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# Seismic Evaluation of URM Building with Flexible Diaphragm using Nonlinear Static and Nonlinear Dynamic Analysis

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**Abstract:** In the rural area, most of the construction is made with unreinforced brick masonry structure. According to census 2011, about 85% of construction is made with brick masonry without any engineering supervision generally called the non-engineered building, brick masonry structure is easy to construct because of low cost and ease of availability of the material. In the past few years during the earthquake, it is observed that masonry building performed worst, results loss of lives as well as property, therefore demand of upgrading or retrofitting the structure is very important to save lives and loss of property, for this purpose seismic evaluation of this type of structure is necessary. But the seismic evaluation of this type of structure is still a challenge due to many reasons.

Present work investigates the seismic evaluation of the brick masonry structure with a flexible diaphragm, situated in the high seismic zone. Nonlinear analysis (static and dynamic) using SAP2000 is conducted on two types of the model (Brick masonry building without bond beams and brick masonry building with bond beams) and comparative study is carried out for the same models. IS 1893:2016 (part-1), FEMA 356 (2009), ASCE 7-16 and NEHRP guidelines are followed for Seismic evaluation of the building, results show the building with bond beams and column is performed better.

**Keywords:** Brick masonry building, Seismic evaluation, SAP2000, Flexible diaphragm, Pushover analysis, Time history analysis

## I. INTRODUCTION

Till the early age, most buildings were masonry constructions. Masonry covers a very wide range of materials, such as bricks, stones, blocks etc. joined with different types of mortars such as lime mortar, cement mortar etc. that exhibit different mechanical properties. Masonry buildings are not only widely used for housing construction not only in India but in many other counties of the world. It is also used as infill panels, partitions etc. in framed buildings, where it is subjected to forces from the displacement of the frame and inertia forces. The masonry construction are innumerable advantages such as thermal comfort, sound control, the possibility of addition and alteration after construction, less formwork, and inexpensive repair, use of locally available materials, need of less skilled labour etc. Masonry structure having a less seismic resistance capacity hence it is not suitable for the seismic prone area the reason behind that the failures of the structure in those areas are low strength of masonry and unskilled labour used for construction. In those areas, reinforced masonry may be used as a primary structural system and can be designed to resist earthquake forces or reinforced concrete and steel constructions can be used as a primary structural system to resist the earthquake force. Mostly masonry buildings are the non-engineered buildings because there is no consideration of the stability of the system under horizontal seismic forces. Generally, it is observed during an earthquake that the performance of existing masonry building is poor this lead to loss of life and property thus, there is a need to do the retrofitting of existing masonry building is not possible without study of the seismic behaviour, the present work deals with the study of the seismic behaviour of the conventional masonry building and masonry building with extra provision.

## II. LITERATURE REVIEW

The study of various research papers is done for this paper

Ali and Page (1988) presented a finite element model for brick masonry subjected to in-plane loading, the proposed model reproduces the nonlinear behaviour of masonry caused by the material nonlinearity and local failure. Nairain and Sinha (1989) conducted an experiment on prototype specimens and half-scale models to investigate the behaviour of brick masonry and developed the stress-strain curve. Kaushik et al. (2007) studied compressive stress-strain relationships for masonry were determined by testing 84 masonry prism specimens constructed using bricks from four different manufacturers and three mortar grades. Narayanan and Sirajuddin (2013) discussed the behaviour of the mechanical properties and non-linear behaviour of the brick

masonry three varieties of brick and three mix proportion of mortar were considered for experiments. Youldash (2014) performed linear time history was performed on the 3 models with two-story, six stories and twenty stories with regular and irregular RC on STAAD-Pro software. SAR (2014) evaluated the seismic vulnerability of un-reinforced masonry building using pushover analysis. Sharma et al. (2016a) investigated the seismic evaluation of unreinforced masonry (URM) walls when subjected to lateral load. Sharma et al. (2016b) investigated the seismic evaluation of unreinforced masonry (URM) walls when subjected to lateral load using the performance-based analysis proposed by FEMA-356 (2000) and results were compared with that of a modified analysis proposed by other researchers.

### III. BUILDING MODELING

A two-story brick URM building is modelled in SAP2000. The building has a 250 mm thick wall for main lateral force resisting element. It has a flexible roof diaphragm, which represents one of the typical building types in India. In the present study of a masonry wall, the homogeneous modeling approach is applied. In the homogeneous modeling approach, the test results and analytical curve suggested by Kaushik et al. (2007) are adopted. The mesh size 32x32 is considered for the analysis.

Table I  
Properties Of The Masonry

PROPERTIES OF THE MASONRY	
Masonry Condition	Fair
Wall thickness	250mm
Compressive Strength	2.5 Mpa
Modulus of Elasticity ( $E_m$ )	1375 Mpa
Modulus of rigidity ( $G_m$ )	592.672 Mpa
Density of masonry ( $\rho$ )	20 kN/m <sup>3</sup>
Poisson's ratio	0.16
Type material	Isotropic
Coefficient of thermal expansion	$1.17 \times 10^{-5}$

Two types of brick masonry model are considered in the study

- 1) Model A brick model without bond beam with flexible diaphragm an opening in door and window with a flexible diaphragm
- 2) Model B brick model with bond beams at diaphragm level, lintel level and sill level with flexible diaphragm an opening in door and window with a flexible diaphragm. Also, reinforcements are provided along the edges and at the door opening. The building is provided with RCC element designed as per IS 4326-1993. The mesh size of wall 32x32 is considered as shown in Figure 1. The reinforcement details are given in Table 2

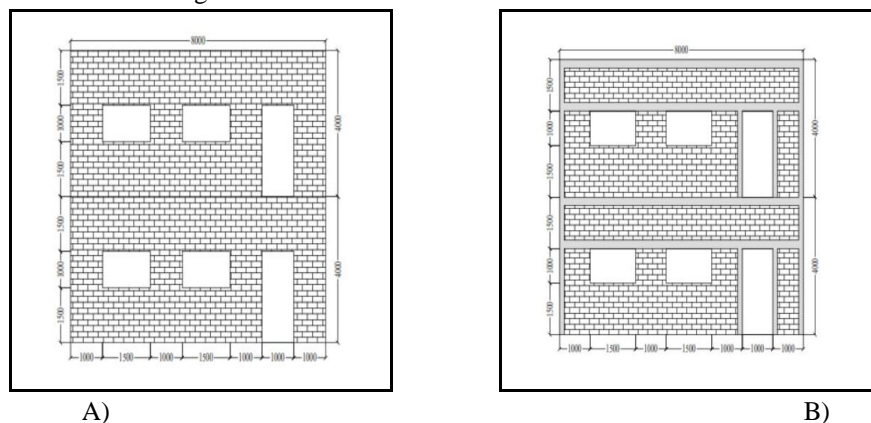


Fig. 1 Model of two-story building with and without a beam



TABLE II  
The Reinforcement Details in MODEL B (masonry building with bond beam)

Levels	Member	Size	Reinforcement detailing
Diaphragm	Concrete Beam	250 mm X 150 mm	12mm#2nos. at top and bottom
Lintel	Concrete Beam	250 mm X 150 mm	12mm#2nos. at top and bottom
Sill	Concrete Beam	250 mm X 250 mm	12mm#2nos. at top and bottom
Edge and door opening	Beam Masonry pier	250 mm X 250 mm	10mm#4 nos.

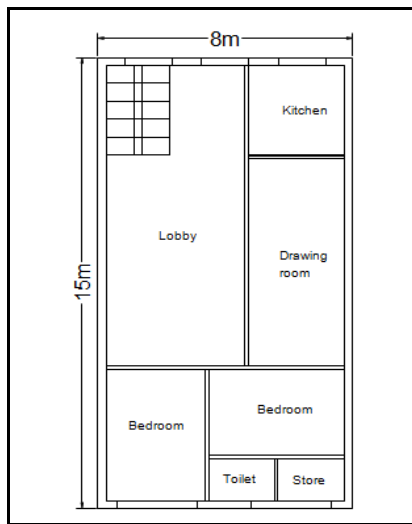


Fig. 2 Plan of a two-story building

#### A. Geometric Modelling of the Masonry Structure

In the present study, the wall having a maximum opening of the building is considered and modelled prepared in SAP2000 software. The thickness of the wall is 250mm. The dead load on the roof is 258.42kN & floor load is 506.82kN. Live load on floor is 60 kN and No live is considered on the roof. All the stresses (tensile and shear) are found within the permissible limit as per IS 1905:1987. In order to model the wall in SAP2000 shell area element is adopted, the shell element is a three or four node formulation that combines separate membrane and plate-bending behaviour. The shell element can be of two types homogenous and shell layered. In the present study, the layered shell area element is considered in order to obtain full shell behaviour to shown in Figure 3. The mesh size of wall 32x32 is considered as shown in Figure 3.

In the present study, two shear walls are provided in the building to carry the lateral load. So that each shear wall

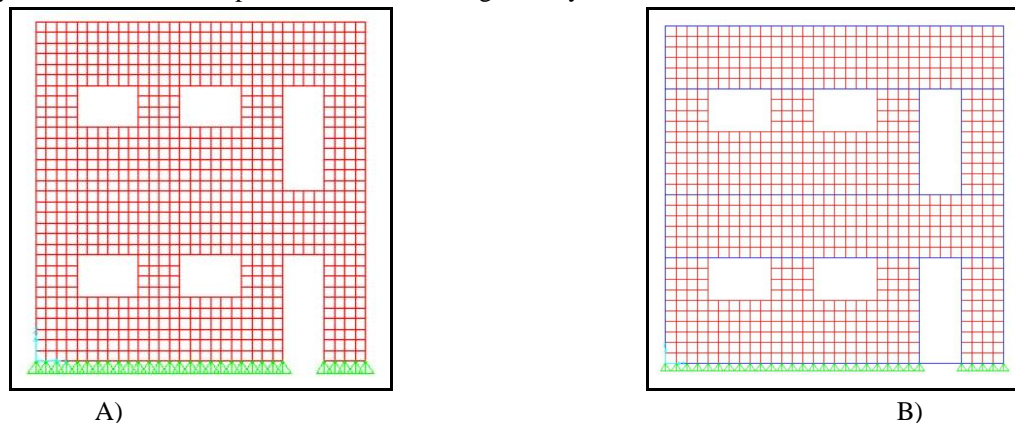


Fig. 3 Modelling of Masonry building without and with the bond beam in SAP2000

#### IV. PUSHOVER ANALYSIS

Pushover analysis is a nonlinear static procedure in which monotonically increasing lateral loads are applied on the building till the target displacement is achieved or structure is unable to resist that load and behaviour of the structure is checked.

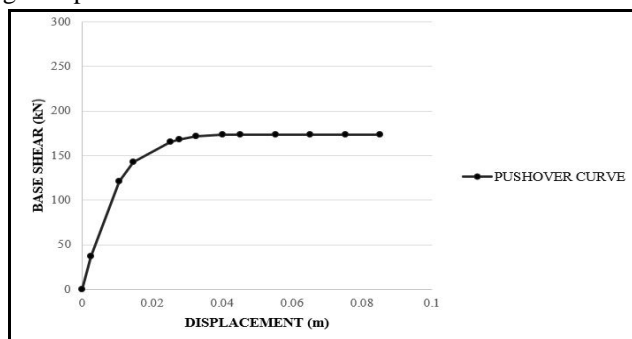


Fig. 4 Pushover Curve for Building without brick masonry model

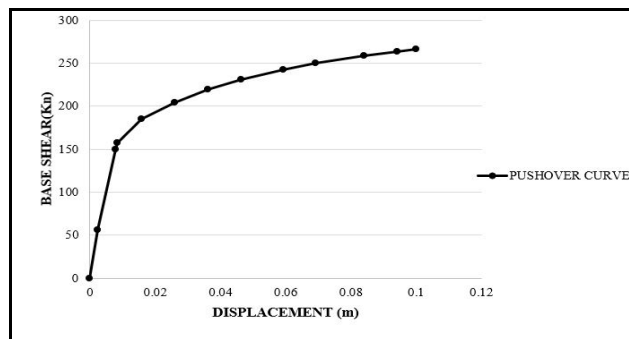


Fig. 5 Pushover Curve for Building without brick masonry model

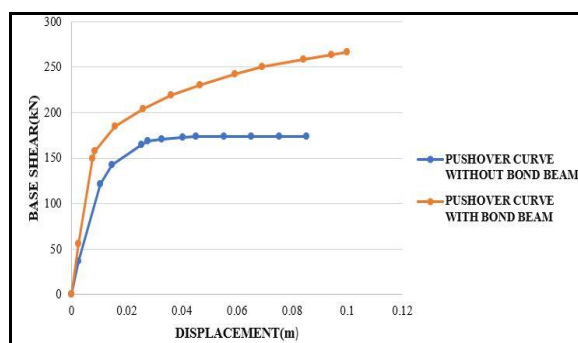


Fig. 6 Comparison of Pushover curve of both models

#### V. TIME HISTORY ANALYSIS

Time history analysis is a nonlinear dynamic procedure in which an actual or artificial ground motion records are applied to the structure and behaviour of the structure is checked.

##### A. Ground Motion

Ground motion is the movement of the earth's surface from blasts or earthquakes. It is generated by waves that are produced by sudden pressure at the explosive source or abrupt slip on a fault and go through the earth and along its surface. According to plate tectonic theory whole world is divided into six continental sized plates which are African, American, Antarctic, Australia-Indian, Euro-Asian, and Pacific plate, 90% of the earthquake are due to plate system. To calculate an earthquake response of the earthquake ground motion is used as input and for the record, this type of accelerations seismograph is used and the signal which is recorded by seismograph known as seismograms. The ground motion has sufficient strength to affect the environment, people and structures called strong ground motion. It has six components is a form of three rotation and three transitions but rotations are in very small amount which may be neglected. The maximum value of the ground motion is absolute ground motion and generally known as peak ground accelerations (PGA).

##### B. Ground Motion Selection

For analysis of a structure, considering 7 different accelerograms, which are qualified the criteria of ASCE 7-16. Earthquake ground motion record is downloaded from the PEER (Pacific Earthquake Engineering Research Centre). To get an actual response of the, for selecting the ground motion record IS 1893:2016 response spectrum is used as Target response spectra. According to NEHRP 2009 guideline the ground motion is scaled overall ground motions, of the 5% damped response spectra for the suite of motions is not less than the  $MCE_R$  response spectrum for the site for periods ranging from  $0.2T_n$  to  $1.5T_n$  where  $T$  is the natural period of the structure in the fundamental mode for the direction of response being analysed.

TABLE III  
Time History Data For Analysis

EARTHQUAKE NAME (STATION NAME)	COUNTRY	YEAR OF EARTHQUAKE	MAGNITUDE	PGA (G)	TIME STEP FOR RESPONSE COMPUTATION (s)	DENOTED BY
SAN FERNANDO (PACOIMA DAM)	U.S.A.	1971	6.61	0.116	0.010	TH-1
CHI-CHI (TCU068)	TAIWAN	1999	7.62	0.129	0.005	TH-2
CHI-CHI (TCU129)	TAIWAN	1999	7.62	0.136	0.005	TH-3
NIIGATA (NIG019)	JAPAN	2004	6.63	0.136	0.010	TH-4
DUZCE (IRIGM 496)	TURKEY	1999	7.14	0.075	0.040	TH-5
DARFIELD (TPLC)	NEW ZEALAND	2010	7.00	0.106	0.005	TH-6
NORTHRIDGE (PARDEE SCE)	U.S.A.	1994	6.69	0.169	0.005	TH-7

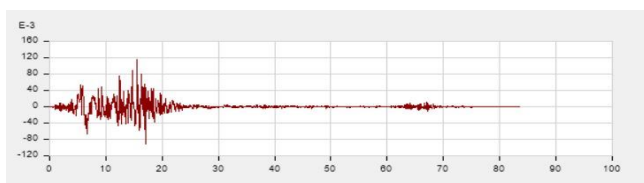


Fig. 7 Time history plot for San Fernando (TH-1)

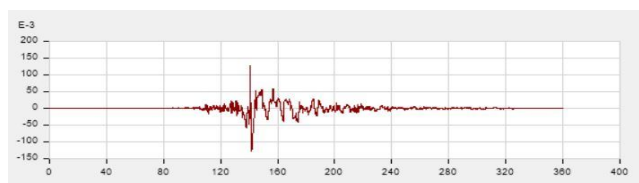


Fig. 8 Time history plot for Chi-Chi (TH-2)

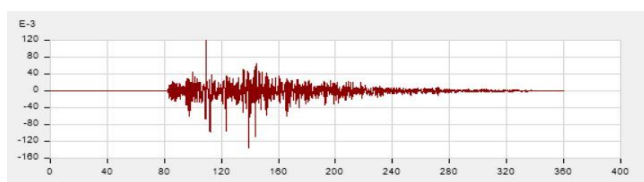


Fig. 9 Time history plot for Chi-Chi (TH-3)

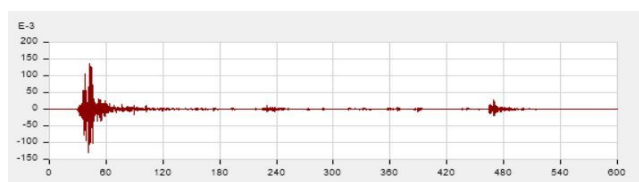


Fig. 10 Time history plot for Niigata (TH-4)

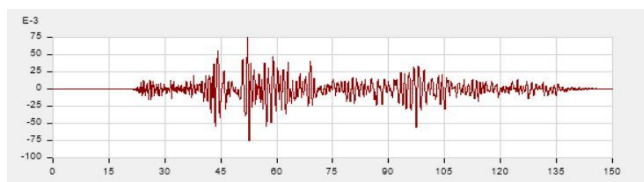


Fig. 11 Time history plot for Duzce (TH-5)

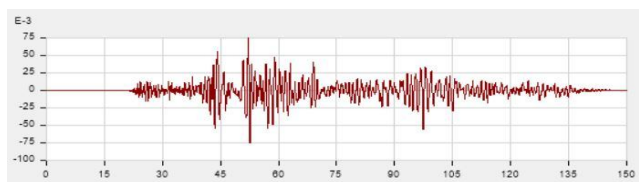


Fig. 12 Time history plot for Darfield (TH-6)

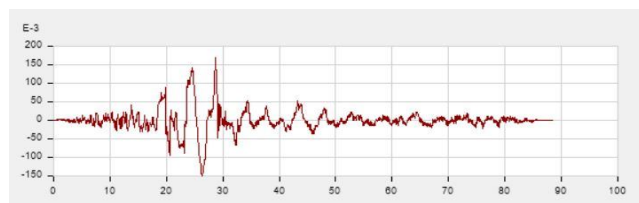


Fig. 13 Time history plot for Northridge-01 (TH-7)

## VI. RESULTS AND DISCUSSION

### A. Result of Pushover Analysis

On the basis of the analysis following points are observed

### B. On the basis of Shear Force

- 1) Model A has the capacity 173.698 kN for both DBE & MCE hazard level, the demands obtained from IS-1893:2016 (part-1) and FEMA 356 are 247.5kN and 173.698 for DBE and 495 kN and 173.698 kN for MCE respectively. Since demand is more than capacity in DBE and MCE hazard level.
- 2) Model B has the capacity of 266.4 kN for both DBE & MCE hazard level, the demands obtained from IS-1893:2016 (part-1) and FEMA 356 are 247.5 kN and 237.311 for DBE and 495 kN and 253.552 kN for MCE respectively Since demand is less than capacity in DBE & and more in MCE hazard level.

### C. On the basis of Displacement

- 1) For Model A achieved displacement from Pushover curve is 85.2 mm and obtain target displacement is 91 mm and 117 mm in DBE and MCE hazard level.
- 2) For Model B achieved displacement from Pushover curve is 100 mm and obtain target displacement is 54 mm and 75 mm in DBE and MCE hazard level.

### D. Result of Time History Analysis

TABLE IV  
Data Obtained From Time History Analysis For Model A

Serial No	Time History	PGA (g)	Base Shear (kN)	Overtuning Moment (kN-m)	Drift Ratio
1	TH-1	0.116	175.21	1176.7982	0.00033
2	TH-2	0.128	281.36	1671.8608	0.00043
3	TH-3	0.136	191.42	1288.2221	0.00035
4	TH-4	0.136	207.14	1217.6179	0.00030
5	TH-5	0.075	175.464	1088.3168	0.00028
6	TH-6	0.105	221.927	1434.1708	0.00038
7	TH-7	0.169	213.514	1169.7818	0.00028

TABLE V  
Data Obtained From Time History Analysis For Model B

Serial No	Time History	PGA (g)	Base Shear (kN)	Overtuning Moment (kN-m)	Drift Ratio
2	TH-1	0.116	190.799	1273.613	0.00031
3	TH-2	0.128	296.141	1737.5	0.00039
4	TH-3	0.136	219.202	1389.989	0.00033
5	TH-4	0.136	210.725	1253.779	0.00029
6	TH-5	0.075	197.658	1328.63	0.00031
7	TH-6	0.105	226.766	1419.889	0.00033
2	TH-7	0.169	227.518	1324.637	0.00030

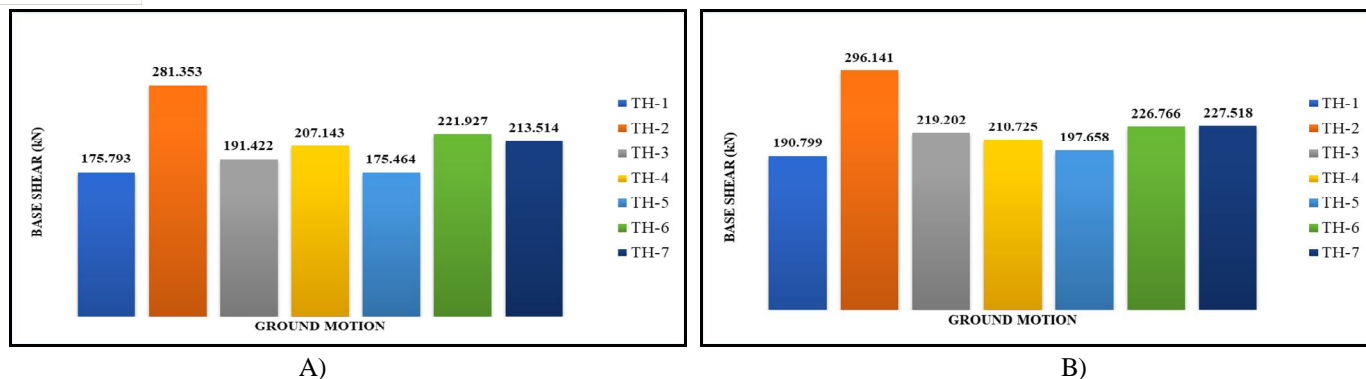


Fig. 14 Base Shear in model A and B in different Time History data

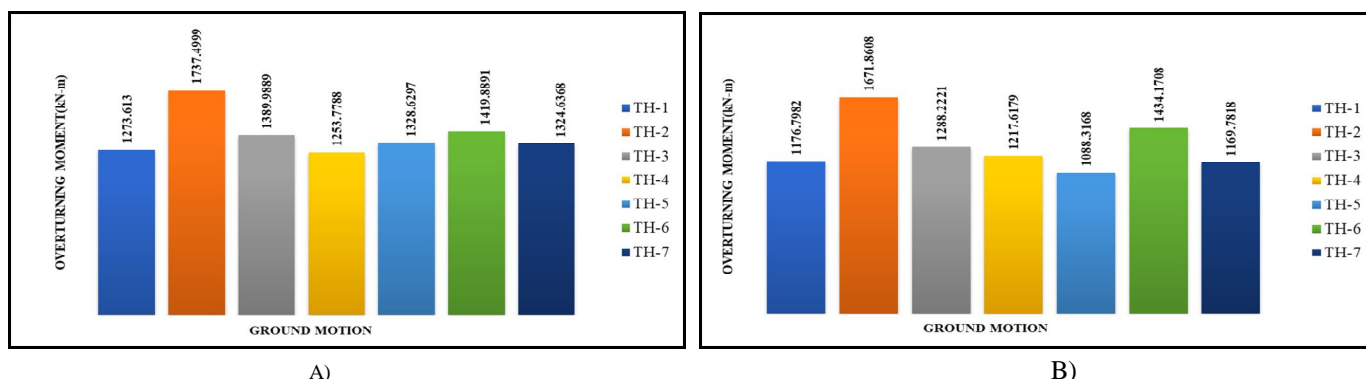


Fig. 15 Overturning Moment in model A and B in different Time History data

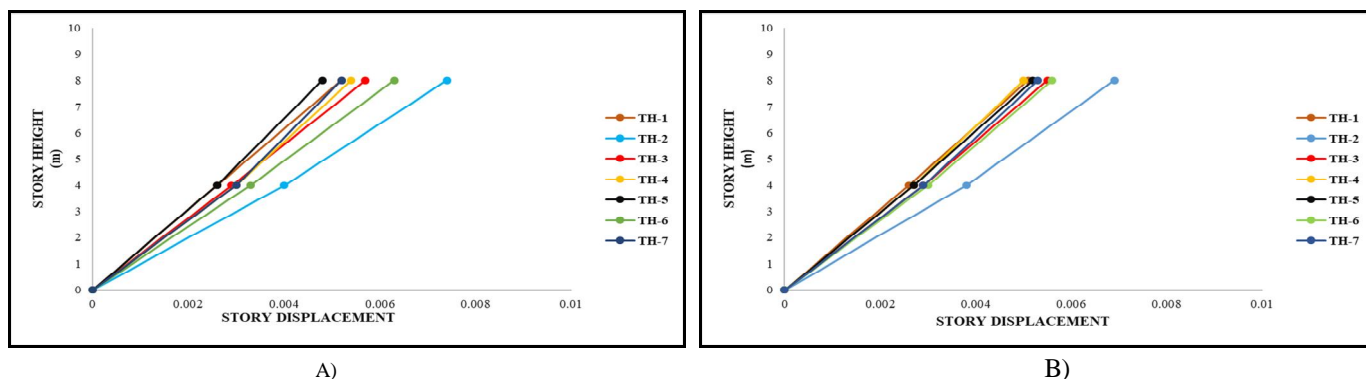


Fig. 16 Story Displacement in model A and B in different Time History data

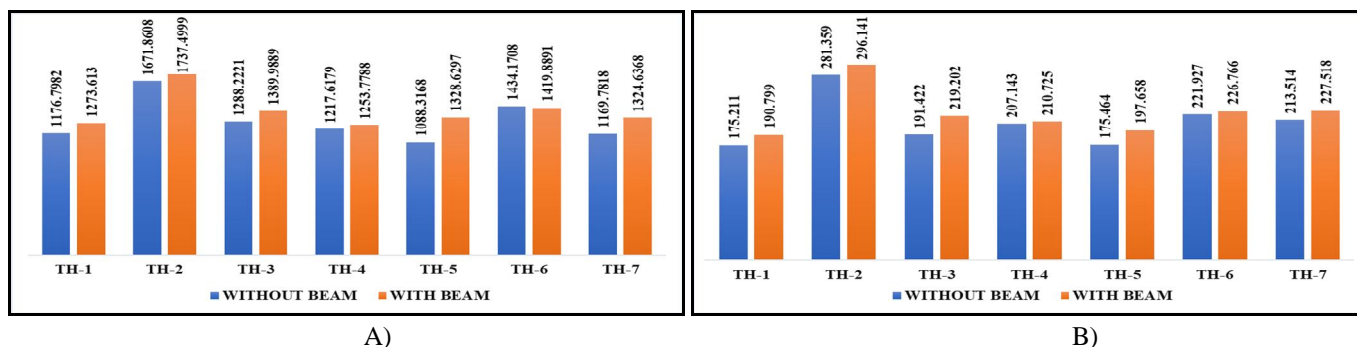


Fig. 16 Comparison of the data obtained from both model A and B



## VII. CONCLUSIONS

### A. Basis of the Nonlinear static Analysis

- 1) Demand is more than the capacity for the masonry building without bond beams.
- 2) Demand is less than the capacity for the masonry building with bond beams.

Hence building with bond beam perform better as compared to conventional building i.e. building without masonry.

### B. Basis Of The Nonlinear Dynamic Analysis

- 1) Base shear is maximum for the Chi-Chi TCU068 in both the cases with and without bond beam.
- 2) The overturning moment is maximum for Chi-Chi TCU068 in both the cases with and without bond beam.
- 3) Story displacement is more in model A (without bond beam) as compared to the Model B (with bond beam).
- 4) Story drift is maximum for model A which is without beam as compared to the model B with the bond beam.

On the basis of the story displacement observed in both the model, we can say that the model with bond beam displaced less as compare to model A (without bond beam).

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