexible non-structural component by using floor response spectra. Chaudhuri and Villaverde(2008) investigated the seismic response of NSE which are attached to steel moment resisting frames and series of linear and nonlinear SDOF by using ensemble of 25 recorded earthquake ground motion and influence of the NSE location, nonlinearity and damping ratio. Dhanani et al.(2013) investigated the seismic response of NSE by using time history analysis, NSE placed on various floor at various place of three story asymmetric building and analysis has been perform to obtain the displacement and acceleration of NSE. Although, some of the work has been done to investigate the seismic response of NSE. However, no work has been reported to obtain the optimum location of NSE when NSEs placed on asymmetric building under bi-direction excitation. The objectives of the study are summarized as: (i) to perform the time history analysis to find the acceleration and displacement for NSEs placed at various locations on single story two-way asymmetric building, (ii) to determine the best suitable location for non-structural elements on single story two-way asymmetric buildings.

II. STRUCTURAL MODEL AND SOLUTION OF EQUATIONS OF MOTION

The system considered is an idealized single-storey building which consists of a rigid deck supported on columns as shown in Fig. 1. Following assumptions are made for the structural system under consideration: (i) floor of the superstructure is assumed as rigid, (ii) force–deformation behaviour of the superstructure is considered as linear and within elastic range (iii) the structure is excited by bi-directional horizontal component of earthquake ground motion and the vertical component of earthquake motion is neglected, and (iv) mass of the columns is ignored and the columns are considered to only provide lateral stiffness. The mass of deck is assumed to be uniformly distributed and hence centre of mass (CM) coincides with the geometrical centre of the deck. The stiffness asymmetry with respect to the CM in two direction and hence, the centre of rigidity (CR) is located at an eccentric distance, e_x from CM in x-direction and e_y from CM in y-direction. The system is asymmetric and therefore, three degrees of freedom are considered for model namely the lateral displacement in x-direction, u_x lateral displacement in y-direction, u_y and torsional displacement, u_θ as represented in Fig. 1. The governing equations of motion of the building with lateral and torsional degrees of freedom of the system are obtained in the matrix form are expressed as:

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

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

The mass matrix can be expressed as:

$$M = \begin{bmatrix} m & 0 & 0 \\ 0 & m & 0 \\ 0 & 0 & mr^2 \end{bmatrix} \qquad \ldots(2)$$

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,
$r = \sqrt{(b^2 + d^2)/12}$; where b and d are the plan dimensions of the building.

The stiffness matrix of the system is obtained as follows:

$$K = \begin{bmatrix} k_{xx} & k_{xy} & k_{x\theta} \\ k_{yx} & k_{yy} & k_{y\theta} \\ k_{\theta x} & k_{\theta y} & k_{\theta\theta} \end{bmatrix} \qquad \ldots(3)$$

Where

$k_{xx}= K_1 + K_2 + K_3+ K_4$,

$k_{yy}= K_1 + K_2 + K_3+ K_4$,

$k_{xy}=k_{yx}= 0$,

$k_{x\theta} = k_{\theta x} = {}^{d}/_{2}\,(K_1 - K_2 - K_3+ K_4)$,

$k_{y\theta} = k_{\theta y} = {}^{b}/_{2}\,(-K_1 + K_2 + K_3 - K_4)$,

$k_{\theta\theta} = ({}^{d^2}/_{4} + {}^{b^2}/_{4})\ (K_1 + K_2 + K_3+ K_4)$,

where,$K_i$denotes total lateral stiffness of the building ofi^{th} column ; k_{xx} denotes total lateral stiffness of the building along x-direction due to force along x-direction; k_{yy} denotes total lateral stiffness of the building along y-direction due to force along y-direction; k_{xy} denotes total lateral stiffness of the building along x-direction due to force along y-direction; k_{yx} denotes total lateral stiffness of the building along y-direction due to force along x-direction; $k_{x\theta}$ denotes total lateral stiffness of the building along x-direction due to torsion in building; $k_{y\theta}$ denotes total lateral stiffness of the building along y-direction due to torsion in building; $k_{\theta\theta}$ denotes total torsional stiffness of the building due to torsion in building.

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,

$$C = \alpha\, M + \beta\, K \qquad \ldots(4)$$

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

The governing equations of motion are solved using the state-space method (Hart and Wong 2000; Lu 2004) and rewritten as:

$$z_{k+1} = e^{A\Delta t} z_k + A^{-1}(e^{A\Delta t} - I)\ddot{u}_g \qquad \ldots(5)$$

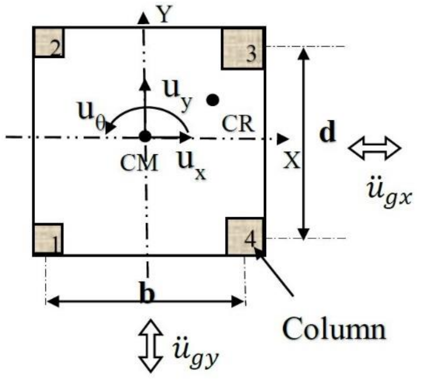
where, $z = \{u \quad \dot{u}\}^T$ is a state vector; A is the system matrix; I is the identity matrix; and $e^{A\Delta t}$ is the state transition matrix. These matrices are expressed as,

$$A = \begin{bmatrix} 0 & 1 \\ -M^{-1}K & -M^{-1}C \end{bmatrix} \qquad \ldots(6)$$

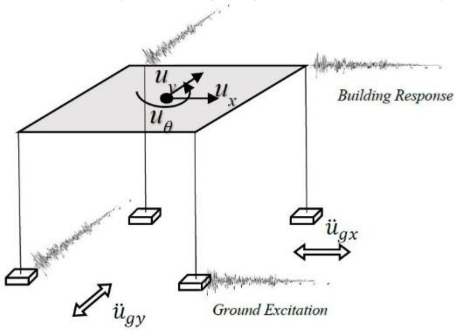
$$\ddot{z}_{k+1} = A\, z_k + H\, \ddot{u}_g \qquad \ldots(7)$$

$$H = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ -1 & -1 \\ -1 & -1 \\ -1 & -1 \end{bmatrix} \qquad \ldots(8)$$

where, $\dot{z} = \{\dot{u} \quad \ddot{u}\}^T$ is a state vector, k denotes the time step; and H is the distribution matrix of excitations.



(a) *Plan of two-way asymmetric building*



(b) *Isometric view of system showing bi-direction excitation and floor response*

Fig. 1 : Plan and isometric view of two-way asymmetric building showing bi-direction excitation and floor response

III. MODEL OF NON-STRUCTURAL ELEMENT AND SOLUTION OF EQUATION OF MOTION

The NSE of steel material (2% damping) placed at various places of two-way asymmetric single story building (5% damping) is shown in Fig. 2. The NSE is placed at stiff and flexible edge (along X direction) and stiff and flexible edge (along Y direction) of the system. The building is analysed under bi-direction earthquake ground motions. Following assumptions are made for NSE under consideration: (i) the NSE is excited by unidirectional horizontal component of floor response due to earthquake ground motion and the vertical component of floor response due to earthquake motion is neglected, (ii) the NSE is assumed to be rigidly connected with floor of building. The governing equations of motion of the NSE with lateral and torsional degrees of freedom of the system are expressed as:

$$m\ddot{u_N} + c\dot{u_N} + ku_N = -m(\ddot{u_g} + \ddot{u}) \quad \ldots(9)$$

where m is mass of NSE; $c= 2\xi\omega_n m$, is damping of NSE; and $k=m\omega_n^2$ is stiffness of the NSE; u_N is the displacement of NSE; $\ddot{u_g}$ is the ground acceleration; $\ddot{u}$ is acceleration of floor, $\ddot{u_{xs}}$ *and* $\ddot{u_{xf}} = \ddot{u_x} \pm \ddot{u_\theta}\,(b/2)$, is acceleration of floor at Stiff and flexible edge (along X- direction) ,$\ddot{u_{ys}}$ *and* $\ddot{u_{yf}} = \ddot{u_y} \pm \ddot{u_\theta}\,(d/2)$, is acceleration of floor at Stiff and flexible edge (along Y-direction).

The governing equations of motion are solved using the state-space method (Hart and Wong 2000; Lu 2004) and rewritten as:

$$z_{n_{k+1}} = z_{n_k} + A_n^{-1}(e^{A_n \Delta t} - I_n)(\ddot{u_g} + \ddot{u}) \quad .(10)$$

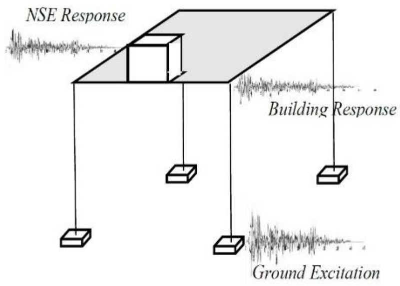
where $z_n = \{u_N \quad \dot{u_N}\}^T$ is a state vector; A_n is the system matrix; I_n is the identity matrix for NSE; and $e^{A_n \Delta t}$ is the state transition matrix. These matrices are expressed as,

$$A_n = \begin{bmatrix} 0 & 1 \\ -m^{-1}k & -m^{-1}c \end{bmatrix} \quad \ldots(11)$$

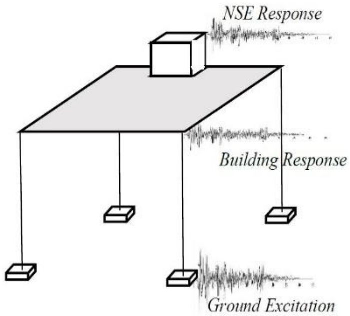
$$\dot{z}_{n_{k+1}} = A_n\, z_{n_k} + H_n\,(\ddot{u_g} + \ddot{u}) \quad \ldots(12)$$

$$H_n = \begin{bmatrix} 0 \\ -1 \end{bmatrix} \quad \ldots(13)$$

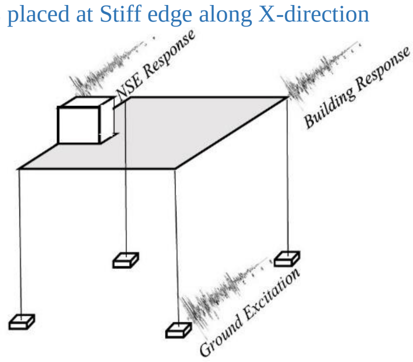
Where,$\dot{z_n} = \{\dot{u}_N \quad \ddot{u}_N\}^T$ is a state vector, k denotes the time step; and H_n is the distribution matrix of excitations.



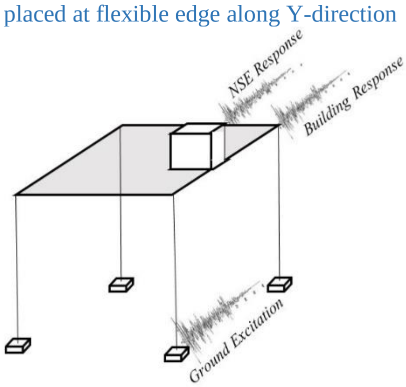
(a) NSE placed at flexible edge along X-direction



(b) NSE placed at Stiff edge along X-direction



(c) NSE placed at flexible edge along Y-direction



(d) NSE placed at stiff edge along Y-direction

Fig. 2 : Isometric view of asymmetric building showing NSE placed at various places and their responses.

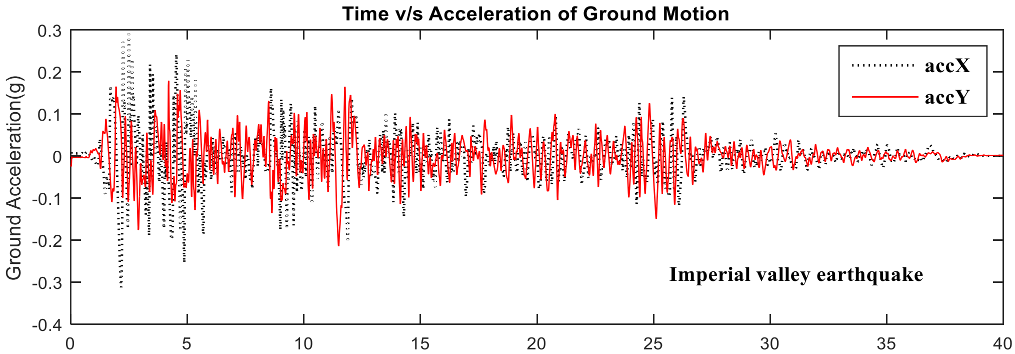
IV. NUMERICAL STUDY

The seismic response of Non-Structural Element placed on asymmetric single story building is investigated by numerical simulation study. The maximum displacements as well as maximum accelerations of NSE are obtained at stiff and flexible edge (along X direction), and the stiff and flexible edge (along Y direction) on asymmetric single story building. The response quantities of interest are lateral and torsional displacements of the floor due to bi-direction earthquake obtained at the CM (u_x ,u_y and u_θ), displacements at stiff and flexible edges (along X-direction) of the system (u_{xs} and $u_{xf} = u_x \pm u_\theta\ ({}^{b}/_{2})$), and at stiff and flexible edges (along Y-direction) of the system (u_{ys} and $u_{yf} = u_y \pm u_\theta\ ({}^{d}/_{2})$), lateral and torsional accelerations of the floor obtained at the CM ($\ddot{u_x}, \ddot{u_y}$ and $\ddot{u_\theta}$), accelerations at stiff and flexible edges (along X-direction) of the system ($\ddot{u_{xs}}$ and $\ddot{u_{xf}} = \ddot{u_x} \pm \ddot{u_\theta}\ ({}^{b}/_{2})$), and at stiff and flexible edges (along Y-direction) of the system ($\ddot{u_{ys}}$ and $\ddot{u_{yf}} = \ddot{u_y} \pm \ddot{u_\theta}\ ({}^{d}/_{2})$).The response is investigated under following parametric variations: uncoupled lateral time period of system ($T_x = {}^{2\pi}/_{\omega_x}$ and $T_y = {}^{2\pi}/_{\omega_y}$), lateral time period for stiff NSE (T=0.25sec) and for flexible NSE (T=1sec). The peak responses are obtained corresponding to the parameters which are listed above and variations are plotted for the four real earthquake ground motions namely, Imperial Valley (1940), Loma Prieta (1989), Northridge (1994) and Kobe (1995) as per the details summarized in Table 1. The time histories of the ground motions of the earthquakes are shown in Fig. 3. The considered earthquakes are most accurately recorded and are widely used by the researchers and they cover the range of all varieties of earthquakes and hence shall be helpful to lead to the generalized conclusions.

The numerical study has been carried out to investigate the peak displacements and peak accelerations of NSE which is placed at various positions on two-way asymmetric building (building height consider for Stiff building is 3.5m and for flexible building it is 25m) under bi-direction excitations. The time period for stiff NSE is taken as 0.25 second and for flexible NSE it is 1 second.

***Table 1**: Details of earthquake motions considered for the numerical study*

Earthquake	Recording station	Duration (sec)	Component for X-direction	PGA (g) for X-direction	Component for Y-direction	PGA (g) for Y-direction
Imperial Valley, 19 May 1940	El Centro (USGS 117, Array# 9)	40	ELC 180	0.3129	ELC 270	0.2148
Loma Prieta, 18 October 1989	Los Gatos Presentation Center (LGPC, UCSC 16)	25	LGP 000	0.9663	LGP 090	0.5872
Northridge, 17 January 1994	Sylmar Converter Station (DWP 74)	40	SCS 142	0.8972	SCS 52	0.6125
Kobe, 16 January 1995	Japan Meteorological Agency (JMA, 99999 KJMA)	48	KJM 000	0.8213	KJM 090	0.5985



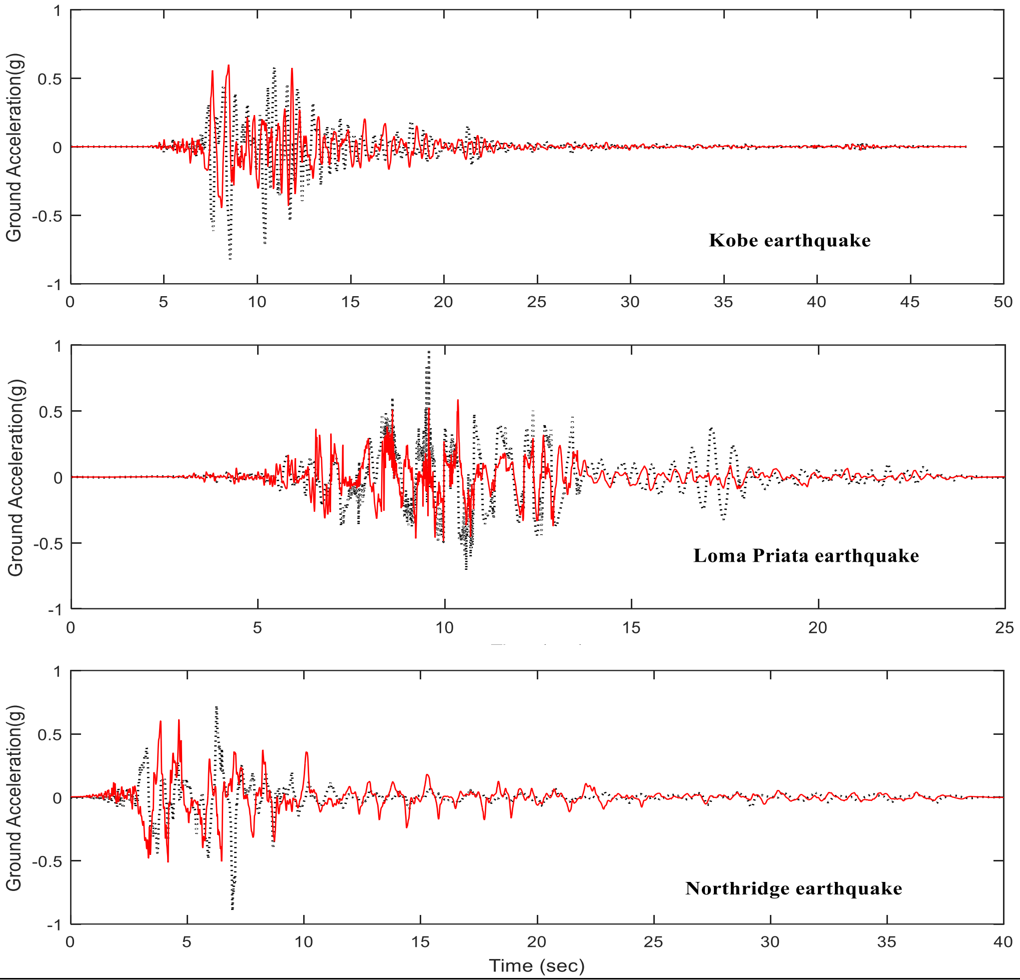


Fig. 3: Earthquake ground motions considered for the study

The time history analysis is carried out for NSE and building. The time histories of displacements and accelerations are plotted for NSE and buildings when NSE is placed at various places (flexible and stiff edge along X-direction and flexible and stiff edge along Y-direction) in building for different conditions (i.e stiff NSE placed on stiff system, Flexible NSE placed on stiff system, stiff NSE placed on flexible system and flexible NSE placed on flexible system) under four earthquakes (i.e Imperial Valley, Kobe, Loma prieta and Northridge). From the seismic responses for the NSE and buildings under the four earthquake excitations considered, the optimum place is selected for NSE to perform effectively under earthquake excitations.

1) Stiff NSE placed on Stiff asymmetric building

The floor acceleration of the building is applied as a ground motion for the NSE and the response of NSE (i.e. displacements and accelerations) are obtained and plotted in Fig. 4. The time histories of displacements and accelerations for NSE, when stiff NSE is placed on stiff asymmetric building at various places (as shown in Fig. 2) under Imperial Valley earthquake are shows in Fig. 4. In which, dnXF and dnXS denotes the displacement of NSE at flexible and stiff edge along X-direction, dnYF and dnYS denotes the displacement of NSE at flexible and stiff edge along Y-direction. AnXF and AnXS denotes the acceleration of NSE at flexible and stiff edge along X-direction and AnYF and AnYS denotes the acceleration of NSE at flexible and stiff edge along Y-direction, respectively. Similarly, the results are obtained for other earthquakes such as Kobe, Loma Prieta and Northridge.

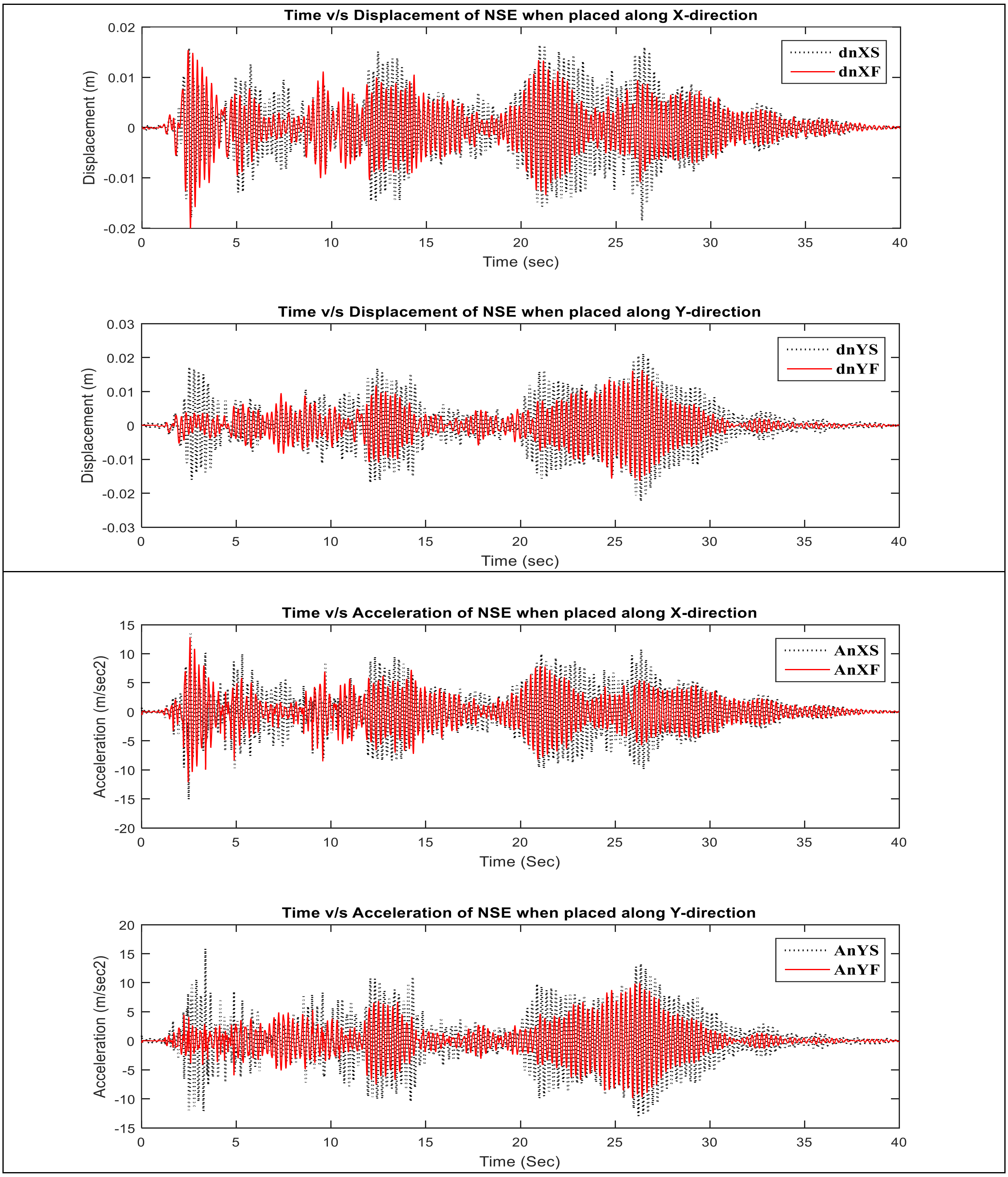


Fig. 4: *Time histories for Displacements and Accelerations of stiff NSE placed (at Stiff and Flexible Edge along X-direction and along Y-direction) on stiff Building under Imperial Valley Earthquake*

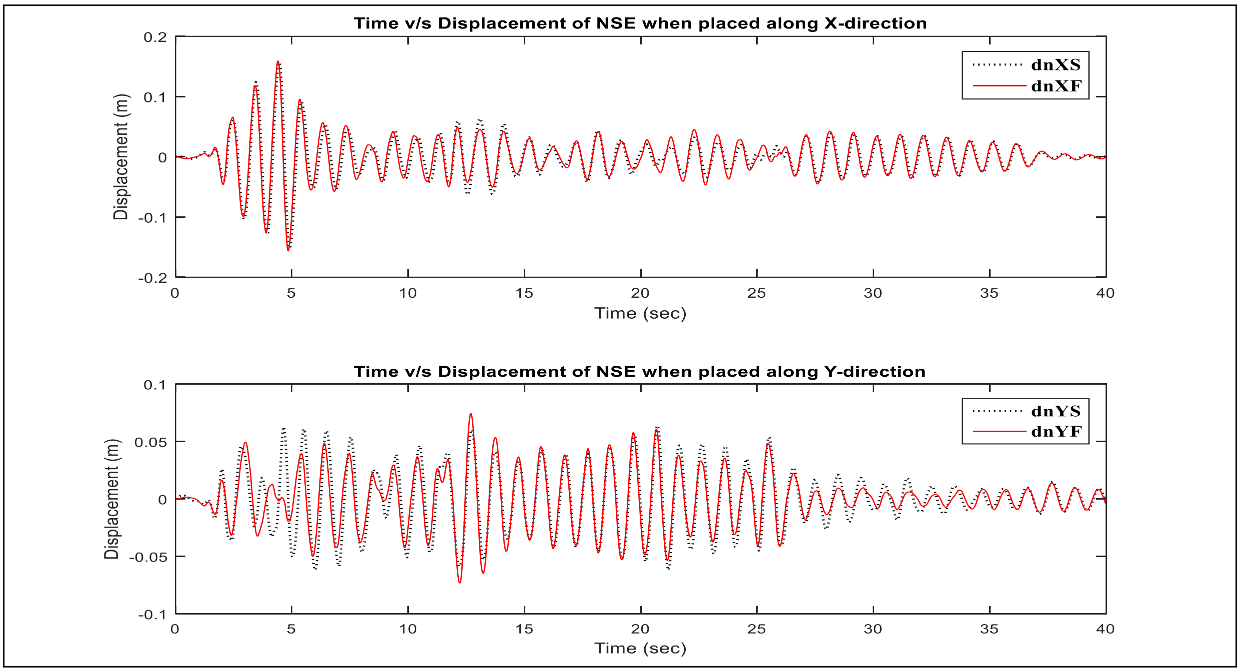
***Table 2**: Peak Displacement and Peak Acceleration for Stiff NSE placed on Stiff asymmetric building.*

Response	Imperial Valley	Kobe	Loma Prieta	Northridge	Average
dn_{XS}(m)	0.0185	0.0544	0.0247	0.0330	0.0326
dn_{XF}(m)	0.0201	0.0320	0.0281	0.0311	0.0278
dn_{YS}(m)	0.0224	0.0598	0.0274	0.0201	0.0324
dn_{YF}(m)	0.0163	0.0259	0.0230	0.0183	0.0208
An_{XS}(m/sec^2)	15.0982	31.4101	28.1518	15.1686	22.4571
An_{XF}(m/sec^2)	12.7881	15.5279	17.8554	12.4447	14.6540
An_{YS}(m/sec^2)	15.8664	32.9884	27.0113	11.5297	21.8489
An_{YF}(m/sec^2)	9.9364	13.8569	13.6852	9.5609	11.7598

Table 2 shows the peak displacement and peak acceleration values for various earthquakes and the average values for stiff NSE placed on stiff asymmetric building. From the Table 2, it is observed that the displacement and acceleration of NSE is less when NSE is placed on flexible edge of building as compared to stiff edge.

2) Flexible NSE placed on Stiff asymmetric building

The time histories of the displacements and accelerations for NSE, when flexible NSE is placed on stiff asymmetric building at various places under Imperial Valley earthquake are shows in Fig. 5. Similarly the results are obtained for other earthquakes such as Kobe, Loma Prieta and Northridge.



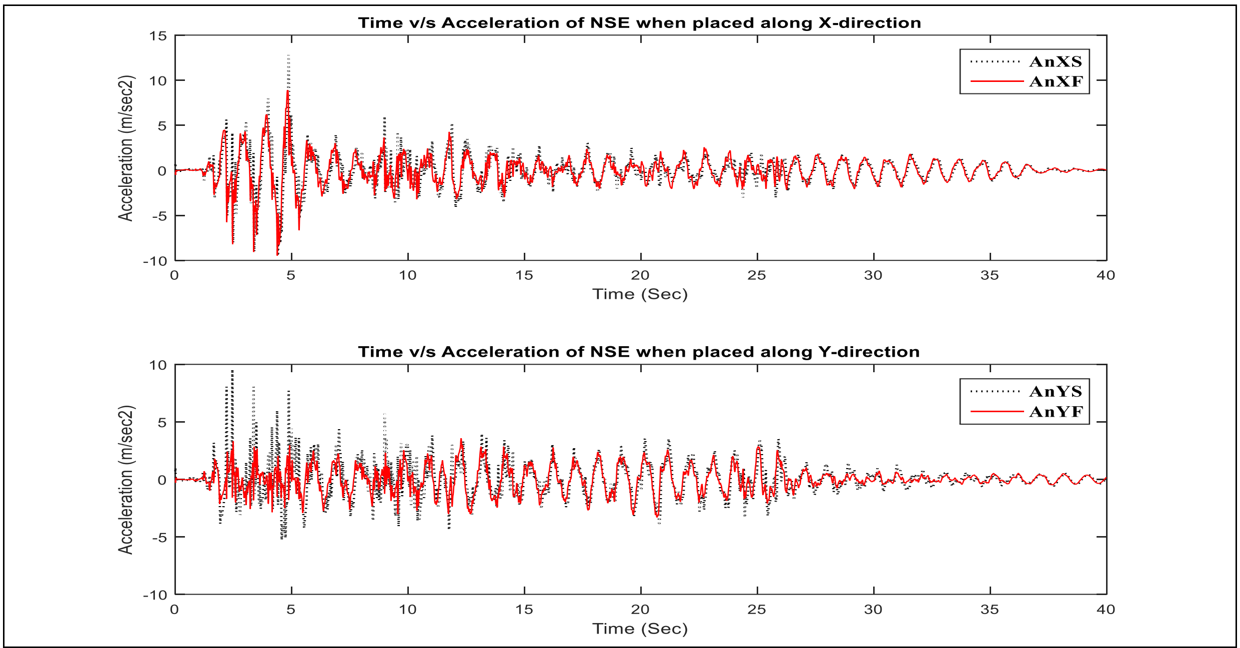


Fig. 5: ***Time histories for Displacement and Acceleration of flexible NSE placed (at Stiff and Flexible Edge along X-direction and along Y-direction) on stiff Building under Imperial Valley Earthquake***

Table 3: ***Peak Displacement and Peak Acceleration for flexible NSE placed on Stiff asymmetric building***

Response	**Imperial Valley**	**Kobe**	**Loma Priata**	**Northridge**	**Average**
dn_{XS}(m)	0.1567	0.3742	0.2806	0.4082	0.3049
dn_{XF}(m)	0.1593	0.4403	0.2814	0.4009	0.3204
dn_{YS}(m)	0.0639	0.4300	0.1277	0.4060	0.2569
dn_{YF}(m)	0.0744	0.3769	0.1334	0.4203	0.2512
An_{XS}(m/sec^2)	12.7982	28.2494	30.1454	17.8892	22.2705
An_{XF}(m/sec^2)	9.4693	21.6578	19.5792	17.8309	17.1343
An_{YS}(m/sec^2)	9.5646	25.1792	27.5009	16.8230	19.7669
An_{YF}(m/sec^2)	3.5693	19.6678	12.1277	17.0077	13.0931

The peak displacement and peak acceleration values for various earthquakes and the average values for flexible NSE placed on stiff asymmetric building are as shown in Table 3. From the Table 3, it is observed that the displacement of NSE is less when it is placed on building along Y-direction as compared to along X-direction and acceleration of NSE less when NSE placed on flexible edge of building as compared to stiff edge.

3) Stiff NSE placed on flexible asymmetric building

The time histories of displacements and accelerations for NSE, when stiff NSE placed on flexible asymmetric building at various places under Imperial Valley earthquake are shows in Fig. 6. Similarly, the results are obtained for other earthquakes such as Kobe, Loma Prieta and Northridge.

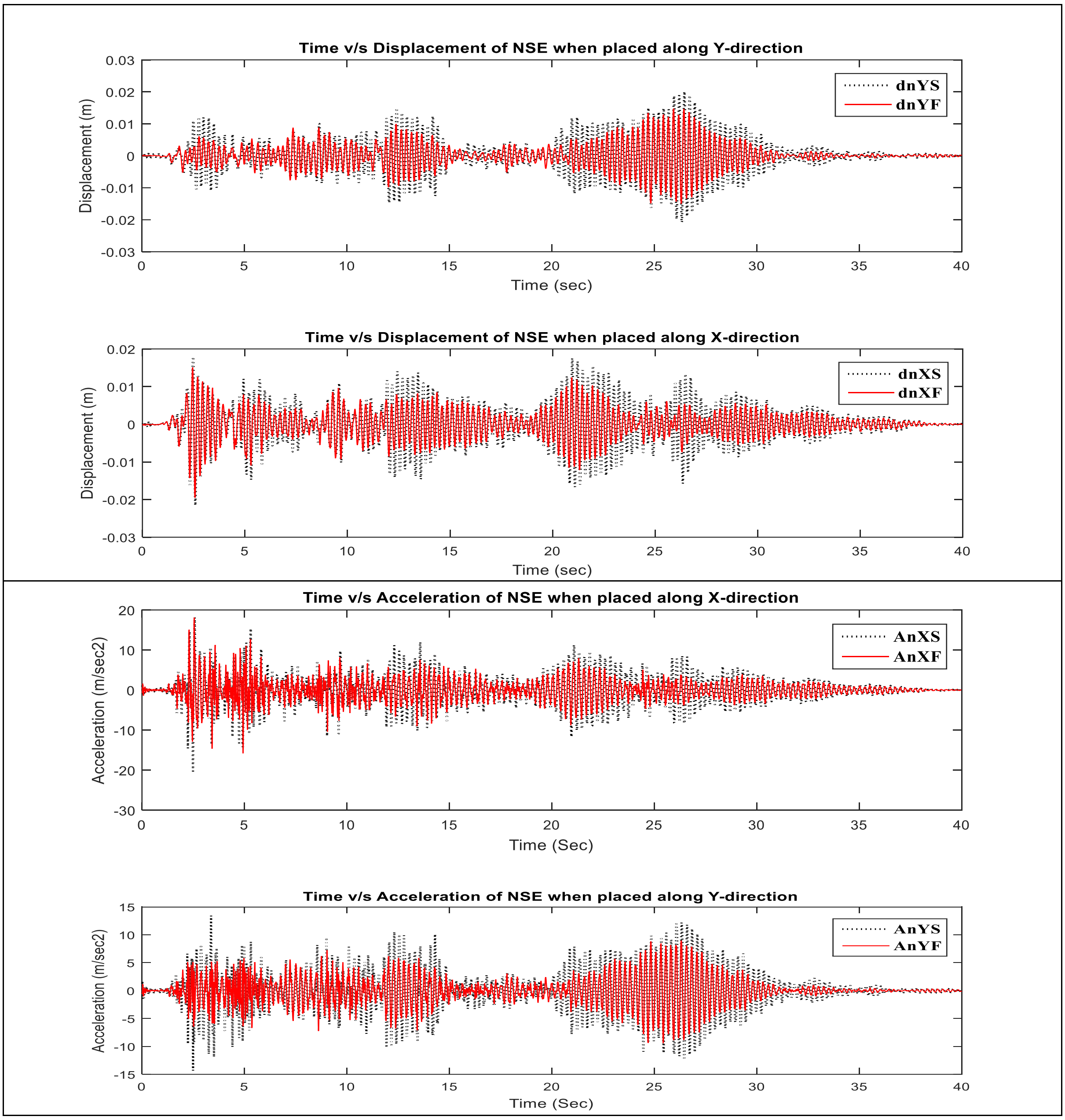


***Fig. 6**: Time histories for Displacement and Acceleration of stiff NSE placed (at Stiff and Flexible Edge along X-direction and along Y-direction) on flexible Building under Imperial Valley Earthquake*

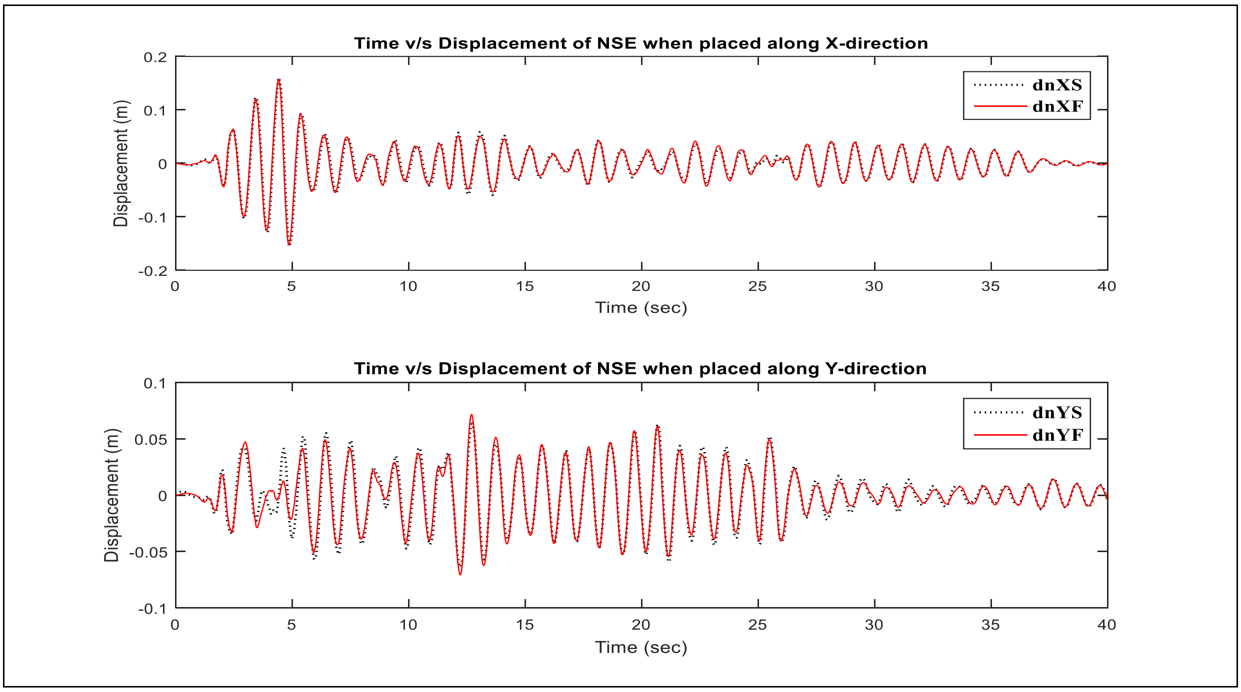
Table 4: ***Peak Displacement and Peak Acceleration for stiff NSE placed on flexible asymmetric building***

Response	Imperial Valley	Kobe	Loma Priata	Northridge	Average
dn_{XS}(m)	0.0216	0.0430	0.0319	0.0430	0.0348
dn_{XF}(m)	0.0195	0.0317	0.0310	0.0351	0.0293
dn_{YS}(m)	0.0208	0.0371	0.0301	0.0266	0.0286
dn_{YF}(m)	0.0150	0.0240	0.0237	0.0190	0.0204
An_{XS}(m/sec^2)	20.3036	23.0869	49.7014	27.6464	30.1845
An_{XF}(m/sec^2)	18.1060	16.2312	37.7042	28.4492	25.1226
An_{YS}(m/sec^2)	14.3309	20.9834	56.3394	20.5907	28.0611
An_{YF}(m/sec^2)	9.4018	12.2900	37.0867	21.1391	19.9794

The peak displacement and peak acceleration values for various earthquakes and the average value for stiff NSE placed on flexible asymmetric building are as shown in Table 4. From the Table 4, it is observed that the displacement of NSE is less when it is placed on building along Y-direction as compared to along X-direction and acceleration of NSE is less when NSE is placed on flexible edge of building as compared to stiff edge.

4) *Flexible NSE placed on flexible asymmetric building*

The time histories of displacements and accelerations for NSE, when flexible NSE placed on flexible asymmetric building at various places under Imperial Valley earthquake are shows in Fig. 7. Similarly, the results are obtained for other earthquakes such as Kobe, Loma Prieta and Northridge.



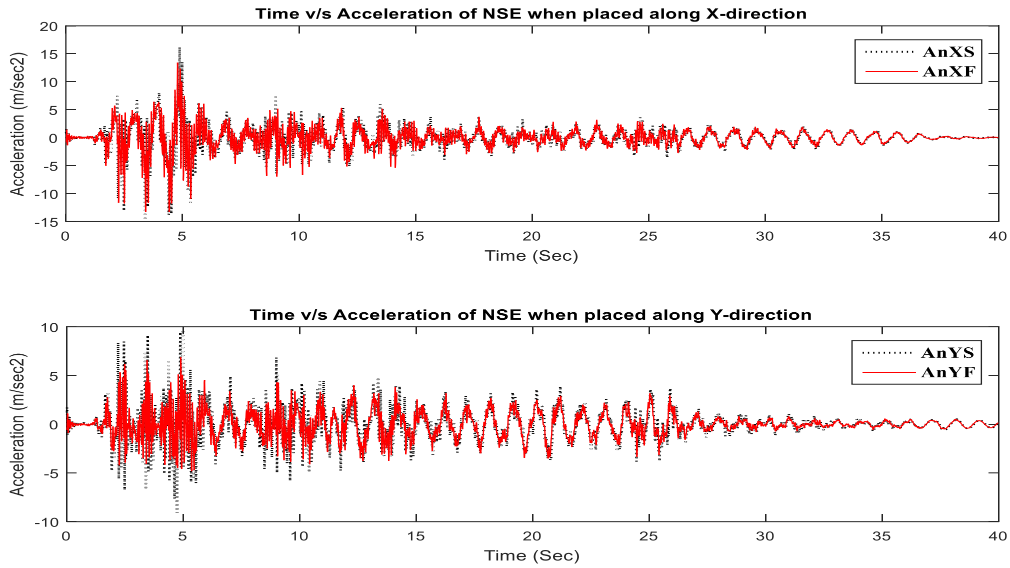


***Fig. 7:** Time histories for Displacement and Acceleration of flexible NSE placed (at Stiff and Flexible Edge along X-direction and along Y-direction) on flexible Building under Imperial Valley Earthquake*

***Table 5**: Peak Displacement and Peak Acceleration for flexible NSE placed on flexible asymmetric building*

Response	Imperial Valley	Kobe	Loma Priata	Northridge	Average
dn_{XS}(m)	0.1599	0.3957	0.2857	0.4144	0.3139
dn_{XF}(m)	0.1582	0.4373	0.2828	0.4017	0.3200
dn_{YS}(m)	0.0655	0.3989	0.1313	0.4116	0.2518
dn_{YF}(m)	0.0716	0.3757	0.1338	0.4194	0.2501
An_{XS}(m/sec^2)	16.1957	23.4060	44.6513	22.9830	26.8090
An_{XF}(m/sec^2)	13.4392	23.1828	41.1663	28.9612	26.6874
An_{YS}(m/sec^2)	9.6969	23.2217	54.2783	22.7902	27.4968
An_{YF}(m/sec^2)	6.8831	19.6746	38.5967	22.1392	21.8234

The peak displacement and peak acceleration values for various earthquakes and the average values for flexible NSE placed on flexible asymmetric building are as shown in Table 5. From the Table-5, it is observed that the displacement of NSE is less when it placed on building along Y-direction as compared to along the X-direction and acceleration of NSE less when NSE placed on flexible edge of building as compared to stiff edge.

IV. CONCLUSIONS:

The seismic response of non-structural element placed on single-storey, two-way asymmetric building under bi-directional excitations is investigated. The seismic response of the system and non-structural element is obtained by numerically solving the equations under the different system parameters. From the present numerical study, the following conclusions can be drawn:

1. The displacement and acceleration of NSE is less when NSE is placed on flexible edge of building as compared to stiff edge when stiff NSE is placed on stiff building. Also, the displacement of NSE is less when it is placed on building along Y-direction as compared to along the X-direction and acceleration of NSE less when NSE is placed on flexible edge of building as compared to stiff edge when stiff or flexible NSE is placed on flexible building as well as flexible NSE is placed on stiff building.

2. The peak displacement and peak acceleration of NSE is less at the flexible edge along the Y-direction of one-story two-way asymmetric building subjected to bi-direction excitations.
3. It is advisable to place the NSE at the flexible edge along the Y-direction of one-storey two way asymmetric building because the seismic responses (i.e., displacement and acceleration) of NSE is less at that place so that it will perform better in earthquake.

REFERENCES:

[1] Murty C.V.R.,Goswami Rupen.(2005) "*Earthquake Protection of Non-Structural Elements in Buildings*" Gujarat State Disaster Management Authority.

[2] Vijayanarayanan A.R.,Goswami Rupen and Murty C.V.R. (2012),"*Determining Levels of Seismic Shaking Effects in Buildings for securing Non-Structural Elements*." Fourth International Conference on Structural Stability and Dynamics (ICSSD 2012), 4–6 January, 2012. Malaviya National Institute of Technology, Jaipur & Texas A&M University, USA

[3] Mondal Goutam and Jain Sudhir K (2005), Design of Non-Structural Elements for buildings: A review of codal provisions by, The Indian Concrete Journal, August 2005.

[4] Mondal Goutam and Jain Sudhir K, Proposed draft for IS: 1893 on design of Non-Structural Elements, The Indian Concrete Journal, and October 2005.

[5] Christoph Adam and Peter a Fotiu, (1997), "*Dynamic response of earthquake excited inelastic primary secondary systems*", EarthquakeEng. Struct. Dyn., vol:22, pp:58–71**.**

[6] VillaverdeRoberto, (1997), "*Method to improve seismic provisions for non-structural components in buildings*", Journal of Structural Engineering, Vol. 123, Paper No. 13719, Pg no: 432-439

[7] Singh, M. P., Suarez, L. E., Matheu, E. E., and Maldonado, G. O., (2006), "*Seismic Design Forces.II: Flexible Non-structural Components*", Journal of structural engineering © ASCE, October 2006 ,Vol. 132, No. 10.

[8] Chaudhuri Samit Ray and Villaverde Roberto, (2008), "*Effect of Building Nonlinearity on Seismic Response of Non-structural Components: A Parametric Study*", Journal of structural engineering © ASCE, April 2008, Vol. 134, No.4.

[9] Dhanani Suresh L., Patel Sumant B., Mevada Snehal V, (2013), "*Seismic Response of Non-Structural Elements*", International Journal of innovations in Engineering and Technology (IJIET), Vol.2.

[10] Hart GC and Wong K, "*Structural Dynamics for Structural Engineers*", John Wiley &Sons, Inc.

[11] Lyan-Ywan Lu (2004). "*Predictive control of seismic structures with semi-active friction dampers*" earthquake engineering and structural dynamics.

[12] Chopra AK., "*Dynamics of Structures*", Third Edition, Pearson Publication.