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Steel Design Guide

Vertical Bracing Connections—Analysis and Design

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Preface

This Design Guide provides guidance for the design of braced frame bracing connections based on structural principles and adhering to the 2010 AISC *Specification for Structural Steel Buildings* and the 14th Edition AISC *Steel Construction Manual*. The content expands on the discussion provided in Part 13 of the *Steel Construction Manual*. The design examples are intended to provide a complete design of the selected bracing connection types, including all limit state checks. Both load and resistance factor design and allowable stress design methods are employed in the design examples.

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Chapter 1
Introduction

1.1 OBJECTIVE AND SCOPE

This Design Guide illustrates a method for the design of braced frame bracing connections based on structural principles, and presents the design basis and complete design examples illustrating the design of:

1. All orthogonal and nonorthogonal connections involving a brace, a beam and a column (corner type)
2. Connections involving a beam or column and one or two braces, such as chevron or K-bracing, and eccentric braces (center type)
3. Connections of braces to columns at column base plates (base type)
4. Both nonseismic and seismic situations are covered

1.2 DESIGN PHILOSOPHY

All structural design, except for that which is based directly on physical testing, is based either explicitly or implicitly on the principle known as the lower bound theorem of limit analysis. This theorem is important because it allows structural engineers to be confident that 1) their assumptions about the internal force field will not over-predict the strength of an indeterminate structure, and 2) different methodologies for determining an admissible force field, while they may vary significantly in their predictions of the available strength, are nonetheless all valid. This theorem, which was first proven in the form given in the following in the 1950s (Baker et al., 1956), states that:

Given: An admissible internal force field (i.e., a distribution of internal forces in equilibrium with the applied load)

Given: Satisfaction of all applicable limit states

Then: The external load in equilibrium with the internal force field is less than, or at most equal to, the connection capacity.

The lower bound theorem is applicable to ductile limit states, and most connection limit states have some ductility. For instance, bolts in shear undergo significant shear deformation, on the order of ⅜ in. for a ¾-in.-diameter bolt, before fracture. Limit states such as block shear and net shear can accommodate significant distortion of the material before fracture. Plate or column buckling, while generally conceived as a nonductile limit state, is in a sense a ductile limit state; when a plate or column buckles, it does not become incapable of supporting any load, but rather will continue to support the buckling load as long as any excess load can be distributed to other components of the structural system. This phenomenon can be observed in the laboratory when a displacement-type testing machine is used. If a force-type machine is used, the load will increase continuously, and kinking and complete collapse will occur.

Actually all structural design relies on the validity of the lower bound theorem. For instance, if a building is modeled by a frame analysis computer program, a certain distribution of column loads will result. This distribution is dependent on thousands of assumptions. Shear connections are assumed not to carry any moment at all, and moment connections are assumed to maintain the angle between members. Neither assumption is true. Therefore, the column design loads at the footings will sometimes be drastically different from the actual loads, if these loads were measured. Some columns will be designed for loads smaller than the true load, and some will be designed for larger loads. Because of the lower bound theorem, this is not a concern.

Ductility can also be provided to an otherwise nonductile system by support flexibility. For instance, transversely loaded fillet welds are known to have limited ductility. If a plate is fillet welded near the center of a column or beam web and subjected to a load transverse to the web, the flexibility of the web under transverse load will tend to mitigate the low ductility of the fillet weld and will allow redistribution to occur. This same effect can be achieved with transversely loaded fillet welds to rigid supports by using a fillet weld larger than that required for the given loads. The larger fillet weld allows the given applied loads to redistribute within the length of the weld without local fracture.

The term "admissible force field" perhaps needs some further explanation. Bracing connections are inherently statically indeterminate. Therefore, there will be many possible force distributions within the connection. All of those force distributions that satisfy equilibrium are said to be "admissible" or "statically admissible." There are theoretically an infinite number of possible admissible force fields for any statically indeterminate structure. There will also be an infinite number of internal force fields that do not satisfy equilibrium; these are said to be "inadmissible." If such a force field is used, the lower bound theorem is not valid and any design obtained with this inadmissible force field cannot be said to be safe; i.e., the failure load may be less than the applied load. When an admissible force field is used, the calculated failure load will be less than, or at most equal to, the load at which failure occurs; therefore, a safe design is achieved.