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Influence of Joint Details on the Local Ductility of Steel MR Frames

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Abstract

During the Northridge and Kobe earthquakes, numerous welded steel moment - resisting frames (MRFs) connections failed at the contact between beam and column. In order to improve the behavior of these connections, some new constructional details are proposed :(i) reducing the beam flange cross section area in the proximity of the connection (dog bone configuration); (ii) increasing the connections strength supply by stiffening the beam flanges. The rotational capacity of these connections are significantly enhanced. The paper presents the increasing of local ductility for these new constructional details, using the DUCTROT computer program.

1. Introduction

For steel moment - resisting frames under sever earthquakes, it is generally assumed in codes that the input energy is absorbed and dissipated primarily by the plastic hinges formed at the ends of beams. But the Northridge and Kobe earthquakes have shown that in some conditions, especially in the case of the near - field ground motions, this code conception does not work, a widespread brittle damage in the welded connection occurring, without any sign that some plastic deformations are produced in beams. There are many also many cases in which plastic hinges occurred in columns, due to the fact that the interaction beam - floor slab was underestimated and the plastic moment capacities of beams were greater than the column plastic moment capacities. In the aim to avoid these damage types and to constrain the developing the plastic hinges only in the beams, it is required by design practice to improve the constructional details, for which a variety of ideas have been proposed.

In the paper, the two solutions are proposed: the decreasing or increasing the moment capacity of beam ends. Taking advantage of using the so called " standard beam " and the DUCTROT computer program, the increasing of the beam ductility in function of constructional details, are proposed. The influence of gravitational and seismic loads is considered, in the aim to use the actual moment diagrams.

2. New constructional details

Since after Northridge and Kobe the reliability of the welded connections has long been questioned, it arises the idea that is better to move the plastic hinge away from the column surface, in the field were the welding does not determinate the node ductility. There two ways to obtain this purposes:

(i) **Weakening** the specific beam section near to connection by trimming the beam flanges . The idea was developed in principle in the 80's by Plumier [1] and was patented by ARBED . This solution is known also as the " dog bone " configuration [2] . The weakening can be obtained by drilled holes, poligonal cuts, with constant reduced section, curved cut with variable section, or adjusted cuts, with variable reduced section in function of the shape bending moment [3],[4],[5],[6]. Due to fact that the last one seams to be the more adequate for developing of the large plastic hinge, it will developed in the paper (Fig.1a).

(ii) **Strengthening** the specific beam near to connection by adding covering plates, lateral reinforcement plates, vertical ribs [3],[6]. These solutions move the plastic hinge away from the column face , but usually increase the amount of field welding, and may lead to very difficult welding procedures in vertical or over - head position . In the paper the solution with vertical ribs is analysed
(Fig.1b).

Considering the column - beam relation, there are two MR frame types :
(i) Weak beam - strong column (WB-SC), for which the plastic hinges are formed only in the beam ends and at column bases; (ii) strong beam - weak column (SB-WC), which develop a plastic mechanism only in the weakest storey, the plastic hinges being concentrated at the column ends . The modern conceptions of codes considers that only the WB-SC solution can offer a good ductility. That means that the moment capacity of columns must be greater than the one corresponding to the beams . But the beam moment capacity depends on the interaction of steel beam with the reinforced concrete floor, interaction which is very difficult to be quantified . Due to this fact, in many cases, the condition of global mechanism is not satisfied, plastic hinges occurring also in columns . In the aim to prevent an uncontrolled behavior , some constructional details are proposed: interruption of connectors or reinforced concrete plate in the field of plastic hinges(Fig. 2)

3. Rotation Capacity

The modern design philosophy is based on the objective to provide structures with sufficient ductility. So, the available local ductility, determined at the level of plastic hinges must be greater than the required ductility, obtained from the full structure behavior, activated by a specific earthquake. For this purpose, a methodology is determined in [7], based on the plastic rotation capacity of a standard beam, determined by the positions in actual structure of the plastic hinges and the inflection points (Fig.3a). The rotation capacity, R, is given by (Fig.3b):

$$R = \frac{\theta_{rp}}{\theta_p} = \frac{\theta_r}{\theta_p} - 1 \qquad (1)$$

Figure 1. Typical details of the analyzed beam-column connection

Figure 2. Typical details for beam-floor connections

where θ_{rp} is the ultimate plastic rotation , θ_p, the rotation corresponding to the first plastic hinge , θr, the total ultimate rotation . The rotation capacity is determined using a plastic mechanism formed by plastic zones and yield lines . A computer program DUCTROT has been elaborated at INCERC Timisoara [8] for determination of the ductility of local mechanism. The available rotation capacity is determined from the relation [7] :

$$R_{av} = \frac{r_s r_N}{\gamma_m} R \qquad (2)$$

Figure 3. Local ductility

where r_s, r_N , are numerical coefficients introducing the effect of cyclic loading and axial forces, respectively γ_m is the partial safety factor to allow for the same time uncertainties in the determining the available rotation capacity ; a value of $\gamma_m = 1,5$ is proposed .

4. Ductility of reduced - beam section

The moving of the plastic hinge away from the column flange is performed by choosing adequate dimensions for reduced section . The main geometrical parameters are presented in Fig.1 . The distance from the column of reduced section is selected in aim to avoid the deterioration of material properties at the heat - affected zone. The distance recommended in the literature [4] is sized between 50 - 120 mm . The transition lengths are chosen to avoid the stress concentrations . The length of reduced section is determined in a manner to allow the occurring of a single plastic hinge . Too short length impedes the formation of a large dissipate plastic hinge, while too long length may allows occurring of two plastic hinges producing an unexpected local beam mechanism . The length of the plastic mechanism is determined in [7] as being :

$$L_m = 0.6\left(\frac{t_f}{t_w}\right)^{3/4}\left(\frac{d}{b}\right)^{1/4} 2b \geq d/2 \tag{3}$$

For the variable reduced cross-section, a medium b value may be used . The reduction of cross-section from the moment diagram, in which the both seismic and gravitational loads must be included

The decreasing of moment capacity with 5 - 10% is proposed in the aim to ensure that yield occurs in the reduced section[4] . So the reduced plastic moment capacity for the two ends, $M_{p.red.1}$, $M_{p.red.2}$, are :

$$M_{p.red,1,2} = (0,90...0,95)Mp\left[\left(\frac{2L_{i,t}}{L}-1\right)+\frac{1}{2\alpha}\frac{L_{i,t}}{L}\left(1-\frac{L_{i,t}}{L}\right)\right] \tag{4}$$

where: L is the beam length, M_p, the unreduced plastic moment of beam, $\alpha = M_p / qL^2$, q the vertical gravitational loads . The value is limited to 0,25 because for smaller values, the maximum moment occurs away from the column face . The reduced moments, in function of gravitational loads are presented in (Fig.4). The increasing of rotation capacity, R, due to the plastic moment or width reductions is presented in Fig.5,6 . The increasing is very important, being about 55% . The importance of considering the gravitational loads results from the Fig.7, the effect being the decreasing of rotational capacity. Neglecting of this effect can be lead to choose incorrect geometrical parameters and, of course, to under estimate the rotation capacity of beam.

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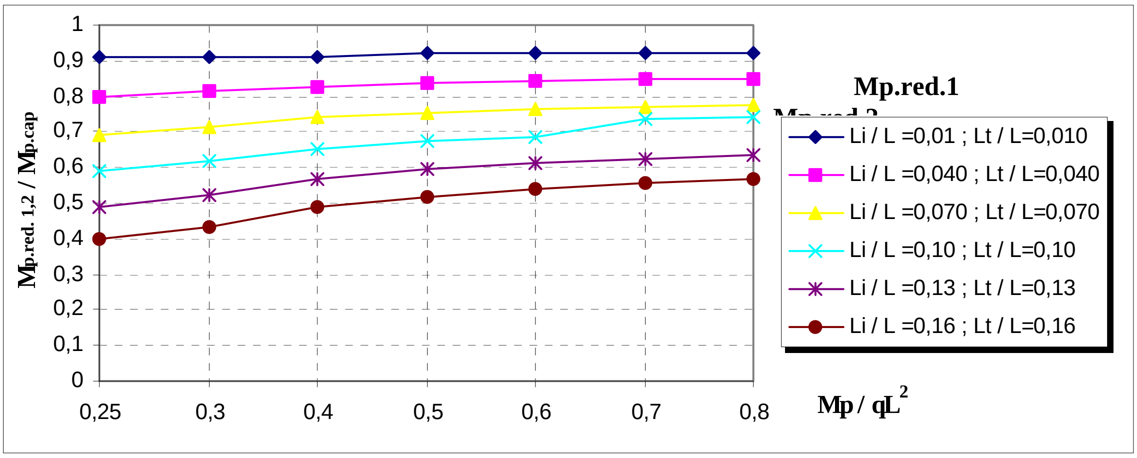

Figure 4. Reduced plastic moments

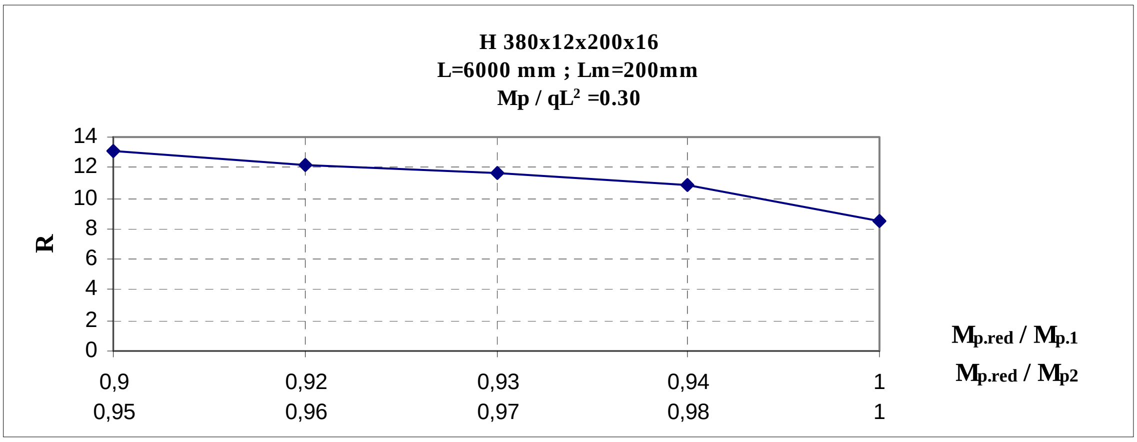

Figure 5. Increasing of rotation capacity

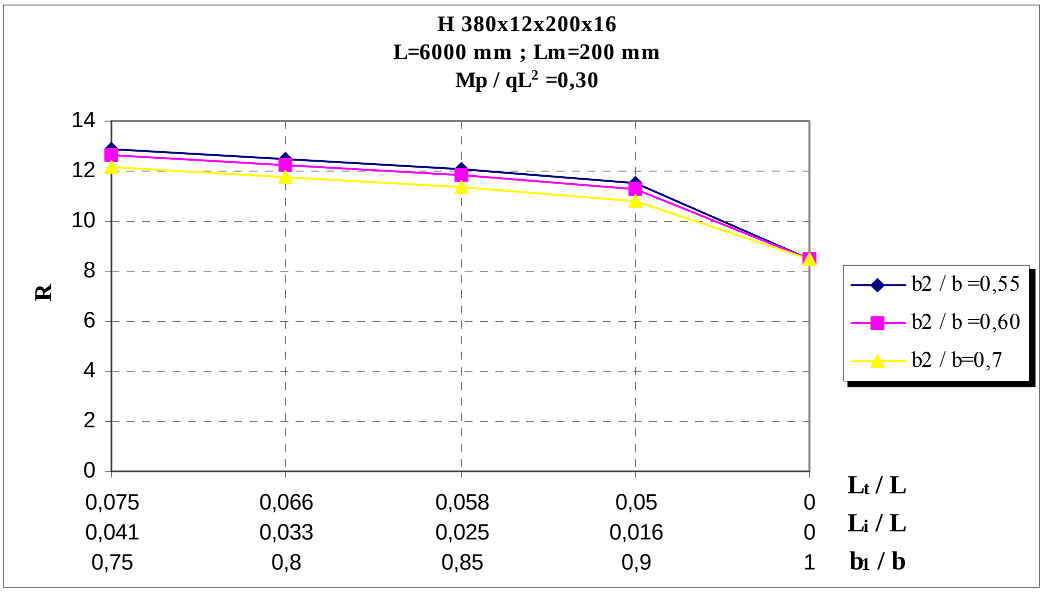

Figure 6. Influence of geometrical parameters and gravitational loads on rotation capacity

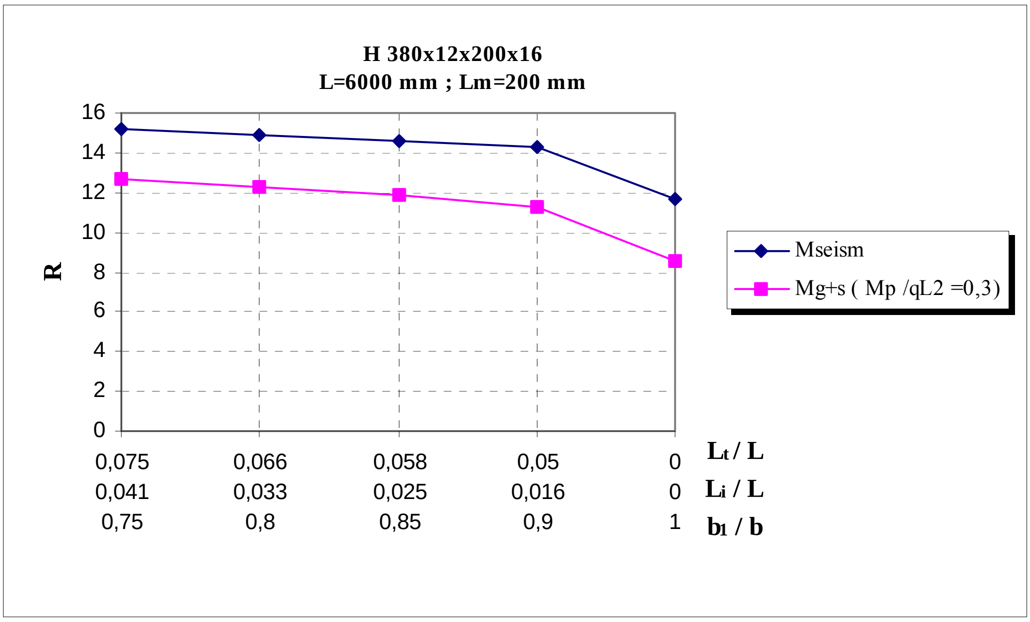

Figure 7. Influence of loading system on rotation capacity

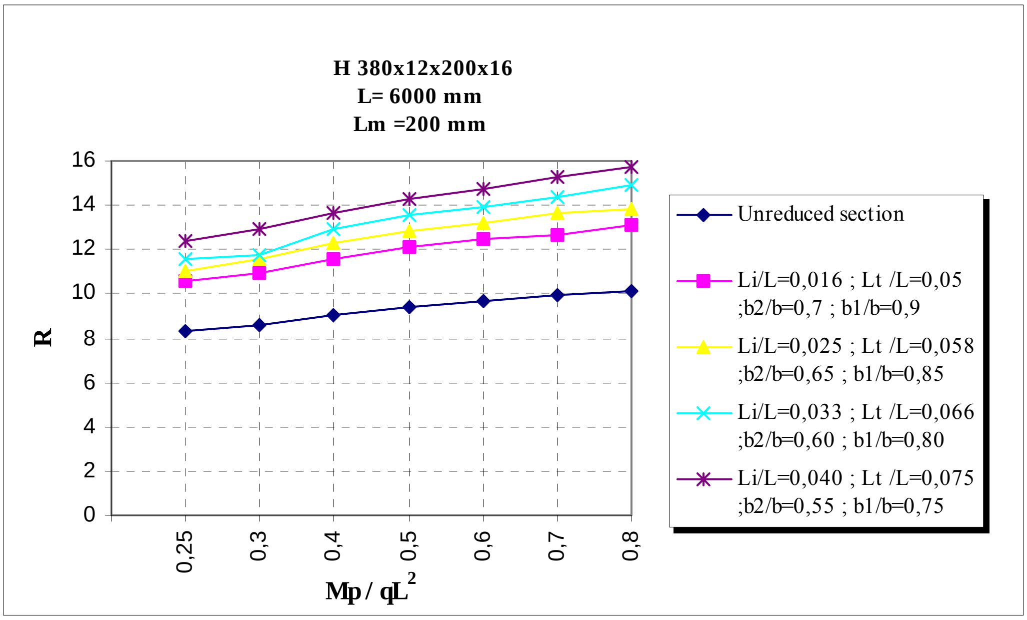

Figure 8. Influence of gravitational loads

5. Ductility of strengthened beam section

The dimensions of strengthened beam are presented in Fig.1b. For this section the plastic hinge occurs at the distance of d/3 from the edge of reinforced connection[6]. For determining the required strengthened section, it is recommended to consider different strain hardening effects for beam and strengthened sections. The over strength of reinforced beam can be of order 20-30% [7], while for the strengthened section may be only 5-10%. So, the plastic moment capacity of strengthened section must be:

$$M_{p,str} = \frac{M_p}{s}\left[\frac{1}{\left(2\,{}^{L_p}\!/_{L}-1\right)+\frac{L_p}{2aL}\left(1-\frac{L_p}{L}\right)}\right] \tag{5}$$

where the coefficient s considers the effect of strain hardening. It is recommended that s =0,75-0,65. The influence of this coefficient is presented in (Fig.9).

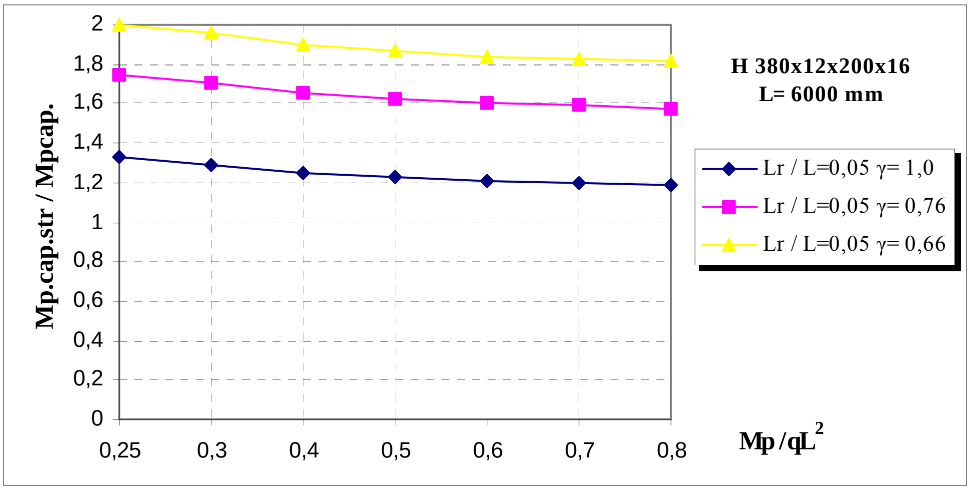

Figure 9. Effect of stain hardening

It is very clearly that the effect is to increase the required strengthening . The influence of ribs length and plastic hinges position on the rotation capacity is presented in Fig.10. One can see that the increasing of distance between column face and plastic hinges give rise to an increasing of rotation capacity of order 8%. The influence of gravitational forces on the rotation capacity is presented in Fig.11, for different rib lengths.

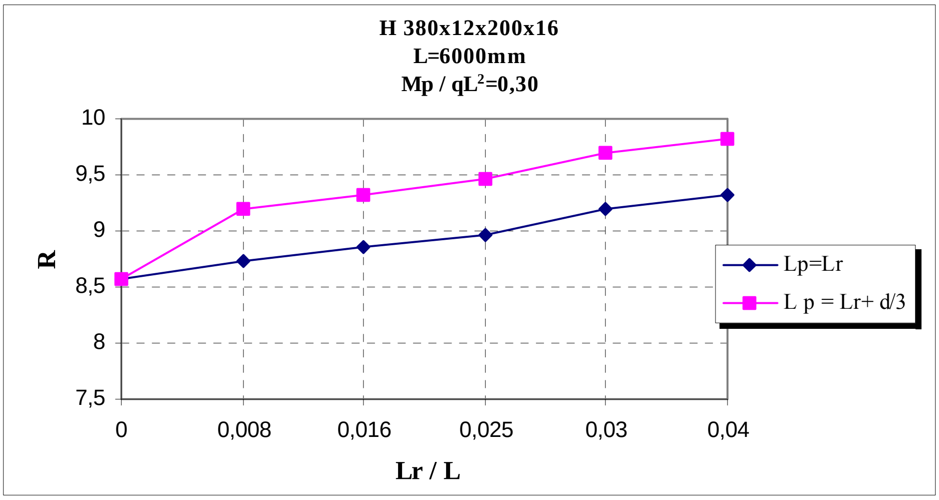

Figure 10. Influence of rib length on rotation capacity

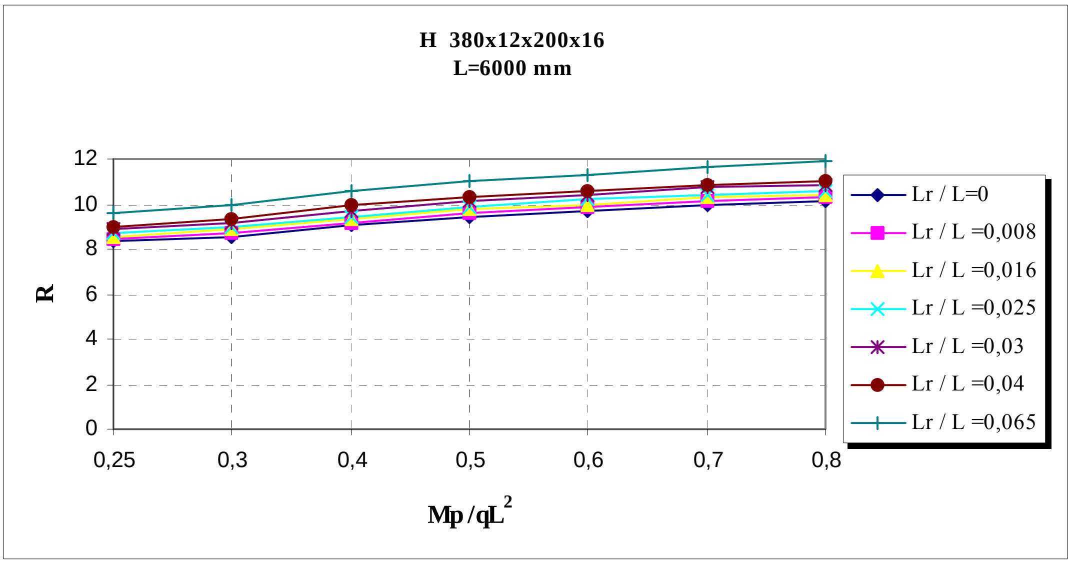

Fig. 11 Influence of gravitational loads on the rotation capacity

6. Conclusions

The weakening or strengthening of beam ends, in the aim to move away the formation of plastic hinges from column faces, is in the same time a very good solution to increasing the local ductility of beams. The weakening of cross section seems to be the most adequate solution, the increasing of rotation capacity being highest than for strengthening solution. The second solution can be effective when the welding material have sufficient toughness and the welding is executed with high quality. It is very important to consider in analysis the influence of gravitational loads, otherwise the above mentioned effect of weakening or strengthening being questionable.

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