PROPOSAL OF NEW STEEL STRUCTURES WHICH LIMIT DAMAGE TO CONNECTION ELEMENTS AT THE BOTTOM FLANGE OF BEAM-ENDS

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Abstract: In the Northridge (1994) and Kobe (1995) Earthquakes, some buildings suffered damage and lost their functions, although many buildings avoided collapse so as to save human life. If a heavy earthquake occurred in urban areas, the stop of the function of urban facilities would cause the severe economical loss. It is very important for structural engineers to consider restoring buildings at the early stage after an earthquake. That is to say, not only structural performances but also easy repairs after an earthquake are required for buildings. One of methods that make buildings have these abilities is the Damage-Controlled-Structure. This system consists of a mainframe and dampers. The mainframe can remain in elastic range during an earthquake, because dampers absorb the input energy of the earthquake. Today, by such a seismic design concept and developments of efficient dampers, many high-rise buildings with easy repairs are being constructed in urban area. However, in urban areas, there are many low-rise or medium-rise buildings which are not suitable for applying dampers. And even if they were buildings with dampers, high rotation capacities might be required at beam-ends of a mainframe. Since the earthquakes above occurred, a lot of studies have been carried out on beam-to-column connections, and new details at beam-to-column connections have been proposed. Nevertheless, the seismic design with these new details is based on plastic rotation capacity of principal members in a mainframe. In other words, these details cannot give easy repairs to structures.

The purpose of this study is to propose new ductile steel structure, which realizes easy repairs as well as structural performances. Main feature of this system is to limit plastic deformations (damage) to the connection elements, the weak-web-split-tee, at the bottom flange of beam-ends.

1. INTRODUCTION

In the Northridge (1994) and Kobe (1995) Earthquakes, some buildings suffered damage and lost structural functions, although many buildings avoided collapse so as to save human life. If a heavy earthquake occurs in urban areas, the loss of the function of urban facilities would cause severe economic loss. In urban areas, social and industrial activities cannot be lost for long. Therefore, it is very important for a structural engineer to consider restoring buildings soon after an earthquake. One of the methods that give buildings this ability is the Damage-Controlled-Structure (Wada et al., 1992 and Y. H. Huang, 1995) and it is shown in Fig.1. This system consists of a mainframe and dampers. The mainframe only supports gravity and can remain in elastic range during an earthquake, because dampers absorb the input energy of the earthquake. Therefore, buildings can be used continuously by repairing and exchanging dampers. Today, many high-rise buildings based on the design method of Damage-Controlled-Structure are being constructed.

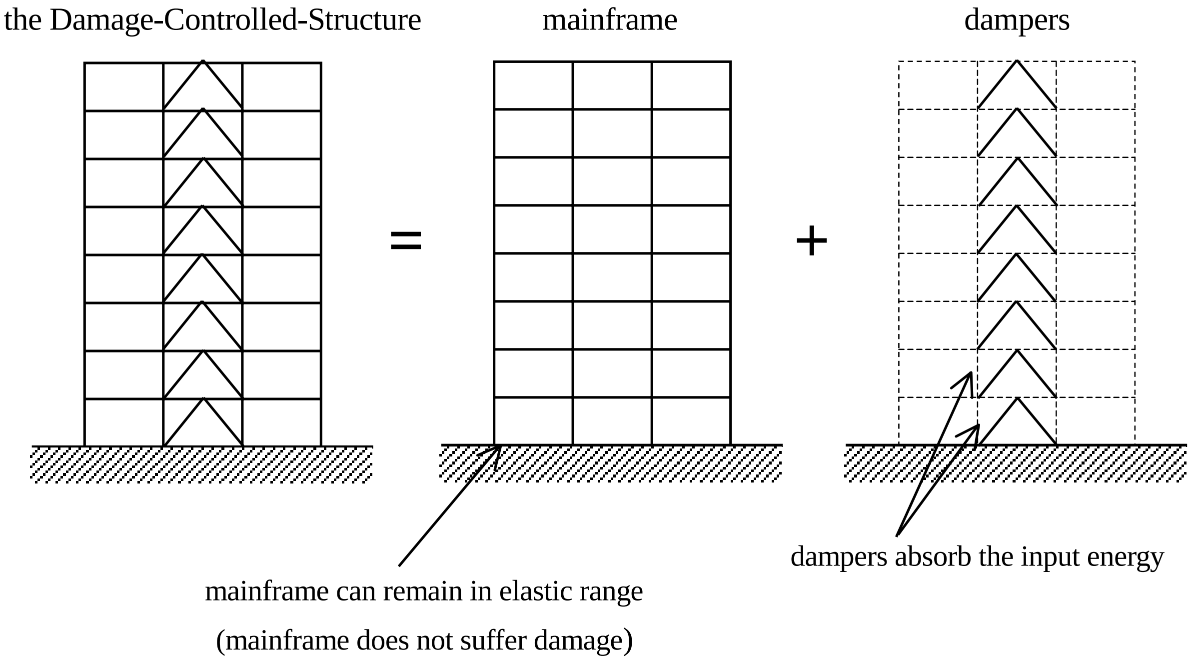
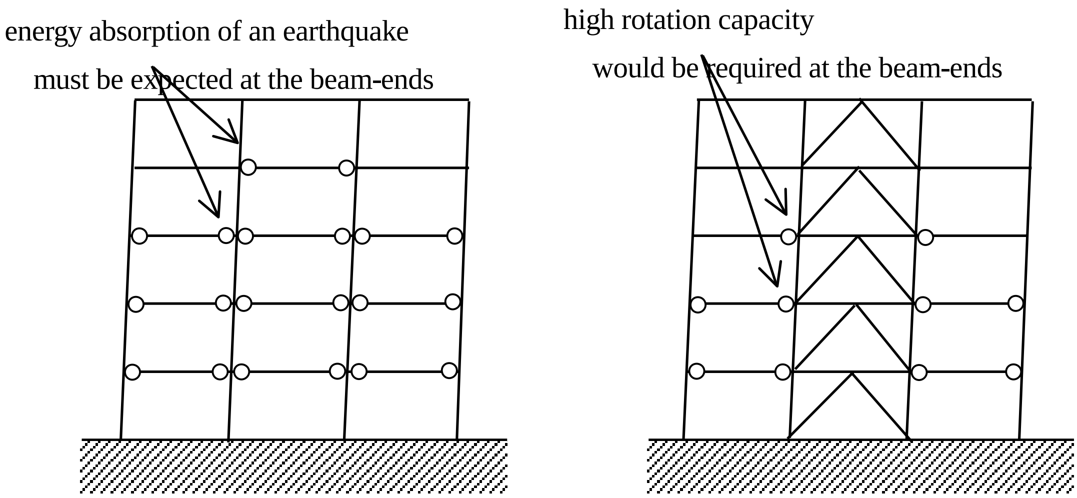


Fig.1 the Damage-Controlled-Structure (Wada et al., 1992 and Y. H. Huang, 1995)

However, in urban areas, there are many low-rise or medium-rise buildings which are not suitable for applying dampers. In the case of these buildings, naturally, energy absorption of an earthquake must be expected at the beam-ends (shown in Fig.2 (a)). And even if there were low-rise or medium-rise buildings with dampers, high rotation capacities would be required at the beam-ends of a mainframe (shown in Fig.2 (b)). It means that most low-rise or medium-rise buildings had been built based on the seismic design permitting damage at the beam-ends.

In the two earthquakes mentioned above, many steel structures suffered damage at beam-to-column connections, and some fractures of bottom flanges occurred at the beam-to-column connections. After these earthquakes, a remarkable number of studies have been made on beam-to-column connection. Some of them tried to investigate the causes of these fractures, and others proposed the new connection details to resolve the issues. Examples of the proposed details are as follows: the reduced beam section detail (RBS), the horizontal-haunch beam detail, the no-weld access hole detail, and the improved weld access hole detail. And many test results have showed us that each of them prevents a premature fracture and has a large plastic rotation capacity. As the result, The RBS detail has been recommended in the U.S. and no-weld access hole detail has been adopted in Japan. Nevertheless, seismic design with these details is based on the plastic rotation capacity of main members in the mainframe. And in those studies, little attention has been paid to repairing the connections. Consequently, we cannot easily repair the buildings when using these details. In other words, these proposed details have not been able to solve the issues that the past disasters caused.

If we can easily repair the mainframe with or without dampers, the buildings can be restored soon after an earthquake. We can do it even if they are naturally low-rise or medium-rise buildings. The purpose of this study is to propose a new ductile steel structure, which realizes not only structural performance but also easy repair after a heavy earthquake. Main feature of this system is that plastic deformation concentrates on connection elements (the weak-web-split-tee, see 2.2.) at the bottom flange of beam-ends in the mainframe. In this paper, first, why damage has to concentrate on the connection elements at the bottom flange is shown. Next, the ability of the connection elements required in order to realize the proposed system is shown. Finally, the detail of the connection elements that satisfy the requirements is shown.



(a) buildings without dampers (b) buildings with dampers

Fig.2 a seismic design based on damage at the beam-ends (low-rise or medium-rise buildings)

2. PROPOSAL OF NEW DUCTILE STEEL FRAMES

2.1 NEW DUCTILE STEEL FRAMES

There are two conditions that must be met to make structures easily repairable. One of them is to constitute structures using exchangeable members. The other is to limit damage to some of these exchangeable elements. In the Damage-Controlled-Structure, dampers on which damage concentrates are connected to a mainframe by exchangeable high-strength bolts. Naturally, beams and columns of the mainframe that are connected by high-strength bolts are more easily repairable than those that are welded. And it is thought that, by designing connection elements (Split-Tee (T-stub) or Angle) that are weaker than the beam and column, it is possible to limit damage to the connection elements. However, conventional Split-Tee (T-stub) shows different behaviors in tension and compression. This characteristic behavior prevents limiting damage to exchangeable elements. A behavior of a frame with conventional Split-Tee is shown in Fig.3. In the state of this deformation, a compression force occurs on the beam because the rotation points of left and right side differ. Consequently, at the connection, stiffness and yield strength would increase with this compression force, and local buckling on the bottom flange might be caused by this compression force. It means that the state of the deformation with conventional Split-Tee is not suitable for limiting damage to connection elements.

With regards to limiting damage, the desirable state of the deformation with bolted connections would be shown in Fig.4. Main feature of this behavior is that plastic deformation is limited to the connection elements at the bottom flange. Consequently, The rotation points of left and right side stay at the top flange. Naturally, it avoids damage to the connection elements on the top flange, which is difficult to exchange. The point we wish to emphasize is that we can concentrate deformations of a mainframe on Split-Tee at the bottom flange, if the connection elements show the same behaviors in tension and compression (see 2.2.). By repairing and exchanging the connection elements at the bottom flange after an earthquake, buildings can continue to be used. Consequently, even if the building is not suitable for applying dampers or cannot absorb the input energy with only dampers, it can be repaired easily, such as the Damage-Controlled-Structure.

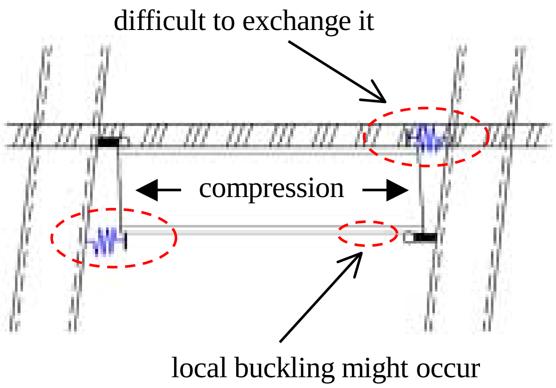


Fig. 3 The conventional deformation
(with conventional Split-Tee)

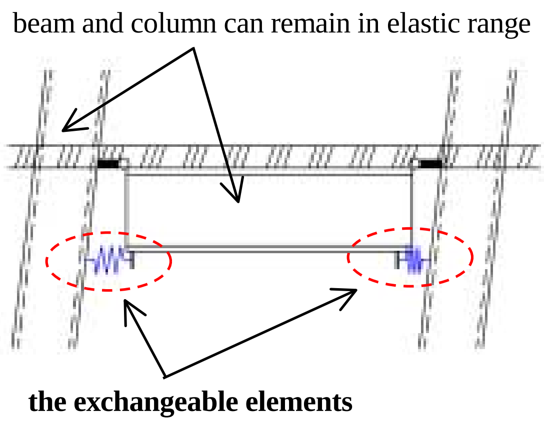
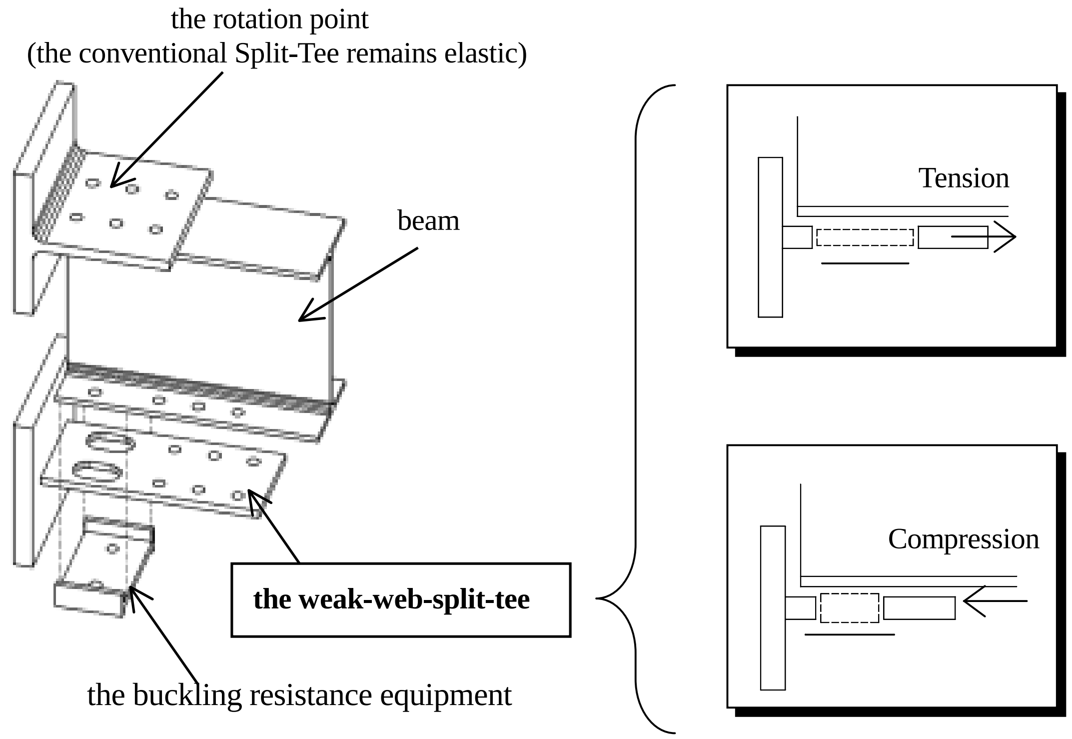


Fig. 4 The desirable deformation
(with **the weak-web-split-tee** (see 2.2.))

2.2 NEW CONNECTION ELEMENTS (THE WEAK-WEB-SPLIT-TEE)

In order to form the desirable deformation to limit damage (shown in Fig.4), the damage must concentrate on the connection elements at the bottom flange. It means that the elements have to show same behavior in tension and compression. The new connection elements (shown in Fig.5), which are proposed by us, satisfy the requirement. A feature of the connection elements is that they have a reduced section at the web plate. By designing the weak section, it allows the connection to reach yield strength earlier than the beam, column, and the connection elements at the top flange. As the result, the rotation point of beam-ends would stay at the top flange, and deformation of the mainframe would concentrate on the connection elements at the bottom flange. Nevertheless, naturally, buckling occurs at the weak section when it is in compression. Therefore, we use the buckling resistance equipment shown in Fig.5 (a). Buckling of the weak web is avoided by putting the weak web between the bottom flange of the beam and the resistance equipment. By using the buckling resistance method, the Split-Tee can show the stable deformation capacities in tension and compression (shown in Fig.5 (b)).



(a) detail of beam-to-column connections (b) behavior of the weak-web-split-tee

Fig. 5 the beam-to-column connection with the weak-web-split-tee

3. CONCLUSIONS

Many steel structures suffered damage at beam-to-column connection under the past heavy earthquakes. After these disasters, although a lot of researchers proposed new connection details, most of them paid little attention to repairing after an earthquake. In urban areas, social and industrial activities cannot stop for long, because it causes the severe economic loss. Therefore, to consider restoring buildings is very important for structural engineers and urban areas. Today, structural engineers and urban areas require buildings that can do it.

The purpose of this study is to propose the new ductile steel frames, which realize not only structural performances but also easy repair after an earthquake. Main feature of this system is limiting damage to connection elements at the bottom flange of beam-ends. In this paper, first, why damage has to concentrate on the connection elements at the bottom flange was shown. Next, the ability of the connection elements required in order to realize the proposed system was shown. Finally, the detail of the connection elements (the weak-web-split-tee, see 2.2.) that satisfy the requirements was shown.

References:

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