INCREMENTAL DYNAMIC ANALYSIS OF CONTAINMENT REINFORCED MASONRY BUILDINGS USING EQUIVALENT FRAME MODEL

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Abstract : Provision of vertically reinforcing material close to the surface is termed as ‘containment reinforcement’. It is a novel technique employed for the enhancement of performance of masonry structure when subjected to earthquake. Plenty of literature is available on experimental and analytical investigations on dynamic and static behavior of containment reinforced masonry. In the present work the FEM model proposed in the literature has been modified to an equivalent frame model (EFM) which is subjected to seismic excitations. Parameters used in equivalent frame model have been evaluated using experimental database. Present work includes evaluation of limiting drift ratios for unreinforced masonry and containment reinforced masonry buildings through incremental dynamic analysis (IDA). Modeling of unreinforced masonry and containment reinforced masonry buildings is carried out in SAP2000. Because of the simplicity and computational efficiency of EFM, it can be used for development of fragility curves for containment reinforced masonry structures.

Keywords— Equivalent frame model, containment reinforcement, masonry models, incremental dynamic analysis.

I. INTRODUCTION

URM buildings are widely used by various developing countries like India .It has widely gained popularity due to easy availability, no super skill required and economical. URM buildings perform well when subjected to gravity loads.URM buildings are vulnerable when subjected to seismic excitations, which results in severe damage. So to improve the efficiency of the structure the reinforced masonry is commonly adopted .There are various methods of providing reinforcement .Providing reinforcement at mid thickness of structure may increase in-plane stiffness but will not contribute towards out of plane flexural strength.

An innovative way of reinforcing masonry was introduced by Jagdish et al.[1] which is known as ‘containment reinforcement’ .Several experiments and results have been carried out by Joshi [2] which includes shear, flexure behavior of containment reinforced masonry and, finite element analysis of two storey symmetric/asymmetric structure of containment reinforced masonry.The two ways suggested by Jagdish et al[1] for providing the reinforcement are:

a) The vertical reinforcement will be provided on the surface of masonry wall and it can be clenched within the position by horizontal ties at every/alternate bed joints. The role of horizontal ties can guarantee integral behavior of masonry and containment. The Exposed containment reinforcement must be protected against corrosion (Fig.1).

b) Laying of masonry unit can be done in such a way that a continuous vertical groove is created to accommodate the vertical reinforcement (Fig.2).

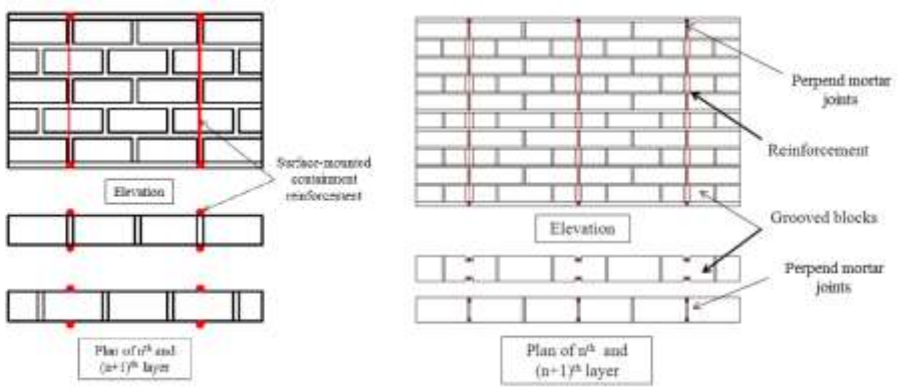

Fig.1 Surface mounted reinforcement and Fig.2 Near Surface mounted reinforcement.

In literature , the half scale containment reinforced masonry was tested on shake table and the results concluded that the role of containment reinforcement and reinforced concrete(RC) band at still and lintel level helped in improving seismic performance of the masonry structures. The FEM of containment reinforced masonry was carried out in abaqus software and validated using the experimentally obtained response by Joshi [2].Non-linear FEM analysis had been performed for symmetric as well as asymmetric masonry structures with containment reinforcement by Rao et al[10]. The results demonstrated that even when subjected to zone-V compatible time histories, a containment reinforced asymmetric masonry building was safe from collapse.

Equivalent frame technique has been used for analysis of two and three dimensional masonry structures to evaluate accuracy by Kappos et al[11]The results of equivalent frame model with offsets were close to finite element model.EFM was found to be effective for nonlinear analysis of masonry structures. Pasticier et al.[4] performed a pushover and incremental dynamic analysis of unreinforced masonry buildings using SAP2000 software. Nonlinear analysis for URM were carried out by Lagomarsino et al.[5] using equivalent frame model in TREMURI program. It was found to be simple to operate and took less computational efforts. Equivalent Frame model was used and hinges were inserted to predict the non-linear behaviour of masonry structure.

2. SCOPE AND OBJECTIVES

Current work adds to the existing literature about containment reinforced masonry structures.A modified equivalent frame model for a typical masonry structure has been developed in SAP2000.Incremental Dynamic Analysis(IDA) has been carried to assess the structural performance of containment reinforced masonry building and URM subjected to seismic loads.Equivalent frame model is subjected to various ground motion records.Each record of earthquake has been scaled to multiple levels of intensity.

Objectives considered in the present study are:-

(a)Developing the IDA curves for containment reinforced and unreinforced masonry buildings.

(b) To assess the effectiveness of containment reinforcement in reducing seismic risk.

3. MODEL DESCRIPTION

3.1 Geometry

Incremental dynamic analysis has been carried out for symmetric single -storey and two-storey masonry structures.The dimensions for single-storey masonry structures are 4.8m x2.4mx 3.2m and for two-storey masonry structures are 4.8m x2.4m x6.4m(Fig.3 and Fig.4).The thickness of reinforced cement concrete slab is considered as 0.12m.The various models considered for analysis are:

(a)Model 1:Single-storey unreinforced masonry building(URM).
(b)Model 2:Two-storey unreinforced masonry building(URM).
(c)Model 3:Single-storey containment reinforced masonry(CRM).
(c)Model 4:Two-storey containment reinforced masonry(CRM).

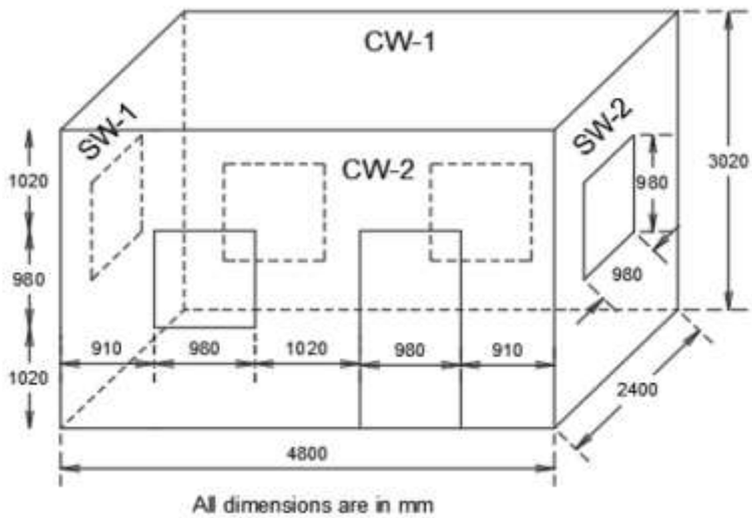

Fig.3 Single -Storey masonry model

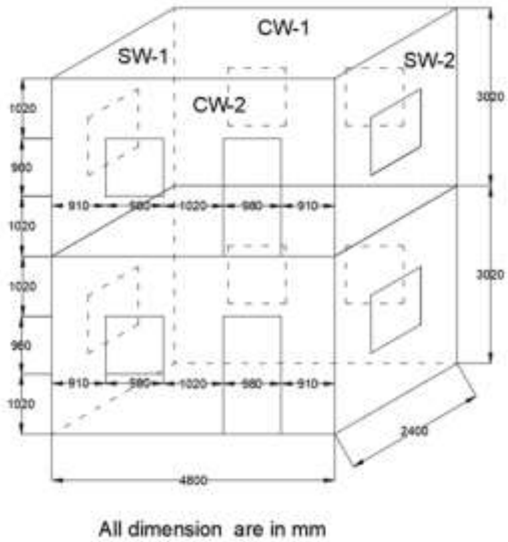

Fig.4.Two-Storey masonry model

3.2 Material Properties

The material properties have been referred from literature where results have already been validated experimentally by Joshi[3].

Table 1.Masonry parameters

Properties	Values
E(Young's modulus)	5490 N/mm^2
G(Shear modulus)	2288 N/mm^2
ϒ(unit weight)	1900 kg/m^3
f_m (design compression strength)	6.95N/mm^2
F_{vod}(design shear strength)	0.7N/mm^2
μ_f(friction coefficient)	0.5

Table 2.Steel parameters

Properties	Values
E(Young's modulus)	2 X10^5 N/mm^2
μ(poisson ratio)	0.3
Fy(Yield strength)	500 N/mm^2
Diameter of bar	8 mm

4. INCREMENTAL DYNAMIC ANALYSIS

In Incremental dynamic analysis the structure is subjected to real ground motion records each scaled to multiple levels of intensity. The peak ground acceleration (PGA) of earthquake record is scaled to cover the entire response of structure. Seven different earthquake ground motions were used for the analysis and their respective characteristics are shown in table 3.The procedure to carry out incremental dynamic analysis are:

a)Earthquake record scaled to PGA=0.1g and analysis is carried out to extract the result.

b) The PGA is increase gradually in increment of 0.1g and again analysis is carried out until and unless the collapse is reached.

c) After the collapse has occurred,the IDA curves has been carried out for earthquake record.

d) IDA curve is a plot of PGA versus maximum drift ratio .The PGA values are plotted on y-axis and maximum drift ratio values are plotted on x-axis.

Table 3: Characteristics of the earthquake ground motions

Earthquake	PGA (m/s^2)	Recording station	Bracketed duration(s)	Epicentral distance(kms)
Oroville	1.04	DWR Garage	0.86	7.03
N.Palm	0.67	Lake Mathews	0.5	79.23
Chamoli	3.66	IITR, Gopeshwar	10.06	17.3
Chichi	3.59	CWB:Taichung	12.59	24.7
NE India	3.31	IITR:Diphu	22.86	210.1
EL Centro	3.19	USGS:E1 Centro Array	29.34	12.2
Bishop Round Valley	0.84	McGee Creek surface	1.08	21.93

5. EQUIVALENT FRAME MODELLING

Modeling of the masonry wall as horizontal and vertical members just like beams and columns in reinforced concrete structure is know as equivalent frame modelling.In this type of modeling deformable elements(certain regions of walls where cracks have been developed during seismic excitations)are connected to rigid zone (the region in wall where no cracks have been developed).Two main structural components may be identified in the structure while considering the in-plane response which are piers and spandrel.Horizontal member is referred as spandrel and vertical member is known as pier.The Fig.5 represents the example of equivalent frame idealization which involves the following steps:-

a) Step 1-Identifying the horizontal distance between two openings where cracks are developed as Spandrels.
b) Step2- Identifying the vertical distance between two openings where cracks are developed as pier.
c) Step3- Identifying the rigid zone or area where no cracks are developed.
d) Last step is Equivalent frame.

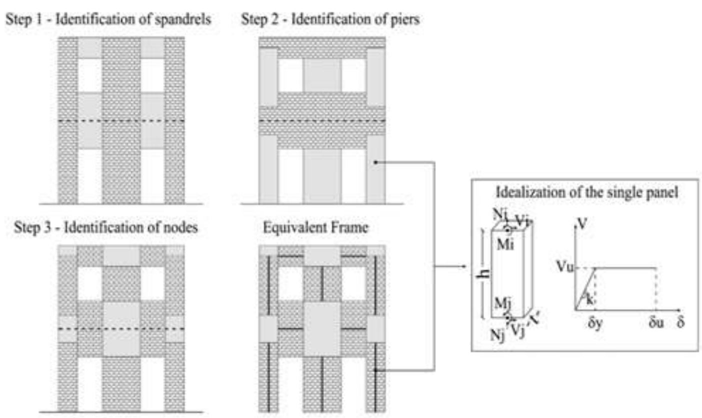

Fig.5 Equivalent Frame Idealization Lagomarsino et al. (2013)

The use of plastic hinge in static pushover analysis does not only predict the elastic limit but also predicts the inelastic limit of the structure .Modelling of the hinges is carried out depending upon the type of cracks formed and their location in structures.Modelling is carried out in SAP2000 software. Fig.6 represents the location of hinges in the frame according to the failure mechanism.

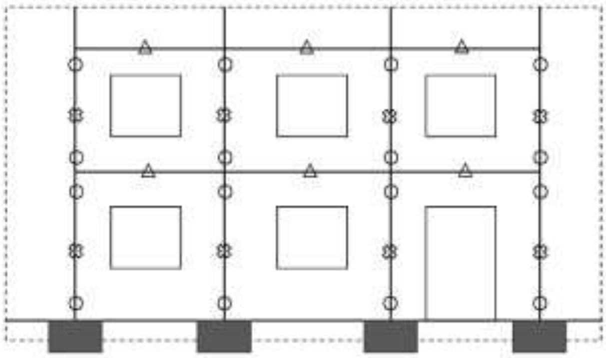

Fig.6 EFM with Hinges

Calculating the Effective height of vertical member (pier) to get the value of aspect ratio. The distance between two flexural hinges is known as effective height. There are two ways by which we can calculate the effective height of pier. The first way is called rigid offset in which pier and spandrel are consider fully rigid and hinges are assigned near the junction of spandrel and pier .The second way is introduced by Dolce[7] which says hinge should be provided at the interaction of 30 degree as mentioned in fig 7.(c)and(b).Rigid offset gives higher strength compared to dolce offset .

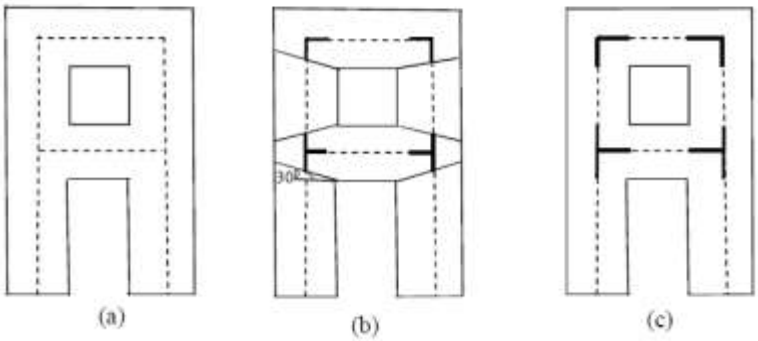

Fig.7(a)Equivalent Frame Model,(b)Equivalent Frame Model(Dolce),(c) Equivalent Frame Model (Rigid Offset)

In the present work ,hinges were provided to predict the structural behaviour accurately and to carry out pushover analysis .By providing hinges it can capture elastic as well as plastic behaviour of masonry structure.The non-linear links were also used for time-history analysis as they are able to define cyclic behaviour accurately.Hinge properties have been defined in terms of ultimate moment and ultimate shear.The strength of ultimate moment is given by equation (1) and shear capacity by equation (2) and (3) .On the basis of experiments the equations were given by Magnese et al.[9].

$$M_u = \frac{\sigma D^2 t}{2}\left(1 - \frac{\sigma}{k f_m}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .(1)$$

$$V_u^f = \frac{1.5 f_{vod} D t}{\varepsilon}\sqrt{\left(1 + \frac{\sigma}{1.5 f_{vod}}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$V_u^S = \frac{1.5 f_{vod} + \mu_f \frac{\sigma}{\gamma m}}{1 + \frac{3H}{\sigma D} f_{vod}} Dt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The ultimate rotation φ_u is taken as 0.8% of the effective height of pier minus the elastic deflection and the ultimate shear displacement δ_u is given by 0.4% of the effective height of pier minus the elastic deflection recommended by Pasticier et al.[4]Piers are modelled as elastoplastic with brittle type behaviour(Fig.8(b)and(c)) having one rocking hinge at the two ends of pier and one shear hinge at the mid height of pier.Only shear hinge is applied at the centre of spandrel with properties shown in Fig.8(d)and(e).

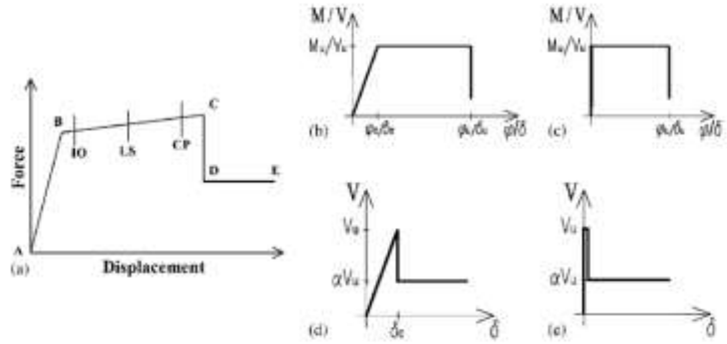

Fig 8.(a)force vs displacement curve of plastic hinge(SAP2000);(b) and (c) behaviour of pier and its plastic hinge representation; d) and (e) behaviour of spandrel and its plastic hinge representation.

5.1 Unreinforced Masonry Model

Single-storey and two-storey unreinforced masonry model from fig.3 and fig.4 has modified to equivalent frame model approach using SAP2000 shown in fig. 9 and fig.10. The hinge properties of moment and shear are assigned to piers and spandrel .Other properties are assigned to the model from Table1.

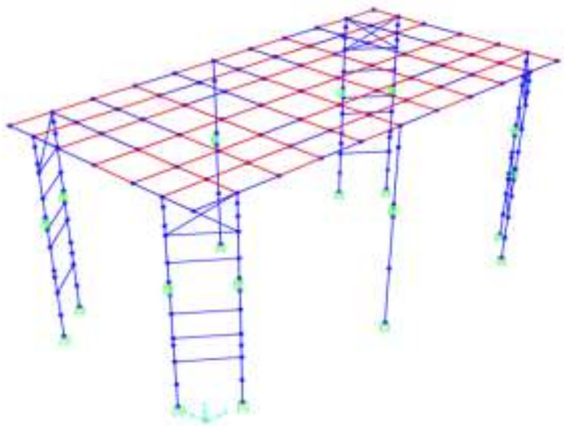

Fig.9. Model 1 Equivalent frame model of single-storey unreinforced masonry structures in SAP2000

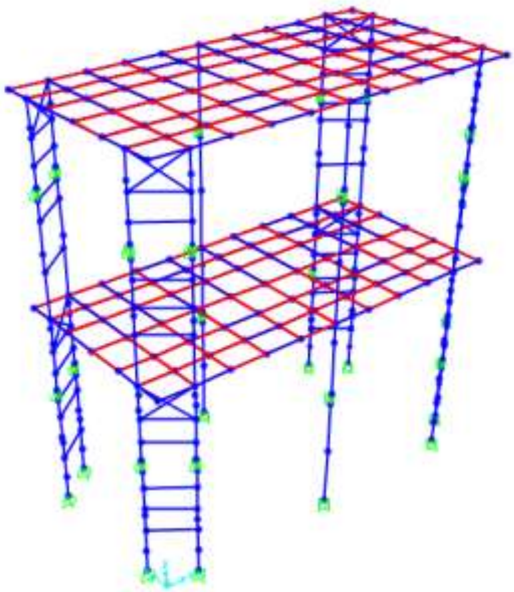

Fig.10. Model 2 Equivalent frame model of two-storey unreinforced masonry structures in SAP2000.

Micro model has been developed for existing single-storey and two-storey unreinforced masonry structures in Abaqus software by Mathada[3].Comparison of mode shapes and natural frequency of current equivalent frame model and micromodel has been shown in fig.11. and table 4. Comparison of IDA curves for single- storey and two-storey unreinforced masonry building has been shown in Fig.13 and Fig.14.The mode shape of two-storey unreinforced masonry structure is shown in fig.12.

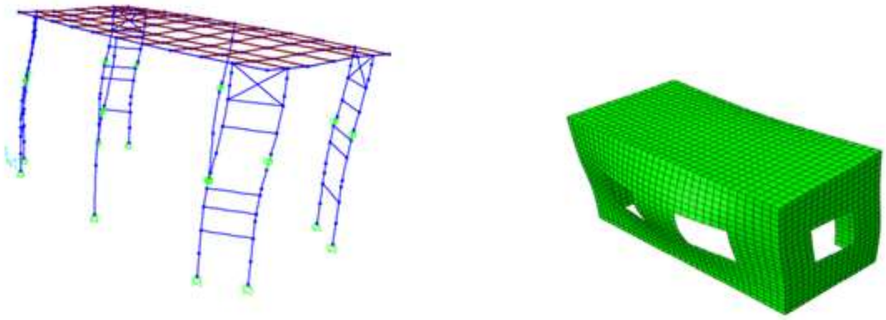

Fig.11 Comparison of Equivalent frame model(EFM) and micro model for first mode shape (single-storey unreinforced masonry)

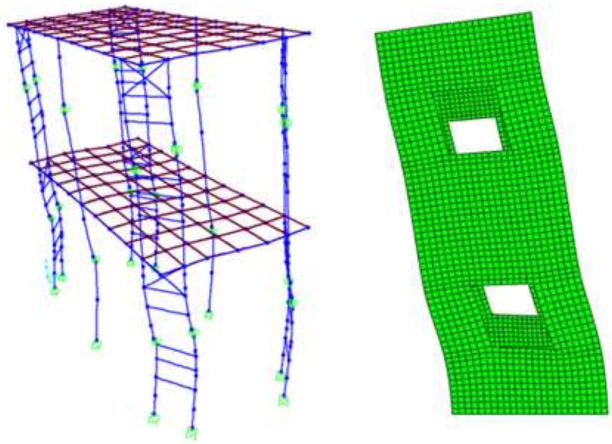

Fig.12 Comparison of Equivalent frame model(EFM) and micro model for first mode shape (two-storey unreinforced masonry)

Table 4 Natural Frequencies of Unreinforced Masonry Buildings

Modes	Natural Frequency of Single- storey in Hz (EFM)	Natural Frequency of two- storey in Hz (EFM)	Natural Frequency of Single- storey in Hz (Micro Model)	Natural Frequency of two- storey in Hz (Micromodel)	Mode shape
1	26.9	11.62	24.88	8.8	Sway in the direction of shear wall

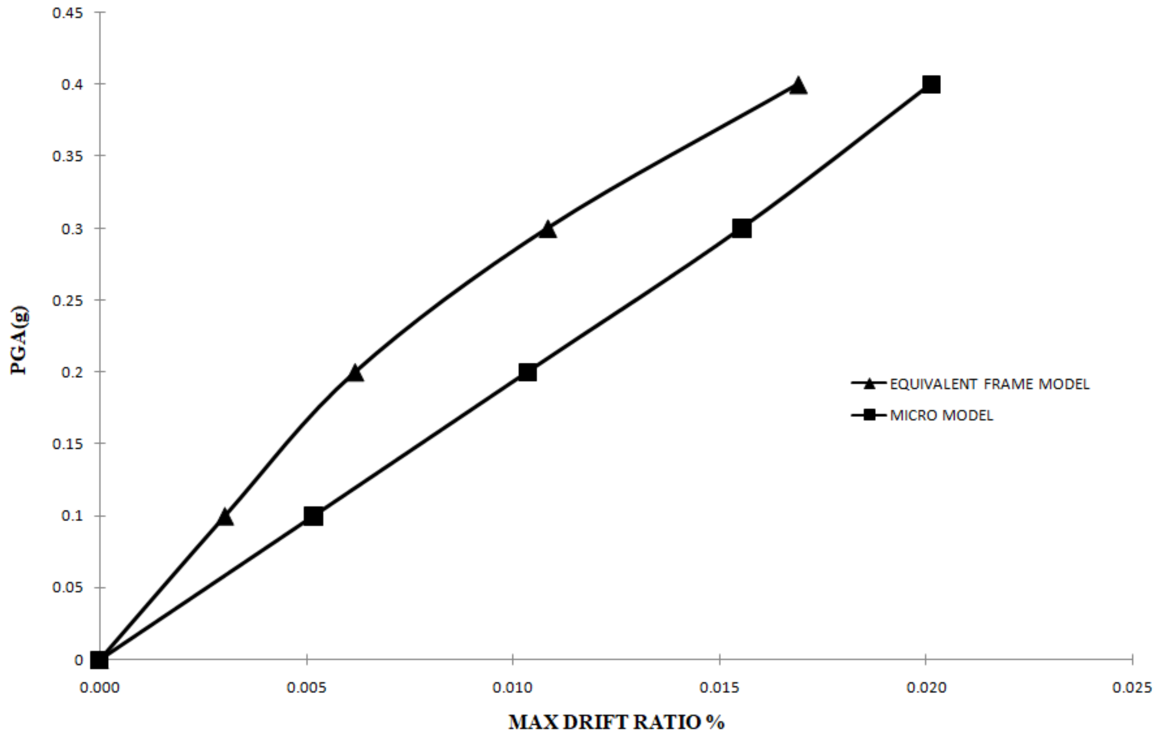

Fig.13. IDA curves for single-storey unreinforced masonry building(Oroville Earthquake)

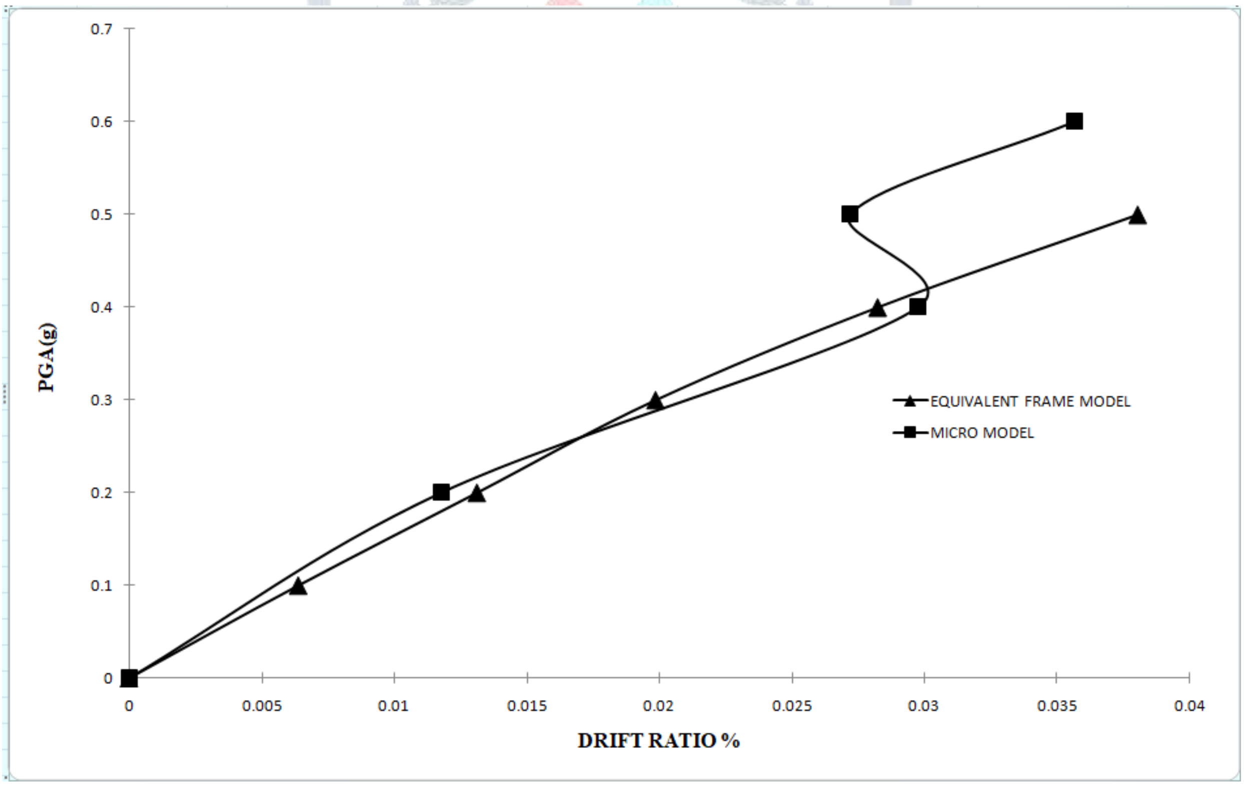

Fig.14. IDA curves for two-storey unreinforced masonry building(Oroville Earthquake)

5.2 Containment Reinforced Masonry Model

The Equivalent frame model for single-storey and two-storey containment reinforced masonry has been developed in SAP2000.The model looks similar as shown in fig.9 and fig.10 with reinforcement provided to it and changing the properties of hinges. The other properties have been obtained from table 1 and table 2. Comparison of IDA curve for single-storey containment reinforced masonry building has been shown in fig.15.

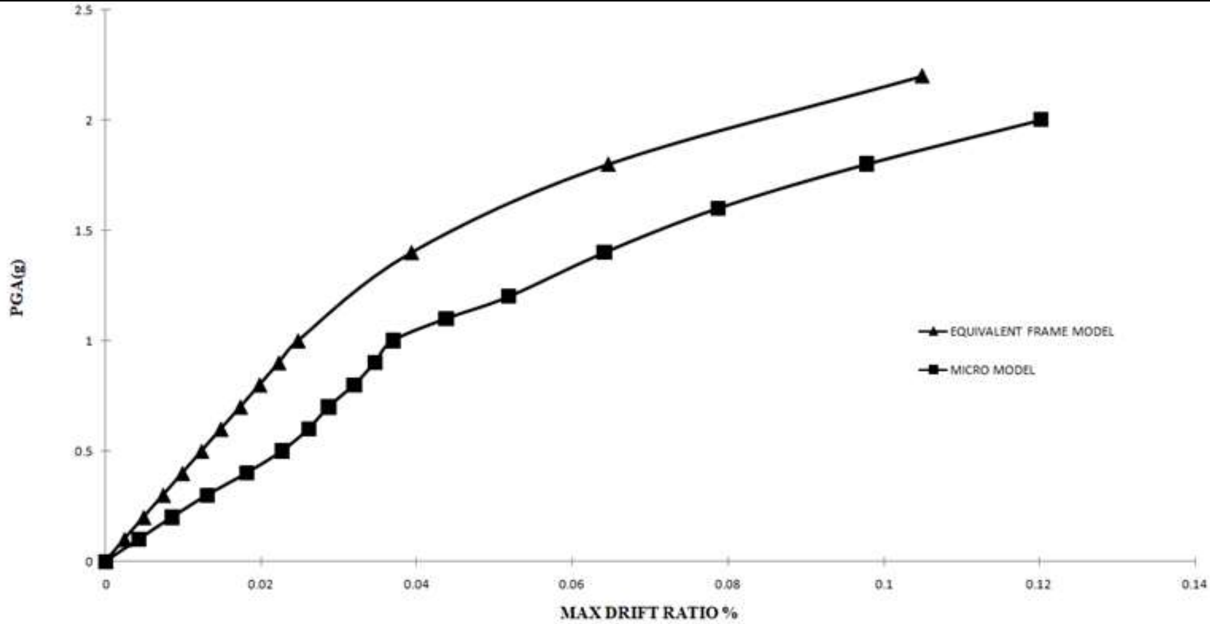

Fig.15. IDA curves for single-storey containment reinforced masonry building(Oroville Earthquake)

6 . RESULTS AND DISCUSSION

6.1 Results

The results of incremental dynamic analysis for unreinforced and containment reinforced single and two storey masonry buildings with rigid roof. Fig.16 and Fig.17 represents incremental dynamic analysis for single-storey and two-storey unreinforced masonry building. The IDA curves have been obtained for seven time histories and their parameters have been shown in table 3. Fig.18 and Fig.19 represents IDA curves for single-storey and two-storey containment reinforced masonry building.

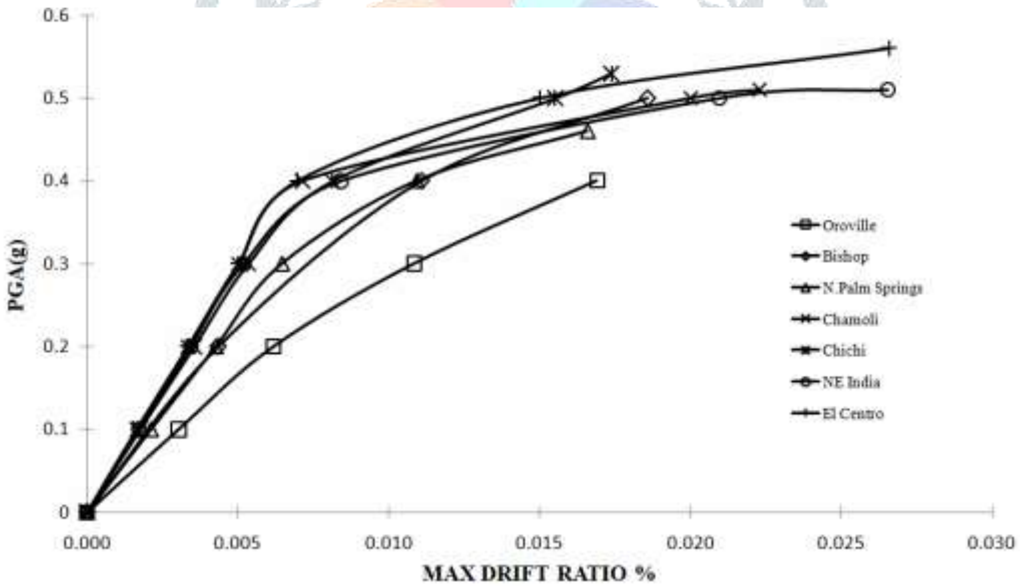

Fig.16. IDA curves for single-storey unreinforced masonry building (Model 1)

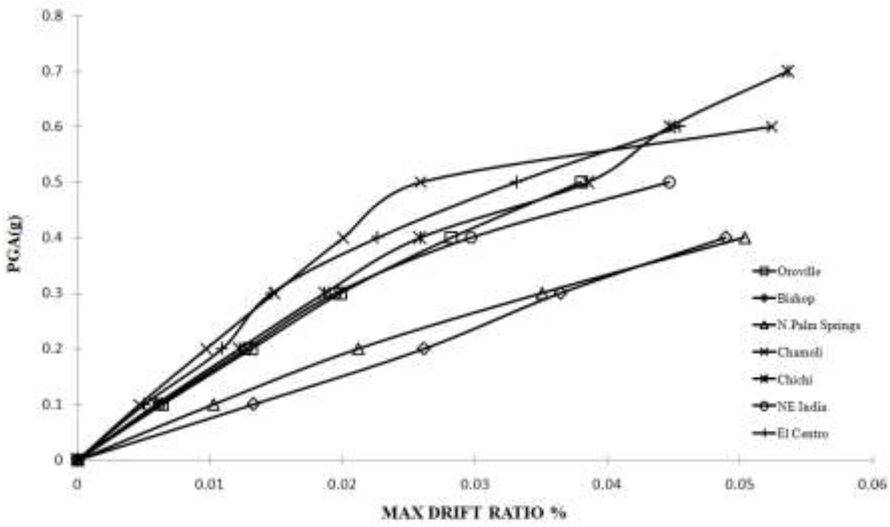

Fig.17. IDA curves for two-storey unreinforced masonry building (Model 2)

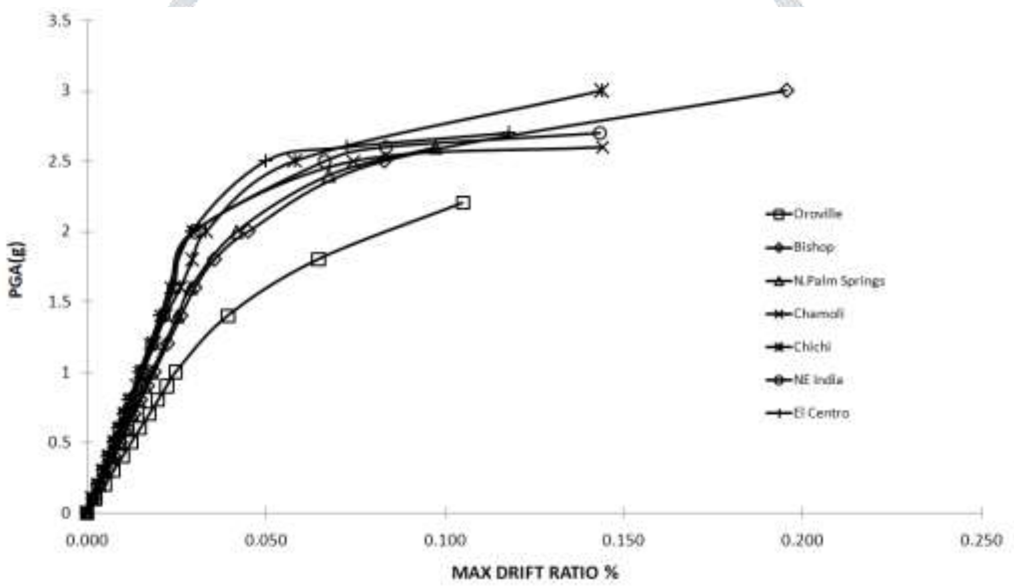

Fig.18. IDA curves for single-storey containment reinforced masonry building (Model 3)

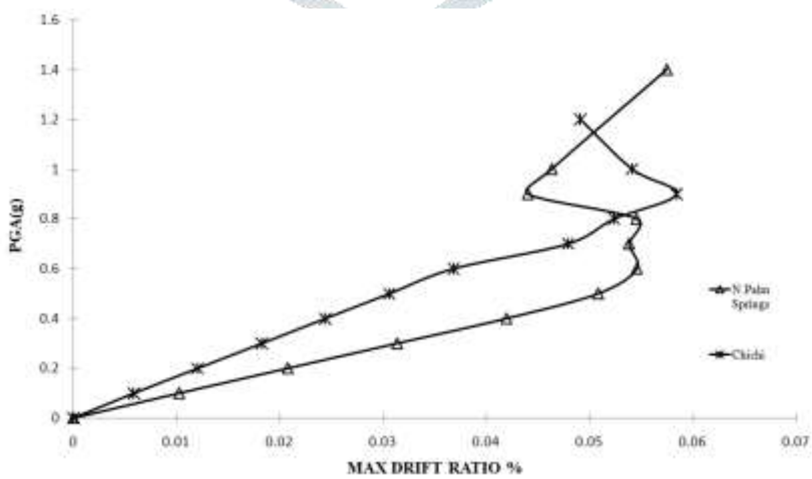

Fig.19. IDA curves for two-storey containment reinforced masonry building (Model 4)

6.2 Discussion

From the IDA curves shown in Fig.16 and Fig.18 of single-storey unreinforced masonry building and single-storey containment reinforced masonry building it is quite obvious that building reinforced with containment reinforcement sustain larger intensity earthquake and they exhibit lot of ductility before collapse.From Fig.17 and Fig.19 ,similar observation can be made about two-storey unreinforced masonry building and two-storey containment reinforced masonry building.Providing containment reinforcement doesn't only increase the capacity of masonry building to sustain higher intensity earthquake but also imparts significant ductility and therefore delays the collapse.

7 CONCLUSION

The following conclusions are evident from the present work:

a) Equivalent frame model significantly reduces the computational cost of seismic analysis of masonry building with or without containment reinforcement.

b) Equivalent frame model for containment reinforced and unreinforced masonry building predicts the drift ratios well in agreement with detailed finite element model in elastic as well as inelastic zone near collapse.

c) Provision of containment reinforcement not only increases the capacity of structure to withstand higher intensity earthquake in comparison with unreinforced masonry building but also adds significant amount of ductility thereby delaying the collapse.

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