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Faculty of Civil Engineering and Geosciences
Structural and Building Engineering
Steel Structures

Requirements for column cap connections used in plastically designed continuous steel beams

Archives
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Technical Note 6-11-1 by:

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May 2011 (revised version)

1 Introduction

One of the most common types of beam-to-column connections in steel building construction is the beam bearing on column, or cap connection. This type of connection is often overlooked by the design engineer. It is usually fabricated with a steel plate that is fillet welded at the top end of a column. The length of the cap plate is selected to provide sufficient space for bolting. The connecting beam is set on top of this plate and bolted into place.

An application of this connection type can be found where columns are required to support the vertical reaction in continuous beams. Support conditions are represented in the structural model by restricting the movement of the specific joints in specific directions. In most cases, this connection is treated as a pin and is designed to transfer the bearing force from the beam. Assumed pin or simple connections must be carefully detailed to prevent inadvertent moment capacity. If this care is not taken, significant moments can be introduced into columns even by notional simple connections.

The objective of this note is to develop recommended details of cap connections in continuous beams bearing on slender columns. In this case, column instability may occur as a consequence of significant axial compressive load. Because the end connection stiffness and column instability are closely related to each other, their interaction effects can have significant effects on the overall system performance. It may be necessary to add extra stiffness to the connection detail to reduce the likelihood of collapse. The design implications of this latter approach are discussed below. First, we compute the maximum load sustained by a continuous uniform beam in the framework of a mechanism analysis. A review of the principles of plastic design is included in this introduction section.

1.1 Principles of plastic design

The methods of plastic analysis and design are based on the two following basic assumptions:

1. the structure is made from a ductile material such as steel that is able to accommodate large plastic deformations; and

2. the deformations of the structural system under loading are small such that the effect of this on the overall geometry may be neglected.

To simplify the analysis we further assume that the actual stress-strain relationship of steels is idealized as an elastic-perfectly plastic type, as shown in Fig. 1.1. Up to the yield stress level, f_y, the material is elastic. After the yield stress level is reached, the strain is assumed to increase infinitely without any change in stress. So the material is assumed to be elastic-perfectly plastic.

2 Mechanism analysis of a two-span continuous beam

Consider the two-span uniform beam shown in Fig. 2.1a. w is the uniformly distributed load. We wish to find the value of w at collapse (w_{max}) from the analysis of a virtual mechanism in which the members remain perfectly straight between plastic hinges. These can be formed at sections B, C and D (Fig. 2.1b). The location of sections B and D is not so obvious. The upper-bound theorem implies that we must consider all possible positions of these hinges and choose that which gives the lowest load factor. This can be done by choosing an arbitrary hinge position defined by the variable x, as shown in Fig. 2.1b and using methods of calculus. Because of symmetry and the fact that the collapse of any span in continuous beams is independent of the adjacent spans, sections B and D are symmetric.

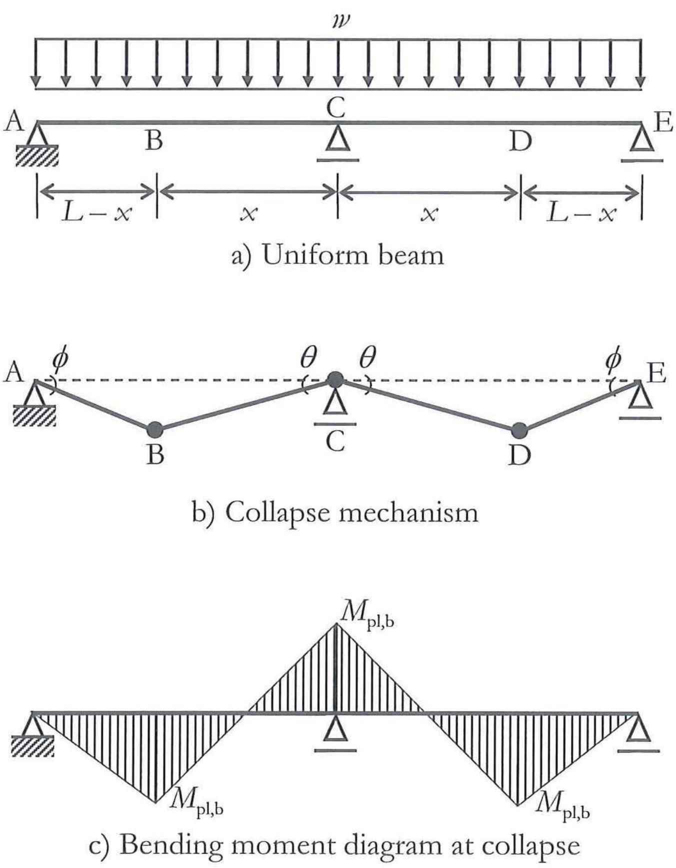

Fig. 2.1: Mechanism analysis of a two-span continuous beam

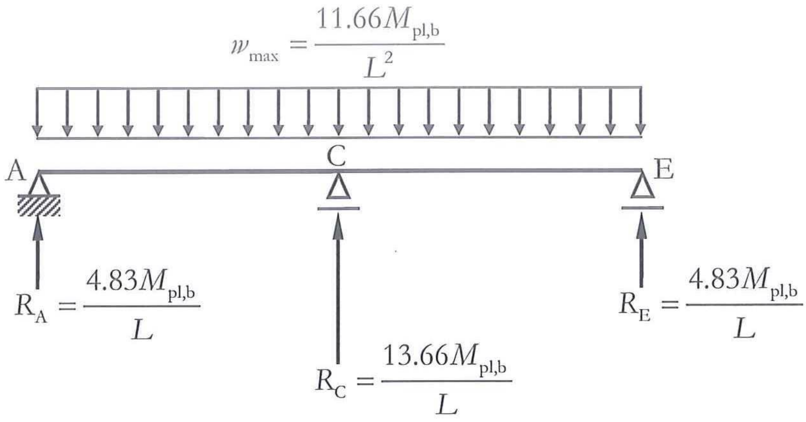

Fig. 2.2: Reaction forces

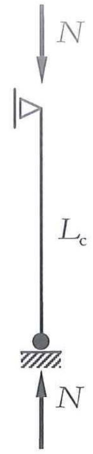

Fig. 2.3: Internal column

and the critical buckling load $N_{cr,c}$ is given by

$$N_{cr,c} = \frac{C\pi^2 EI_c}{L_c^2} \tag{2.12}$$

whereby A_c: area of the column cross-section;
I_c: second moment of area of the column cross-section;
L_c: column length;
E: Young modulus;
C: end fixity factor, which depends on the type and degree of restraints at the column ends. (This factor is equivalent to the so-called effective length $L_{eq} = KL_c$ of a column with arbitrary end conditions, which represents the length of the equivalent Euler column; $C = 1/K^2$.)

To comply with the restraints at the internal support and assuming that the column base does not transmit moment from the steel column to the concrete foundation, the column is then modelled with pin-ended restraints, as shown in Fig. 2.3. In this case, the end fixity factor is equal to unity.

The column has to be designed to transmit the reaction force R_C, given by Eq. (2.10), and to satisfy the two conditions from Eqs. (2.11) and (2.12). Eq. (2.11) requires the column section to have an area at least equal to

$$A_c \geq \frac{13.66 M_{pl,b}}{L f_{y,b}} \tag{2.13}$$

The stability requirement, from Eq. (2.12), requires the column section to have a second moment of area at least equal to

$$I_c \geq \frac{13.66 M_{pl,b}}{\pi^2} \frac{f_{y,b}}{E} \frac{L_c^2}{L} \tag{2.14}$$

3 Design guidance on column cap connections

In practice, the beam spans are often designed as simply supported members, as shown in Fig. 3.1. According to this design method, the internal column has to carry a support reaction equal to

$$R^*_{C,l} + R^*_{C,r} = R^*_C = \frac{8M_{pl,b}}{L} \tag{3.1}$$

However, the column has to transfer a higher axial load, as given by Eq. (2.10). The cap connection at section C cannot be designed as a hinge. Such connection must have some stiffness in order to provide this extra column resistance (Fig. 3.2). In this figure, the column of length L_c is spring-supported at the top end ($K_\theta > 0$ is the rotational spring constant). The end fixity factor C is now higher than 1. The maximum value is $C = 2.045$, for the case of one end fixed ($K_\theta \rightarrow \infty$) and the other simply supported).

3.1 Details of the column cap connection

The method of connection must be compatible with the design requirements and the structure of which it is part. The axially loaded column discussed above must develop strength of magnitude

$$\frac{13.66M_{pl,b}}{L} \tag{3.2}$$

as given in Eq. (2.10). The end fixity factor that complies with this requirement is therefore calculated as

$$\frac{C\pi^2 EI_c}{L_c^{\ 2}} = C \times \frac{8M_{pl,b}}{L} = \frac{13.66M_{pl,b}}{L} \Leftrightarrow C_{min} = 1.708 \tag{3.3}$$

A safe approach is to design the column cap connection as rigid ($C = 2.045 > 1.708$). An appropriate arrangement is shown in Fig. 3.3. The supporting column is fitted with a cap plate and the beam or truss bears directly on this, and is secured by bolts. A thin cap plate that is proportional to the beam flange thickness should be chosen to improve the connection ductile behaviour. The thickness of the cap plate still has to be checked to resist the uniformly distributed bearing force transferred from the beam. The bolts are selected to be compatible with the size of the beam and the column. Local stiffening can also be provided to the column web, as shown in Fig. 3.3, with some provision for minimizing eccentricity.