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BEAM-TO-COLUMN CONNECTIONS IN STEEL STRUCTURES PLACED IN SESIMIC AREAS, CHARACTERISTIC FOR STRUCTURES WITH TUBULAR COLUMNS

BY

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Abstract. Steel structures are widespread in areas with high seismic activity due to the ductile behavior and efficient energy dissipation capacity. Tubular columns have a better behavior at the lateral forces by seismic actions due to the effective distribution of the material. Combining of these two elements is a real challenge due to the inefficient distribution of the stress in the classical (welded) beam-to-columns joints, which lead to the premature failure of the column flanges by buckling, crushing or veiling which categorically contradicts the "strong column – weak beam" principle, which guides the design of joints according to Eurocode 3. This paper describes several types of beam-to-column connections, designed to solve the problem of the stress distribution in the beam-to-column joints, and to ensure efficient energy dissipation. The joints were divided into two different categories depending on the shape of the column section: circular or rectangular; each having a specific design of the joints. However, it should be noted that both types of joints can be adapted to the shape corresponding to the used column section.

Keywords: seismic actions; tubular columns; beam to column connections; energy dissipative connections; ductile design; plastic hinges.

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1. Introduction

Structures with tubular or "closed" sections have a series of superior features to U or H cross-section columns in terms of seismic resistance. Due to the symmetrical and uniform arrangement throughout the section, they have the same behaviour on different directions, they have the same stiffness on two orthogonal directions and do not have the problem of weak axis. The beam joint can be executed in both orthogonal directions in the case of rectangular posts or in any direction in the case of circular section columns. Tubular columns, whatever the type of section, can be filled with concrete, which greatly increases the compressive strength, and the "steel package" is equivalent to the longitudinal and transverse reinforcement which is located at the maximum possible distance from the neutral axis of the section also it confines the core of the concrete, at the same time the concrete core prevents the buckling of steel column. All this contributes to increasing the moment that can be taken up by this type of columns. Due to the efficient distribution of the material, the tubular columns have a smaller thickness of the flanges, less weight per linear meter than open sections columns, this considerably reduces the amount of material used for building the structure. However, the tubular section columns, due to constructive reasons, have another problem, namely the buckling of the flanges, especially in the connection area, where the compressed flange of the beam are pushing the column flange, which leads to the creation of the plastic hinge in the column section, that is totally unaccepted by the actual design principles of structures. There should be made a distinction between circular cross-section and rectangular cross-section columns, since the local behaviour of the element is different, resulting in different behaviours of the node.

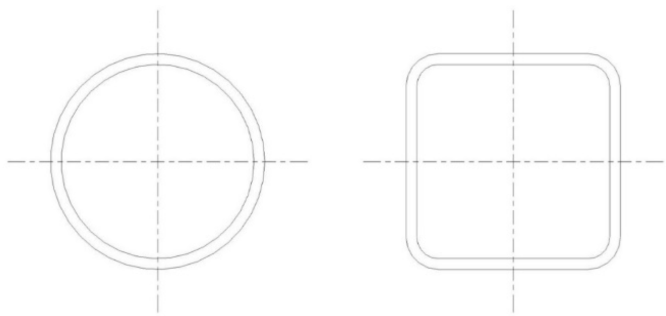


Fig. 1 – Types of tubular cross-sections: a) circular cross-section; b) rectangular cross-section.

2. Solutions for Circular Cross-Section Columns

2.1. Connections with Reduced Beam Sections

Research made by Ricles *et al*., (2004) and Qin *et al*., (2014), which proposed the implementation of horizontal stiffeners, showed an increase in the rigidity of node. With increasing the rigidity of the node, there was a significant increase in stresses in the area of the beams, which may lead to premature failure of the joint and possible crushing of the column flange. To avoid premature failure of the joint, but also to avoid adding stiffeners to the beam (Rui *et al*., 2017) proposed to cut some portions of the beam to loosen "RBS", similar to the connections used for the open-sections columns proposed by Engelhardt *et al*., (1996).

- First of all, cutting the flanges of the beams, to facilitate the formation of plastic hinge in the beam;
- Welding the beams to the columns by means of stiffening diaphragm arranged horizontally at the flanges of the beams in order to avoid stress concentrations at the contact area of the beam flanges with the column and more even distribution of the stresses transmitted to the column. (Fig. 2).
- Studied the action of the concrete slab on the "RBS" beam-to-column joint.

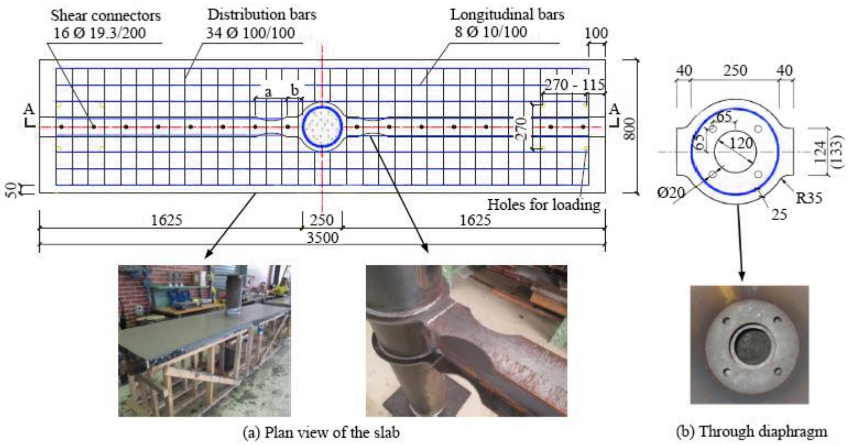
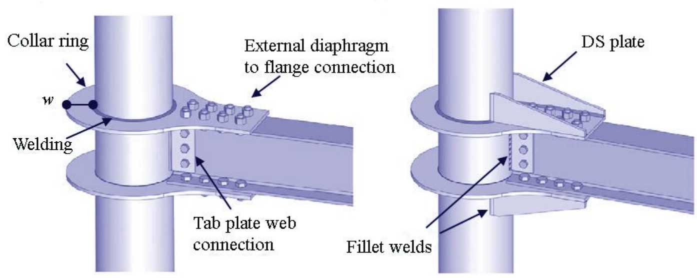


Fig. 2 – Beam-to-column joint with "RBS" and reinforced concrete slab.

Following the experimental study (Rui *et al*., 2017) have found that reducing the section of the beam, leading to the formation of plastic hinge in the beam and the concrete slab, increases the stiffness and strength of the joint, but considerably reduces the energy dissipation capacity of the joint.

2.2. Connections using External Diaphragms

In 2013, Alireza Bagheri Sabbagh, Tak Ming Chan, James Toby Mottram, proposed a new method to distribute the beam loads from the beam to the CHS column in order to avoid stress concentration in the welding area and to avoid local failure of the column, the main purpose being to move the plastic hinge in the beam. Thus, it was proposed to weld some external diaphragms along the entire contour of the column, with an extension for connecting the beam. The shear force is taken over by a welded tab plate (Fig. 3).



a *b*

Fig. 3 – Beam-to-column joint (*a*) with external diaphragms (*b*)with external diaphragms and DS plates.

This type of joint employs an energy dissipation mechanism similar to the classic DST joints (Herrera *et al*., 2013). Alireza Bagheri Sabbagh, Tak Ming Chan, James Toby Mottram, (2013) also proposed an optimized variant, with a dissipative element (Fig. 4), which can be replaced after having major degradation, thus reducing the costs and time required for the repair of the structure.

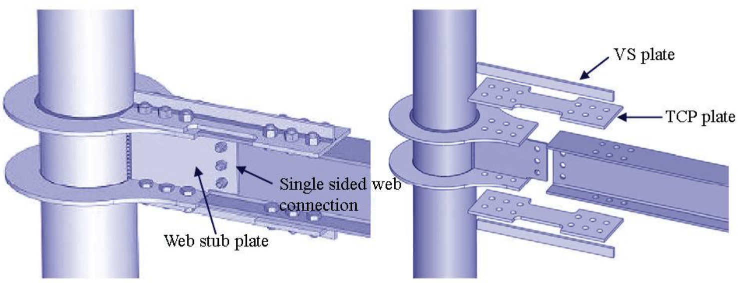


Fig. 4 – Beam-to-column with external diaphragm and dissipative elements.

2.3. Connections with Extended Beam Sections

This type of joint was proposed and tested in 2009 by Wang J.F., Han L.H., Uy B. The concept of joining beam-to-column with extended flanges has been previously proposed by Chen C.C., Lin C.C., Lin C.H., (2006), but Chen proposed direct welding of the beam to the rectangular columns. The joint involves the use of a curved end plate, in the case of rectangular columns a straight end plate can be used, and the beam to have a pair of triangular extensions for the top and bottom flanges (Fig. 5). Another feature of the proposed joint is the use of "blind screws" that eliminates the need for access inside the column to tighten the bolts.

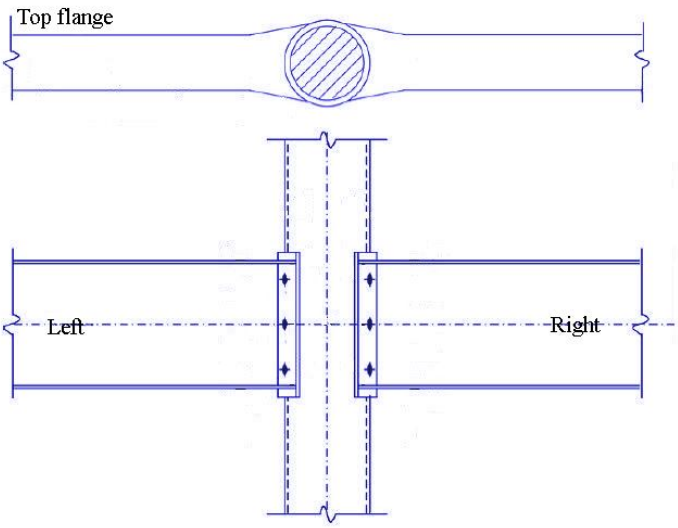


Fig. 5 – Connection with extended beam sections.

It should be noted that the thickness variation of the end plate can considerably influence the stiffness and strength of the joint.

3. Solutions for Rectangular Cross-Section Columns

3.1. Beam-to-Column with Flange Plates Connections

This type of joint was analysed by Gholami M., Deylami A., Tehranizadeh M., (2013) and involves joining the beam to the column by means of welded elements (Fig. 6).

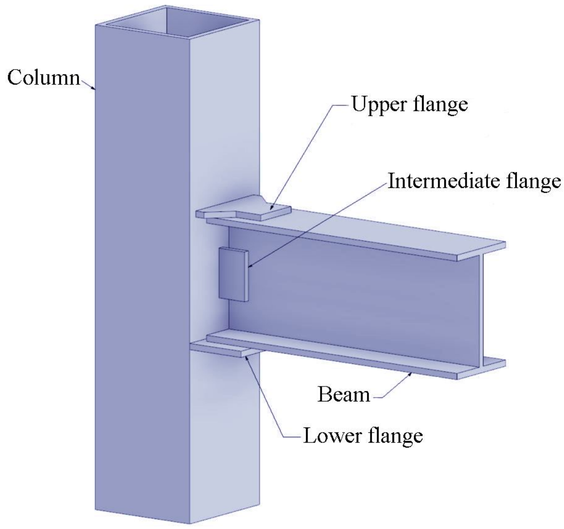


Fig. 6 – Connection with flange plates.

The joint is made up of a welded plate perpendicular to the column over which the beam is supported. The beam is welded to the plates. The lower plate has a constant width and is larger than the beam width. A plate with variable section is welded over the upper beam flange, this plate also is welded to the column. The shear force is taken by a plate that is connected to the beams web and to the column flange. This joint type increases the dissipative characteristics of the node by moving the plastic hinge to the beam due to the increase of the rigidity of the node, thus avoiding the brittle failure of the weld, while the overall height of the joint is not much larger than the beam height. Defects that may occur in welding due to site execution may be one of the disadvantages of this type of joint.

3.2. Beam-to-Column Joint with ConXL Elements.

This type of joint was proposed by Simmons R.J., (2005). Subsequently, analyses and optimizations of this type of joint were made (ANSI/AISC358-16, 2016; Alireza Rezaeian *et al*., 2014). The concept of the node starts from the idea of eliminating the need for site welding and increasing the performance of the joint. The joint is made up of an assembly of upper flanges, lower flanges, intermediate flanges, and a series of corner flanges. The lower, upper, and intermediate flanges are welded to the beam flanges. The corner flanges are welded to the column corners. All welds are executed in a workshop with a strict quality control. Due to the specific shape of the upper and lower flanges they fit perfectly with the angular flanges by means of high-strength bolts (Fig. 7).

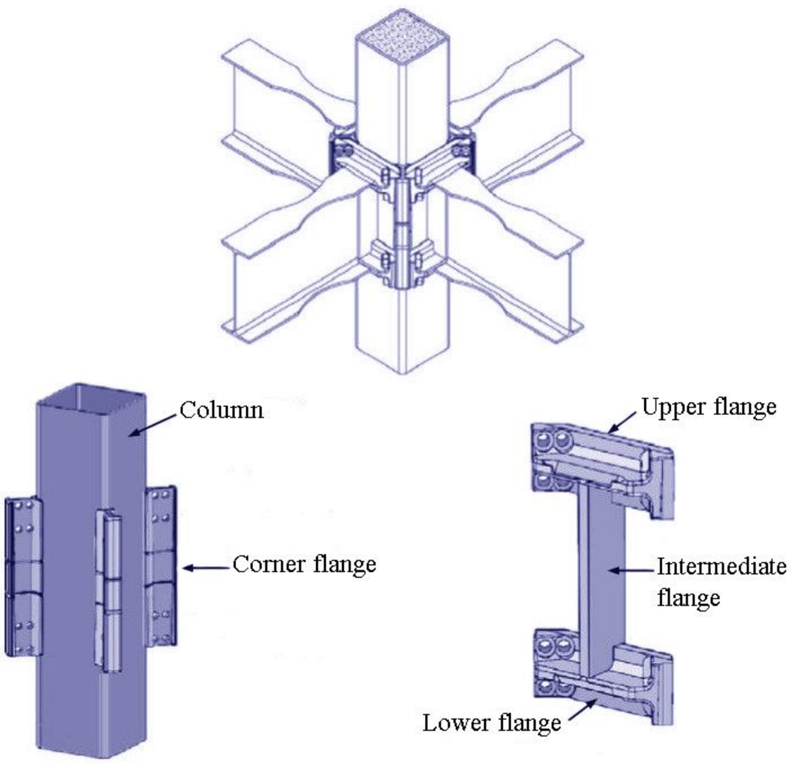


Fig. 7 – ConXL connection

This whole assembly forms a rigid casing around the column, which allows an efficient distribution of stresses, and prevents the local failure of column flanges. However, this joint requires a high degree of accuracy and precision during the execution due to the large number of joined elements.

3.3. Beam-to-Column Joint with a Short Stub Beam

This joint implies sharing the biaxial rigidity and stiffness of the column with a closed rectangular section and the flexibility and increased energy dissipation capacity characteristic of end plate joints. At the same time, the disadvantages of direct welding of the I beam to the rectangular column or the direct joint with the end plate, respectively, the poor quality of the welding performed in situ, and the difficulty or even impossible access inside the column for tightening the bolts, are excluded. Previously, some effective and reliable solutions have been proposed to solve these problems, but (Saeed Erfani *et al*., 2016) proposed a solution as simple as possible without incurring any extra costs. The joint consists of welding a short beam element (aprox. 10 cm) in a workshop, respecting all the technological requirements, in order to obtain a high-quality weld without defects. At the end of the short beam is welded an extended end plate, which has some additional connections with the column, by means of stiffeners, which represents the end plate for the column. On the other side of the end of the normal beam is welded an end plate. All weldings are therefore executed in a workshop with strict quality control, and the two end plates are connected by means of bolts on site, in short time and at minimal costs. (Saeed Erfani *et al*., 2016) proposed two types of joining that involve two ways of transmitting beam-to-column stresses (Fig. 8).

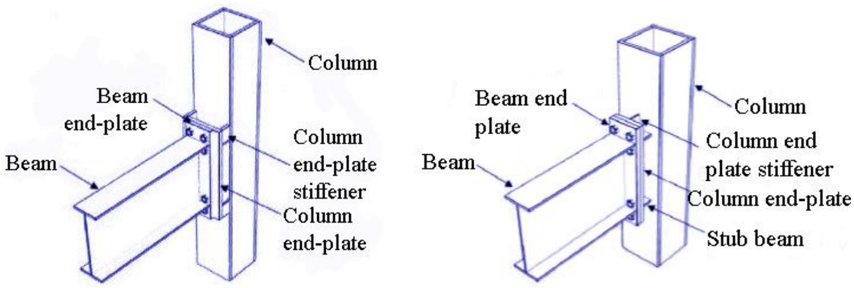


Fig. 8 – Typical configurations of connection model of connections with short stub beam.

As a result of the analyses, it has been observed that the use of the first type of joint may require continuity plates for the beam flanges in the column, in the second type, the necessity of using the continuity plates is eliminated, the beam reaction forces are transmitted directly at the perpendicular flanges of the column.

4. Conclusions

The design rules for steel structures subject to seismic actions require the dissipation of seismic energy in the elasto-plastic domain. The main condition is embedded in the expression “strong column – weak beam”, which implies the formation of plastic hinges at the end of the beams and at the base of first level columns.

It has been found that closed cross-section columns have a better behaviour under earthquakes due to the double symmetry and the distribution of the material exclusively on the contour. At the same time, the columns with this type of section can be filled with concrete, which increases their bearing capacity and increases their stiffness, and the sealing of the section, which is an indisputable advantage in the behaviour of the structure, creates some problems in the execution of the joints.

In order to follow the principle of "strong column – weak beam" and to solve the problems created in the joints, the researchers proposed several types of joints, inspired by the "classic" joints for lamellar columns, but adapted to the closed section of the circular and rectangular columns.

One of the variants is to reduce the sections of the beam flanges by adding a stiffening ring to the beams top and bottom flanges, for optimisation of stress transmission method from beam to column. Another method is involving the gradual increase of the beam section near the column. Both options create a weak area outside the column and the weld zone, which leads to the plastic hinge being formed in the beam.

In other perspective it should be mentioned the possibility of stiffening the joint by means of special flanges which prevent the formation of stress concentrations in the welding area and direct the plastic hinge into the beam. The use of special features such as those proposed by Simmons R.J., (2005), or short stub beams (Saeed Erfani *et al*., 2016) allow efficient stress distribution, which eliminates the possibility of brittle failure of the welding or forming the plastic hinge in the column.

All these joints respect the principle "strong column – weak beam" imposed by the rules for the design of steel structures.

It should be noted that the joints characteristic for the circular column can be adapted to the rectangular columns and vice versa. The possibility of using blind bolts allows the use of joints characteristic for lamellar columns.

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ÎMBINĂRI METALICE GRINDĂ-STÂLP PENTRU STRUCTURI AMPLASATE ÎN ZONE SEISMICE, CARACTERISTICE STRUCTURILOR METALICE CU STÂLPI TUBULARI

(Rezumat)

Structurile metalice sunt forte răspândite in zonele cu activitate seismică ridicată, datorită comportării ductile şi capacității de disipare a energiei; stâlpii cu secțiune tubulară au o comportare mai bună la acțiunile forțelor laterale provenite în urma mişcărilor seismice, datorită distribuției eficiente de material. Punerea la comun a acestor două elemente constituie o adevărată provocare datorită distribuției ineficiene a

efortrilor din îmbinările grindă – stâlp clasice (sudate) ceea ce crează cedări premature a pereților stâlpilor prin flambare, strivire sau voalare, ceea ce contrazice categoric principiul „stâlp puternic – grindă slabă", care dirijeaza proiectarea imbinărilor conform Eurocod 3. În acest articol au fost analizate câteva tipuri de îmbinări menite să rezolve prolema distribuției de eforturi în îmbinările grindă – stâlp şi să asigure disiparea eficientă a energiei. Imbinăile au fost împărțite în două clase diferite în funcție de forma secțiunii stâlpului: circular sau rectangular; fiecare având mod specific de proiectare a îmbinărilor. Însă trebuie menționat faptul ca ambele tipuri de îmbinări pot fi adaptate la forma corespunzătoare stâlpului folosit.