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Capacity of exposed column base connections subjected to uniaxial and biaxial bending moments

Mohammad Ali Khaksar Fasaee [a,c], Mohammad Reza Banan [a,*], Sina Ghazizadeh [b]

[a] Department of Civil and Environmental Engineering, Shiraz University, Shiraz, Iran
[b] Department of Civil & Environmental Engineering, University of Alberta, AB, Canada
[c] North Carolina State University, Raleigh, NC, USA

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ABSTRACT

Current guidelines do not address the design of column base connections under combined biaxial bending moment and axial load. An analytical study is conducted to develop a biaxial moment-axial load interaction curve for design of exposed, unstiffened column base plates. First, a 3D finite element analysis model is developed for these connections. The response of the model is validated through a series of existing experimental data. Next, the model is used to investigate the response of a few connections subjected to various biaxial moments and axial loads. Based on simulation results, a simple and reasonably accurate interaction equation is proposed. Since the uniaxial capacities of the connection are involved in the interaction curve, an analytical method for predicting the uniaxial capacities, is also presented. This analytical method, which is based on formation of plastic mechanisms, is able to predict the strength of flexible base plates with high accuracy. The behavior of exposed base plates with I-shaped columns under minor-axis moments is also studied. Findings of this study assists practitioners with a reliable and convenient column base connection design.

1. Introduction

In steel structures, column base connections transfer the column loads to the foundation. Response of column base connections affects the ductility demands and force distribution in the structure [1, 2]. Failure of these connections can even trigger the whole frame collapse. Despite the importance, some aspects of design of these connections are not well addressed in the literature.

Fig. 1 shows a typical exposed, unstiffened base plate, which is commonly used in design practice. Major part of the studies conducted on this type of connection focused on either the capacity or rotational stiffness of it under uniaxial (major-axis) moments. The early experimental programs [3–8] and analytical studies [9–15] led to the development of current design guidelines, such as the Steel Design Guide One [16], published by the AISC. The methods outlined in this design guideline assumes that the connection reaches its capacity when one of the components touches its limit state. A recent study conducted by Gomez et al. [18] showed that this assumption can be highly conservative for flexible base plates. The strength and behavior of flexible plates are controlled by interactions between different components at the inelastic stage.

This issue motivated researchers to study the inelastic response of such connections. Kanvinde et al. [19] developed a finite element (FE) analysis model to study the internal stress distribution of column base plates subjected to axial load and uniaxial (major-axis) bending moment. Trautner et al. [20] investigated the effect of anchor rods on the post-yield behavior, rotation capacity, and ultimate strength of column base connections. Rodas et al. [21] discussed the potential of exposed base plates as energy dissipative elements. Latour and Rizzano [22] presented an analytical model for rotational capacity by considering the plastic mechanisms. To increase the strength prediction accuracy of eight-rod connections, Kanvinde et al. [23] refined the Steel Design Guide One assumptions by incorporating the inner rods force in an explicit way. The highest accuracy for characterizing the strength of flexible base plates can be attributed to the method proposed by Gomez et al. [18]. In this mechanism-based approach, formation of different plastic mechanisms are considered, and the connection capacity is calculated. Despite the high accuracy, this method is not quantitatively expanded to be used by design engineers.

Mentioned studies investigated the response of base plate under uniaxial (major-axis) bending moment and axial load. Many base plates may be subjected to biaxial bending moment in real-life construction due to the bidirectional effects of seismic and wind loads. The axial load-biaxial moment interactions are not addressed properly in the literature for these connections. Presence of biaxial bending compromises the strength of connection, especially when an I-shaped column is used

* Corresponding author.
E-mail address: banan@shirazu.ac.ir (M.R. Banan).

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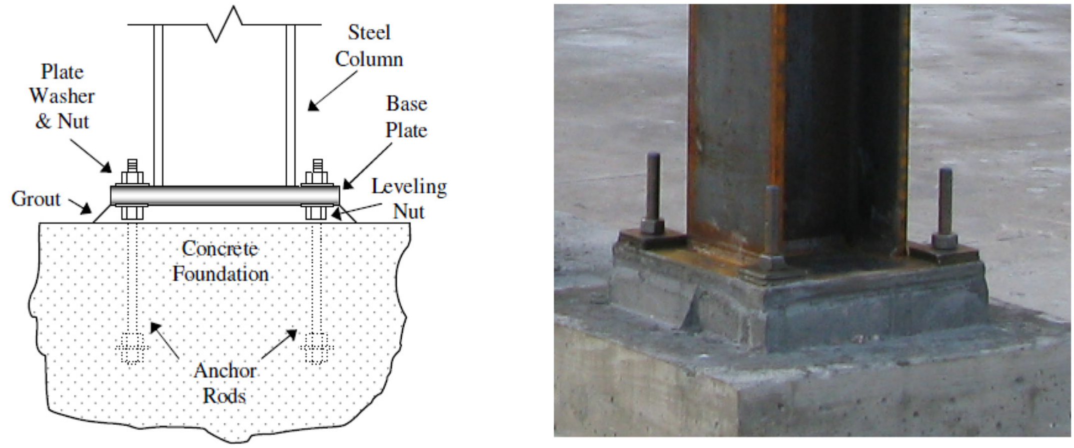

Fig. 1. A typical exposed, unstiffened column base connection [18]

in the design. The only available interaction curve by the authors' knowledge, is the interaction formula proposed by Choi and Ohi [24] for base plates with HSS columns based on virtual work principle. In this method, response of two multi-spring models has to be examined to identify the interaction curve between major-axis and minor-axis moments.

The other subject that is not sufficiently studied in the literature is the capacity of base plates with I-shaped columns under minor-axis (weak-axis) moments. Lee et al. [25, 26] investigated the response of column base connections under minor-axis moments both numerically and experimentally. The comparison of results with the available design method (D&E method) [10] showed the limitations of D&E method for design purposes.

In the current paper, an analytical study is carried out to address the biaxial capacity and minor-axis capacity of column base connections. First, a valid analysis model for a typical exposed, unstiffened column base connection is developed in ABAQUS finite element platform. Finite element modeling (FEM) is a powerful tool for predicting the response of such complex connections. After validating the analysis model with six available uniaxial tests data from the literature, the biaxial behavior and capacity of three connections with different axial loads are determined. The obtained results are used to develop a simple and reliable interaction equation for design of base plates subjected to biaxial moment and axial load. Since the interaction equation is expressed in terms of the uniaxial capacities, a mechanism-based analytical method for calculation of the uniaxial capacities is expanded and simplified. The application of this method for base plates with I-shaped columns under minor-axis moments is also studied. The proposed interaction equation and analytical method are useful tools at the disposal of design engineers. Such analytical studies would save the time and expenses of conducting experimental programs to some extent.

2. Finite element modeling

2.1. Analysis model and validation

Gomez et al. [18] conducted an experimental program to investigate the response of seven exposed column base connections subjected to combined axial compression load and major-axis bending moment. The specimens were representative of customary US construction practice (as shown in Fig. 1). Kanvinde et al. [19] simulated these experiments in ABAQUS to present some behavioral insight by focusing on internal stress distributions. Since the validation of developed model was rigorously accomplished based on three different benchmarks (lateral load-displacement curve, base plate deformation profile, and anchor rods strain data), the same approach is followed for developing and validating the FE model in the current study.

Suitable modeling of contacts, geometrical complexities, and nonlinear constitutive responses are the important features of this simulation process. In this paper, the FE model is developed using the measured material and geometrical properties of six specimens tested by Gomez et al. [18]. The base plate configuration, material properties and test results are shown and summarized in Fig. 2 and Table 1. The model consists of the column, base plate, foundation, pedestal, grout, anchor rods, washers, and nuts. Since there is no symmetric plane when the specimen is subjected to biaxial bending, the whole connection is simulated instead of half-model which was used by Kanvinde et al. [19].

A strong bond with no separation and failure was observed during the tests between the grout and concrete (pedestal and foundation) [18]; therefore, these two members are modeled monolithically, as shown in Fig. 3a. For the same reason, two more monotonic assemblies are built during the modeling: (I) base plate-column assembly (Fig. 3b) and (II) rods-nuts-washers assembly (Fig. 3c). The complete assembly is

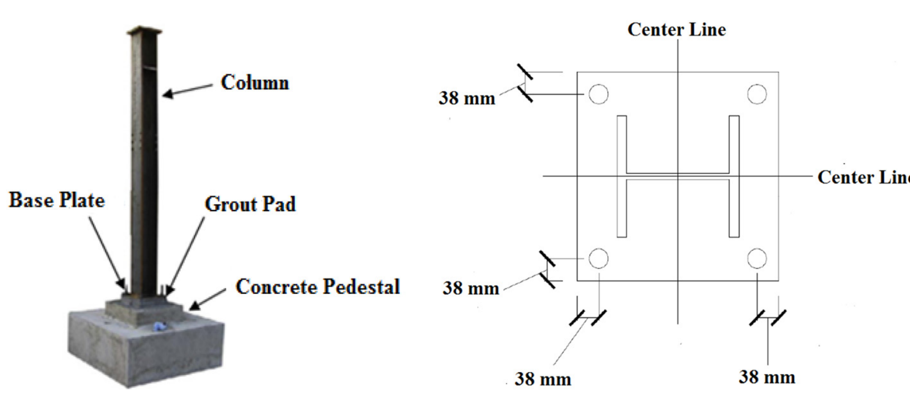

Fig. 2. The test specimen and base plate configuration [18]