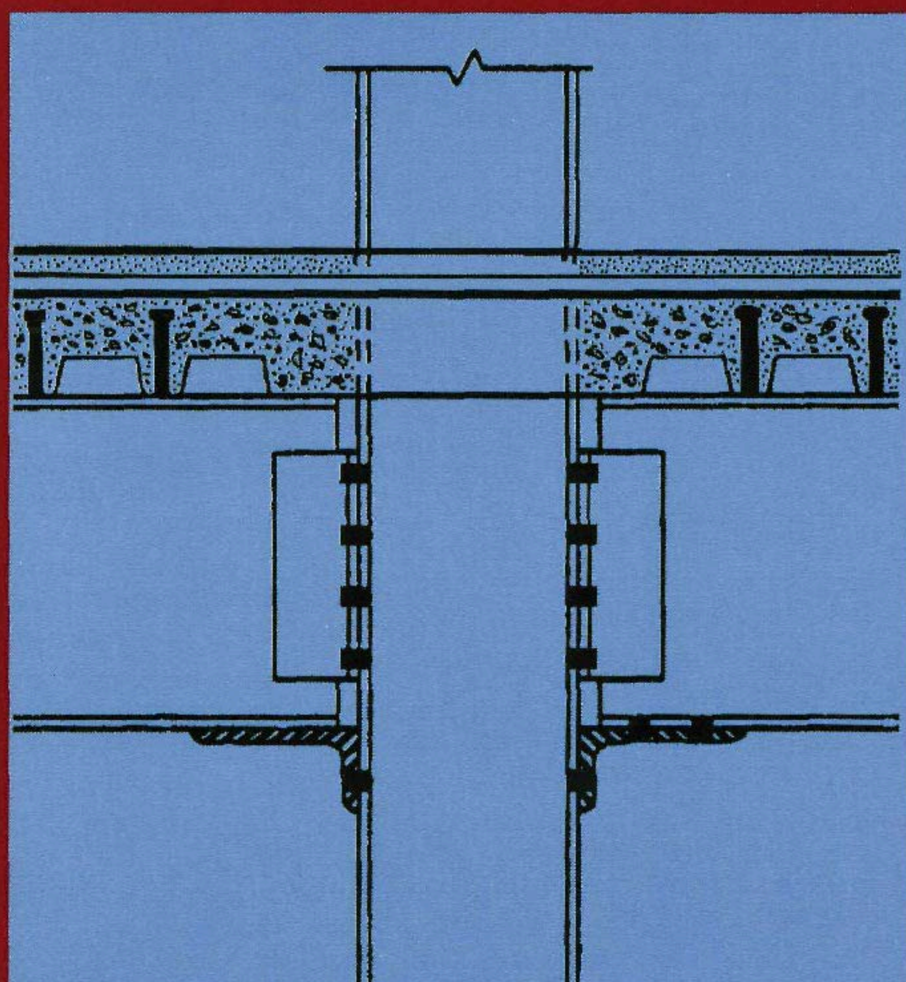
Steel Design Guide Series

8

Partially Restrained

Composite Connections



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8

Partially Restrained Composite Connections

A Design Guide

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Preface

This booklet was prepared under the direction of the Committee on Research of the American Institute of Steel Construction, Inc. as part of a series of publications on special topics related to fabricated structural steel. Its purpose is to serve as a supplemental reference to the AISC *Manual of Steel Construction* to assist practicing engineers engaged in building design.

This document is intended to provide guidelines for the design of braced and unbraced frames with partially restrained composite connections (PR-CCs). The design procedures and examples in this guide represent a refinement of the work presented by Ammerman and Leon[7,8] and is thoroughly documented in more recent work by the authors.[12,21] The design of structures utilizing PR-CCs for gravity and wind loads falls under the provisions of Section A2.2 of the LRFD Specification for Structural Design of Buildings. Design for seismic loads is allowed under Section 7.4.1 of the latest version of the NEHRP provisions.

The guide is divided into four parts. The first part is an introduction dealing with topics pertinent to partially restrained (PR) analysis and design, and discusses some of the important design choices utilized in the design procedures and examples. The second part contains detailed, concise design procedures for both braced and unbraced frames with partially restrained composite connections. The third part consists of a detailed design example for a four-story building. The design is for an unbraced frame in one principal direction and for a braced frame in the other. The fourth part contains design aids in the form of Tables and Appendices.

It is important that the reader recognize that the guide is intended to be a self-contained document and thus is longer than comparable documents dealing with similar topics. The reader is advised, on a first reading, to read Parts I and III carefully, consulting Part IV as necessary. Once the reader is familiar with the topic, he/she will only need to consult Parts II and IV in doing routine design work.

The design guidelines suggested by the authors that are outside the scope of the AISC Specification or Code do not represent an official position of the Institute and are not intended to exclude other design methods and procedures. It is recognized that the design of structures is within the scope of expertise of a competent licensed structural engineer, architect, or other licensed professional for the application of principles to a particular structure.

Acknowledgments

The authors would like to thank the following people who have been very helpful in the writing of this design guide and have also been key players in its development: Heinz Pak, former Manager of Building Engineering for AISC, initiated and sponsored the guide; Larry Kloiber of LeJeune Steel provided input particularly in the practical fabrication aspects of the connection; Dave Galey, Zina Dvoskin, and Johanna Harris of HGA's Structural Engineering Department who helped developed the first draft of this guide and provided invaluable input and assistance throughout the project; Bob Lorenz, Director of Education and Training, and Nestor Iwankiw, Vice President of Technology and Research for AISC, whose patience and support made this document possible.

Part I
BACKGROUND

1. INTRODUCTION

Partially restrained connections, referred to as PR connections in the LRFD provisions[1] and Type 3 connections in the ASD provisions,[2] have been permitted by the AISC Specifications since 1949. With some notable exceptions, however, this type of connection has not received widespread application in practice due both to (a) the perceived complexity of analysis required, and (b) the lack of reliable information on the moment-rotation characteristics of the connections as required by design specifications. The notable exceptions involve specific types of connections that have been demonstrated, through experience in the field and extensive analytical work,[3,4] to provide equivalent response under design conditions to that of rigid connections. The Type 2 or "wind" connections allowed under the ASD provisions are a good example of this approach. In these cases the specification essentially prequalifies a simple connection under gravity loads as a rigid connection under lateral loads. In reality, of course, these connections are neither fully rigid (FR) nor simple but partially restrained (PR). The code uses this artifice to simplify the analysis and design, but requires a guaranteed rotational and strength capacity from these connections.

After 10 years of research and development a new type of semi-rigid connection, labelled the Partially Restrained Composite Connection or PR-CC,* can be added to this list.[5-12] The word "composite" is used to indicate that this connection engages the reinforcing steel in the concrete slab to form the top portion of the moment resisting mechanism under both live loads and additional dead loads applied after the end of construction (Figure 1). The bottom portion is typically provided by a steel seat angle with web angles providing the shear resistance. This connection may be used to economize beam sizes for gravity loading or to resist lateral loads in unbraced frames. The design of this type of system is based not only on the work of the senior author at the University of Minnesota,[5-12,21] but also on that of many researchers throughout the U.S. and Europe.[11,13-19] The extensive experimental work required in the development of these connections is discussed elsewhere[5,6,9] and will not be repeated here.

Part I of this design guide is organized as follows. First, some discussion of partially restrained connection behavior will be given to put PR-CC design in its proper context. Second, the advantages and limitations of PR-CCs are discussed in the context of simplified or code-oriented design. Third, the assumptions and theory applied in their design are described. Fourth, detail recommendations for the connections under both gravity and lateral loads are given. In Part II a step-by-step procedure is presented in outline form followed by corresponding detailed calculations for an example problem in Part III. The 1993 *Load and Resistance Factor Design* (LRFD) Specification[1] is used in the design and ASCE 7-93[20] is used for load determination. Tables and design aids are included in Part IV to facilitate the design.

2. CHARACTERIZATION OF CONNECTION BEHAVIOR

The behavior of structural connections can be visualized for design purposes with the aid of moment-rotation M-θ curves (Figure 2). These curves are generally taken directly from individual tests or derived by best-fit techniques from the results of multiple tests.[22,23] All design specifications require that the structural engineer have a reliable M-θ curve for the PR connections to be used in design since such curves syn-

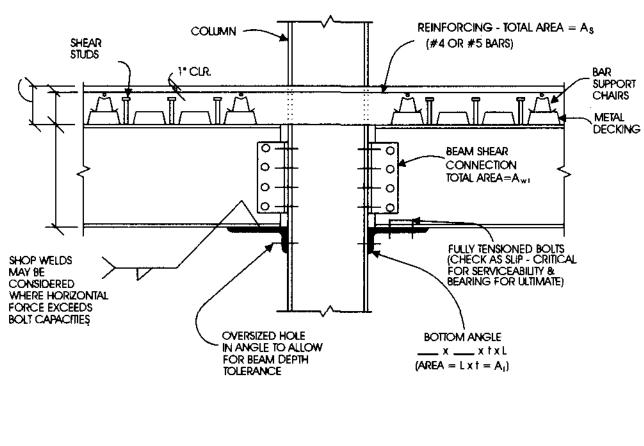

Fig. 1. Partially restrained composite connection (PR-CC).

* The label PR-CC is meant to encompass the connections previously labelled semi-rigid composite connections (SRCC) by the senior author.

the size the connection's main characteristics: stiffness, strength, and ductility.[6] The application of PR-CCs to design implies that reliable M-θ relationships have been developed and are simple enough to use in design. The M-θ equations developed for SRCCs will be discussed in detail in Section 4.

In Figure 2(a), the stiffness of the connection corresponds to the slope of the M-θ curve. For most connections, such as PR-CCs, the slope changes continuously as the moment increases. The real stiffness of the connection at any stage of the M-θ curve corresponds to the tangent stiffness ($K_{\tan} = \Delta M / \Delta\theta$). However, for design purposes it is customary to assume a linear approximation for the service range ($\theta < \theta_{ser}$), generally in the form of a secant stiffness ($K_{conn} = M_{ser} / \theta_{ser}$). This stiffness is generally less than the initial stiffness of the connections (K_i), and corresponds closely to the unloading stiffness ($K_{unloading}$).

Based on the initial (K_i or service stiffness (K_{conn}), connections can be classified as fully restrained (FR), partially restrained (PR) or simple depending on the degree of restraint provided (Figure 2(b)). The current approach in design is to assume that for members framing into relatively rigid supports, if the connection stiffness is about 25 times that of the girder (i.e, $(K_{conn}L_g / EI_g) > 25$), the connection can be considered rigid. Conversely, if the connection provides a stiffness less than 0.5 times that of the girder, then it should be considered simple.* The classification by stiffness is valid only for the service load range and for connections which do not exhibit significant non-linear behavior at M_{ser}.

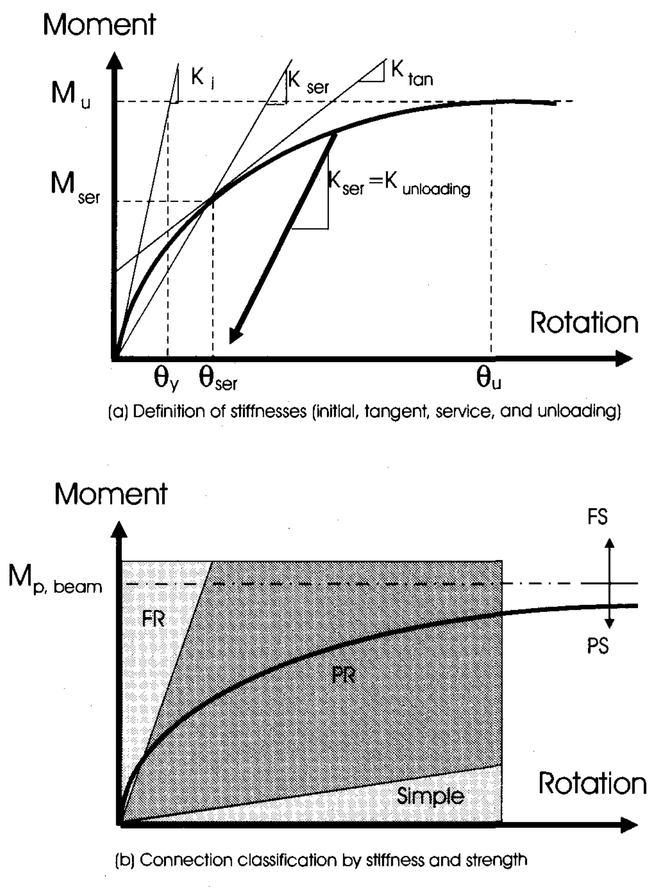

Fig. 2. Characterization of connection behavior.

Insofar as strength is concerned, joints can be classified either as full strength (FS) when they are capable of transferring the full moment capacity of the steel beam framing into them or as partial strength (PS) when they are not (Figure 2(b)). The schematic moment-rotation curve for a PR-CC shown in Figure 2(b) does not reach the full M_p capacity, and thus is a partial strength connection. Partial strength is desirable in seismic design because it permits a calculation of the maximum forces that a structural element will be required to withstand under the uncertain ground motions that serve as an input. If the designer knows what is the maximum moment that a connection can transmit, he/she can insure that other key elements, columns for example, remain elastic and suffer no damage even when the seismic input far exceeds the code prescribed forces. This design philosophy, known as capacity design,[24] is employed in this design guide. Capacity design requires that any hinging region be carefully detailed to dissipate energy and that all other elements in the structure remain basically elastic when the maximum plastic capacity of these regions is reached. Following this design philosophy, the detailing of the PR-CCs is driven by the need to provide a stable, ductile yielding mechanism such as tension yielding of the angle legs rather than a sudden, brittle failure such as bolt shearing.

Ductility is required in structural design so that some moment redistribution can occur before the connection fails. In applications for unbraced frames, and particularly if seismic loads are important, large ductilities are required. Ductilities can be defined in relative terms (θ_u / θ_y, or ultimate rotation capacity divided by a nominal yield one, see Figure 2(a)) or in absolute terms ($\theta_u > 0.05$ radians, for example). The required ductilities are a function of the structural system being used and whether large cyclic loads need to be considered in the design. In general cyclic ductilities greater than 6 (relative ductility) or 0.035 radians (absolute ductility) are desirable for frames with PR-CCs designed in areas of low to moderate seismic risk. Demands in unbraced frames for areas where wind governs the design or for braced frames are lower.

* The values of 25 and 0.5 selected here were chosen arbitrarily; ranges from 18 to 25 for the FR limit and 0.2 to 2 for the simple limit are found in the literature. The selection of specific values is beyond the scope of this guide. These values are cited only for illustrative purposes.