A New Type Safety-Door for Earthquake Disaster Prevention - Part I

Daniel Y. Abebe, Jaehyouk Choi

***Abstract*—From the past earthquake events, many people get hurt at the exit while they are trying to go out of the buildings because of the exit doors are unable to be opened. The door is not opened because it deviates from its the original position. The aim of this research is to develop and evaluate a new type safety door that keeps the door frame in its original position or keeps its edge angles perpendicular during and post-earthquake. The proposed door is composed of three components: outer frame joined to the wall, inner frame (door frame) and circular hollow section connected to the inner and outer frame which is used as seismic energy dissipating device.

***Keywords*—Earthquake disaster, FE analysis, Low yield point steel, Safety-doors.

I. INTRODUCTION

THE English dictionary of oxford defines door as a hinged, sliding, or revolving barrier at the entrance to a building, room, or vehicle, or in the framework of a cupboard [1]. Early doors, used throughout Mesopotamia and the ancient Egyptian era, were merely hides or textiles. Doors of rigid, permanent materials appeared simultaneously with monumental architecture. Doors for important chambers were often made of stone or bronze [2]. Since then the development of door has been continued

Although the development of door has a long history, the safety of doors during earthquake is not given much attention by researchers. Most of the literatures and standards available on the door are concerned on the size, shape, safety against fire door requirement, and operating system [3]-[5]. However, as the statics from the past earthquake events show that a significant number of human life was lost at the exits. People in the building try to leave the building when earthquake occurred but they face difficulty because the doors are deviates from its original position and unable to be opened as shown in Fig. 1. As shown in the figure γ is the angle of deviation or rotation angle caused by lateral load of earthquake. In this situation huge object may fall or even the building may collapse while peoples are in the building which leads casualties.

In this research, we proposed a new type safety door shown in Fig. 2 which keeps the door in its original position during and after the earthquake. As shown in the figure, the proposed door has three main components: first, the outer frame which is connected to the wall. Second is the inner frame that holds the door. The last is the circular hollow section steel welded on the outer and inner frames and used as a seismic energy dissipation device. This dissipating device is a type of passive energy dissipation systems which have been considered an effective and inexpensive way to mitigate earthquake risks to structures because these devices do not rely on external power supply as required by the active energy dissipation devices; because, it dissipate seismic energy through metallic deformation.

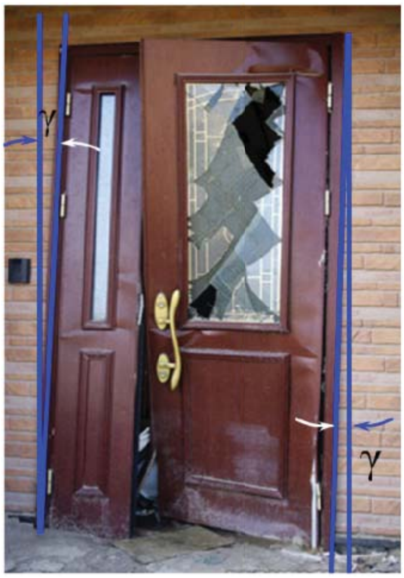
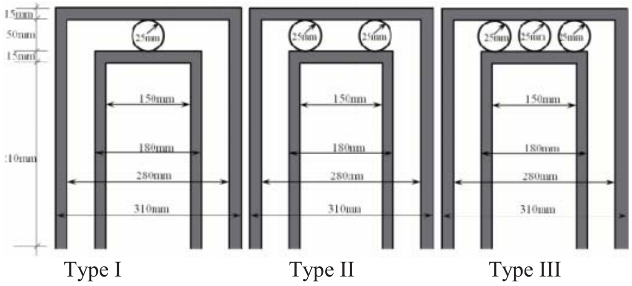


Fig. 1 Damaged door by earthquake



Type I Type II Type III

Fig. 2 Specimen Detail

II. HOW THE PROPOSED DOOR ACTUALLY OPERATED

As explained in the first chapter, the proposed door has three main components while the existing door frame has only one frame. Two components added, the outer frame and the circular hollow section damper are used to resist the applied lateral earthquake load. The damping device, circular hollow section,

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is made of low yield point steel or the yield and maximum force of CHS should be designed to have less than the yield force of door frame therefore, the upcoming load is dissipated before propagated to the inner frame (door frame) so that the door frame remains in its original position. The CHS (circular hollow section) dissipates much energy even before entering to plastic range or in elastic range only by changing the circular shape to elliptical under cyclic loading that gives the proposed door frame high energy dissipating capacity

III. NONLINEAR FE ANALYSIS

Finite element analysis was conducted to evaluate the feasibility, structural and seismic performance of the proposed door. A commercially available FE simulation program called Abaqus Version 6.10.1 is used [6]. The outer and inner frames are modeled using conventional steel SS400 having yield and ultimate strength of 355MPa and 421MPa respectively and the circular hollow section damper is modeled using low yield point steel (LYP225) having yield and ultimate strength of 202.6MPa and 265.4MPa respectively. Material nonlinearity was included in the finite element model by specifying a stress–strain curve in terms of the true stress and plastic strain. A 3-D meshed analysis specimen model is shown in Fig. 3. As shown in the figure a shell element of S4R quadrilateral elements through mesh generation by Python script is found to be more efficient.

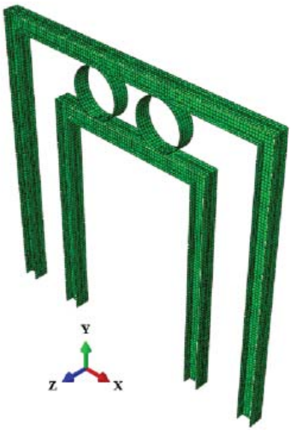
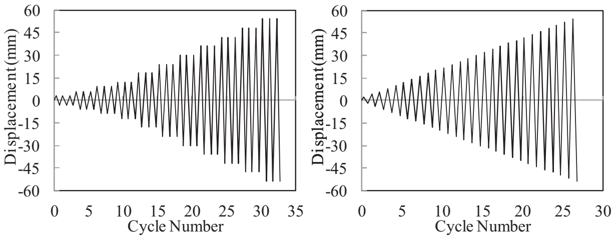


Fig. 3 3D analysis model of Type II door



(a) AISC, severe loading (b) uniformly varied loading

Fig. 4 Loading protocol

The boundary and method of loading condition adapted in finite element analysis on the proposed door follows the practical condition. All the translational and rotational displacement components are fixed at the lower end of both outer and inner frames. A cyclic load was applied on the outer frame beam in X-direction fixing the translation in other direction free rotation. A constant strain loading is implemented in which the load is applied by controlling the displacement with the displacement protocol shown in Figs. 4 (a) and (b).

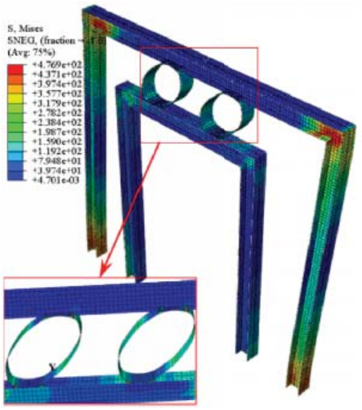
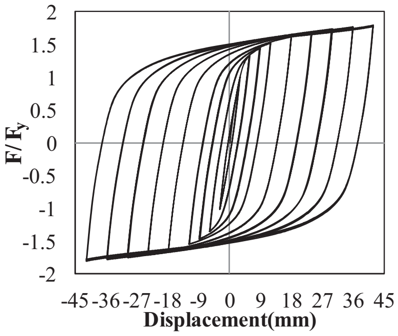
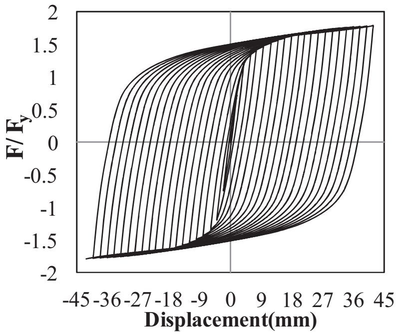


Fig. 5 Deformed shape with von Mises stress distribution of Type II door with d/t=15.63 of CHS damper



(a) Hysteresis loops of AISC severe protocol



(b) Hysteresis loops of uniformly varied protocol

Fig. 6 Shear force-Inelastic rotation relationship of Type II door with d/t=15.63 of CHS damper

IV. Results and Discussions

The deformation shape with von Mises' stress distribution of analysis specimen with two CHS damper is shown in Fig. 5. As shown in the figure, the outer frame and CHS damper is deforms but the inner frame is not deform though a small amount of stress is transferred to the inner frame and keeps its original position or its perpendicularity. The corresponding hysteresis loops for both displacement protocol of this analysis specimen is presented in Fig. 6. The hysteresis loops are stable for both displacement protocol.

As we discussed in the previous chapter, the advantage of the proposed door is keeping its original position under lateral earthquake load. The deformed shape with von Mises' stress contour of analysis result shown in Fig. 7, the outer frame rotates γ and the CHS damper also deforms inelastically however, the inner frame (door frame) couldn't deform under considered cyclic loading. As shown in Fig. 7, stress distribution around the corners edges of inner frame is seen but it is too small to cause deformation. From the analysis result we can say that the proposed door will avoid the problem of the door that do not opened during and after earthquake because of deviation from its original position so that the risk at caused at the exit will be avoided significantly.

V. Parameters Considered

The main parameters considered in evaluating the proposed safety-door are number of CHS damper and diameter-to-thickness ratio of CHS damper. Of course the effect of cross section shape of frames has also been considered but it is found that it has no significant effect. To evaluate the maximum resisting capacity for different number of CHS damper with various d/t ratios, monotonic loading analysis is conducted as presented in Fig. 8 for all Type I, Type II and Type III. As shown in Fig. 8, number of CHS damper has a slight difference on resisting capacity, but D/t ratio has significant effect on maximum resisting capacity, yield strength and initial stiffness. The maximum resisting capacity of Type I, Type II and Type III with respect to d/t ratio is summarized in Fig. 9. As shown in the figure, the maximum force increases when number of damper increases from Type I to Type II but relatively slight increase for Type II to Type III. The resisting capacity and initial stiffness linearly increase with a decrease in d/t ratio as shown in Fig 8 and summarized in Fig 9. Fig 10 shows the hysteresis loops for different number of CHS dampers for d/t=15.63 ratio. As shown in the figure, number of CHS damper has no effect on hysteresis loop behavior. However, both initial and second stiffness are generally higher as the number of CHS damper increase as shown in Fig 11.

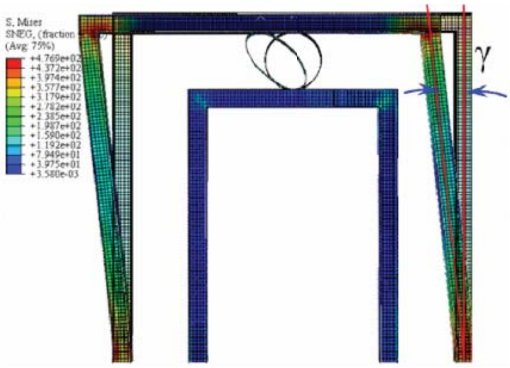


Fig. 7 Deformed shape with von Mises' stress contour of Type I door of d/t=15.63 CHS damper

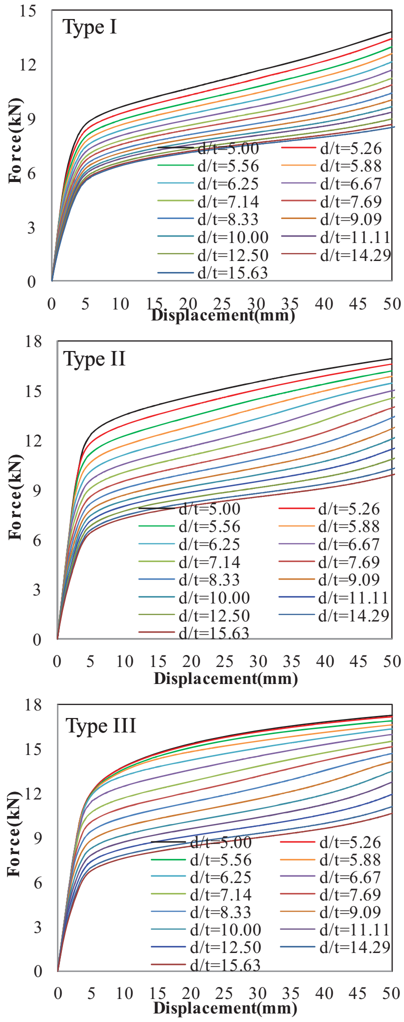


Fig. 8 Effect Diameter-to-thickness ratio (D/t) on a new type safety door lateral load resisting capacity for single, double and triple CHS dampers respectively

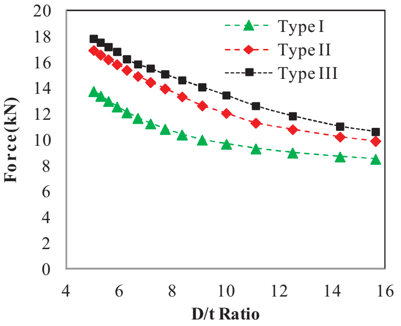


Fig. 9 Comparison of maximum resisting capacity of Type I, II, III doors

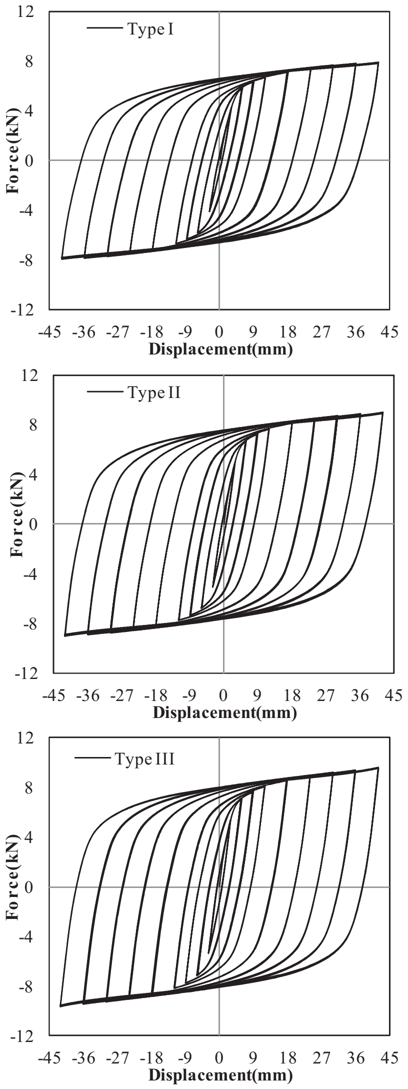


Fig. 10 Hysteresis loops using severe AISC loading protocol of Type I, II, III doors with d/t=15.63 CHS damper respectively

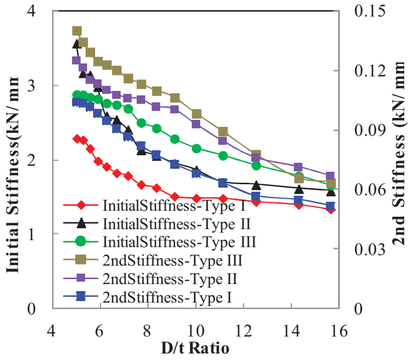


Fig. 11 Comparison of initial and 2nd stiffness of door with single, double and triple CHS dampers with respect to d/t ratio

VI. CONCLUSION

The newly proposed safety door has evaluated analytically and satisfactory result was obtained. According to the FE result obtained, the developed seismic resisting door has had a good advantage to be used in seismic active areas.

ACKNOWLEDGMENT

This work was financially supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No.2013-056169).

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