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Particularities of the beam-to-column joints in steel structures placed in seismic areas

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Summary

Steel structures are very widespread in areas with high seismic activity due to high performance, and relatively simple and fast execution. This paper describes the drawbacks of the types of classic joint used up to 1994 Northridge and 1995 Kobe earthquake. Also, this paper describes the new types of joints that were designed to eliminate their drawbacks and optimized for better behavior and the guiding of the plastic hinge into the beam, according to the principle of "strong column – weak beam" which suppose that the plastic hinge should are allowed in the ends of the beams and the base of the column at the first level. The main scope of the steel beam-to-column joins is absorbing energy from seismic actions and ductility behavior. Most of codes and rules regulates the principle of designing of the steel beam-to-column, and the behavior of the joins.

Keywords: beam to column joints, ductility, plastic hinge, earthquake, enhanced performance.

1. INTRODUCTION

In areas with high seismic activity, steel frame structures are wide spread due to high ductility behaviour, and relatively simple and fast execution. In the past, welded joints were considered optimal in terms of strength, stiffness and ductility. However, in the 1994 Northridge and 1995 Kobe earthquakes have had effects destructive and metal structures, many of them even collapsed. This has shown that welded metal joints are susceptible to premature and fragile failure.

The stress concentrations, weld defects and material imperfections are some of the causes that have led to brittle failure.

2. ASPECTS OF JOINING METAL STRUCTURES

Since 1994, numerous research has been carried out to create new types of joints between the components of steel structures, with increased ductility and energy dissipation capacity. Thus, was watched the implementation and realization of the "strong column – weak beam" principle, according to which the plastic hinge can be formed exclusively in the beam ends and at the base of the column at the first level [5](Engelhardt, M.D., Husain, A.S., 1993), as shown in Figure 1.

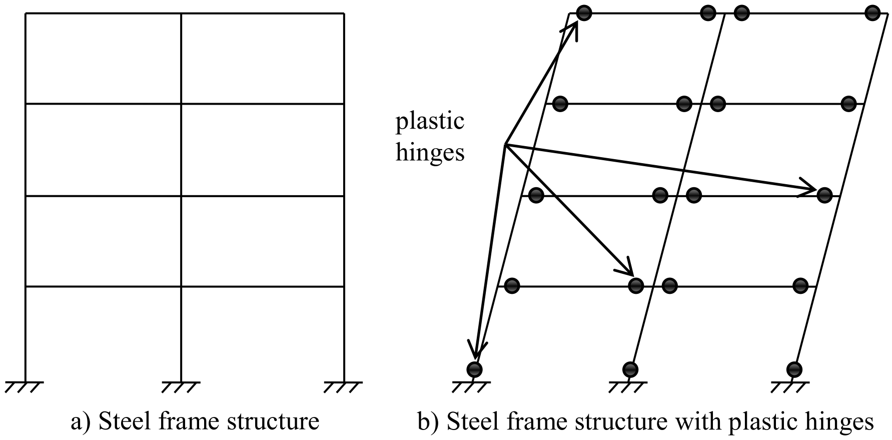

Figure 1. "strong column – weak element" principle

Considering the ductile failure requirement of steel structures, namely the possibility of plastic deformation without loss of major resistance and energy dissipation, the design codes require the use of seismic force reduction factors, which means the significant reduction of seismic forces in calculation.

From a formal point of view, the node and the joint are the joint are different notions, Figure 2:

- The joint is made up of elements that make the connection between the beam and the column. The elements from which the joint is composed are characteristic of each type of joints (for example: screws, end plate, welding, etc.).
- The node is composed of a joint and its interaction zone, with the joined elements, an example is the column flange which directly takes over the efforts [3].

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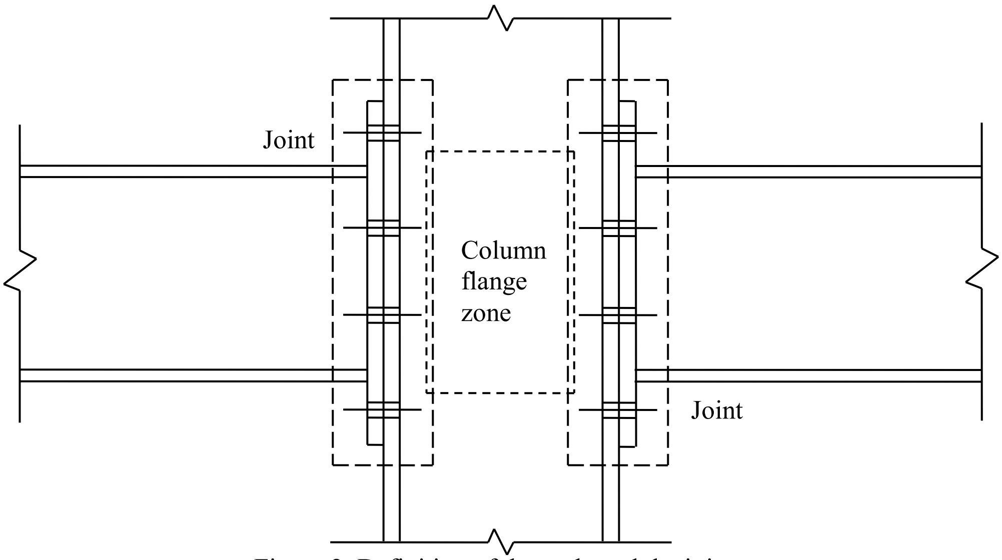

Figure 2. Definition of the node and the joint

To be considered as moment resistant nodes they mush have the following characteristics:

- Stiffness (denoted by $S_{j,ini}$ in [6])
- Resistance to bending moment ($M_{j,Rd}$)
- Ductility or plastic deformation capacity (φ_u)

These characteristics can be easily identified on the interdependent moment-rotation curve of a moment rezistant joint. Figure 3 [6].

Ductility is an important characteristic that is the ability to dissipate energy and characteristic imposed on the joints of structures in seismic areas.

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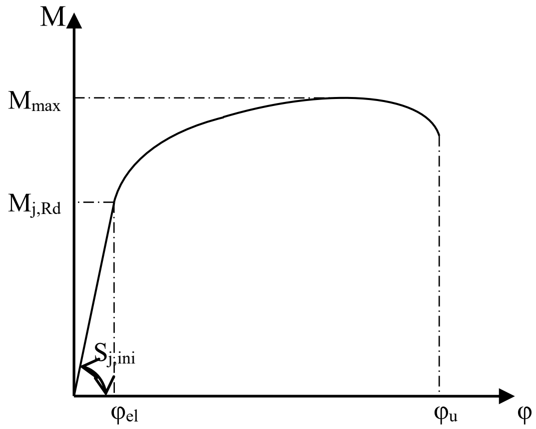

Figure 3. The interdependent moment-rotation curve of a moment rezistant joint

Prior to the events at Northridge (1994) and Kobe (1995), the beam-to-column joints were considered either perfectly rigid, either hinged. The hinged joints are those that can't take bending moments, and rigid joints are considered those that have the ability to make bending moment transfer from one element to another.

As results of the research, it was proved that many nodes considered rigid had a semirigid behaviour, and many of the nodes considered hinged had a capacity to take up the bending moment, thus was introduced the notion of "semirigid joints", Figure 4 [3].

Depending on the bending moment resistance, the joints can be: totally resistant, partially resistant, and hinged.

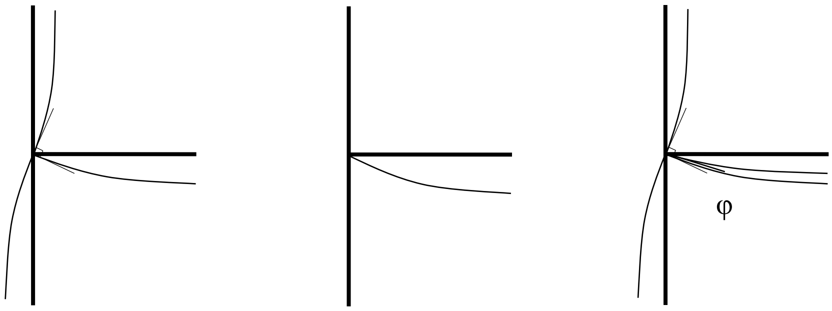

Figure 4. Types of joints according to the beam to column relationship

To characterize the nodes in terms of stiffness and strength, three new notions were introduced: continuous nodes, semi-continuous nodes and simple nodes.

3. BEAM-TO-COLUMN JOINT WITH EXTENDED END PLATE

Beam-to-column joint with extended end plate (Figure 5) was also used before the Northridge and Kobe earthquakes in 1994 and 1995 respectively.

Due the presence of stress concentrations in the screw holes, of the non-linear phenomena occurring in the actual joint, such as sliding or frictional forces that provide the joint with a non-linear global behaviour, this type of joint has not had a widespread spread. However, it has a number of superior features to welded joints, for example: welding between the beam and the end plate is no longer executed in situ but in the workshop, which allows for better quality control under special working conditions.

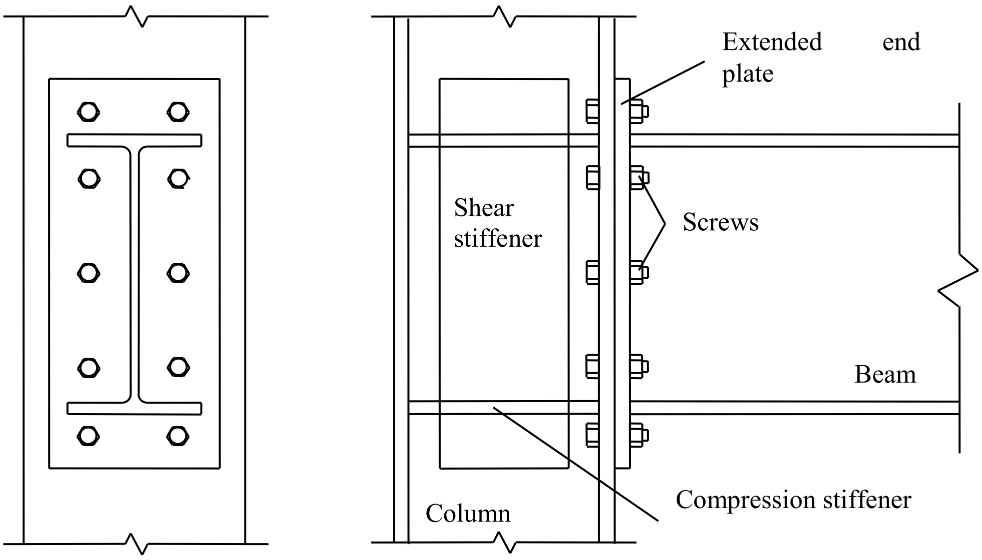

Fig. 5 Beam-to-column joint with extended end plate

A series of further studies [11] have shown that this type of joint exhibits almost rigid behavior when the end plate is thick, the diameter of the screws is large and there are stiffening on the column which takes up the compresion.

The extended end plate beam-to-column joint has semi-rigid behaviour when stiffeners are removed, the end plate becomes thinner and the diameter of the screws are smaller.

(Eurocod 3. SR EN 1993-1, 2006)[6] requires all components of the joint to be checked (Component Method) to determine rigidity and strength of the node. Chines code [10] and Americand Design Codes [1] consider the perfectly rigid end

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joint to be the only proof of resistance. The tests performed by [11] showed that the ratio between the thickness of the end plate and the diameter of the screws should be equal 1,2 in order to obtain an efficient sizing of the joint. If the thickness of the end plate is approximately equal to the diameter on the screws, the stress distribution in the screws is more uniform (tension screws), if diameter of the screws is smaller than thickness of the end plate, the stress distribution in the screws becomes more uneven, the row of screws below the top flange of the beams being more stressed.

The high thickness (respectively stiffness) of the plate leads to the failure of the screws (Mode 3 of failure) (Figure 6), usually a frangible failure, which contradicts the ductile design principles.

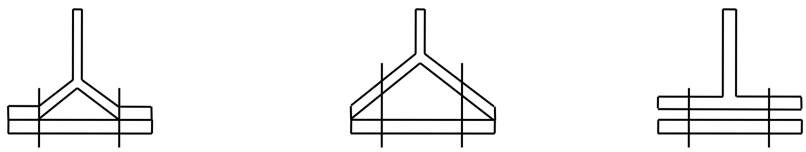


Figure 6. Modes of failure

In the extended end plate, there are tension concentrations in the welding between the end plate and the beam, where the formation of the plastic joints must be avoided. For this purpose, the end extended end plates joints are stiffened with haunches (Figure 7) which may have different shapes and layouts. They make an important contribution to the stiffening of the beam section, the redistribution of the forces to avoid the excessive formation of the stress concentrations in the welded area, but also lead to the movement of the plastic hinge in the beam. When using this type of joint it is important to observe the principle of "strong column-weak beam".

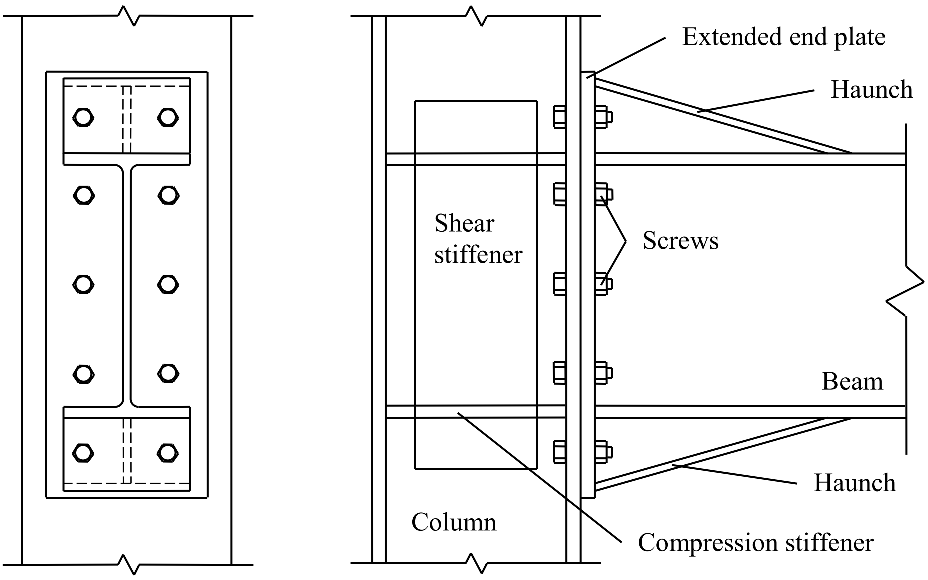
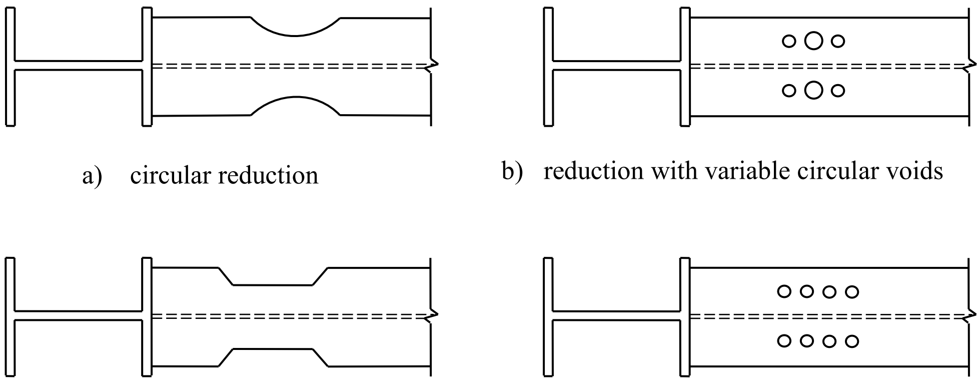


Figure 7. Beam-to-column joint with extended end plate and haunches

4. BEAM-TO-COLUMN JOINT WITH REDUCED BEAM SECTION

After the Northridge and Kobe earthquakes, numerous studies have been carried out to replace the stiffening of the beam with haunches by reducing the section of the beam. The first studies were conducted by Engelhardt, Winnebeger, Zekany and Ptyaraj [4].



a) circular reduction
b) reduction with variable circular voids
c) rectangular reduction
d) reduction with constant circular voids

Figure 8. Types of beam section reduction

The use of reduced beam section (RBS) allows the use of welded joints due to the fact that the plastic hinge is guided in the reduced section of the beam. For the practical application of this solution, additional checks must be carried out in addition:

- Check the modulus of resistance in the reduced area
- Check the principal and tangential max. tensions in reduced area.

The max. moment resistance of the joint is imposed by the moment capacity of the beam. It should be noted that the reduced beam section joints have a higher degree of susceptibility to loss of general stability.

The analyses performed by Rahnavard, Hassanipour and Siahpolo [12] have shown that RBS joints have good hysteretic behavior. The strength of these joints has decreased due to the reduction of the section of the beam. Total rotation of the joint is about 2-3% of total beam rotation. Therefore, the rotation of the joint is independent of the beam rotation. Beams with variable voids reduction (Figure 8c) have the greatest efficiency in terms of energy dissipation and stability.

5. CONCLUSIONS

Design codes for seismic action foresee the capacity of elastic dissipation of energy resulting from low intensity earthquake. In case of high intensity earthquake, it is necessary to dissipate the energy through plastic deformations, but without allowing major structural degradation.

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Frame structures must follow the principle of “strong column – weak beam”, which implies the possibility of forming the plastic hinge in the beam end and at the base of column at first level. It is important to avoid the formation of plastic hinge in the joint or at the column. For this purpose, different types of joining configurations have been proposed, which have advantages and disadvantages. In this paper are presented a series of joints, specific to the steel frame structures in seismic areas. The most common is extended end plate joint, in which the rigidity of the joint is directly proportional to the rigidity of the end plate and the diameter of the bolts.

The optimized version is the extended end plate with haunches. This type of joint is perfectly rigid and provide acceptable ductile behaviour, the plastic hinge being formed in the unreinforced area of the beam. Haunches can also be used in welded joints because the rigidity of the node is large enough and the weld failure is avoided. The disadvantages of this type of joining are the high cost of work and the architectural inconveniences created by the haunches.

Another type of joint is the reduced beam section, this can also be used for welded joints. Execution of these joints is cheaper, at the same time the haunches, which create architectural inconveniences, are removed. However, they have some problems because of reduced section, which provide a decrease of stability.

In practice, both variants can be used, or new solutions can be implemented as long as the “strong column – weak beam” principle is respected and at the same time ductile behaviour of the joint and the structure itself is ensured.

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