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Fuse performance in steel frames with knee element connections under cyclic loading

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ABSTRACT: This paper describes the development of a ductile fuse system to reduce Seismic demand in steel frames with knee element connections. In this type of structures, connections often require reinforcement to withstand the tensile capacity of the brace to comply with the capacity design process. To overcome this problem, it is necessary to think of a solution to prevent the premature failure of the connection. For this purpose, in this research, different models of ductile fuses consisting of a reduced cross-sectional area are placed on the Knee element brace in a braced frame. The fuses are designed to reduce the tensile capacity of the knee element braces to the capacity of the joints. The results show that the braced frame with a fuse can be used to reduce the seismic load demand to the connections sufficiently, to prevent the strengthening of the connection caused by the application of capacity design principles. It was also observed that the properly designed fuse system in braced frames shows a stable hysteretic response under cyclic loading and maintains sufficient ductility with a reasonable reduction in the compressive strength of the braced members. Also, the results showed that the failure of all samples occurs in the fuse, and as a result, by using the fuse, it is possible to use the full capacity of the connection and brace. Finally, based on the results of the study, the best fuse models that create both Sufficient ductility and compressive strength to an acceptable level were identified for design applications.

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1- Introduction

The philosophy of seismic design in most building codes is to provide sufficient strength, stiffness, and ductility to ensure that designed structures meet the following criteria[1]:

Adequate strength and lateral stiffness must be provided to prevent both structural and non-structural damage in the case of a minor earthquake and to prevent structural damage in the case of a moderate earthquake.

In the case of a severe earthquake, sufficient ductility must be provided to prevent building collapse, albeit limited structural damage is permitted.

To accomplish these aims, building codes have proposed various lateral-load-resisting structural systems such as moment-resisting frames (MRFs), concentrically braced frames (CBFs), and eccentrically braced frames (EBFs). MRFs demonstrate stable hysteretic behavior and do not make architectural obstructions. Nevertheless, the relatively low lateral stiffness of MRFs and the dependency of their seismic behavior on the quality of materials and workmanship, particularly at the beam-to-column connections, can lead to undesirable seismic performance[2,3]. CBFs have great lateral stiffness; however, they make architectural limitations and their seismic behavior is severely dependent on the post-buckling behavior of the braces. The strength of the braces might be considerably reduced after buckling, resulting in an asymmetric cyclic behavior and reduction of systems ductility[4,5]. The performance of EBFs relies on the yield of a ductile link beam; despite creating a stable hysteretic response, it leads to the creation of large deformations in the floor beam, which is not so desirable[6]. To overcome this problem, researchers proposed knee element connections that combine the key features of lateral braced frames and MRF.

2- Methodology

The proposed fuse consists of a reduced cross-section with a gentle angle that is placed at both ends of the knee element brace. The proposed fuse is easy to manufacture can be easily fabricated and installed at the construction site and can be easily created without the help of skilled technicians, which is a significant advantage for the fuse. Figure 1 shows an overview of the geometry and location of the proposed fuse. For simplicity, the fuse is shown for a single-story frame, but it can be used in a multi-story building. This fuse can be made outside the workshop under proper supervision. After making the fuse, connecting the Knee element brace to the gusset plates does not need to be reinforced, which is one of the goals and advantages of making a fuse.

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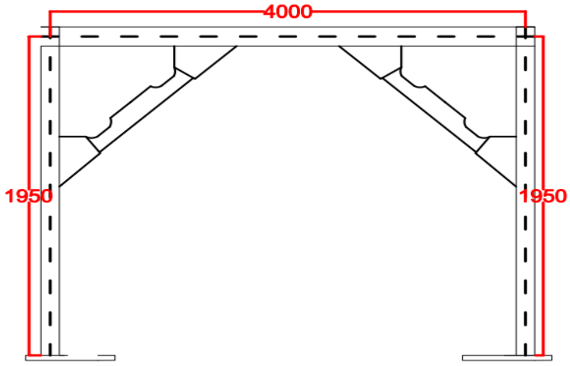

Fig. 1. An overview of the geometry and location of the proposed fuse

3- Results and Discussion

As you can see, the stress concentration happened at the fuse location and the fuses are the first place to yield. It can be seen that the yielding fuses have stable, reliable, and complete hysteretic curves. Under cyclic loading, the fuse can absorb energy with a reasonable reduction in the compressive strength of the bracing members up to the point of failure. So it can be trusted as a deformable fuse with flexible behavior. The important point is that the resistance of the fuse increases after it is yielded. Although this is considered an advantage, it should be considered in the design of connections and bracing elements. The fuse can withstand 3 to 4 times the deformation associated with yielding; Therefore, its ductility can be considered about 4. All the studied models endured at least as load cycle as the reference test. As expected, the failure of all studied models occurred due to failure in the fuse, which shows the correct design of the fuse. Model a, with four fuses placed at the beginning and end of the knee-braced element, endured more load cycles than models b and c, whose fuses are similarly placed at the beginning and end of the knee-braced element, which is due to the geometry and location of the fuse. After that, Model C endured a decent load cycle. Models d and e were among the models where the fuse was located at the beginning, end, and middle of them and had similar hysteretic behavior. Model f with fuses placed at the beginning, end, and middle compared to the same samples as e and d showed more load cycles and less resistance drop, and this shows the importance of the location of the fuse. Table 1 shows the summary of the hysteretic results of the studied models and shows the maximum displacement, the failure mode, and the maximum and minimum load applied by the frame during the test.

4- Conclusion

In this article, the modeling performance of yielding fuses in different parts of the knee element member in the knee element connections was evaluated. Fuses are designed with a tensile capacity equal to the capacity of the connections to prevent failure of the connection. Based on the modeling research, the following results are obtained:

1- In terms of ductility, the brace equipped with two fuses placed at both ends of the knee element (model a) showed the highest ductility. Models f and c are placed after model a. Also, models b, d and e had similar ductility.

2- As a summary, it can be said that the fuse model used for modeling a, f, and c were the most efficient, unlike models b, d, and e, especially model b, which had poor performance

Table 1. Summary of hysteretic results of studied models

Models	Maximum displacement(m)	Failure mode	Maximum floor load(KN)	Minimum floor load(KN)
Model a	0.06	Fuse failure	249	250
Model b	0.04	Fuse failure	231	226
Model c	0.05	Fuse failure	242	263
Model d	0.04	Fuse failure	213	214
Model e	0.04	Fuse failure	220	220
Model f	0.05	Fuse failure	263	258

mainly due to the improper geometry of the fuse.

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