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Analysis of Masonry Infilled RC and Steel Frames with Seismic Infill Wall Isolator Subframe System

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ABSTRACT: The Seismic Infill Wall Isolator Subframe (SIWIS) system is developed in this study for use in building frames with masonry infill walls in order to prevent damage to columns or infill walls and to minimize life-safety hazards during potentially damaging earthquakes. Because of the conventional tight-fit construction within structure frames, infill walls participate in resisting wind and seismically induced loads. Although beneficial during wind loads and minor earthquakes, the lateral load resistance of infill walls during strong events can damage the wall or the frame because the infill wall is usually treated as a non-load bearing wall, and, thus, is not designed to carry in-plane loads. Complete isolation of infill walls by separation gaps as an alternative construction suffers from lack of convenient and satisfactory solutions for fire and acoustic protection of the gap and the out-of-plane stability of the wall. The SIWIS system, which consists of two vertical and one horizontal sandwiched light-gauge steel studs with SIWIS 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 severe damaging events. The SIWIS system acts as a “sacrificial” component or a “structural fuse” to protect the infill wall and frame from failure. An experimental testing program planned and carried out tested the concept of the SIWIS system. The experimental program mainly included a series of tests on three different designs for fuse element (centerpiece) including concrete disk, steel disk, and lumber disk followed by a series of in-plane static pushover tests on a scaled two-bay three-story steel frame in three forms of bare frame, rigid frame, and pinned frame equipped with an SIWIS device. Generalized nonlinear finite element modeling schemes were developed for infilled steel frames with and without SIWIS system. Validation of modeling schemes was accomplished by comparing the experimental observations with the numerical predictions for: (1) a previously tested and studied single-bay single-story infilled steel frame selected from the literature; and (2) the tested two-bay three-story steel frame. The analytical and experimental results show that the concept of the proposed system works as a “seismic isolation” system for infill walls by utilizing, initially, the beneficial stiffness and strength effects of the infill wall up to a predefined point, but, ultimately isolating the infill wall from the frame for their safety. Practical design approaches were proposed and applied to three examples including: low rise, mid-rise, and high-rise buildings in high seismic and wind zones to demonstrate the performance of the proposed system.

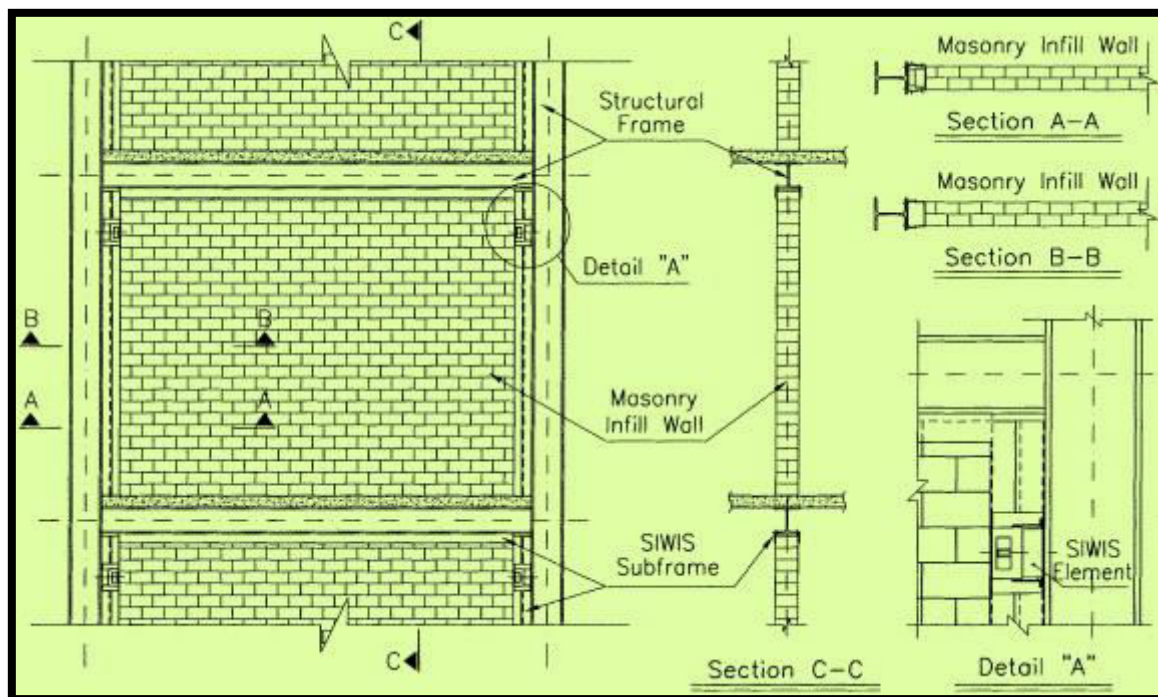
KEYWORDS-Seismic Infill Wall Isolator Subframe (SIWIS) system, Finite Element Modeling, Infill Wall

I. INTRODUCTION

The Seismic Infill Wall Isolator Subframe (SIWIS) system is 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. The SIWIS system, which consists of two vertical and one horizontal sandwiched light-gauge steel studs with “rigid-brittle” 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 SIWIS system acts as a “sacrificial” element just like a “fuse” to save the infill wall and frame from failure. Nonlinear finite element models for two cases, a single-bay, single-story steel frame and a two-bay, three-story steel frame, in three forms including bare frame and infilled frame with and without SIWIS system were performed to

develop an understanding of how the system responds to lateral loading. Analysis results show that the concept of SIWIS system works in providing initially high stiffness followed by an isolation of infill wall from interaction with the confining frame. Practical design guidelines are proposed and applied to an eight-story office building.

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 [1]. 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 [2]. 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.



(Figure 1: Masonry Steel Infill Frames)

It has been widely documented by many researchers that masonry infill walls significantly influence the in-plane behavior and response of structural frames [3–18]. 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 comprehensive literature review on these issues is presented by Aliaari [19].

The structural properties of masonry infill walls are often overlooked by designers who do not consider the increase in stiffness and potential decrease in ductility introduced into structural frames by the addition of unreinforced masonry infill materials. Typically, concrete and steel building frames are designed to resist all of the gravity and lateral loads, including wind and seismic forces. Infill walls are often treated as nonstructural elements even though they have a significant influence on the in-plane behavior and seismic performance of the structure [20].

Ignoring the contribution of masonry infill walls to the strength and stiffness of building frames can lead to damage in the masonry walls as well as resulting in an inefficient use of materials and uneconomical design [21]. According to Colombo et al. [22], neglecting the effects of the infill panels, as suggested by various building codes, does not lead to a safe seismic design. The assumption that masonry infill walls in concrete and steel frames will only increase the lateral load capacity of these structures is a common misconception [23]. This oversight can result in severe structural

damage and collapse in buildings where the ability of the frame to safely dissipate seismic input energy has been significantly overestimated. Overstressing of the masonry walls and the formation of a collapse mechanism in the structural frame can occur if the composite interaction between masonry infill walls and bounding frames is not accounted for during design.

Two common design philosophies have been developed which consider the influence of infill walls on the response of structural frames to lateral loads [24]. One approach is to isolate the masonry infill walls from the bounding frame with a physical gap [25]. This allows the frame to act independently of the masonry walls and to be designed without consideration of the interaction between the frame elements and the infill panels. Isolating the infill panels from the frame can prevent severe cracking and damage to the masonry materials. This is an important consideration since falling debris from damaged and collapsed infill walls is a major life safety issue for buildings in seismic areas. By isolating the infill walls from the concrete or steel frame, the structure can dissipate the seismic input energy in a predictable and safe manner.

A new concept in the performance and design of masonry infill walls is the idea of a structural fuse system [19,25–27]. 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 salient objectives of the present study have been identified as follows:

- The SIWIS system acts as a “sacrificial” component or a “structural fuse” to protect the infill wall and frame from failure.
- The Seismic Infill Wall Isolator Subframe (SIWIS) system is developed in this study for use in building frames with masonry infill walls in order to prevent damage to columns or infill walls and to minimize life-safety hazards during potentially damaging earthquakes.
- An experimental testing program planned and carried out tested the concept of the SIWIS system.
- The experimental program mainly included a series of tests on three different designs for fuse element (centerpiece) including concrete disk, steel disk, and lumber disk followed by a series of in-plane static pushover tests on a scaled two-bay three-story steel frame in three forms of bare frame, rigid frame, and pinned frame equipped with an SIWIS device.

II. LITERATURE REVIEW

Sr. No	Name of Author	Paper Title	Findings
1	Drysdale RG, Hamid AA, Baker LR.	Masonry Structures – Behavior and Design	Behavior of SIWIS system.
2	Paulay T, Priestley MJN	Seismic Design of Reinforced Concrete and Masonry Buildings	The discussion includes the design of reinforced concrete ductile frames, structural walls, dual systems, reinforced masonry structures, buildings with restricted ductility and foundation walls.
3	Benjamin JR, Williams HA	The behavior of one-story brick shear walls. ASCE, Journal of Structural Division. 1958;84:1723.1-1723.30	Results of investigation to develop data on resistance of shear walls could be used in design of structures to resist atomic blast loads; approximate relationships suggested for predicting load deflection curves for walls.

4	Stafford-Smith B	Lateral stiffness of Infilled frames. ASCE, Journal of the Structural Division. 1962;88(ST6):183-199	Methods for predicting approximate lateral stiffness of single and multistory frames; stiffness of frames is considered by assuming equivalent diagonal strut to replace infill; effective width for equivalent strut is derived theoretically and checked by model experiments.
5	Holmes M.	Steel frames with brickwork and concrete infilling. Proceedings, The Institution of Civil Engineers. 1961;19:473-478	THE ULTIMATE LOAD CARRYING CAPACITY OF SLENDER STANCHIONS BENT ABOUT THE MAJOR AXIS.

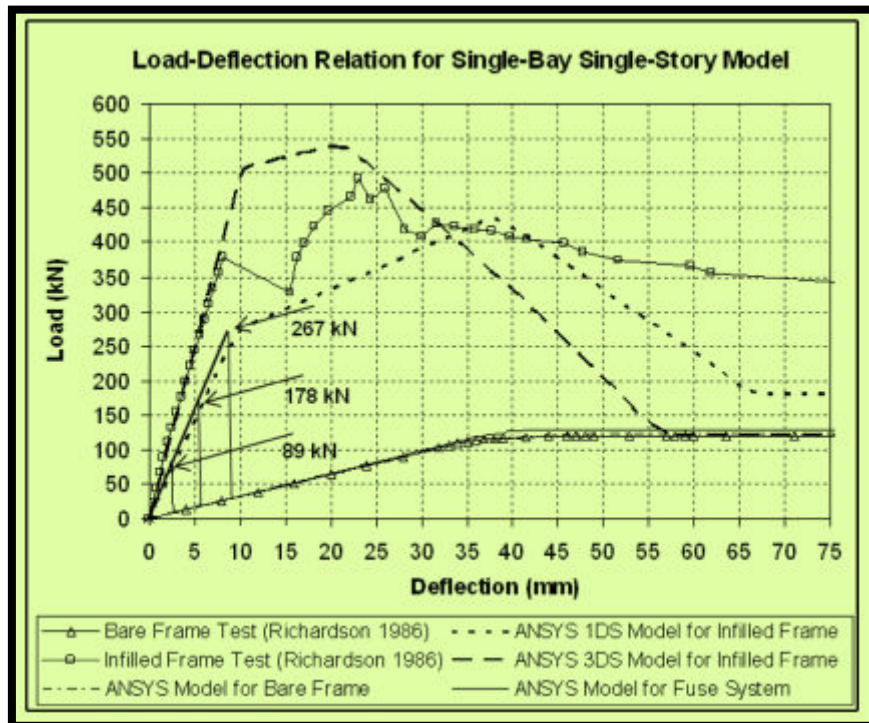
III. PROPOSED METHODOLOGY

Discussion of the single-bay, single-story model analysis results:

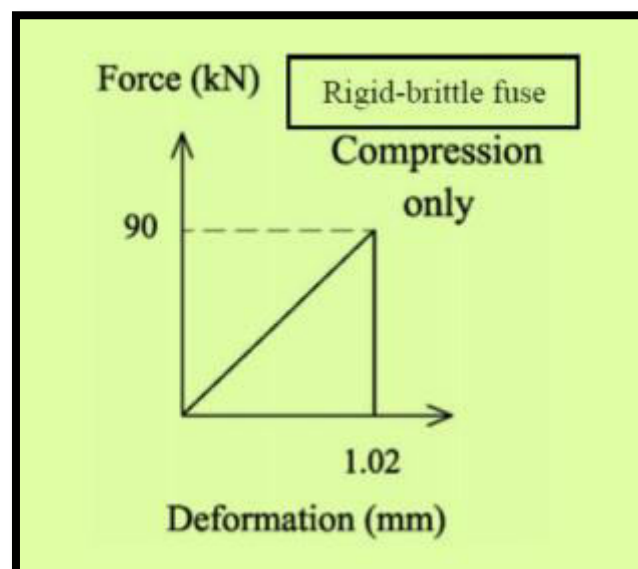
Pushover analysis of single-bay, single-story infilled frame with fuse element model was carried out to compare the response with infilled frame without fuse element. The results of this analysis are shown in Figure 9 along with the results from the experimental study of the bare frame and infilled frame. For better clarity, Figure 14 shows the plot of the initial deflection portions with larger scale. The effect of varying the fuse capacity on the system response is illustrated in Figure 9 with three different values for the fuse capacity (i.e., 89 kN, 178 kN, and 267 kN). The figure shows two stages of response consisting of (a) prior to breakage of the fuse and (b) after breakage. During the first stage shown by line OA in Figure 14, the fuse transfers lateral loads from the frame to the infill wall and as such, the slope of the line OA represents the combined larger stiffness of the steel frame and the masonry infill wall. Upon breakage of the fuse at point A (capacity of fuse), there is sudden drop in the force level, line AB, followed by load-deflection relation along BC, which represents the response of the bare frame. This means that the infill wall is disengaged from the steel frame and only the bare frame is resisting the total load.

Comparison of the response of the model having fuse element with those of the bare frame and infilled frame in Figure 9 shows that the stiffness of the system with fuse element is slightly smaller than that resulting from tested infilled frame (about 75% of the infilled frame). This, however, is about ten times the stiffness of the bare frame. Although as shown in Figure 9, higher strength fuse elements increase the strength capacity of the system, but it should be noted that the objective is to prevent failure of the wall. For example, based on the test results (shown on the figure), the tightly fitted masonry infill wall cracks around a lateral load of 378 kN. The smaller the fuse capacity, the larger will be the margin of safety against cracking.

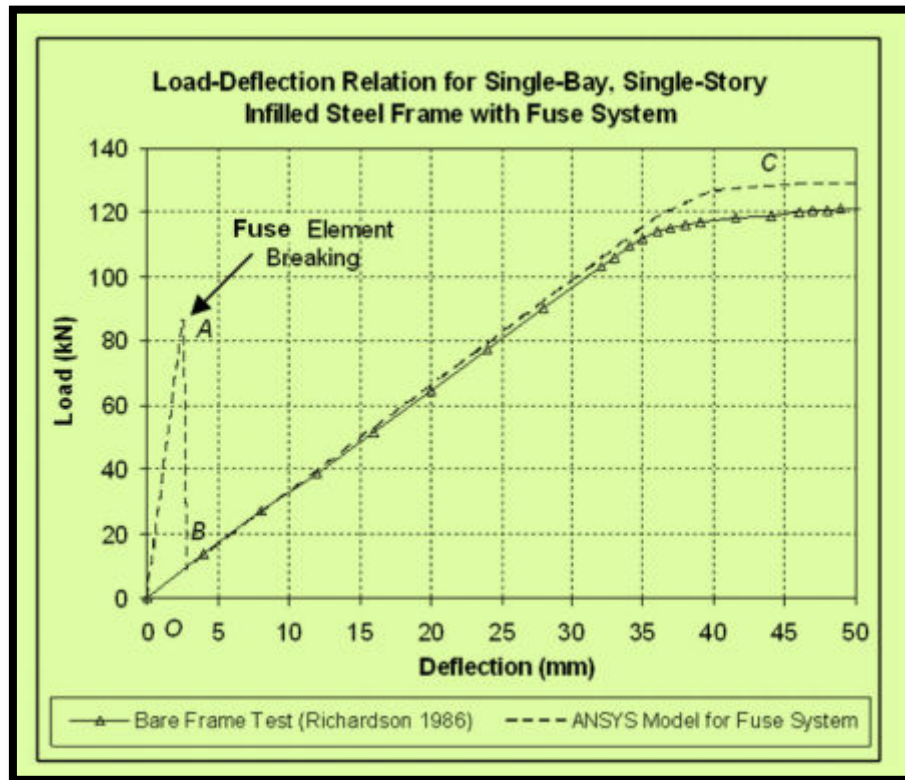
The fuse element model shown in Figure 13 describes a condition where upon breakage of the fuse, the force transfer across the fuse becomes zero. Since this could imply a shock-type response, but which is more like cracking of reinforced concrete or masonry system, it is possible to develop fuse elements that show more ductile response. For example, if the fuse element can be described by the trilinear or multilinear models shown in Figure 15, the corresponding load deflection plots for the infilled frame will be those shown in Figures 16 and 17, which show a more gradual drop of the force across the fuse and a smoother transition to the bare frame condition. It should be noted that depending on the mechanism of failure or design function of the fuse, different types of infilled frame response can be obtained. Examples of such mechanisms could include friction damper mechanism for energy dissipation and enhanced seismic response of the structure.



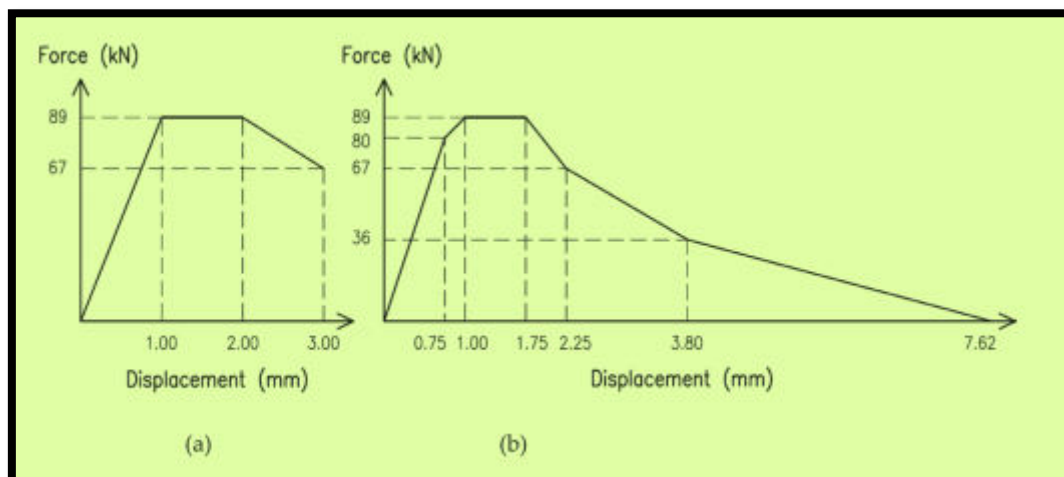
(Figure 9. Load-deflection relation for single-bay, single-story system)



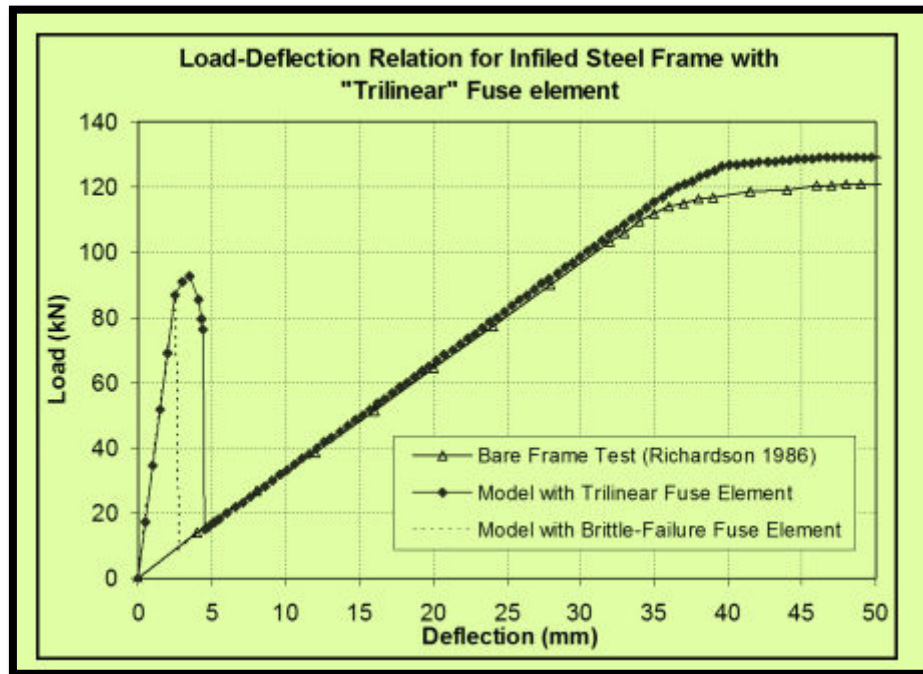
(Figure 13. Force-deformation responses for the rigid-brittle fuse element)



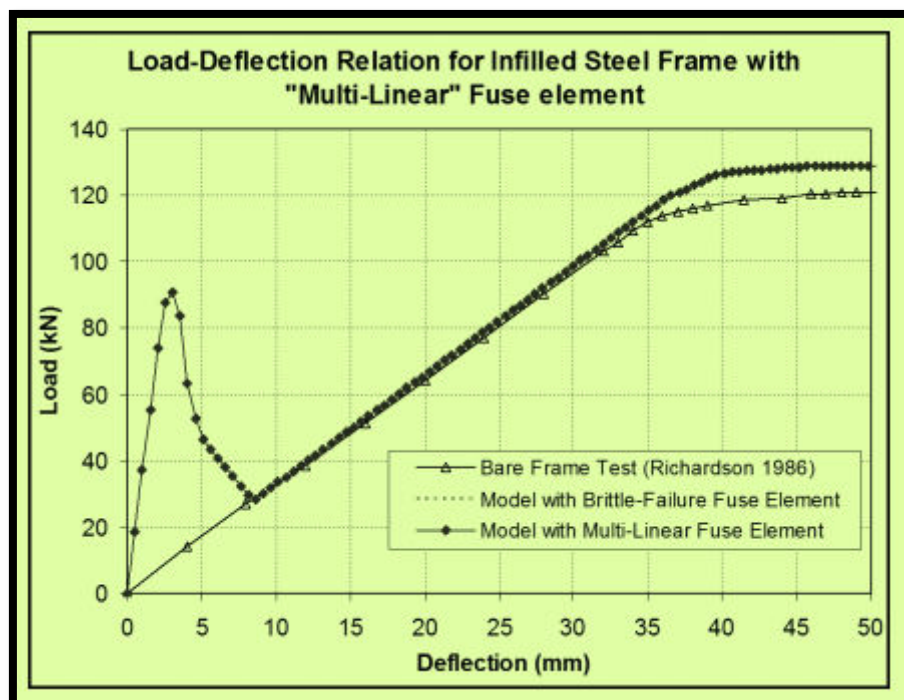
(Figure 14. Load-deflection relation for single-bay, single-story model with “brittle-failure” fuse element)



(Figure 15. Assumed force-deformation responses for fuse element (a) “trilinear” and (b) “multilinear”)



(Figure 16. Load-deflection relation for single-bay, single-story case study with “trilinear” response for fuse element)



(Figure 17. Load-deflection relation for single-bay, single-story case study with “multilinear” response for fuse element)



IV. CONCLUSION

The study presented has shown that existing commercial software (such as ANSYS or other similar software) can be used to effectively model complex use of masonry walls. The study has shown how various finite elements can be used to model masonry, structural fuse, as well as infilled frame for analysis under in-plane lateral loading. The available library of finite elements seems to be well-developed for this purpose. Aside from concluding the appropriateness of existing of modeling capabilities to capture various behavioral aspects of masonry infills used in conjunction with fuse elements, some conclusions and remarks can also be mentioned related to the proposed use of fuse concept to mitigate damage to masonry infill walls and/or infilled frames. The concept of using structural fuse elements as sacrificial components in masonry construction is practical and should be given consideration for follow-up R&D studies and more refined design and detailing for practical application. The use of finite element modeling for parametric study of the proposed concept has shown that the effect of frame joint stiffness on the overall mode of behavior is not as much as the stiffness of the frame members. The latter affects the design of the fuse capacity, and for a given frame stiffness, the overall behavior will be sensitive to the fuse capacity. The finite element model analysis also showed that higher positions of the fuse element add efficiency to fuse element performance. While the presented study focused on proof of the concept for masonry infill within steel frames, the concept is equally applicable for concrete frames as well. In fact, variations of the presented concept can be expanded to develop energy dissipating fuse systems for application to steel and concrete frames as well as light frame construction infilled with other materials than masonry.

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