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Analysis of Masonry Infill Wall Failure with Structural Fuse Sub-frame System Due To Lateral Loads

Saranya S[1], Arun H J [2]

[1]Mtech Student, Sree Narayana Institute of Technology, Adoor, Kerala, India
[2]Assistant Professor, Department of Civil Engineering, Sree Narayana Institute of Technology, Adoor, Kerala, India

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Abstract - *This paper presents the research work on the analysis of masonry infill wall failure with structural fuse due to lateral loads using ABAQUS Software. In-filled frame structures are commonly used in buildings, even in those located in seismically active regions. Masonry infill walls increase the stiffness of structural frames, and in general help to limit building deflection under lateral loads. In order to prevent damage to columns or infill walls and to minimize life-safety hazards during potentially damaging earthquakes, the use of gaps between the infill wall and the frame is one alternative. Brittle failure of the infill walls or frame elements is prevented by the introduction of a structural fuse mechanism in the gap provided, which isolates the infill wall from the frame under higher loads.*

Key words— Infill wall, stiffness, structural fuse, Concrete

1. INTRODUCTION

Masonry infill walls are a common building element found throughout the world. Infill walls constructed of various masonry materials are often used in both concrete and steel structures to infill the frame openings .This type of construction is particularly common in developing countries where masonry materials such as clay bricks, concrete masonry units, and hollow clay tiles are readily available. In many cases, infill walls are treated as architectural elements and their influence on the behavior of the structure is not considered. This design philosophy can lead to uneconomical design as well as unexpected behavior and even catastrophic collapse. It has been widely documented by many researchers that masonry infill walls significantly influence the in-plane behavior and response of structural frames.

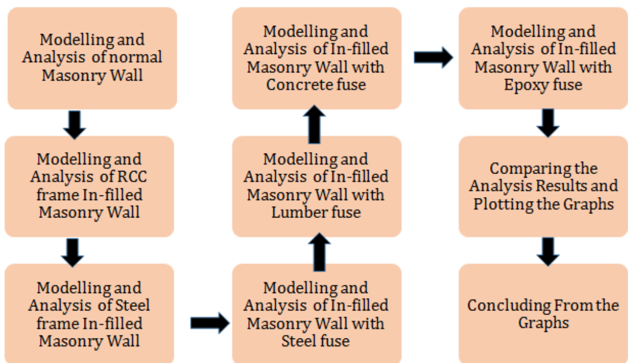
Masonry infill walls increase the stiffness of structural frames, and in general help to limit building deflection under lateral loads. Although this increase in stiffness is beneficial for limiting building drift during wind storms and minor to moderate earthquakes, it can have a negative impact on the performance of structures during major seismic events. A Seismic Infill Wall Isolator Subframe system is introduced in detail and several alternatives are developed for use in building frames with masonry infill walls in order to prevent damage to columns or infill walls and minimize life-safety hazards during potentially damaging earthquakes. This system, which consists of two vertical and one horizontal sandwiched light-gauge steel plates with "fuse" elements in the vertical members, is designed to allow infill wall-frame interaction under wind loading and minor to moderate earthquakes for reduced building drift but to disengage them under damaging events.

The main scope and objective of this study is as follows.

1. Failure of the masonry infill occur when there is irregularities in the building like soft storey, openings in undesirable locations, vertical irregularities etc.
2. In order to prevent this, a separation gap should be provided in between the infill and the frame.
3. In case of masonry and frame isolated using separation gap, there is a chance of instability.
4. In order to prevent this a new technique called Structural fuse system is inevitable
5. Finding out the performance of Structural Fuse Sub-Frame System in isolating masonry infill from structural frame

2. METHODOLOGY

The following flow chart shows the methodology of this project



3. STRUCTURAL FUSE

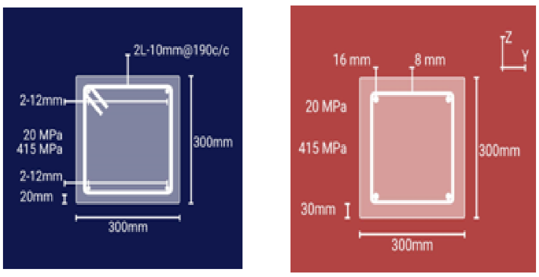
A new concept in the performance and design of masonry infill walls is the idea of a structural fuse system.

The structural fuse concept combines the two common design approaches by allowing masonry infill walls to be engaged with the bounding frame up to a predetermined level of lateral load. Brittle failure of the infill walls or frame elements is prevented by the introduction of a fuse mechanism, which isolates the infill material from the frame under higher loads. For lower levels of load, the strength and stiffness of the masonry material work compositely with the structural frame to limit lateral deflections. Under higher lateral loads, the infill panels are disengaged from the structure using the fuse mechanism, which prevents damage to the masonry walls and the formation of a frame failure mechanism. With this system, the structural frame can be designed to resist high lateral forces without the influence of the masonry material.

The fuse mechanism successfully isolated the infill panels from the frame, preventing damage to the brick masonry material. The fuse element is the key component of the structural fuse system. The purpose of the fuse is to serve as a link between the structural frame and the masonry infill walls and prevent damage to the infill material. This seismic isolation system allows for composite interaction between infill walls and the structural frame under normal lateral loads. Brittle failure of the infill walls or frame elements is prevented by the introduction of a fuse mechanism which isolates the infill material from the frame under higher loads.

4. MODELLING

For modelling of Concrete and steel frame, 8-node three-Dimensional element (C3D8R) was used. The average compressive strength of the concrete for samples is considered to be 25MPa. The modulus of elasticity of concrete based on the compressive strength is $5000\sqrt{f_{ck}}$. The Poisson ratio of Concrete is 0.2. The bottom of the columns and the infill wall were well anchored with the base. Binding constraint was applied on the wall-sub frame and sub frame-main frame interfaces.



RC Beam Section RC Column Section

Fig -1 : beam and column section

The bilinear ideal elastic-plastic model was adopted for the reinforcements. The type of element used for reinforcement was B31, which is a type of elements of a 3-dimensional beam with a linear function and the stirrups were modelled as a rectangular shape without bending performance, because in this modelling the bending effect of rebars are not considered.The embedded region was used to model interaction between concrete and rebar.

Simplified micro modeling is used for modeling masonry walls. For masonry materials, the element used is C3D8R. The plastic damage model of ABAQUS is used for the masonry. It should be noted that, the bricks were considered as a micro model which means that each brick must be assembled individually. For the masonry wall, the elastic modulus in compression was considered the same as that in tension. It assumes that the main two failure mechanisms are tensile cracking and compressive crushing of the material. To determine the interaction between bricks, two behaviours are used:

1. Adhesion in shear and tensile phases
2. Friction in the shear phase

To define adhesion behaviour, it is necessary to define the stiffness values of the mortar in the direction of vertical (tensile), the shear in the x direction in the general coordination system and shear in axis y direction. The variables related must be defined to the creation and evolution of failure in the adhesion phase.

In ABAQUS software each and every element of structural fuse like fuse holder, fuse element and connecting rod is modelled and finally combined together. The materials used for fuse elements are concrete, steel and lumber. For steel fuse two Steel disks are joined together by Epoxy Adhesive.

Sub-frame system consists of two vertical members and one horizontal member placed between infill wall and the structural frame. Sub-frame is made of two light gauge steel plates sandwiching EPS filler within it to provide sound insulation and fire-resistance. Upon Loading at breaking point, one steel disk slides away from other

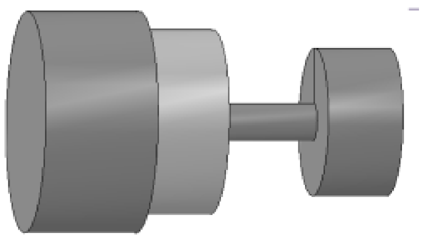


Fig- 2: Structural Fuse

The material properties used for modeling is shown in below table1.

TABLE -1: Material properties

Element		Density (kg/ m³)	Young's Modulus GPa	Poisson;s Ratio
Brick	Clay	2100	2.65	0.15
Rebar	HYSD 415	7850	20	0.26
frame	Concrete (M30)	2550	27.38	0.2
	Steel (Fe250)	7850	21.5	0.3
Fuse Element	Concrete (M30)	2550	27.38	0.2
	Steel (Fe250)	7850	21.5	0.3
	lumber	7000	13	0.27
Fuse holder	Cast iron	7300	21	0.25
Connecting rod	Cast iron	7300	21	0.25
Sub Frame	EPS	1100	3	0.3
	Light Gauge Steel Plate	7850	21.5	0.3

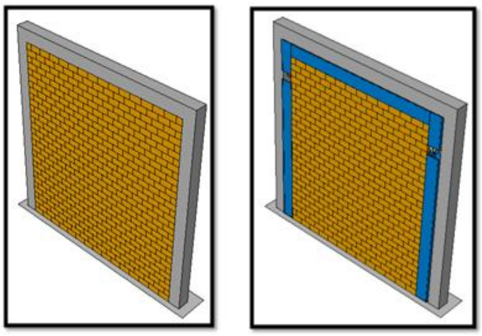


Fig. -3: RC frame without and with Fuse

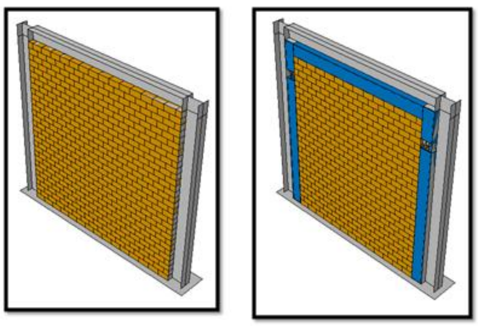


Fig. -4: Steel frame without and with Fuse

5. ANALYSIS

A Nonlinear finite element analysis was performed on the masonry in-filled frames under monotonic horizontal load. A vertical load and a monotonic horizontal load with displacement increment were applied at the left end of the top of the frame. FEM analysis has been carried out using ABAQUS software and analysis type was chosen dynamic implicit.

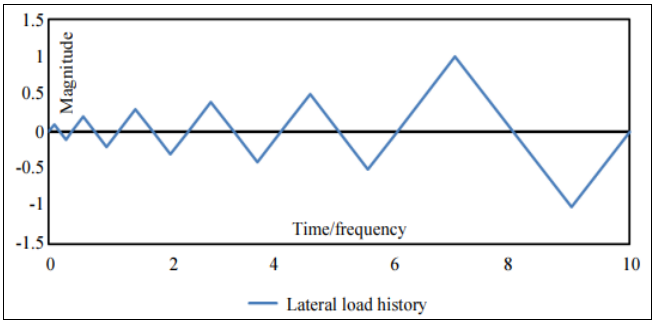


Chart -1: Incremental Load Plot

For accessing maximum capacity of the Fuse or the infill, best option is to use nonlinear analysis (static or dynamic) through the use of an implicit solver. For non linear problems there is a set of non linear equations. Here applying an incremental loading to break the problem into a solution of many linear problems and computing the result. The advantage of implicit solutions is their accuracy in terms of mechanical behaviour. Usually, an implicit algorithm is more accurate but takes longer time to complete.

5.1 MAXIMUM LATERAL FORCES

Steel Frame with Fuse system is most efficient in resisting lateral loads because when load acts on it, the steel connection will yield, there by dissipating energy. The frames with fuse system more resist lateral loads than frames without fuse system.

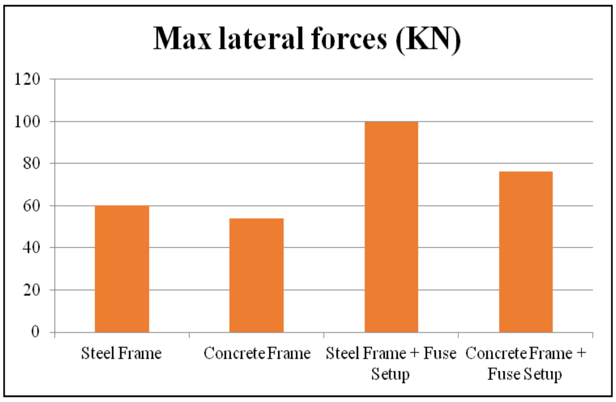


Chart-2: lateral load analysis

5.2 INITIAL STIFFNESS

The stiffness is maximum for concrete frame since the beam column connections are purely rigid. Stiffness also related to modulus of elasticity ($E_c > E_s$)

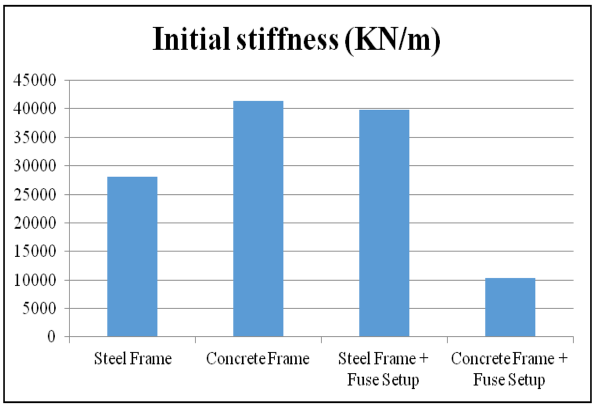


Chart-3: Intial stiffness comparison of various frame

5.3 MAXIMUM DRIFT

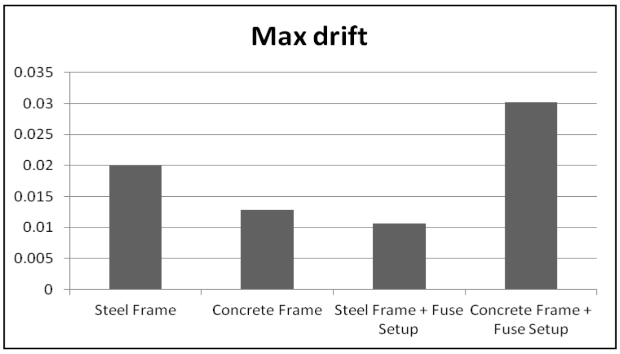


Chart-4 : maximum drift comparison graph

Steel Frame with Fuse system have least drift which implies there is less structural damage.

5.4 LOAD DEFLECTION CURVES

Load - deflection graph can be plotted with concrete, steel and lumber disk fuse with steel as well as concrete frame . analyse and comparing the results with these graphs infer that Masonry In-filled Steel Frame has more Load Bearing Capacity than Concrete Frame when Steel Structural Fuse installed.

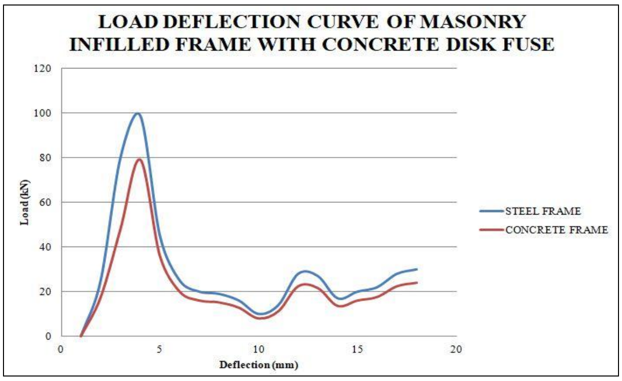


Chart-5: load -deflection graph with concrete disk fuse

Masonry In-filled Steel Frame has more Load Bearing Capacity than Concrete Frame when Concrete Structural Fuse installed.

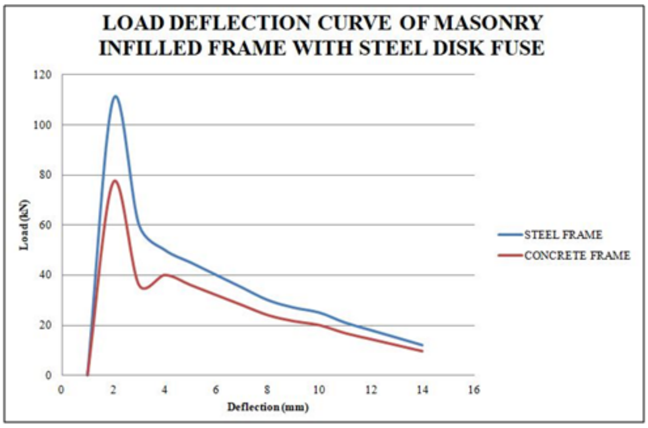


Chart-6: load – deflection curve with steel disk fuse

Masonry In-filled Steel Frame has more Load Bearing Capacity than Concrete Frame when Steel Structural Fuse installed. Masonry In-filled Steel Frame has more Load Bearing Capacity than Concrete Frame when Lumber Structural Fuse installed. And analyse the load carrying capacity of lumber disk specimens. Capacity of lumber disk increases with increase in thickness. When large fuse element used, the privacy purpose of masonry wall will be gone. So a fuse element of maximum 25mm thickness is good.

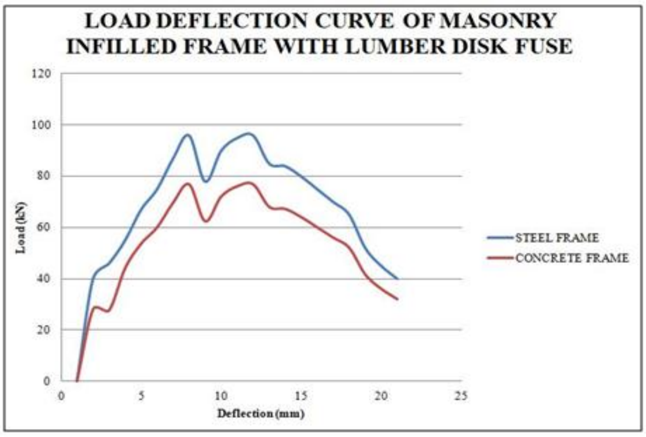


Chart-7: load – deflection curve of frame with lumber disk fuse

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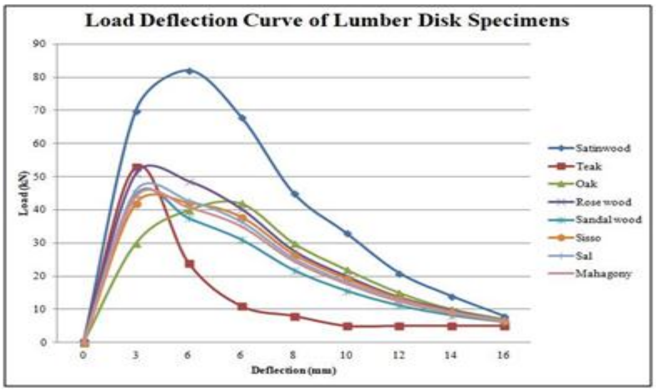

Chart-8: load deflection curve of lumber disk

For making Lumber Structural Fuse, Satinwood is the best material than teak, oak, rose wood etc.. since it has maximum stiffness and strength and deforms at a slower rate.

5.5 LOCATION OF FUSE ELEMENT

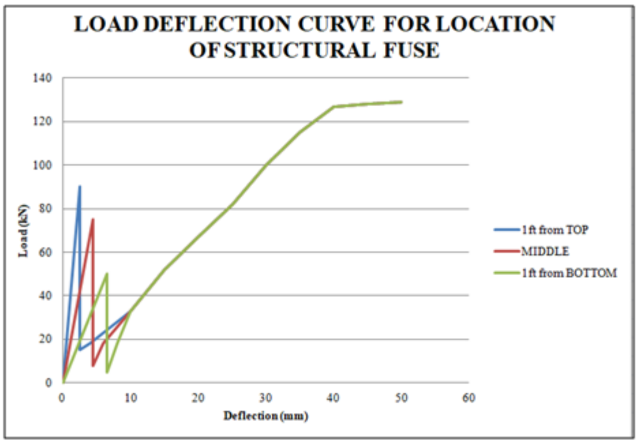

Chart- 9: load -deflection curve for location of fuse element

Lower the position of fuse element, larger the frame drift at fuse breakage points. By lowering the position of the fuse, the initial stiffness of the entire system will be reduced and the fuse breaks at larger deflection Fuse at top position enhances the effectiveness of the fuse function

5.6 FRAME CONNECTION AND FRAME SIZE

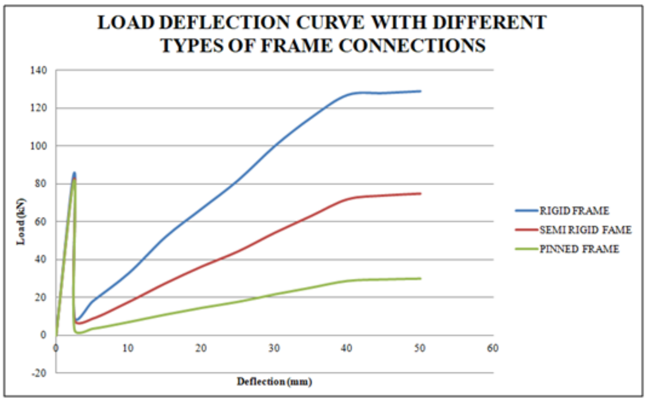

Chart-10: load- deflection curve of different frame connection

Reducing the stiffness of the joints, then frame become more flexible. The effect of fuse performance is independent on joint stiffness of the frame

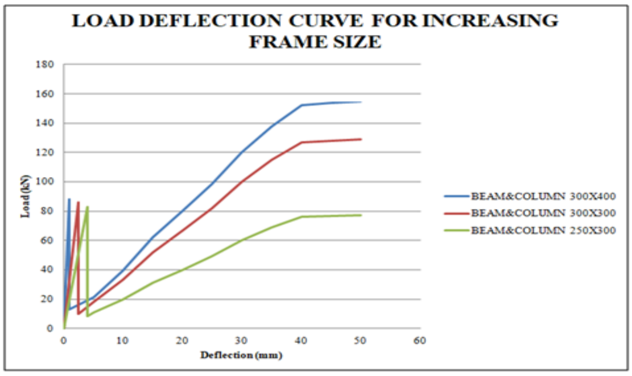

Chart- 11: load- deflection curve for different frame size

Size of frame is a matter for fuse performance. Heavier Sections provides stiffer and stronger system. In Heavier frames, Fuse breaks at lower displacements. A frame with higher ultimate load capacity should be used with fuse elements with larger capacity.

5.7 INFILL WALL CONSTRUCTION WITH AND WITHOUT FUSE

The steel frame has more capacity than the others, since steel frame with fuse is taken for the analysis. And also steel frame with various fuses are analysed.

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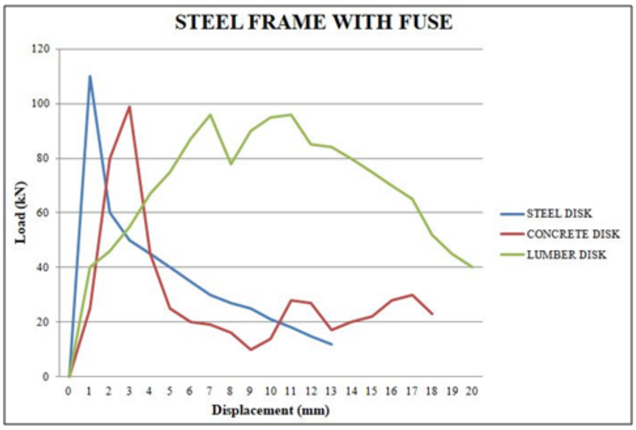

Chart-12: steel frame with fuse load- deflection graph

From this graph, Steel Disk has maximum stiffness and Lumber Disk has minimum stiffness. Lumber Disk shows more deformation, thus more ductility compared to the other two cases. After peak load, steel and concrete shows sudden drop in resisting load but lumber drop resisting load at a slower rate. The sudden drop of load causes undesirable effect on the building, so lumber disk is well suited as a fuse element.

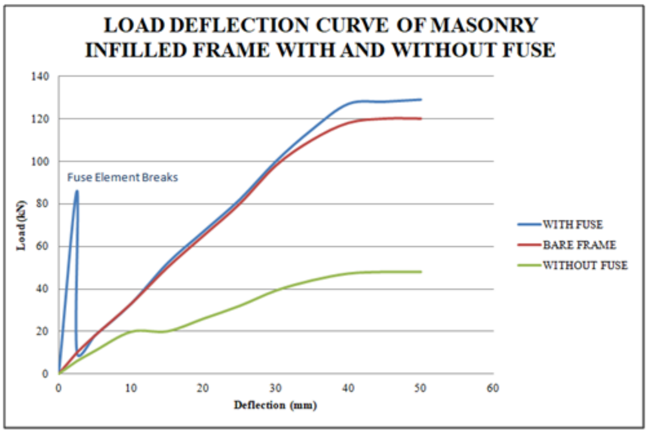

Chart-13: load – deflection curve with and without fuse

When fuse is installed stiffness of the whole structure increases thus reducing deflection. Steel frame with fuse element takes more load and breaks at its ultimate load capacity. When Fuse Element breaks, the frame behaves as Bare Frame.

5.8 SOFT STOREY PROBLEM DUE TO OPEN GROUND STOREY

ETABS software is used for the soft storey analysis of a building. A 10 storey building is to be modelled with an open ground storey for the parking purpose. The cases taken for the analysis are with and without fuse element.

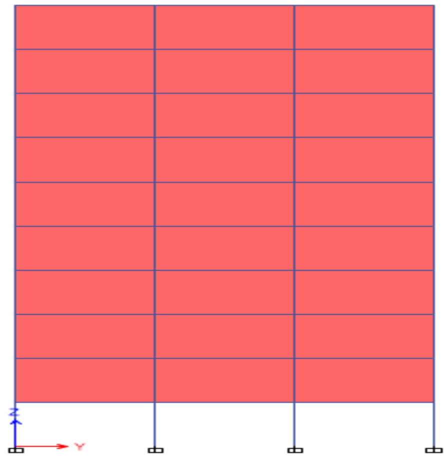

Fig -5: Elevation of a building

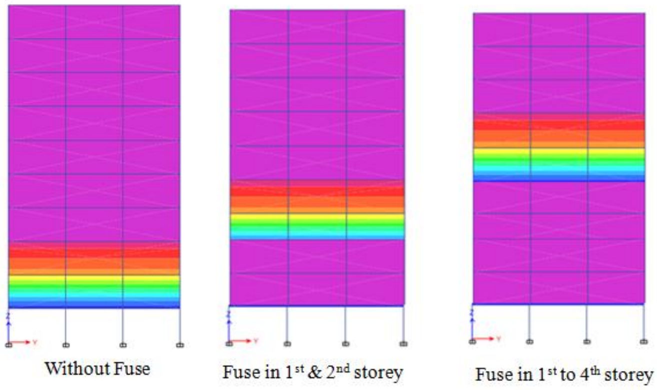

Fig-6: stress distribution in infill wall

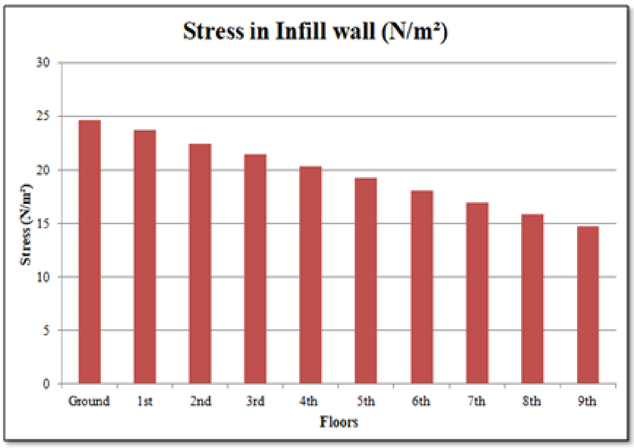

Chart-14: Stress variation in each floor

When high intensity seismic load acts on a building with soft-storey, the adjacent storeys with infill wall experience more stress and it leads to its failure after a particular limit. When given fuse breaks, these storeys act as soft storey again and the adjacent storeys to it will experience stress. So for more safety, structural fuse should be provided in all storeys. Since stress in infill wall decreases with increase in height, a decrease in fuse capacity can be implemented with increase in height. In case of short column and openings in infill wall also, we should provide fuse in a similar way to soft storey problem.

5.9 FAILURE SEQUENCE ANALYSIS

TABLE -2: Failure Sequence Analysis Result

Storey #	Storey Shear (kN)	Storey Shear Ratio	Fuse Capacity (kN)	Storey Fuse Capacity (kN)	Storey Fuse Capacity / Storey Shear	Fuse Failure Sequence	Fuse Capacity / Wall Capacity
1	1989	1.02	401	1602	**0.81**	**10**	1.00
2	1954	1.05	383	1533	0.78	**9**	0.96
3	1869	1.08	355	1420	0.76	**8**	0.89
4	1731	1.13	313	1252	0.72	**7**	0.78
5	1526	1.22	257	1029	0.67	**6**	0.64
6	1255	1.38	187	748	0.60	**5**	0.47
7	912	1.83	102	409	0.45	**4**	0.26
8	498	1.14	89	358	0.72	**3**	0.22
9	436	1.36	66	263	0.60	**2**	0.16
10	320	NA	40	160	**0.50**	1	0.10

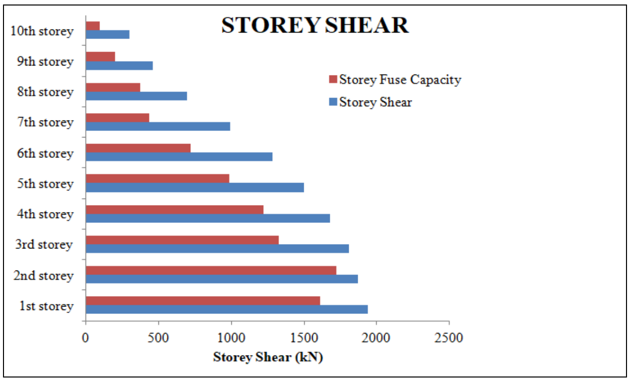

Chart-15: Storey shear

From Table and graph, it is clear that , The top storey fails first at 50% of the total seismic load designed . The bottom storey fails last at 81% of the total seismic load designed. The bottom infill wall should be isolated using fuse having same capacity of the wall. Using Fuse, the infill wall is unaffected under low to medium intensity earthquakes. Only the upper stories get failed under medium to high intensity earthquakes. Floor deflection get reduced when fuse is provided because the fuse acts as a partial damping device

6. CONCLUSIONS

For minimizing the failure of masonry in-filled frame in case of irregularities in the building, providing structural fuse is a good option. Structural Fuse Performs well in In-filled Steel frame than In-filled Concrete Frames. Since Lumber fails at a slower rate than concrete and steel fuses, Lumber Structural fuse is the best option. When thickness of fuse increases, performance also increases. But for aesthetic appearance and privacy concerns, Fuse thickness of maximum 25mm is good. When Fuse Element breaks, the frame behaves as Bare Frame. Due to higher stiffness, strength and durability, Satinwood is the best option as a lumber structural fuse. Steel Frame with Fuse system is most efficient in resisting lateral loads because when load acts on it, the steel connection will yield, thereby dissipating energy. Fuse near to top beam enhances the effectiveness of the fuse function. The effect of fuse performance is independent on joint stiffness and dependent on stiffness of the frame members. A frame with higher ultimate load capacity should be used with fuse elements with larger capacity.

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