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A Consideration on Steel Frame Classification of EC3 using Numerical Analysis.

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Abstract : Among the three well-known steel construction classification (ASD, LRFD specifications of AISC and EC3 code), EC3 code distinctly demarcated the three groups of connection with precise value. Using the data-base compiled by Kishi-Chen (1986) an effort was made to locate the real moment-rotation curves in the EC3 coded classification frame. Most of the curves found to run either from semirigid to flexible zone or rigid to semirigid zone indicating a mixed characteristics.

Introduction

In steel frames connection stiffness ranges from zero (pinned connections) to infinity (rigid connections). Zero stiffness of pinned connections implies that the connection undergoes through the necessary rotation without producing any moment and on the other hand infinite stiffness of rigid connection implies that the connection transfers moment without allowing any relative rotation . Although this orthodox classification drastically simplifies structural problems, in reality it is hardly possible to have an ideally pinned or an ideally rigid connection. In fact, all of the real connections exhibit some sort of flexibility ranging from low to high, in other words all types of connections exhibit a Moment-Rotation behavior that falls within the two extreme cases of ideal pinned and rigid connections. Inevitably a concept of classifying connections depending upon the degree of stiffness was introduced in the design specification.

The American Institute of Steel Construction listed three types of construction in the Allowable Stress Design (ASD) specifications (AISC,1989). They are rigid framing, simple framing and semi-rigid framing. Later AISC categorized two types of construction in the Load and Resistance Factor Design (LRFD) specifications (AISC, 1986): Type FR (fully restrained) and Type PR (partially restrained).

Obviously this classification was developed in general term without laying any distinct boundary lines for these two categories. European Code 3 provided a non-dimensional system of classification formatted with precise values for the boundaries between the different families. In this classification both moment axis and rotation axis are normalized with reference to full plastic moment and plastic rotation of the connected beam respectively. The location of the boundaries between rigid and semirigid (respectively full strength and partial strength) are shown in Fig.1.

In present days, in steel frame construction, the following types of connections are widely in use, they are: 1) Single web-angle/ Single plate, 2) Double web-angle, 3)Header plate , 4) Top- and seat-angle with/without web-angle, 5) Extended end-plate and 6)Flush end-plate connections. Kishi and Chen (1986) compiled a voluminous data base for experimental test data on the above mentioned beam-to-column connections. It must be important to locate the moment-rotation curves of real connections in the EC3 classification graph. In this study, using the data base

compiled by Kishi and Chen (1986), a verification on the level of rigidity of different connections was made in the light of EC3 code. Furthermore, executing numerical analysis for one-bay one-story unbraced frame with various connection test data, we tried to consider the EC3 criteria of locating different connections with respect to stiffness in real connections.

Eurocode 3

Eurocode 3 popularly known as EC3, classified beam-to-column connections on the basis of i)moment resistance ii)rotational stiffness. The following discussion is kept limited within the later classification system. In this classification system, similar to AISC specification, EC3 mentioned three types of connection viz., i) rigid ii) semirigid and iii) nominally pinned or flexible. The difference with AISC specification is that EC3 drew clear demarcation with precise values among these three groups. Besides EC3 recognizes the wide variation of semirigid action depending upon the type of structure such as braced or unbraced frame. Thus EC3 provided two different classification system both for braced and unbraced frame.

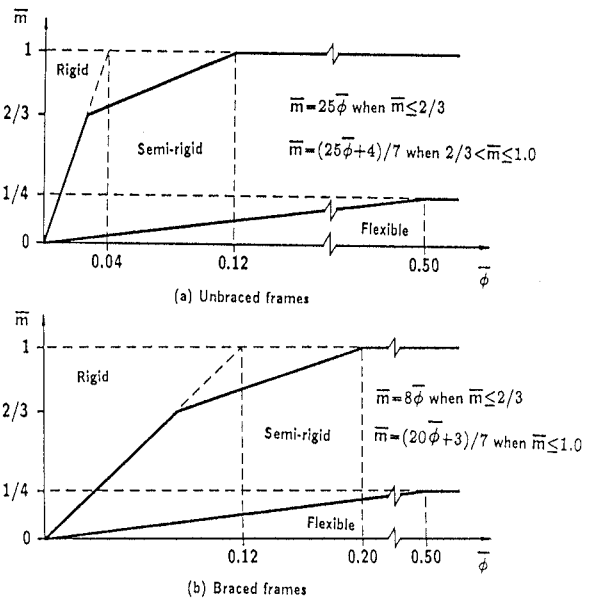


Figure 1. EC3 Classification System

For graphical representation, moment axis is nondimensionalized with reference to the full plastic moment of the connected beam (M_p) i.e., $\overline{m}=M/M_p$ and the rotation axis is nondimensionalized with reference to the plastic rotation ϕ_p i.e., $\overline{\phi}=\phi/\phi_p$ with $\phi_p=M_p/(EI/L_b)$ where L_b and EI are the length and the bending rigidity of the connected beam respectively. Boundary line between semi-rigid and rigid region consists of a tri-linear line and for semirigid to flexible region the code divided the region by an axially bilinear leaned line.

Figure 1 shows the three types connection classification for braced and unbraced frames.

The numerical values for the boundaries, regarding the stiffness, have been chosen in order that the drop in carrying capacity, due to the semi-rigid action, will be not more than 5% (in terms of Euler buckling load). Regarding the strength, the full plastic moment of the beam is the boundary. Furthermore there is a cutting off of the knee on the bilinear diagram, because the bilinear diagram is too much severe due to the general non linear curves of most of the connections.

On the other hand, the boundary between semi-rigid and flexible connection is i) 0.5 EI_b/L_b in terms of stiffness and ii) 0.25 M_p in terms of strength.

Comparison between EC3 classification and real connection test data

In EC3 classification system the rigidity of connection has been defined on the

basis of prescribed concept.

Generally, Single web-angle, Double web-angle and Header plate connections are classified as flexible connection and Top- and seat-angle with/without double web-angle connections are mentioned as semi-rigid connections. Extended and Flush end-plate connections are said to be included in rigid connection type.

However, till date these general classification are never numerically justified. Here, we will try to compare between EC3 classification of connection and real connection test data. Nondimensional $M-\phi$ curves of real test data are superimposed on the EC3 classification diagram as shown in Fig.2. Conversion of real $M-\phi$ curve into a nondimensional one is executed by assuming the connecting beam length L_b =300 in and un-altering the beam section used in each corresponding experiment. In the Figure 2., to separate semi-rigid region from rigid region two trilinear curves are drawn. One is for braced frame (the dashed line) and the other one is for unbraced frame (the bold line). The axially leaned bold line divides the region into semirigid and flexible for both braced and unbraced frame.

The following discussion encompasses the cases both for braced and unbraced frame.

1) Single web-angle/Single plate connections : A significant number of $\overline{m}-\overline{\phi}$ curves initially lie in the semi-rigid region and then with rotation increment the curves enter into flexible region, which implies that at the begining of loading the connections behave like a semirigid connection but later, with increasing load the behavior changes into flexible connection.

On the other hand a good number of curves absolutely lie in the flexible region. Maximum moment-capacity for the stiffest curve seems to be 1/10th of M_p which is much much lower than $0.25M_p$, upper limit for flexible connection according to EC3 code. The meaning of these fact are simple, that the weight to put this connection in the category of flexible connection is clearly high.

2) Double web-angle connections : Even though the level of rigidity is greater than that of Single web-angle/Single plate connections, very few $\overline{m}-\overline{\phi}$ curves absolutely lie in the semirigid zone. The distributions of $\overline{m}-\overline{\phi}$ curves display a mixed character of flexible and semi-rigid connections. Moreover, there are a significant no. of connections having limited rotational capacity.

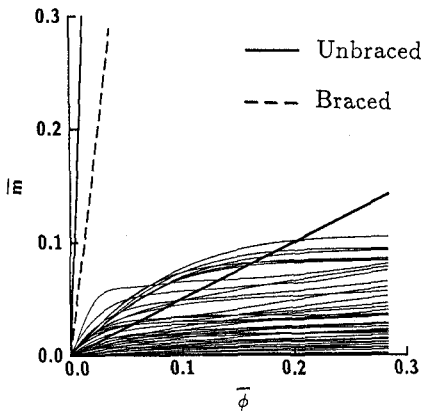
3) Header plate connections : The distribution of $\overline{m}-\overline{\phi}$ curves display a more or less same character with that of Double web-angle connections. Only the difference is that there is no curve having limited rotational capacity.

4) Top- and seat-angle with double web-angle connections : The $\overline{m}-\overline{\phi}$ figure displays a mixed behavior of rigid and semirigid connection. Some connections are purely semirigid but some display a high stiffness at initial level of rotation then dissipating the stiffness, $\overline{m}-\overline{\phi}$ curves enter into the semirigid region. In EC3 code this behavior is mentioned as rigid having partial strength. The moment capacity varies from 1/5 M_p to 4/5 M_p while the rotation capacity is sufficient.

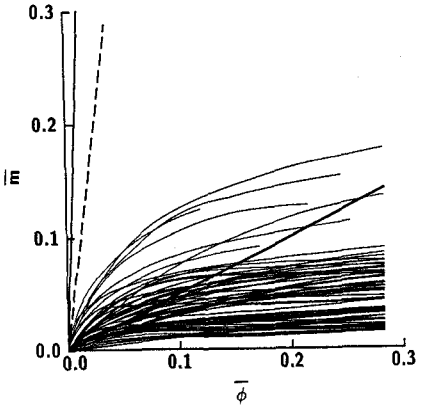
5)Top- and seat-angle without double web-angle connections : The moment-rotation characteristics are almost same as that of previous connections. The exceptions are : These types of connection clearly display a comparatively low level of rotational capacity and moment capacity . The moment capacity ranges from 1/10 M_p to 1/2 M_p.

6) Flush end-plate connections : With few exceptions, this connection can be classified as a semirigid connection.

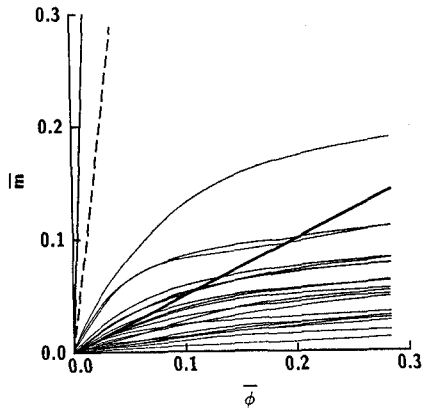
7) Extended end-plate connections : This is the stiffest connection among the seven type of connections. Even then, $\overline{m}-\overline{\phi}$ figure meagrly justify that it's a pure



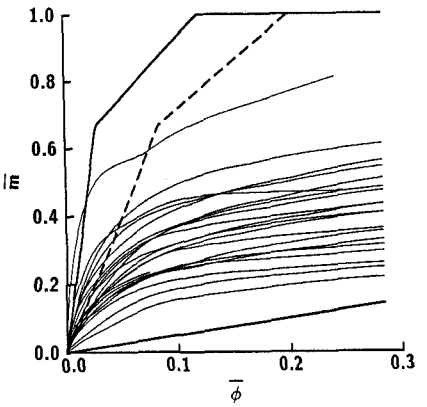
(a) Single web angle/plate



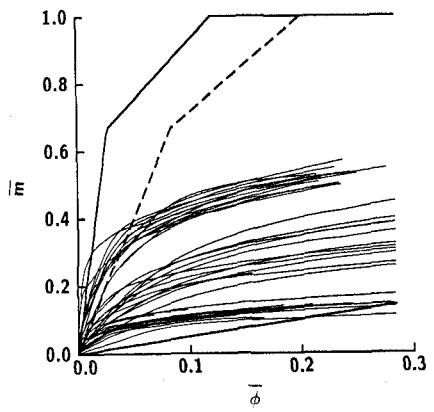
(b) Double web angle



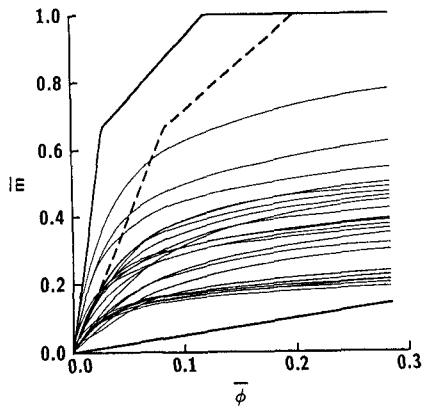
(c) Header plate



(d) Top and seat angle with double web angle



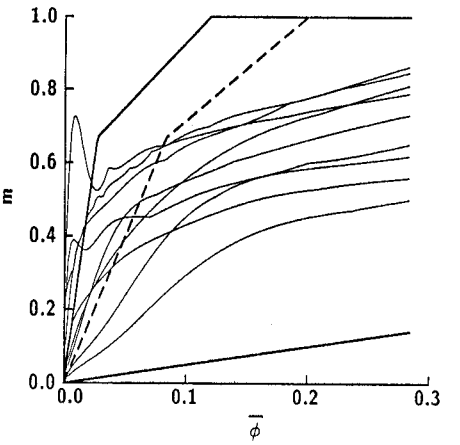
(e) Top and seat angle without double web angle



(f) Flush end plate

Figure 2. Comparison between EC3 and real $\overline{\mathbf{m}}-\overline{\phi}$ curves

rigid connection. Similar to Top- and seat-angle connections these connection also has a high initial stiffness then loosing stiffness, these connections start to behave as semirigid connection. The moment capacity is quite high ranging from 2/5 M_p to 9/10 M_p , and rotation capacity is sufficient.



(g) Extended end plate

Figure 2. (Contd.)

Numerical Analysis

To classify real connection test data on the basis of EC3 code, numerical analysis using flexibly jointed frame are executed. A general view of 1 bay 1 story is shown in Fig.3. For columns and beam of the frame W10x39 and W14x22 members are chosen. Three types of connections: Single web angle, Double web-angle and Header plate connections are studied. Other types of connections are excluded from this study as because they are directly affected by the beam size. 20 psf roof dead load, 20 psf roof live load and 20 psf wind load are employed. Calculations for sway frame are carried both for service load (D+L) and factored load (1.2D+0.5L+1.3W). Building drift are considered at service load and end moments at factored load. For analytical method, second-order elastic analysis developed by Goto-Chen(1987) is used, in which geometrical nonlinearity and nonlinear M$-\phi$ relation of connection are considered.

Numerical results and discussion

A comparison is made numerically between the above mentioned three types of real test data and EC3 classification. For space limitation, only the results of Single web angle connections are discussed here.

Fig.4. shows the comparison of building drift at service load which is obtained

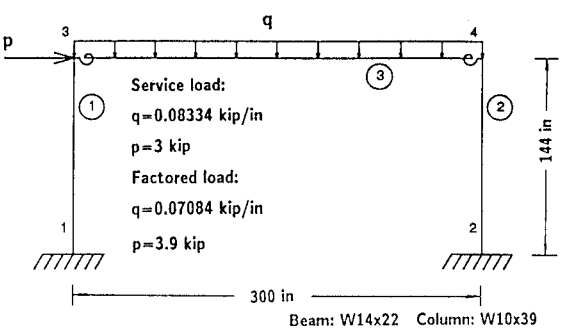


Figure 3. 1 Bay 1 Story Frame

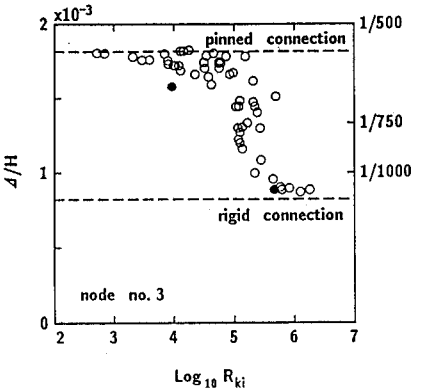


Figure 4.

from the ratio of Δ/H with respect to $\log_{10}R_{ki}$. In this figure, the area enclosed by the fine thread lines denotes the semirigid zone. Upper and lower lines of the area are the boundaries of flexible and rigid zone respectively. As evident in the figure, about 40% of test data of Single web-angle connections belong to EC3 semirigid connection. Figure 5 shows the result of end moments in case of surcharging factored load. Figures (a) and (b) of Fig. 5 are for node no. 1 and 3 . Both the figures show that the data gradually shift from pinned to rigid connection with increasing initial stiffness $\text{Log}_{10}R_{ki}$. The number of test data lie in the semi-rigid region for node 3 is greater than that of node 1. However, for both nodes, more than 50% test data are found to lie in the semirigid region of EC3 classification system.

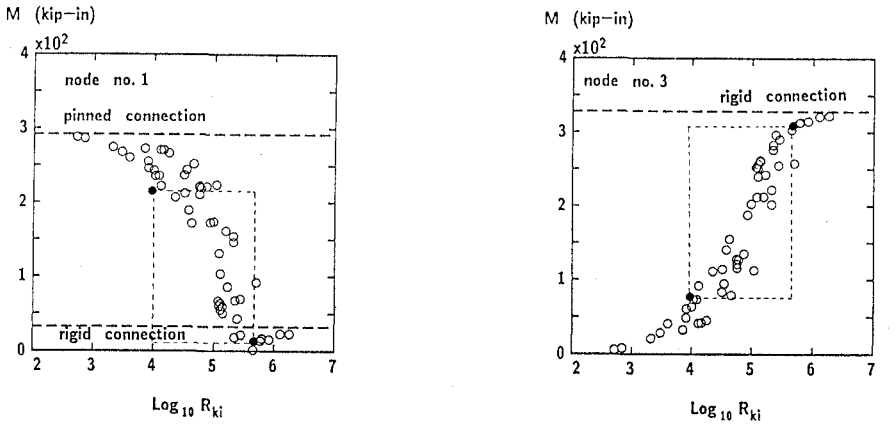


Figure 5.

Conclusion

It is obvious from the above discussion that with respect to EC3 classification system, except Flush end plate connection, no connection out of seven connection types can be figured out as purely flexible or purely semirigid connections. Rather it reveals that they bear a mixed characteristics either of i) flexible semirigid or ii) semirigid-rigid connections. Single web-angle/plate, Double web-angle connections fall in the 1st category while Extended end-plate connections fall in the 2nd. Top- and seat-angle connections lie in the midway.

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