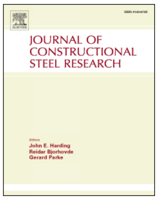
Journal of Constructional Steel Research 129 (2017) 240–249

Contents lists available at ScienceDirect

Journal of Constructional Steel Research



Embedded column base connections subjected to seismic loads: Strength model

D.A. Grilli [a], A.M. Kanvinde [b],*

[a] Wiss, Janney, Elstner Associates, Inc., Emeryville, CA, United States
[b] Department of Civil and Environmental Engineering, University of California, Davis, CA, United States

ARTICLE INFO

Article history:
Received 1 September 2016
Accepted 15 November 2016
Available online xxxx

Keywords:
Column bases
Moment frames
Steel connections

ABSTRACT

Seismically designed mid- to high-rise steel moment resisting frames in the United States are commonly constructed with the lowest portion of the first story column embedded into a concrete footing to transfer large moments and forces. Despite their prevalence, these Embedded Column Base (ECB) connections have not been experimentally examined until recently, such that strength estimation methods for other types of connections are usually adapted for their design. Based on recent experiments, current approaches for designing ECB connections are examined, and a new strength characterization method is presented. Mechanisms for internal force transfer within the connection are postulated; these include horizontal bearing of the column flange against the concrete, panel zone shear, and vertical bearing of the embedded base plate against the concrete. The proposed approach has two components: (1) a process for moment distribution between the horizontal and vertical bearing mechanisms, and (2) idealized stress distributions for estimation of associated limit states. The proposed method is able to characterize the experimentally observed specimen strengths with good accuracy, such that the average test-predicted ratio is 1.01, with a coefficient of variation 0.06. No significant bias in accuracy of the method is observed with respect to test variables. Limitations of the study are discussed; these arise from its empirical aspects which may not be generally extrapolated to configurations significantly different from the experiments upon which the method is based.

1. Introduction

Embedded Column Base (ECB) connections are commonly used to connect steel columns to concrete foundations in seismically designed Steel Moment Resisting Frames (SMRFs). In these connections, the lowest portion of the column and the attached base plate is embedded into a concrete footing – see Fig. 1a and b. These connections resist base moments and provide fixity through bearing of the concrete against the column flanges, as well as by restraining rotation of the base plate. These details are economical for mid- to high-rise frames in which exposed base plate connections (affixed to the footing with anchor rods – see Fig. 1c) are impractical owing to the necessity of thick base plates and numerous anchor rods. In mid- to high-rise frames, the embedment is often expressly purposed to resist large base moments, resulting in “deep” embedments (greater than ~500 mm), as shown in Fig. 1a. In this paper, the term “ECB connections” is used to denote connections with such designed embedments, to distinguish them from shallowly embedded connections, in which the embedment is incidental owing to the presence of a slab-on-grade overtopping an exposed base plate connection, resulting in shallower embedments (lower than ~300 mm), as shown in Fig. 1b. In the latter case, primary resistance is derived from mechanisms similar to exposed base plate connections, i.e., anchor rod tension and complementary vertical bearing stresses under the base plate, with only secondary resistance derived from the embedment. In the former (i.e., ECB connections, that are the focus of this study), anchor rods are often not present (or provided only for erection safety) and primary resistance is derived from horizontal bearing of the column flanges against the embedment.

In contrast to exposed base plate connections, for which seismic design guidelines (e.g., the AISC Steel Design Guide One, Fisher and Kloiber, [1]; SEAOC Seismic Design Manual [2]) are well-supported by extensive experimental (Gomez et al., [3]; Astaneh and Bergsma [4], Burda and Itani [5]) and analytical (e.g., Ermopoulos and Stamatopoulos, [6]) research, design practices for ECB connections have not been validated by experimental results. As a result, practitioners rely on ad hoc adaptations of strength models and design guidelines for similar components, such as composite beam-column connections (ASCE [7]) or steel coupling beams embedded in concrete shear walls (Marcakis and Mitchell [8]; Mattock and Gaafar [9]; Gong and Shahrooz [10]; Motter et al. [11]). The AISC Seismic Design Manual [12] suggests the use of the method proposed by [9,10] for coupling beams to be used for strength estimation of ECB connections. In the absence of test data, these ad hoc adaptations variously disregard effects that are peculiar to ECB

---

* Corresponding author.
E-mail address: kanvinde@ucdavis.edu (A.M. Kanvinde).

http://dx.doi.org/10.1016/j.jcsr.2016.11.014

Notation

α	Fraction applied moment resisted by vertical bearing mechanism
B	Base plate width perpendicular to plane of lateral loading
β,β_1	Factors to account for concrete confinement and effectiveness in bearing
b_f	Column flange width
b_j	Effective joint width, outer joint panel zone width
C, C_0, C_1	Constants defining interaction of column with concrete
d_{embed},$d_{effective}$	Embedment depth, effective embedment depth
d_{ref}	Depth at which horizontal bearing stresses attenuate to zero
d_L	Depth of lower horizontal concrete bearing stress block
d_U	Depth of upper horizontal concrete bearing stress block
E_{steel}, $E_{concrete}$	Moduli of elasticity of steel and concrete.
F_{flange}^{top}, F_{flange}^{bottom}	Forces in column flanges at the top and bottom of embedment zone
h	Web height of column
I_{column}	Moment of inertia of column cross section in direction of bending
λ	Spring stiffness per unit area of concrete in horizontal direction
M_{base}	Generic notation for base moment
$M_{base}^{capacity}$	Base moment capacity as determined by the proposed method
$M_{base,SDM}^{capacity}$	Base moment capacity as determined by the Seismic Design Manual
M_{base}^{y}	Base moment associated with onset of significant nonlinearity
$M_{base}^{\max}$	Maximum base moment observed in tests
M_{HB}	Moment resisted through horizontal bearing stresses
$M_{HB}^{bearing}$	Moment capacity provided by horizontal bearing
M_{VB}	Moment resisted through vertical bearing mechanism
N	Base plate length in the direction of loading
P	Axial force in column
V_j	Vertical shear force in the joint panel
V_{column}	Imposed column shear

connections, such as concrete confinement (which is modest around coupling beams), the presence and anchoring effect of the embedded base plate, and other effects such as the development of a concrete panel between the flanges of the embedded column, or presence of axial load.

Grilli and Kanvinde [13] recently conducted a series of tests on ECB connections representative of United States construction practice. These experiments subjected five cantilever column specimens with embedments in the range of 508–762 mm to axial and cyclic lateral loads. For convenience, these are referred to hereafter as the UCD tests after the University of California, Davis where they were conducted. The main objective of this paper is to use the findings of this test program to present a strength characterization method suitable for the strength design of ECB connections. Barnwell [14] and Cui et al. [15] recently examined shallowly embedded base connections where 203–406 mm slabs-on-grade overtopped exposed type connections. As discussed above, these specimens are distinct from ECB connections in key behavioral aspects, since they derive primary strength from anchor rod tension such that the embedment is incidental, rather than designed to resist moment. Consequently, they are used as supplementary qualitative input into model development and assessment.

The paper begins by briefly providing relevant background, including the test findings from the UCD study, and the prevalent approach for estimating the strength of embedded column bases. The new strength estimation approach is then presented and evaluated against test data. The paper concludes by discussing limitations of the approach, as they pertain to the design of ECB connections.

2. Summary of experimental results from the UCD study

Table 1 summarizes the test matrix and key results of the UCD study [13], while Fig. 2a shows the test configuration. Table 1 also indicates model predictions; these are discussed later. Referring to Fig. 2, all test specimens were cantilever columns of height ~ 3 m, with their lower portion embedded into a concrete footing, which was attached to the test floor. The footings included only nominal reinforcement, and were sized to minimize the boundary effects of the floor attachments on connection response. These tests were approximately full-scale, considering that the point of inflection (at the top of the ~3 m cantilever) corresponds to roughly 2/3rd of the first story height. All specimens were subjected to a cyclic lateral deformation history (consistent with the ATC-SAC protocol – Krawinkler et al. [16]) applied in the presence of a constant axial load. Referring to Table 1, the main variables were the embedment depth, the axial force, and column size. Fig. 2b photographically shows the observed modes of failure of Test #1 (the other tests were qualitatively similar). The connection details (described comprehensively in [13]) reflect construction practice in the United States, such that the bottom base plate provides stability during erection and resistance to tensile uplift of the column. The top plate (similar to a stiffener) provides a load path for column compression. Numerous quantities were recorded during the tests, in addition to the load and

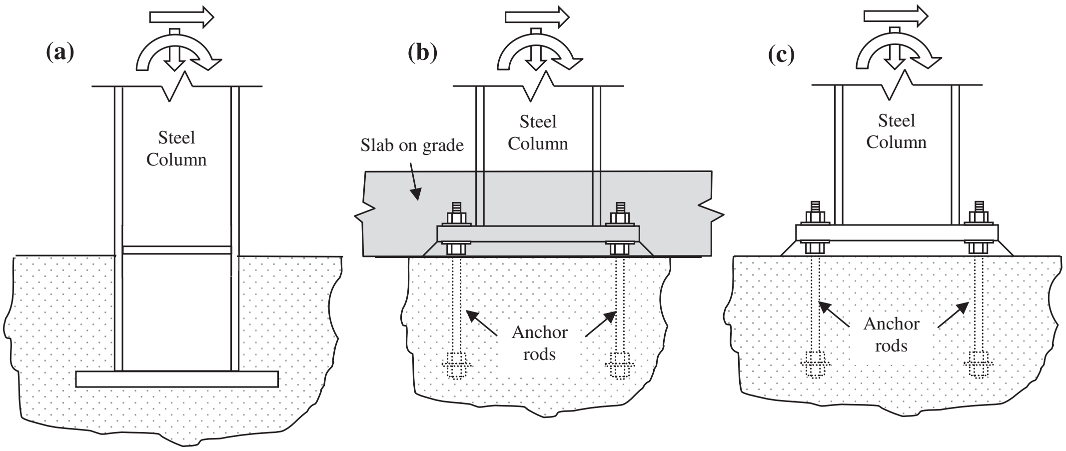


Fig. 1. Column base connection types: (a) deeply embedded, (b) shallowly embedded due to overtopping slab, and (c) exposed with base plate and anchor rods.