Research Corner

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Evolution of the L-shaped spandrel beam

Andrew Osborn and Gary Klein

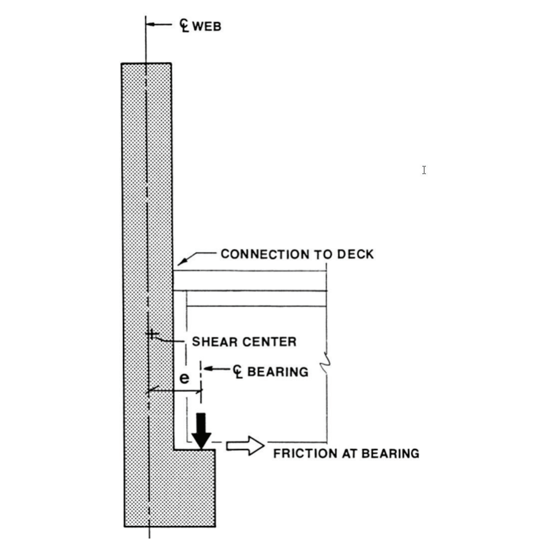
Numerous PCI-sponsored research projects over the years have endeavored to improve the design of precast concrete components. One such component is the beam with an integral ledge.

Beams with ledges may be inverted-T shaped or L shaped. This Research Corner will describe research funded by PCI pertaining to the L-shaped beam, also called an L beam. The PCI-funded research had a profound impact on the evolution of design procedures for such beams.[1–3]

L beams are typically placed at the perimeter of a precast concrete structure and support double-tee-beam floor components. As used in parking structures, the web of the *L* often extends above the floor surface to function also as a barrier wall. Such beams are often referred to as deep or slender spandrels. The beams may be prestressed or mild reinforced. Both styles are common.

The double-tee beam stems bear on the ledge, creating a series of eccentric forces.These impose a torsional load on the L beam that is usually restrained by connections to the columns at both ends. The top flanges of the double-tee beams, typically at each double-tee stem, are fitted with an embed plate to provide a welded connection to the L-beam web. At the ledge surface, double-tee beams are supported on bearing pads to spread concentrated load effects and reduce undue restraint to volume change forces.

The first edition of the *PCI Design Handbook: Precast and Prestressed Concrete*[4] mentions L-shaped beams and provides a design chart for standard sections, but no design procedure was given. In the second edition of the *PCI Design Handbook*[5] a ledge design is provided but a complete design for the entire L beam is not presented. The third edition of the *PCI Design Handbook*[6] presented a complete L-beam design procedure and references several *PCI Journal* papers. In this procedure, assumptions are made regarding the design of the hanger steel and handling of the torsional reaction at the L-beam ends. End torsion reinforcement and hanger reinforcement designs are based on the recently developed compression field theory from Collins and Mitchell.[7] That design procedure resulted in increased end-of-beam reinforcement compared with the previous torsion



Configuration of typical L-beam. Source: Reproduced by permission from Lucier (2010), Fig. 2-4, p. 7.

design method. Notably, for hanger reinforcement, a footnote in section 6.14 of the third edition of the *PCI Design Handbook*[6] states, “A consensus on the design procedure for hanger reinforcement, A_{sh}, has not been reached as of publication, and future recommendations may differ from that shown here.” Several references that also discuss the issue are noted.[8,9]

PCI realized that the L-beam design procedures relied on certain assumptions of behavior rather than physical test data. PCI also sought to reduce the conservative design assumptions of the compression field theory approach. Accordingly, PCI underwrote specially funded research project 5. The research[1] involved physical testing, finite element analysis, and a literature review. The focus of the report was a more rational approach for the design of hanger steel and end-of-span reinforcement. One of the findings of that research was that the PCI design method for punching shear may be unconservative.

Subsequently, PCI funded two relevant Jenny Fellowship projects. Yazdani[10] performed finite element studies of L beams, pocketed spandrels, and discrete corbel spandrels. The research reviewed the ACI 318-95[11] design procedures, which, similar to the third edition of the *PCI Design Handbook*,[6] were based on the compression field theory. Similar to Klein,[1] Yazdani found that the design procedure resulted in highly congested steel reinforcement near the L-beam ends. Lini[12] performed similar research focused on thin spandrels and had similar findings.

PCI funded further research at North Carolina State University (NCSU) and Wiss, Janney, Elstner Associates Inc. (WJE).[2] Alternative torsion design procedures were developed for slender spandrels based on separate consideration of the plate bending and twist components of torsion across an inclined failure plane. As a result, closed transverse reinforcement was no longer required, and reinforcement congestion at L-beam ends was greatly reduced.

Failure mode near beam end. Source: Reproduced by permission from Lucier (2010), Fig. 3-47, p. 63.

Additional research was conducted at NCSU and WJE[3] to address the potentially unconservative punching shear design procedure presented in *PCI Design Handbook* through the seventh edition.[13] It was found that design for punching shear must consider global flexural and shear stress in the portion of the L beam below the ledge.

The PCI design procedures for L beams were substantially changed in the eighth edition of the *PCI Design Handbook*[14] as a result of the Lucier[2] and Rizkalla[3] research and are being further modified for the ninth edition of the *PCI Design Handbook*, which is under development. The alternative torsion design procedure for slender beams, those with a web height–to–depth greater than 4.5, has also been recognized by ACI 318-19[15] section 9.5.4.7. Further code change proposals are pending.

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Punching shear failure mode. Source: Reproduced by permission from Rizkalla (2016), Fig. 4-15b, p. 96.

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