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Analysis Of Asymmetrical Buildings With Base Isolator, Shear Wall And Bracing System Located At Near Fault Region Using Non Linear Time History

[1]Osama Ahmed, [2]Dr.s.Amaresh Babu
[1]Post graduate student, [2]head of Civil department
Nawab shah alam khan college of engineering and technology

Abstract - **Engineering seismology and earthquake engineering building have a few complicated topics common to each of them, namely the portrayal of seismic motion near fault lines and its resulting effect on the lifespan of the structure. Near fault ground motion are knowns by its characteristics of large amplitude pulse with low frequency in both velocity and displacement time histories in the fault region of 16-20 km. The high input energy generated in the structure results in varied structural responses in comparing to far fault earthquake. Yet existing reports, for instance, ATC-40 (1997), FEMA-273 (1997), characterize a purpose behind seismic structure by considering near fault shaking effect for the change of elastic response spectra, they don't currently consider the amplified inelastic demands that may occur during the near fault shaking. As such, there is a need to look at and perceive the inelastic response of the structures in near fault territories. Non-Linear Time History Analysis (NL-THA) is the base of this study of asymmetrical structures in near-fault region by seeing the effects of the seismic resistance devices like, shear wall and bracings and base isolators on the seismic parameters (like base torsion & base shear and story drifts). RCC moment restricting housings of five, ten and fifteen stories was stacked with gravity loads (dead weight and live weight), static seismic tremor stacking and NL-THA was performed using ETABS 15. Four models were painstaking studied to test the effect of the seismic control devices in close inadequacy districts. Model one filled in as the basic model while model two executes shear dividers, model three had a base isolator participated in it and model four completes bracings. By studying the ground motion data of "Loma Prieta (1989)" seismic tremor information/data is used for performing the time history analysis. The results unveiled that for five and ten storied structures, to control most outrageous story displacement & story drift .Shear walls are considerably useful, however to control base shear and base torsion, base isolator are successful contraptions. For fifteen story non-symmetrical structures, base isolators are incredible devices for controlling all the seismic parameters in near fault ground motion.**

keywords - **Non-Linear Time History Analysis, Near Fault Region and Seismic Control Devices**

I. INTRODUCTION

Constructed or engineered buildings are typically prone to tons of wind, earthquake, and loads of gravity, snow etc. Among these forces, the most dangerous force a structure can experience is seismic excitation. To avoid a collapse of the framework, it is necessary to follow earthquake resistant engineering during the construction of the structure. The waves that emerge during seismic activity have a monstrous fast pace and travel through the foundations to the top of the roof when any structure is affected by inelastic damage/distortion. There might be the likelihood of breakdown of entire structure or most likely it will endure, contingent on the plan embraced, yet without a doubt the structure will have some major fixing and reinforcing works which will be expensive In some cases, seismic vibrations cause damage that destroys buildings are extremely high Tremors create inner forces in a structure because of inertia. Inertia can be portrayed as the tendency of a body stationary to stay very still and a body in movement stays in movement. The internal forces rely upon the course of ground movement brought about by an earthquake and act even horizontally and vertical. The more articulated tremor powers are typically level for example horizontal powers acting forward and backward parallel to the ground. Since the ground movement moves forward and backward, the impacts of inertia cause a structure to be distorted and can bring about extreme damage. Previous experiences show that the structures that are asymmetrical in plan and geometry are more prone to mammoth damages caused due to seismic excitations. The earthquakes in recent past history caused many damages to structures with, strength and uneven distribution of mass and stiffness. Because of different kinds of practical and design prerequisites, asymmetrical building structures are practically unavoidable in present day development.

The utilization of ductility, for dispersal of the energy discharged by the tremors to the structure, gave the creators adequate space for making a decision about the exhibition of the structures and checking the equivalent forces while planning. The plan of the structures dependent on the presentation under the loading likely could be anticipated by demonstrating the structure numerically. This can be proficiently done by any of the product accessible in the market, for structural modelling, analysis and design of structure. The forecast of the exhibition of a structure, intended for a predetermined example of loadings and level of wellbeing holds significance for the practising structural engineers. There are numerous accessible procedures for the analysis of the structures and to assess their presentation under the given loading, the most precise among them being the non-linear time history analysis. For the structures with less significance or seismic danger, some other traditional strategies have been created called as Non-Linear analysis techniques.

1.2 Data used in this Analysis

The "Loma Prieta (1989)" seismic tremor data is utilized as ground movement information for performing time history examination. The Loma Prieta tremor happened in the Santa Cruz Mountains in northern California. The greatness of this seismic tremor was 6.93 and the profundity of centre was eighteen kilometres. The reaction history of the structure was shown at each time step was shown inside the yield by the product bundle ETABS 2015 including relocation reactions, power reactions and different elective reactions.

1.3 Near-Fault

A difficult investigation subject in design seismology and earthquake engineering is that the portrayal of near-fault seismic movements and their impacts on the performance of structures. The seismic tremor ground movement in the region inside fifteen to twenty kilometre of the fault is portrayed by large amplitude pulse with low frequency in both the velocity and displacement time history. In earthquake building practice, the seriousness of the ground motion is normally estimated by the peak ground acceleration (PGA) though for the close issue records this isn't generally the situation. The acceleration in the close near fault may contain high PGA value that relates to a brief length pulse with next to no or little effect on the structure. Then again, a low PGA with long duration pulse may have serious harming impacts on structures. In the near fault, the propagation of the fault burst toward a site at a speed near the shear wave velocity makes the vast majority of the seismic energy from the rupturing procedure in single enormous pulse of motion. The attributes of ground movements recorded near a active fault in a seismic tremor are subjectively not the same as the standard far-fault ground motion. Near fault shortcoming ground movements are the world's quick displacements which are produced at fault direction due to shear wave propagation.

1.4 Need of the Study

Major seismic tremors {example: Northridge(1994), Kobe(1995), Chi Chi(1999), Bam(2003), Loma Prieta (1989)} featured that structures built inside a couple of kilometres of a fault rupture zone and planned by ongoing codes can experience extreme, very unanticipated, damage. This conduct can be considered as a result of the design arrangements embraced, which consider the impacts of far-fault ground movements, however can be lacking for near fault movements. Albeit existing archives, for example, ATC-40 (1997), FEMA-273 (1997) and Uniform Building Code (UBC, 1997) for the most part define a reason for seismic structure by considering near fault shaking impacts for the improvement of elastic response spectra, they don't at present consider the increased inelastic demand that may happen during the near fault shaking. In this manner, there is a need to examine and recognize the inelastic reaction of the structures in near and far-fault areas.

As indicated by numerous scientists, Non Linear Time History Analysis (NL-THA) is considered the most exact and precise for seismic assessment of the structure which gives the reaction of the structure at any time. The requirement for this investigation is to offer a general comprehension of the seismic performance enhancements of the average RC structures asymmetrical in plan, resting in near fault region, by the usage of shear wall, bracing system and base isolation strategy. Because of this thesis, building proprietors and development industry experts can perceive the advantages of actualizing base isolation strategy for elevated structures in near fault region on a more extensive scope of projects, along these lines making the potential for a critical increment in the innovation's utilization.

1.5 Model details

This thesis manages non-linear investigation of asymmetrical structures with near fault area contemplations by joining impacts of seismic control devices like shear wall, base isolators and bracing system. Four models were considered for 5, 10 &15 story structures. Model one filled in as fundamental model while model 2, 3 and 4 executes models with shear wall, base isolator and bracings individually. The structure is assessed as per IS 456-2000 and seismic code IS 1893-2002 utilizing non-linear Time History Analysis with the assistance of ETABS.

1.6 Objectives of the Study

- To study the effects of ground motion on torsional response of asymmetrical buildings.
- To study the effects of providing base isolator, shear wall & bracing system in an asymmetrical buildings subjected to near fault ground motion.
- To compare the seismic parameters like storey drifts, storey displacements, base shear and base torsion of an asymmetrical buildings under near fault regions.

2 Literature Review

Ghobarah (2004) surveyed nonlinear static and dynamic response (using inelastic time history analysis) of reinforced concrete moment restricting frame structures of various dynamic characteristics presented to near fault ground motion. Four RCC moment resisting frames of 3, 6, 12 and 20-stories were proposed to current Canadian codes NBCC were presented to picked tremor time history analysis recorded by stations arranged in the near fault territory. The structures were believed to be arranged in the city of Victoria on Canada's west coast. The four structures have the identical symmetrical floor plan of 3 by 3 bays. Every bay is 6.00 m wide and the story height is 3.6 m. The arranged moment resisting frames are presented to a set of picked near fault tremors. All of the seismic tremors are greater than size 6 with short epicentral distance of under 5 km. The response quantities, for instance, the maximum inter story drift, the maximum roof drift and the base shear are resolved and compared.

It was found that the response of structures to near fault ground motion is essentially not exactly equivalent to the response to far-field sesmic records. For a comparable base shear, the static pushover analysis gives conventionalist evaluations of the displacement of the structure. The nonlinear static pushover approach is particularly proper for displacement based analysis of structures to NFE.

Ghasemi and Shakib (2008) surveyed torsional response of structure models which have different distribution of the strength and stiffness eccentricity under near fault and far-fault excitations. The effects of near fault and far-fault developments on torsional response in the different stories were considered. Displacement demands, story drift and story ductility demand underground motion are resolved and compared.

The makers assumed that in the near fault ground motion the minimum rotational response considering strength-stiffness dependent behaviour can be achieved, when strength and stiffness centre are arranged despite what might be opposite side of the mass centre. The proportions of torsional demands of idealized one-story structures are more than the equivalent proportions of multi-story structures. In higher records of the multi-story structures, identical to the ordinary direct, the evacuating of the fragile side part is more than the expulsion of the strong side segment. While, in the lower stories the displacement of the solid side is more than the fragile side displacement. In higher stories, the story drift demand of the fragile side additions by the extension of solidarity whim. Regardless, opposite to the firm side, in lower stories this technique is convoluted. In near fault motion, the story drift demand increases from higher stories to the lower ones. Under far fault motion, it is exchanged.

Amiri et al. (2008) performed the linear and nonlinear time history analysis using SAP2000 programming, by choosing 5, 8 and 12 stories structures planned by IRAN 2800 code, to look at the impacts of Near-fault Earthquake (N.F.E.). These structures are geometric regular and their normal story stature and bays width is 3.20m and 3m, respectively. This article communicates the impacts of N.F.E on frames responses by the linear and nonlinear time history reactions of structures to the earth movements at Far and Near-Source zones. 12 Near-Fault records of IRAN and the remainder of the world and 3 Far-Fault records of Northridge, Landers and Chichi are utilized in this examination. The enrolled records under 15km are picked as the Near-Source standard and Far-Fault ground movements of chronicles are chosen over 50 km. The creators inferred that as per nonlinear analysis the measures of forced interest of N.F.E were more than Far-fault Earthquake, because of inefficiency of 5, 8 and 12 stories structures as per a few N.F.E, particular contemplations for planning and reinforcing of structures situated at Near-Source zones of IRAN are required. The forced seismic demand on the structures under N.F.E records is a lot of more prominent than that of F.F.E records.

Mortezaei and Ronagh (2010) have appeared in the present paper that in a wall frame structure exposed to near fault seismic tremors, the full 3D time history displaying can essentially differ the analysis results, thus is a significant thought in plan. The impacts of floor slabs on seismic response of medium and skyscraper loft building structures were explored in this analysis under near fault and far-fault quakes. Nonlinear dynamic analysis is directed so as to explore worldwide conduct, for example, load-deformation relationship on wall frame system. For FE displaying, an analysis tool which depends on layered nonlinear finite element strategy to explore the nonlinear conduct of wall frame structure has been utilized. The real perceptions and discoveries are outlined as pursues:

1. In a wall frame system structure, the impact of the flexural firmness of slabs on the lateral response of the structure is generally huge, particularly in taller structures.

In the event that the flexural stiffness of the slabs is completely overlooked, the lateral displacements might be overestimated and the seismic loads per the construction regulation, base shear might be essentially thought little of. It is prescribed that the flexural stiffness of sections is incorporated into the investigation of wall frame structures.

2. It might be imperative to decide the amount of the flexural stiffness of slabs ought to be incorporated into the analysis of a wall frame system structure, since the amount relies upon the lateral response of a structure. Future examinations can concentrate on finding the methods of slab twisting in a wall frame system structure under lateral loads. Related to the flexural stiffness of slabs, it might be important to consider the out-of-plane flexural stiffness of the shear wall, which may cause an impressive bending moment requiring extra support in the wall.

3. The slab ought to be subdivided into countless shell components so as to incorporate the flexural stiffness of sections, while a shear wall might be all the more effectively modelled with just a single component for every story.

3.1 Methodology

The reason for the non-direct time history examination (NLTHA) is to assess the non- linear response of structural framework concerning torsion and rotation and to contrast these parameters with accessible structures with arrangement of centres, base isolators and shear walls that will be tried in this project. Time-History analysis is a well ordered strategy where the loading and the response history are assessed at progressive time increases, t – steps. During each step the response is assessed from the initial conditions existing toward the start of the steps (displacements and velocities) and the loading history in the interval. With this technique the non-linear behaviour might be effectively considered by changing the basic structural properties (for example stiffness, k) starting with one stage then onto the next. Hence this technique is one of the best for the arrangement of non-linear response, among the numerous strategies accessible.

The inelastic dynamic time history examination can be seen as a technique for anticipating seismic force and deformation demands, which records in an estimated way for the redistribution of internal forces happening when the structure is exposed to latency inertia forces that no longer can be resisted within the elastic range of structural behaviour. The NLTHA is relied upon to give data on numerous reaction qualities that can't be acquired from a linear elastic analysis and linear dynamic analysis whose precision is as yet flawed, verification of the completeness and adequacy of load path, considering all the elements of the components of the structural system, all the connections, the stiff non-structural elements of significant strength, and the foundation system. The NLTHA is maybe the main methodology which catches the realistic response of the structures when exposed to genuine earthquake loading. Clearly, these advantages come at the expense of extra analysis effort related with consolidating extremely significant elements, demonstrating their inelastic load- deformation characteristics, and executing steady inelastic examination, ideally with a three-dimensional analysis model. As of now, with couple of exemptions, satisfactory investigative instruments for this reason for existing are either very cumbersome or not accessible, unfortunately to perform NLTHA a code or an investigation record isn't accessible not normal for linear seismic static analysis or linear seismic dynamic analysis for which each nation has its code or for non-linear static analysis which has special documents pursued worldwide for playing out the equivalent as ATC-40, FEMA-273 (1997) archive and so on. As we know in the NLTHA the response are determined at every time step of the earthquake loading which urges the structure to advance into the inelastic disfigurement.

3.2 Analysis Procedure

Each structure vibrates under outside excitation. The response essentially relies upon its mass, stiffness, damping and boundary conditions. These parameters can be communicated by a solitary parameter frequency 'f 'or time period 'T 'of vibration. A structure might be idealized into single degree of freedom system (SDOFS) or a multi-degree of freedom system (MDOFS). These idealized system would can then be analysed and its response to different excitations can be assessed. The analysis procedure can be divided into linear procedure (linear static and linear dynamic) and non-linear procedure (non-linear static and nonlinear dynamic).

Table 1 Code Provisions of IS 1893-2002 about the Seismic Weight

Provisions for imposed load on the structure	
Imposed uniformly distributed floor load (KN/m2)	Percentage of imposed load
Up to and including 3.0	25
Above 3.0	50

4. Case study

The aim of the present work is to evaluate the seismic response of the structure subjected to earthquake excitation with the help of ETABS 2015. The layout of the plan is asymmetric in both X and Y direction with re-entrant corner having bay length of 5m in X direction and 4m in Y direction. The models considered are reinforced concrete ordinary moment resisting frame of five, ten and fifteen stories with same column sizes, with base isolators, with shear walls & with bracings. All these buildings have been analysed by non- linear dynamic analysis [time history analysis]. The typical storey height is 3m for all models. The “Loma Prieta” earthquake data is used as ground motion data for performing non-linear time history analysis.

The plan configurations consists of; Models for five, ten and fifteen storied building

Model 1 - Building is asymmetric in both X & Y directions, all column sizes are same. (Basic model with column sizes 300 x 450 for 5 stories, 300 x 600 for 10 stories and 380 x 750 for 15 stories)

Model 2 - Building is asymmetric in both X & Y directions, all column sizes are same. (Basic model with columns and shear walls of 300mm).

Model 3 - Building is asymmetric in both X & Y directions, all column sizes are same. (Basic model with base isolator).

Model 4 - Building is asymmetric in both X & Y directions, all column sizes are same.(Basic model with columns and Reinforced Concrete X-bracings of size 300x450mm)

Table 2 Assumed Preliminary Data Required for the Analysis

S.no	Variable	Data
1	Type of structure	Moment resisting frame
2	Number of stories	5, 10 and 15
3	Bottom storey height	3m
4	Typical storey height	3m
5	Dead load	15 kN/m
6	Live load	10 kN/m
7	Grade of concrete	M20
8	Grade of steel	Fe 415
9	Size of beams	300 x 450mm
10	Specific weight of RCC	20 KN/m^3
11	Seismic Zone	IV
12	Importance factor	1
13	Reduction factor	5
14	Type of soil	Medium

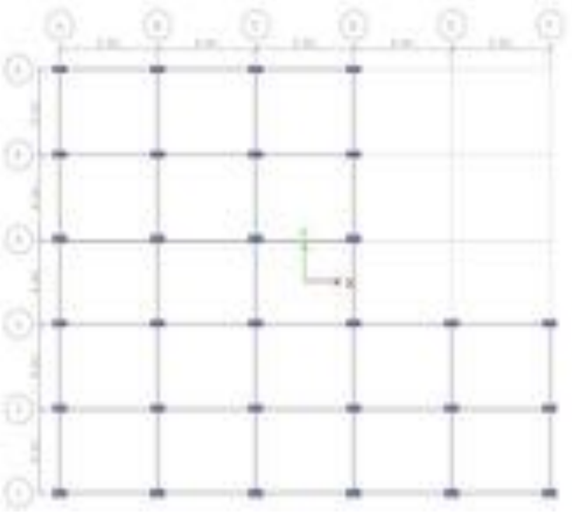

Fig. 3 Plan View of the Models 1, 3, 4

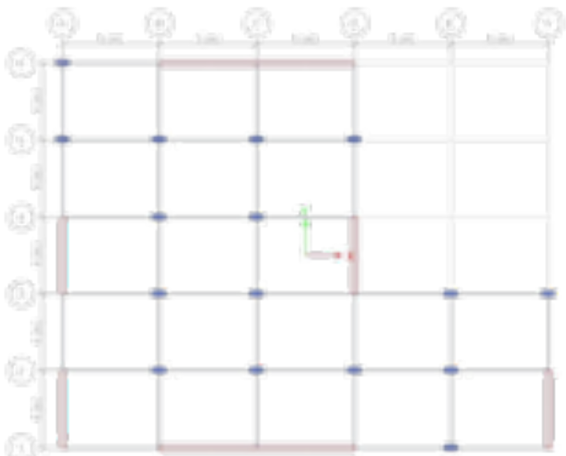

Fig. 4. Plan View of the Model 2 (Shear Walls)

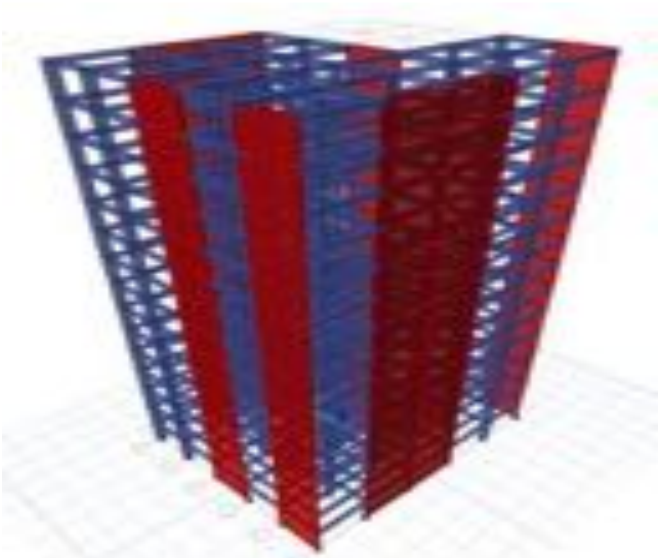

Fig. 5 Isometric View of the Model 2 (Shear Walls)

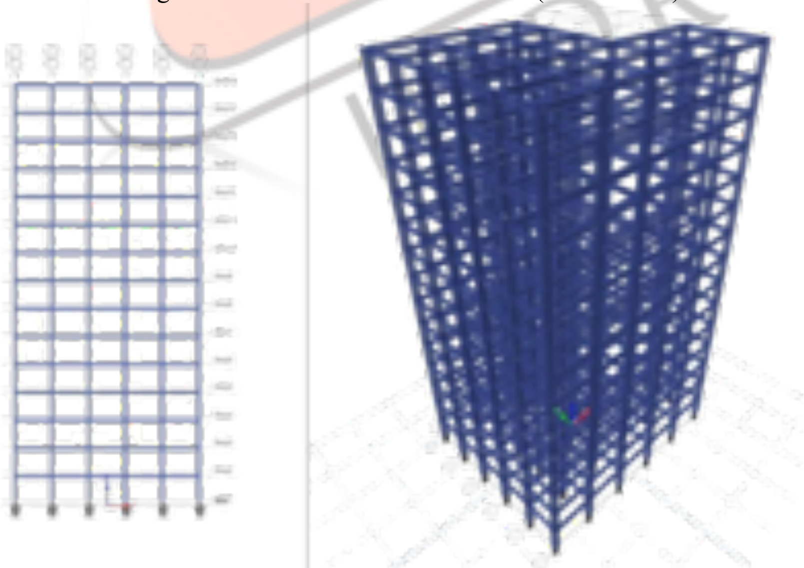

Fig. 6 Elevation & Isometric View of Model 3 (Base Isolator)

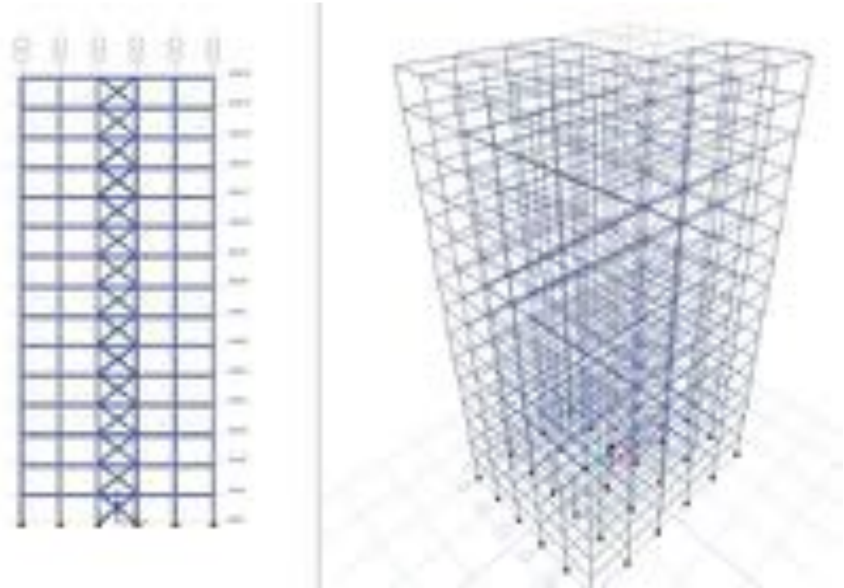

Fig. 7 Elevation & Isometric View of Model 4 (X-Bracings (300x450mm))

5 Non-Linear Time History Analysis

NLTHA is one of the strategies and the most exact technique accessible to comprehend the conduct of structures exposed to quake powers. As the name infers, it is the way toward discovering the historical backdrop of response for the duration of the life expectancy of the dynamic loading like a seismic tremor ground acceleration record until the structure achieves a point of limit state. The dynamic loading comprises of applying an earth-tremor ground acceleration record of lateral loads to a model which catches the material non-linearity of a current or recently planned structure, and monotonically increasing those loads which differ with time so the peak response of the structure is assessed.

The "Loma Prieta(10/18/1989)" seismic tremor information (of greatness 6.93) is utilized as ground movement information for performing time history analysis. The records are characterized for the speeding up focuses concerning a time period interim of 0.005 second. The quickening record has units of m/s2 and the most important information focuses which are of the most noteworthy power are the first 5,000 acceleration data coordinates directions have been considered. Peer Ground Motion Data base is utilized for the tremor records for investigation. The Corralitos station (Record Sequence Number (RSN)-753) was approximately 6.9 km from the fault and is considered as a near fault earthquake.

6. Results and discussion

The following are the results obtained by carrying out the Non-linear Time History Analysis for different models. Subsequent discussions are made about the results based on torsion and other seismic parameters with respect to near fault and far fault regions consideration. The effects of base isolator, shear wall & bracings on the seismic parameters of asymmetrical buildings in near fault regions were also discussed.

6.1 Torsional Variation

The following table contains the results of the analysis carried out for the models as discussed earlier. The absolute values tabulated are for base torsion (mz). Torsional variation for non-linear dynamic analysis (Time history analysis) of five, ten and fifteen storey asymmetrical buildings is due to the effects of near fault & far fault ground motions.

6.2 Comparison of Torsion

Table 3 Base Torsion of Five Storey Buildings

Model (5-storey)	Torsion(k-Nm)	Torsion (k-Nm)
	NLTHY-X	NLTH-Y
M-1 Basic model (bm)	1542.471	1305
M-2 Shear wall (sw)	3560	4941
M-3 Base isolator (bi)	199.177	7.8402
M-4 Bracing (br)	2972.41	5065

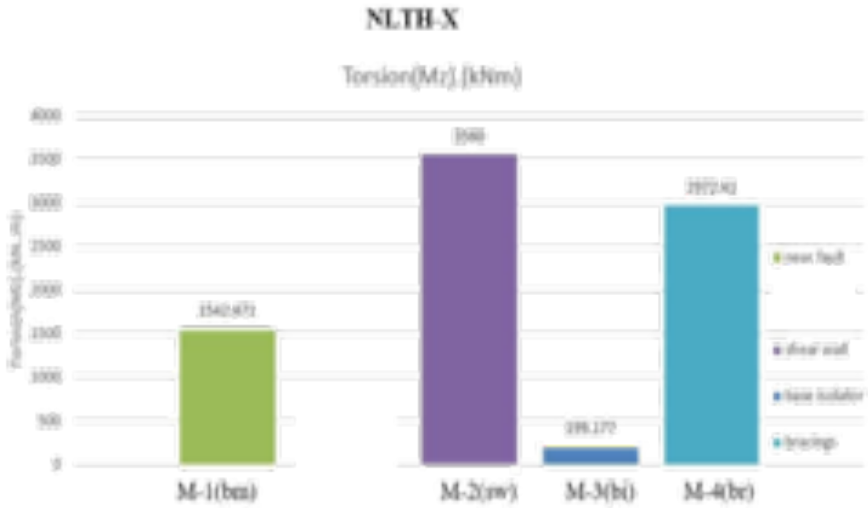

Fig 8 Variation of base torsion of 5 story building in X direction

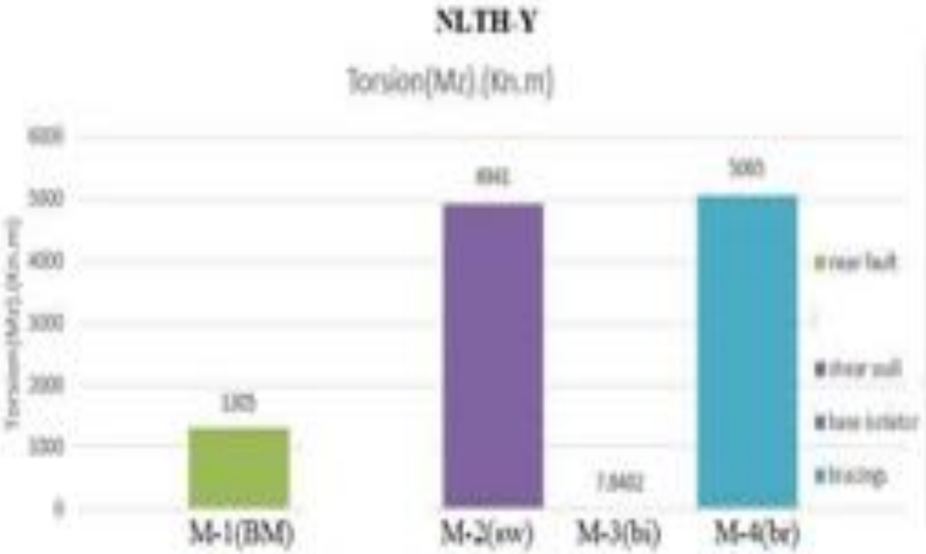

Fig 9 Variation of base torsion of 5 story building in Y direction

After performing Non-Linear Time History Analysis (NL-THA) in X-direction for the above models, from Fig. 8 the results showed that the variation of maximum base torsion (MZ) for five storey building was decreased by 87% in M-3(bi) and it was increased by 57% & 48% in M-2(sw) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions.

Similarly performing NL-THA in Y-direction, from Fig. 8 it was observed that the variation of maximum base torsion (MZ) for five storey building was decreased by 99% in M-3(bi) and it was increased by 74% & 74% in M-2(sw) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions.

Table 4 Base Torsion of Ten Storey Buildings

Model (10-storey)	**Torsion(k-Nm)**	**Torsion (k-Nm)**
	NLTHY-X	**NLTH-Y**
M-1 Basic model (bm)	1518	2019
M-2 Shear wall (sw)	5130.86	4532.79
M-3 Base isolator (bi)	385.55	67.638
M-4 Bracing (br)	2008.851	5387.329

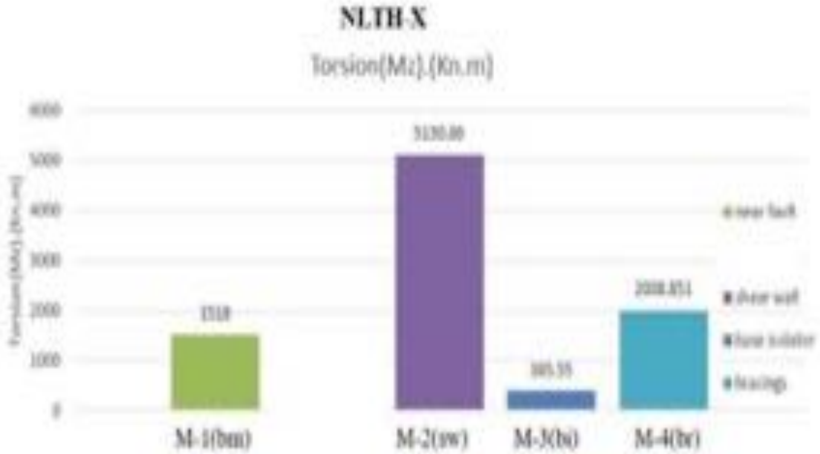

Fig 10 Variation of base torsion of 10 story building in X direction

Fig 11 Variation of base torsion of 10 story building in Y direction

After performing NL-THA in X-direction for the above models, from Fig. 10 the results showed that the variation of maximum base torsion (MZ) for ten storey building was decreased by 75% in M-3(bi) and it was increased by 70% & 24% in M-2(sw) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions.

Similarly performing NL-THA in Y-direction, from Fig. 11 it was observed that the variation of maximum base torsion (MZ) for ten storey building was decreased by 97% in M-3(bi) and it was increased by 55% & 63% in M-2(sw) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions.

Table 5 Base Torsion of 15 Storey Buildings

Model (15-storey)	**Torsion(k-Nm)**	**Torsion (k-Nm)**
	NLTHY-X	**NLTH-Y**
M-1 Basic model (bm)	1544	1822.322
M-2 Shear wall (sw)	5895.603	3532.979
M-3 Base isolator (bi)	327.8465	452.367
M-4 Bracing (br)	3853.598	4412

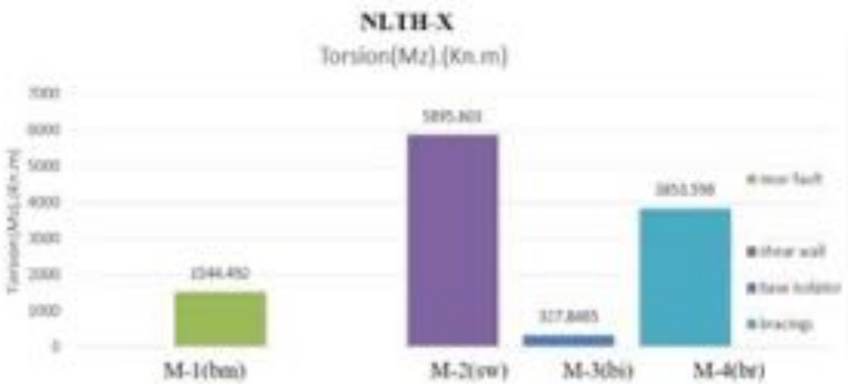

Fig 12 Variation of base torsion of 15 story building in X direction

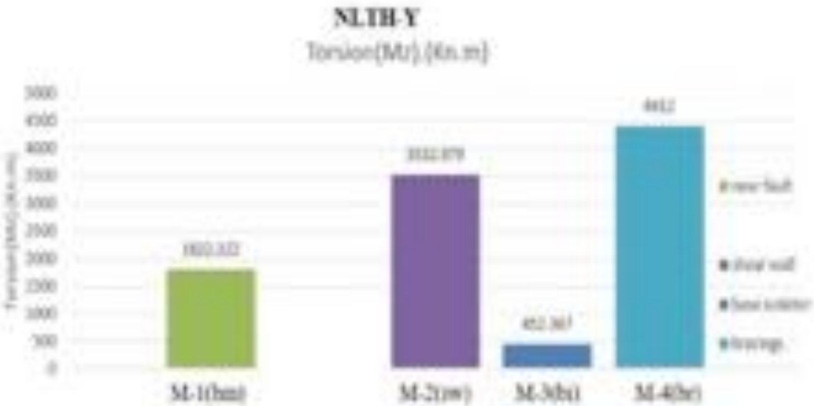

Fig 13 Variation of base torsion of 15 story building in Y direction

After performing NL-THA in X-direction for the above models, from Fig. 5.5 the results showed that the variation of maximum base torsion (MZ) for fifteen storey building was decreased by 79% in M-3(bi) and it was increased by 74% & 60% in M-2(sw) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions.

Similarly performing NL-THA in Y-direction, from Fig. 5.6 it was observed that the variation of maximum base torsion (MZ) for fifteen storey building was decreased by 75% in M-3(bi) and it was increased by 48% & 59% in M-2(sw) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions.

6.3 Base Shear

The following table contains the results of the analysis carried out for the models as discussed earlier. Base shear for non-linear dynamic analysis of five, ten and fifteen storey buildings.

6.3.1 Comparison of Base Shear

Table 6 Base Shear of Five Storey Buildings

Model (5-storey)	Base Shear (KN)	Base Shear (KN)
	NLTHY-X	NLTH-Y
M-1 Basic model (bm)	1051.644	556.714
M-2 Shear wall (sw)	2209.998	2399.797
M-3 Base isolator (bi)	162.5	3.957
M-4 Bracing (br)	1652.217	1283.226

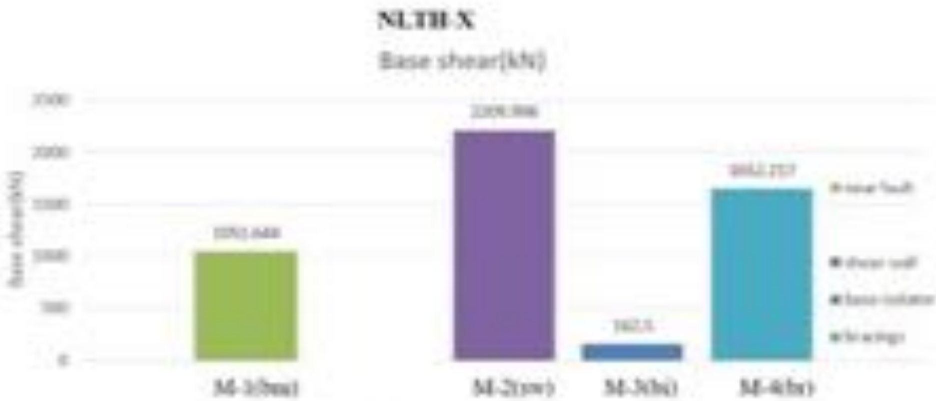

Fig 13 Variation of Base shear of 5 story building in x direction

Fig 14 Variation of Base shear of 5 story building in Y direction

Table 7 Base Shear of Ten Storey Buildings

Model (10-storey)	**Base Shear (KN)**	**Base Shear (KN)**
	NLTHY-X	**NLTH-Y**
M-1 Basic model (bm)	837.092	1027.784
M-2 Shear wall (sw)	2470.09	2105.585
M-3 Base isolator (bi)	284.998	33.5533
M-4 Bracing (br)	1107	995.933

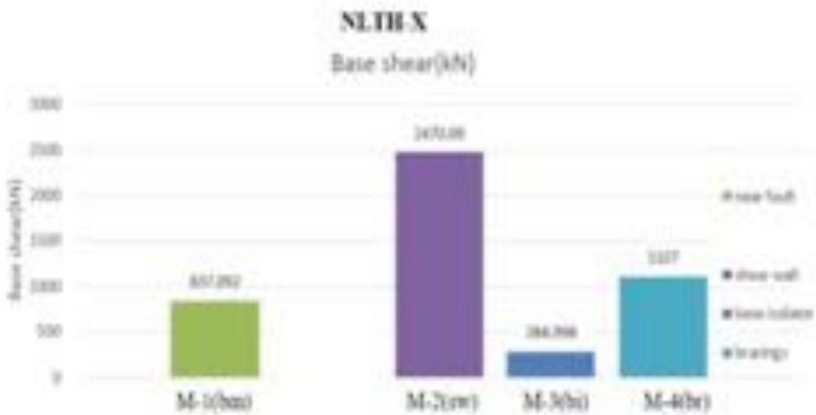

Fig 15 Variation of Base shear of 10 story building in X direction

Fig 16 Variation of Base shear of 10 story building in Y direction

After performing NL-THA in X-direction for the above models, from Fig. 15 the results showed that the variation of Base shear for ten storey building was decreased by 66% in M-3(bi) and it was increased by 66% & 24% in M-2(sw) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions.

Similarly performing NL-THA in Y-direction, from Fig. 16 it was observed that the variation of Base shear for ten storey building was decreased by 97% in M-3(bi) and it was increased by 51% & 3% in M-2(sw) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions.

Table 8 Base Shear of 15 Storey Buildings

Model (15-storey)	**Base Shear (KN)**	**Base Shear (KN)**
	NLTHY-X	**NLTH-Y**
M-1 Basic model (bm)	924.782	820.181
M-2 Shear wall (sw)	2596.749	1807
M-3 Base isolator (bi)	217.1805	207.863
M-4 Bracing (br)	1625.388	1241

Fig 16 Variation of Base shear of 15 story building in X direction

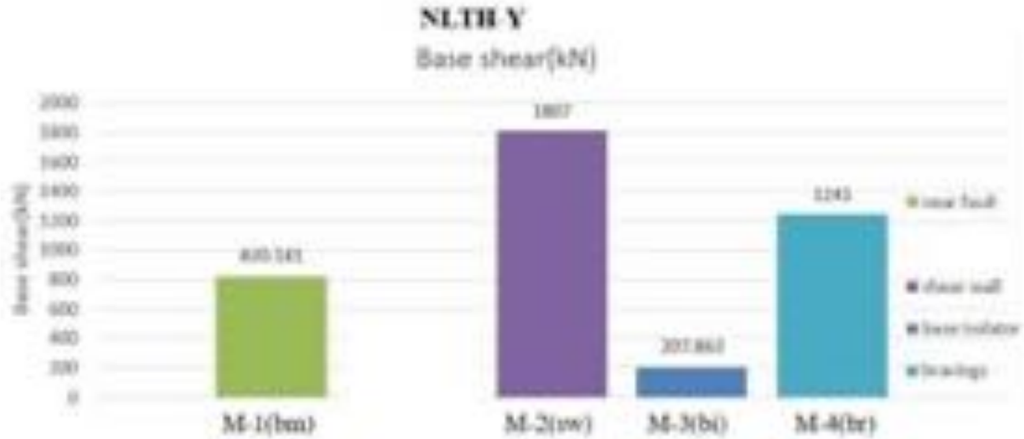

Fig 17 Variation of Base shear of 15 story building in Y direction

After performing NL-THA in X-direction for the above models, from Fig. 5.11 the results showed that the variation of Base shear for fifteen storey building was decreased by 77% in M-3(bi) and it was increased by 64% & 43% in M-2(sw) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions.

Similarly performing NL-THA in Y-direction, from Fig. 5.12 it was observed that the variation of Base shear for fifteen storey building was decreased by 75% in M-3(bi) and it was increased by 55% & 34% in M-2(sw) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions.

6.4 Maximum Storey Drift

Table 8 Maximum story drift of 5 Storey Buildings

Model (5-story)	Story drift (mm)	Story drift(mm)
	NLTHY-X	NLTH-Y
M-1 Basic model (bm)	13.227	11.65
M-2 Shear wall (sw)	1.329	6.872
M-3 Base isolator (bi)	12.386	8.27
M-4 Bracing (br)	9.864	10.4581

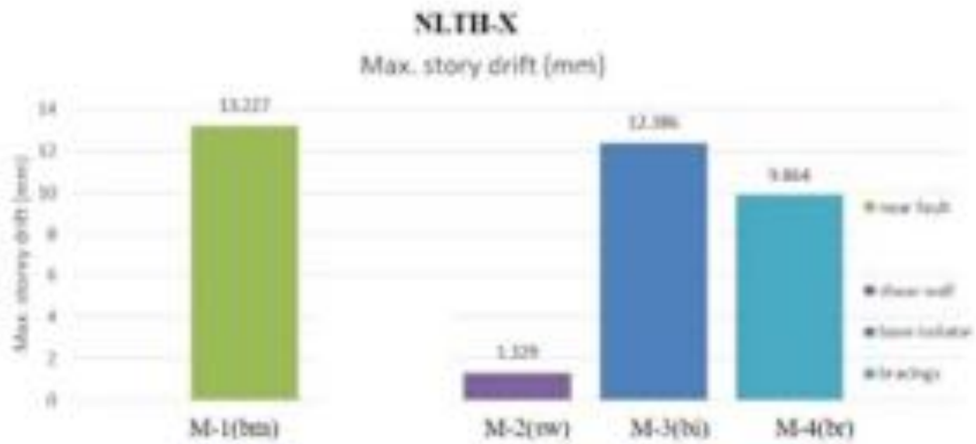

Fig 18 Variation of max story drift of 5 story building in X direction

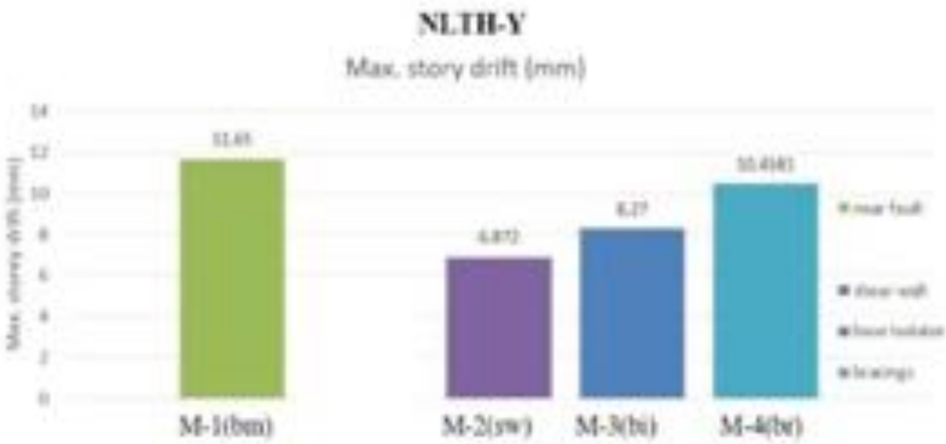

Fig 19 Variation of max story drift of 5 story building in Y direction

After performing NL-THA in X-direction for the above models, from Fig. 5.19 the results showed that the variation of Maximum storey drift for five storey building was decreased by 90%, 6% & 25% in M-2(sw), M-3(bi) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions.

Similarly performing NL-THA in Y-direction for the above models, from Fig. 5.20 the results showed that the variation of Maximum storey drift for five storey building was decreased by 41%, 29% & 10% in M-2(sw), M-3(bi) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions.

Table 9 Maximum story drift of 10 Storey Buildings

Model (10-story)	**Story drift (mm)**	**Story drift(mm)**
	NLTHY-X	**NLTH-Y**
M-1 Basic model (bm)	16.93	21.165
M-2 Shear wall (sw)	1.023	14.49
M-3 Base isolator (bi)	14.262	8.297
M-4 Bracing (br)	12.353	17.153

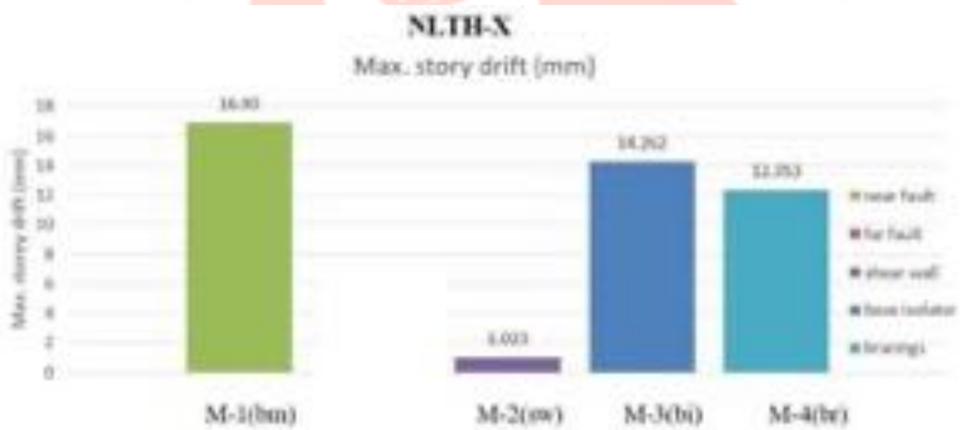

Fig 20 Variation of max story drift of 10 story building in X direction

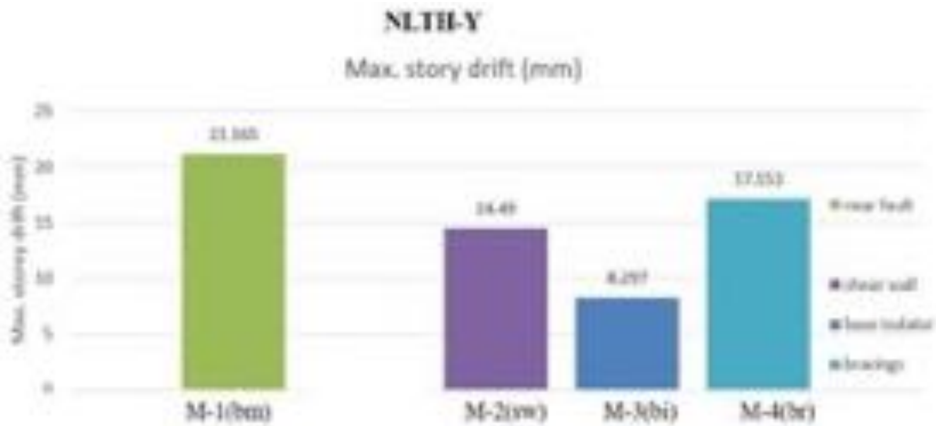

Fig 21 Variation of max story drift of 10 story building in Y direction

After performing NL-THA in X-direction for the above models, from Fig. 5.21 the results showed that the variation of Maximum storey drift for ten storey building was decreased by 94%, 16% & 27% in M-2(sw), M-3(bi) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions.

Similarly performing NL-THA in Y-direction for the above models, from Fig. 5.22 the results showed that the variation of Maximum storey drift for ten storey building was decreased by 32%, 61% & 20% in M-2(sw), M-3(bi) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions

Table 10 Maximum story drift of 15 Storey Buildings

Model (15-story)	Story drift (mm)	Story drift(mm)
	NLTHY-X	NLTH-Y
M-1 Basic model (bm)	21.683	20.042
M-2 Shear wall (sw)	13.507	20.715
M-3 Base isolator (bi)	13.431	13.71
M-4 Bracing (br)	19.452	20.833

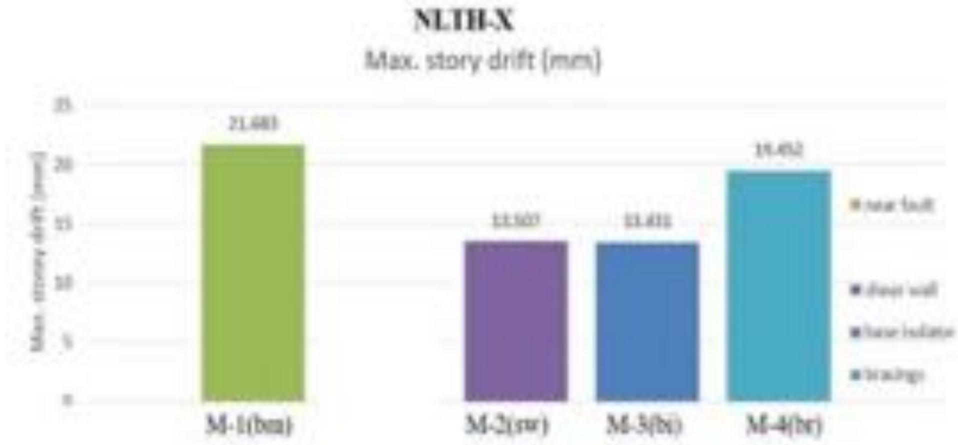

Fig 22 Variation of max story drift of 15 story building in X direction

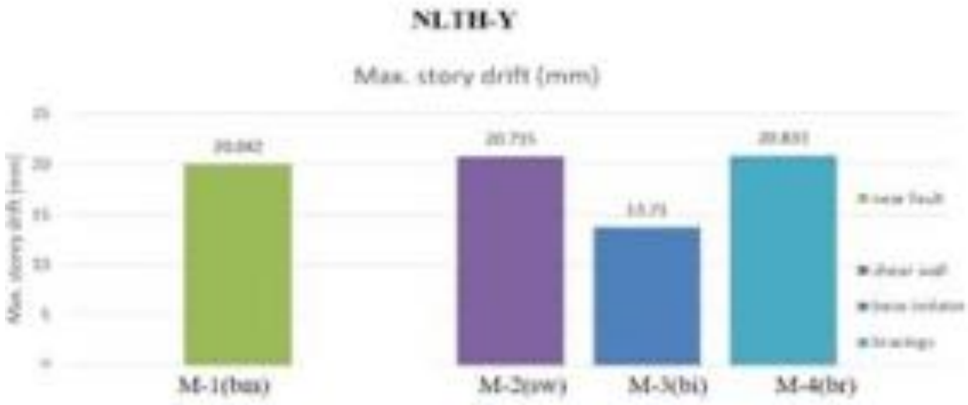

Fig 23 Variation of max story drift of 15 story building in Y direction

After performing NL-THA in X-direction for the above models, from Fig. 22the results showed that the variation of Maximum storey drift for fifteen storey building was decreased by 37%, 38% & 10% in M-2(sw), M-3(bi) & M-4(br) when compared with basic model M-1(bm) in near-fault ground motions.

Similarly performing NL-THA in Y-direction, from Fig.23 it was observed that the variation of Maximum storey drift for fifteen storey building was decreased by 32% in M-3(bi) and it was increased by 3% & 4% in M-2(sw) & M-4(br), when compared with basic model M-1(bm) in near-fault ground motions.

5.6 Discussions of Results

- It was found that the variation of maximum base torsion (MZ) between far fault ground motion and near fault ground motions is 88%, 75% and 87% for five, ten and fifteen storey models respectively.
- The maximum decrease in base torsion is by 87%, 75% and 79% in model-3 (i.e. model with base isolator) for five, ten and fifteen storey as the base isolator isolates the base of the structure from the strong ground movement.
- The maximum decrease in storey drift for 5 & 10 storey buildings was 90% & 94% in model-2 (i.e. model with shear walls)
- Base shear was greatly reduced by 85%, 66% & 77% in model-3 (i.e. model with base isolator) for five, ten and fifteen storey buildings.
- For fifteen storey buildings, all the seismic parameters like base shear, base torsion, & drift was greatly reduced by 77%, 79% & 38% in model-3 (i.e. model with base isolator) for five, ten and fifteen storey buildings.

6.2 Conclusions

- Asymmetric structures with bracing system, showed reduction in story drift up to 27%, whereas base shear and base torsion was increased up to 60%, when compared with basic model for five, ten & fifteen stories in near-fault ground motions. Suggesting the ineffectiveness of bracing system when compared with base isolators and shear walls.
- Structures with shear walls provided showed the highest reduction in storey drift up to 94% for five and ten storey models, whereas the base shear and base torsion was increased by 74%, when compared with basic model in near-fault ground motions. Hence shear walls are efficient in controlling storey displacement & storey drift for low-rise and medium-rise buildings
- For fifteen storey shear wall model drift was reduced up to 35%, whereas base shear and base torsion was increased up to 67%, when compared with basic model in near-fault ground motions. Hence the shear wall model for high-rise buildings, did not fare any better than the base isolator model.
- Structures with base isolators provided showed the highest reduction in base shear and base torsion up to 87% for five and ten storey models, whereas the storey drift was decreased marginally by 11% when compared with basic model in near-fault ground motions. However the fifteen storey base isolator model showed highest reduction in storey drift (up to 38%) and base shear, base torsion (up to 79%).
- Therefore by performing NLTHA, it can be demonstrated that for low-rise and medium-rise buildings, Shear walls are effective to control story drift, whereas base isolators are efficient devices to control base shear and base torsion. For high-rise buildings, only base isolators are excellent devices for controlling all the seismic parameters.

6.3 Scope for Further Study

As the various researchers are getting attracted towards the NLTHA, the scope for the further study under the particular topic can be stretched to wide horizons. Soil structure interaction has always attracted many researchers as an interesting topic for static procedures, the same can also be done for NLTHA using soil structure interaction in near faults regions. The effects of Stiffness and Strength Assignments could also be applied and NLTHA could be performed considering near faults regions. The seismic behaviour of the structure can also be observed by using seismic control device like tuned mass damper in near faults regions.

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