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Evaluation of existing provisions for design of "pinned" column base-plate connections

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ABSTRACT

Low-rise metal buildings are used in all geographic locations, including high seismicity regions. In the design of low-rise metal building systems, column base connections are commonly modeled as pinned supports with no rotational stiffness or moment capacity. However, past studies have indicated that base connections, which are designed as pinned supports, exhibit a non-negligible level of rotational stiffness and strength. Neglecting the rotational stiffness of the base connection may result in a significant overestimation of the lateral displacement of the frames. This additional displacement is addressed by increasing the flexural stiffness of the frame members thereby increasing the cost of low-rise metal buildings. The moment capacity may similarly be exploited for strength design. However, there is a lack of design guidelines to support the use of rotational stiffness or moment capacity at the pinned column bases. This study evaluates the applicability of existing code-formulations to pinned colum base-plate connections. Both the rotational stiffness and the moment capacity from past experiments are compared with those calculated based on the provisions of the European and American design codes. It was found that the Eurocodes do not accurately estimate the rotational stiffness of the connections. A modification to the Eurocodes is recommended to capture the characteristics of pinned connections. It was also observed that the moment capacity of the connections was conservatively estimated by the existing codes.
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1. Introduction

Moment-rotation (M-θ) curves are typically used to characterize the behavior of column base-plate connections. These curves are generally empirical in nature. Prior research indicates that the use of "fully-restrained", "partially-restrained" or "pinned" connection details at the column bases may lead to a significant variation in the stiffness and strength of the frames [3, 4, 12, 13, 17, 29, 35]. Additionally, it has been observed that the assumption of zero rotational stiffness of the column base-plate connection results in a significant underestimation of the overall lateral stiffness of horizontally loaded moment frames, leading to less economical designs [4, 13, 20]. For this reason, numerous studies have been performed to investigate the overall behavior of column base-plate connections and to estimate their rotational stiffness and moment capacity [9, 12, 15, 17, 18, 21, 25, 27, 30, 32–34].

Murray [22] was the first to propose a method to design column base-plate connections subjected gravity and uplift loads. However, in addition to the gravity loads, the column base-plate connections are, in certain cases, expected to withstand wind loads without failure of any of the connection components (e.g., anchor rods, base-plate, concrete foundation). An acceptable approach is to compare the available strength of each connection component with the strength demand. For example, the axial tension is expected to be sustained by the anchor rods, the bending moments by the base-plate and the bearing stresses by the concrete foundation. When the column base-plate connections are designed for seismic loads, the inelastic cyclic behavior also needs to be checked and accounted for.

Currently, in the United States, column base-plate connections are typically designed according to the American Institute of Steel Construction (AISC) Steel Construction Manual [2], while in Europe, Eurocode 3 [6] is used for the same purpose. AISC Design Guide 1 [14] is a supplementary guideline to the AISC Steel Construction Manual [2] and includes provisions for strength design according to the Allowable Stress Design (ASD) and the Load and Resistance Factor Design (LRFD). Eurocode 3 [6] also provides a step-by-step procedure for calculating the rotational stiffness of column base-plate connections. This procedure follows the component-based method, in which the connection is considered to be a combination of individual components. However, the AISC Steel Construction Manual [2] and the AISC Design Guide 1 [14] only include strength design and no provisions for rotational stiffness calculation. In Canada, the column base-plate connections are designed according to Canadian Institute of Steel Construction (CISC)

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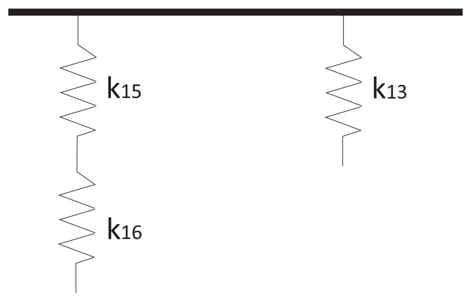

Fig. 1. Mechanical model of the column base-plate connection adopted in Eurocode 3 [6] Section 6.3.

Handbook of Steel Construction [7], which follows a very similar procedure to that in AISC Design Guide 1 [14].

The design of column base-plate connections follows that of the beam-to-column connections in many aspects. The fixed column base-plate connections (with the anchor rods outside the flanges) are most extensively studied in the literature among other types of column base-plate connections, and therefore, the code formulations are mainly intended for fixed connections. As a result, in most cases, assumptions need to be made in order to design a "pinned" column base-plate connection (anchor rods inside the flanges) according to the current code provisions. The current code formulations for calculating the moment capacity and rotational stiffness of the base-plate connections are described in the following sections.

2. Objectives and scope of the paper

The column base-plate connections examined in this research are widely used in metal building industry in the United States and around the world. As mentioned previously, the applicability of the current design guides in the United States, Europe and Canada to calculate the rotational stiffness and moment capacity of the pinned column base-plate connections is not clear. The purpose of this paper is to provide some quantitative data on this matter using direct comparisons with experimental data on such connections from the literature. It is anticipated that the findings from this research will guide practicing engineers and researchers in using and developing new formulations to design low-rise metal buildings with due consideration of the rotational stiffness and strength given to the pinned column base-plate to foundation connections.

3. A Review of existing design provisions

As mentioned previously, in the United States, the AISC Design Guide 1 [14] is used for column base-plate connections, which includes provisions for strength design. American Concrete Institute (ACI) 318 Appendix D [1] is referenced for the design of the reinforced concrete foundation and the embedment requirements for the anchor rods. AISC Design Guide 1 [14] is used to calculate the base-plate thickness of the connections subjected to compressive and tensile axial loads, small and large moments, and shear. AISC Steel Construction Manual [2] is used alongside the AISC Design Guide 1 [14] to calculate the moment capacity. Anchor rod rupture, concrete crushing, flange yielding, and web yielding are considered as the limit states in the moment capacity calculations. The moment capacity is then determined as the minimum obtained from these limit states. On the other hand, Eurocode 3 [6] has provisions to calculate the rotational stiffness of the column base-plate connections in addition to the moment capacity. Specifically, the moment capacity of the connection is calculated following a similar procedure to that in the AISC Steel Construction Manual [2]. Section 6.3 of Eurocode 3 [6] provides a step-by-step procedure for calculating the rotational stiffness. This procedure is based on the component method, in which, the connection is considered to be composed of a number of individual components. In the following sections, the provisions for the design of column base-plate connections are presented in more detail.

3.1. Rotational stiffness

Eurocode 3 [6] Section 6.3 provides a step-by-step procedure to calculate the rotational stiffness of column base-plate connections. This procedure follows the component-based method, in which the connection is considered to be composed of a number of individual components: the reinforced concrete foundation, the steel base-plate and the anchor rods. The stiffness is determined using a mechanical model of the components of the connection. Accordingly, the base-plate is modeled as a rigid bar connected with three springs (see Fig. 1). Each one of the springs represents either the stiffness of the concrete, the anchor rods, or the base-plate in tension. The springs representing the anchor rods, k_{16}, and the base-plate in tension, k_{15}, are in series and they are in parallel with the spring representing the concrete, k_{13}, all of which are connected to the rigid base-plate. The stiffness coefficient of the spring representing concrete in compression (including grout) is given by

$$k_{13} = \frac{E_c \cdot \sqrt{b_{eff} \cdot l_{eff}}}{1.275 \cdot E} \quad (1)$$

where E_c is the Young's modulus of the concrete, E is the Young's modulus of the steel, b_{eff} is the effective width of the T-stub flange (see Fig. 2), and l_{eff} is the effective length of the T-stub flange (see Fig. 2). Please note that the figures are modified here, as needed, to show the authors' interpretation of how these variables would be applied for pinned base-plate connection design, as it was mentioned previously that the code formulations are intended for fixed connections.

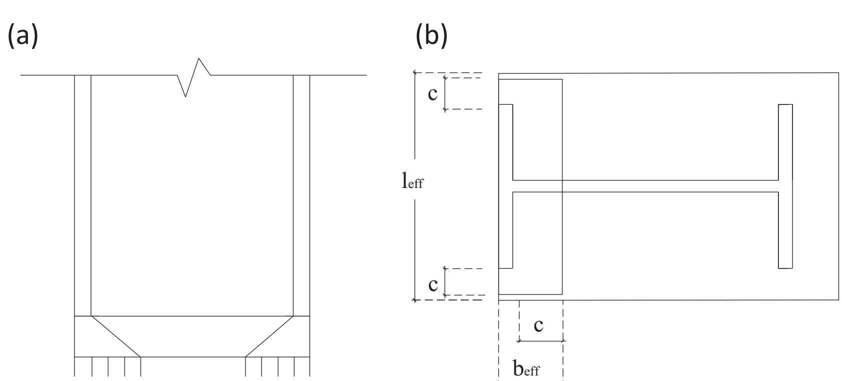

Fig. 2. Area of equivalent T-stub in compression for large projection: (a) elevation view, (b) plan view.

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