Monotonic Response of Exposed Base Plates of Columns: Numerical Study and a New Design Method

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Abstract: This paper describes a numerical study of the behavior of exposed base plates of columns under the action of axial and bending loads. The aim of this research is to evaluate numerically the failure mechanisms on stiffened and non-stiffened base plates and propose a new design method. The effects of base plate thickness, location of anchor rods, location of stiffeners and tensile strength of anchor rods were considered in the analysis. Sixteen finite elements simulations were performed considering different combinations of the above mentioned parameters. The results show a fragile response in the base plates when high resistance anchor rods are used. The anchor rods worked as fuse elements in base plates with a large thickness or many stiffeners. Additionally, the models with anchor bars located outside of the column flanges showed lower flexural strength and rotational stiffness compared to the models with anchor rods located between column flanges. The simulations showed that the base plate strength was determined by the simultaneous failure mechanisms of two or more components, different to what is stated in current design guides. Finally, the new method is suitable to design base plates with stiffened and not stiffened configurations, which unlike traditional design methods, show a good adjustment with numerical models.

Keywords: exposed column; base plate; stiffeners; yield line; anchor rods; rotational stiffness; ductility

1. Introduction

The base plates correspond to one of the most frequent column connections of steel structures. These connections are responsible for transferring loads from the superstructure to the foundations. However, the performance of these connections was deficient during recent seismic events in the USA and Japan, where significant damage and failure of these joint elements was reported [1,2].

An exposed column base consists of several components, such as: column sections, base plate, stiffeners, anchor rods, concrete foundation and shear-lug. Each of these components affects the connection’s capacity to withstand axial load, shear load and bending moments. Current design methods, such as those presented in the AISC Steel Design Guide 1 [3], provide design procedures that allow for sizing of the base plate of exposed columns and their anchor rods. However, these design methods do not consider combined failure mechanisms, such as those observed in several experimental studies [4], resulting in non-conservative designs. In other cases, as the current guidelines do not consider joint configurations with stiffeners, the design often specifies plates with thicknesses that is not commercially available [5].

Numerical studies using finite elements indicate that the base plates designed using the current guidelines do not behave as expected, leading to premature crushing of concrete when using base plates...
Metallic alloys with thickness higher than 25 mm [6]. A recent experimental study on exposed base plates considering axial load and bending moment [7] showed an important correlation between the thickness of the base plate and the performance of the connection. This study concludes that despite complying with the design guidelines, flexural capacity may not be reliable due to plate interaction with other components such as the anchors. On the other hand, few studies have addressed the behavior of column bases with stiffened base plates, which are very common in the practices of detailing and construction of steel structures, as it allows for reducing the thicknesses of base plates [8,9]. However, there are no numerically or experimentally validated design procedures that consider the different performance of stiffened and non-stiffened base plates. The response of connections in terms of stiffness, strength, rotational capacity and energy dissipation is heavily dependent on the details of connection and, therefore, on the components considering their location and individual strength [10]. These problems could be alternatively solved by improving material properties or by the use of novel nanostructured materials, which have emerged to allow the synergy of high strength and high ductility modifying failure mechanisms [11]. However, it is usually preferred an engineering and constructive solution, using currently commonly used materials.

The exposed and embedded base plate connection have been researched by [12–15], obtaining that rotational fixity of base plate in steel moment resisting frames strongly influences their seismic response. However, the stiffened base plates were not considered by this investigation.

In this investigation, a numerical study on the behavior of stiffened and non-stiffened base plates is carried out, considering the contribution of different components to each configuration. The aim of the research is to evaluate numerically the failure mechanisms in stiffened and non-stiffened base plates. Additionally, due to currents design methods are focused in non-stiffened base plates a new design method is proposed. The numerical study was conducted using finite element models considering material, geometric and contact nonlinear properties. Axial load and bending moment were simultaneously applied with the goal of identifying the behavior of the base plate and its interaction with the stiffeners and anchor rods. The welds were designed to remain within the elastic range and to develop the inelastic behavior of the connected elements, being considered as ideal monolithic contacts in the numerical models. Similarly, concrete was designed to remain elastic. These conditions are like those observed on typical connection tests that intend to evaluate the seismic performance of the links, avoiding a fragile failure of elements with limited inelastic capacity, such as, welding and concrete. In the final part of the paper, the authors propose a new design method based on yield lines theory, suitable to design base plates with stiffened and not stiffened configurations.

2. Numerical Study

2.1. Specimens under Analysis

Five base plate configurations were defined by varying the location and steel quality of the anchor rods and the stiffener configuration, as shown in Figure 1. The UBP-1 configuration corresponds to a base plate model without stiffeners and anchor rods located on the outside and parallel the column flanges. The UBP-2 configuration also represents a base plate model without stiffeners, but the anchor rods are located on the outside and inside of column flanges and parallel to the section web.

The SBP-1 configuration represents a base plate model with anchor rods parallel to the flange and stiffeners between each anchor rod, while the SBP-2 configuration is similar to the previous one but without the web stiffener. Finally, SBP-3 configuration is like the SBP-1 but eliminating the web and external stiffeners. All the specimens were constructed using a standard HEB-300 columns section with ASTM-A36 steel quality [16]. All the stiffeners were 10 mm thick and made of the same material used for the column section. The specimens were modeled as cantilever elements designed to withstand axial load and bending moment.

As seen in Figure 1, each configuration has 8 anchor rods (4 on each side) with a nominal diameter of 22 mm (7/8 inch) and an embedded length of 400 mm. The analysis considered two steel qualities