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Moment and energy dissipation capacities of post-tensioned precast concrete connections employing a friction device

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ABSTRACT

This paper describes an analytical investigation into the design of unbonded post-tensioned (PT) precast concrete beam-column connections that employ a friction device. Design formulas related to the moment capacities, hysteretic energy dissipation capacities, and self-centering capabilities of the PT connections are developed in normalized form. The validation of the design formulas and the effect of normalized parameters such as friction force, initial post-tensioning force and the location of the friction device on the moment and energy dissipation capacities are investigated. A design procedure to achieve desired design moment and energy dissipation capacities for the PT connections is also developed using the design formulas. Contour plots for the linear limit moment and hysteretic energy dissipation ratio are provided for determining the required values of the normalized parameters. The investigation is based on the analytical responses from a nonlinear section analysis method for a number of PT connections with various sets of normalized parameters. The results confirm the adequacy of the design formulas and design procedure.

1. Introduction

Precast concrete beam-column connections that use unbonded post-tensioning between the beams and columns can resist seismic loads without incurring significant residual deformation and structural damage, but they have low inherent damping. In order to enhance their capacity to dissipate energy and thus reduce displacement due to earthquakes, the use of energy dissipation devices placed across the beam-column interfaces of the connections has been proposed, starting with the PRESSS Program [1,2]. The energy dissipation devices provide supplemental energy dissipation for connections through displacements that occur as a result of opening and closing gaps at the beam-column interfaces during earthquakes. Various kinds of energy dissipation devices such as steel yielding devices [1–3], lead extrusion damping devices [4,5], and friction damping devices [6–9] have been suggested and their application has been experimentally validated in tests of their components and in beam-column connection tests.

The most attractive features of unbonded post-tensioned (PT) energy dissipating precast concrete beam-column connections are their self-centering behavior and their adequate hysteretic energy dissipation (flag-shaped hysteresis). To perform satisfactorily, the PT connections need to be designed to achieve the required moment capacities, hysteretic energy dissipation capacities, and self-centering capabilities. Although these requirements can be satisfied by any one of an infinite number of combinations of unbonded post-tensioning tendons and energy dissipation devices, to date there is limited research on selecting suitable combinations to achieve design purposes. Morgen and Kurama [10] provided a seismic design procedure to satisfy the design beam-end moment demand and energy dissipation requirements for an unbonded PT precast concrete beam-column connection that had friction devices placed on both the top and bottom surfaces of beam. To develop design formulas, they decomposed the nominal moment capacity into moment resistances due to the post-tensioning forces and friction forces based on the equilibrium of the forces at the beam end. They assumed that the friction forces acting in opposite directions to each other were equal for the two friction devices, and that the compression force in the equivalent compression stress block was equal to the post-tensioning force. The validity of the design procedure was confirmed by nonlinear analyses of PT beam-column subassembly models with various design parameters.

In recent years, there has been some research on PT connections employing friction devices with different configurations aiming to eliminate the possibility of interfering with energy dissipation devices in the floor slab. Sugiura et al. [7] proposed a PT connection with a beam bottom friction device (BFD), where a friction device is placed on only the bottom surface of the beam. The results of cyclic

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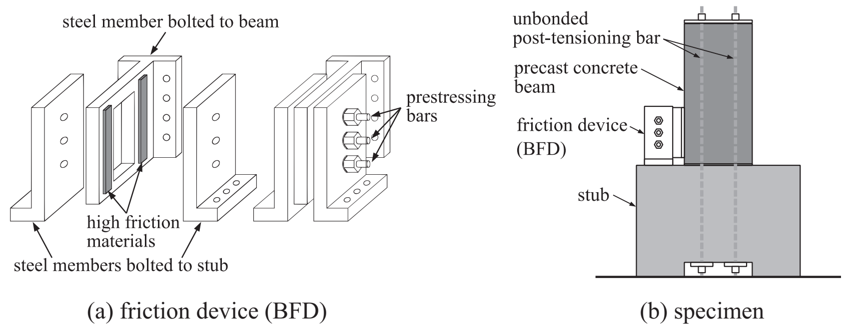

Fig. 1. Test configuration for a PT connection with a BFD (adapted from Sugiura et al. [7]).

tests on the PT connection specimens shown in Fig. 1 demonstrate that the BFD can provide satisfactory energy dissipation to PT connections. Song et al. [8] developed an armored precast concrete beam-column connection with a friction device located at the web of the beam, called a beam web friction device (WFD). They conducted experimental and numerical studies on its hysteretic behavior, and found the connection to have good seismic performance with respect to energy dissipation, self-centering, and preventing local damage. Further studies on the same connection were conducted by Song et al. [9], where the performance of PT connections with WFDs was investigated experimentally through a series of cyclic tests on a 0.5-scale, one-bay, one-story frame subassembly. Research and development of similar connections for steel frames has also been conducted by several other researchers (Tsai et al. [11], Iyama et al. [12], Wolski et al. [13], Guo et al. [14], and Lin et al. [15]).

Unlike PT connections with friction devices on both the top and bottom of the beam, the moment resistances due to the post-tensioning force and the friction force correlate to each other in these PT connections because they are in equilibrium with the compression force. In addition, the location of the friction device may have a significant effect on the moment and energy dissipation capacities of PT connections. This paper presents an analytical investigation focusing on this issue in the design of PT connections having a friction device. Design formulas related to the moment capacities, hysteretic energy dissipation capacities, and self-centering capabilities are developed using normalized parameters suitable for such PT connections. Results obtained using the design formulas for the capacities are compared with results from nonlinear analyses using a section analysis method that can predict the relationship between the moment and relative rotation at the beam-column interface under cyclic loading. The effect that using normalized parameters has on the capacities of the PT connections is also examined. Based on the design formulas, a design procedure to determine the parameter values necessary to satisfy the required moment and energy dissipation capacities is presented and analytically validated.

2. Design formulas for unbonded PT connections with a friction device

The PT connections that employ either a WFD or a BFD studied in this paper are shown schematically in Fig. 2. The precast beam is joined to the column by an axial post-tensioning force provided by a group of unbonded post-tensioning tendons that run straight at the beam centroid and through the beam-column connection. The friction device, placed on the outside of the beam web (Fig. 2(a)) or on the bottom surface of the beam (Fig. 2(b)), is connected to the beam end and the column face. When relative displacement occurs between the beam end and the column face, a friction force develops in the friction device and provides moment resistance together with the post-tensioning force.

In a properly designed PT connection, the behavior is primarily dominated by the opening and closing of a gap that occurs at the beam-column interface. Fig. 3 shows the idealized moment-rotation behavior for PT connections with WFDs and BFDs. The term M represents the moment in the beam at the beam-column interface and θ represents the chord rotation of the beam. A positive rotation corresponds to the gap opening at the bottom of the beam-column interface. As shown in Fig. 3, properly designed PT connections have flag-shaped hysteresis curves under both positive and negative rotations, where the unloading curve goes back to the origin as the energy corresponding to the area enclosed by the loading and unloading curves is dissipated. The moments M_{ll^+} and M_{ll^-} that occur during the loading curves are the linear limit moments [16,17] that are taken as the nominal moment capacities under positive and negative rotations. The moments when the unloading curves rejoin the loading curves are denoted as M_{lr^+} and M_{lr^-}. Since the positive and negative moment resistances may be different depending on the location of the friction device, the symbols for these moments are given separately for positive and negative rotations using + and − indices. The design formulas for the PT connections are based on idealized moment-rotation behavior. PT connections with friction devices on both the top and bottom of the beam are not covered by the design formulas.

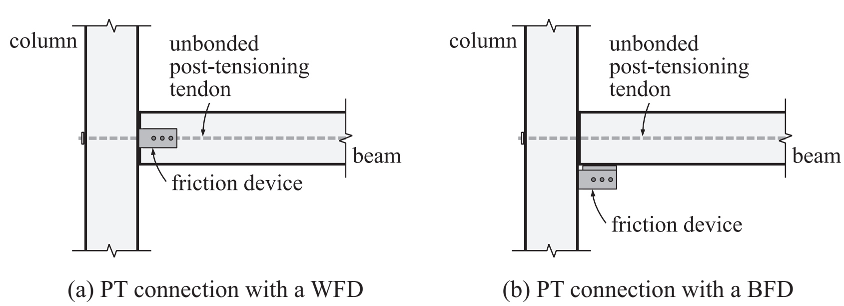

Fig. 2. Schematic diagram of unbonded PT precast concrete connections with friction devices.