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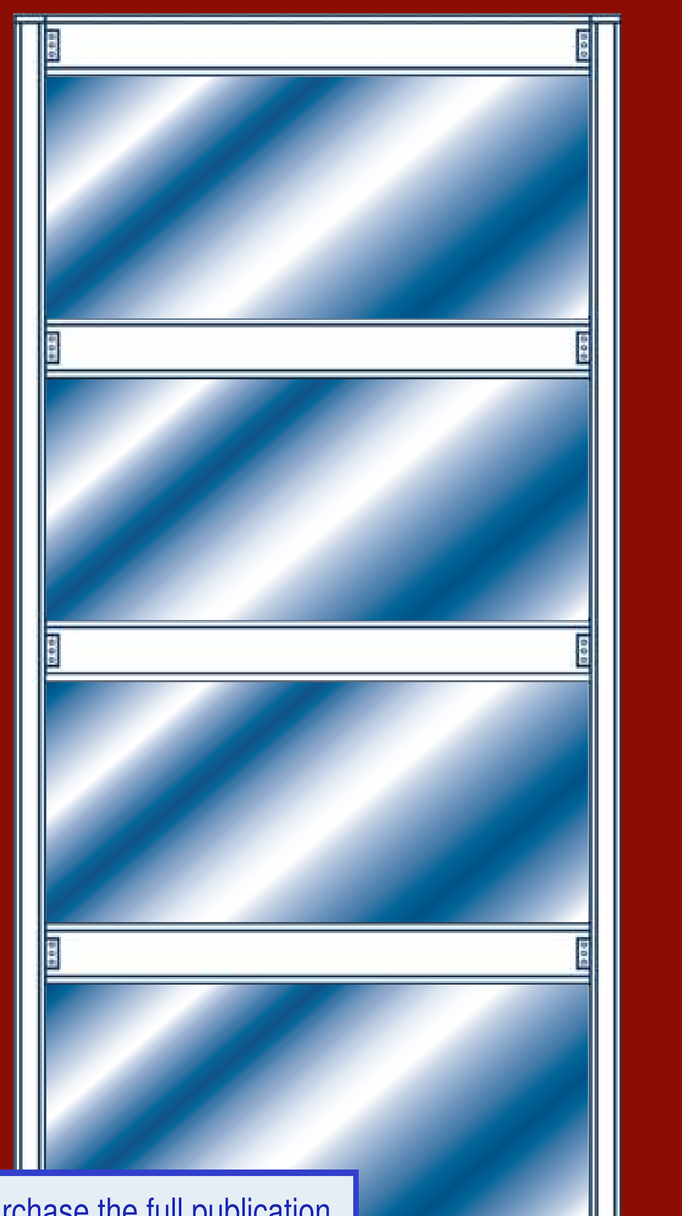
Steel Design Guide

Steel Plate Shear Walls



20 Steel Design Guide

Steel Plate Shear Walls

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Chapter 1

History of Steel Plate Shear Walls

1.1. INTRODUCTION

Steel plate shear walls (SPW) have been used in a significant number of buildings, beginning decades ago, before the existence of design requirements specifically addressing this structural system. Implementation has accelerated significantly since the recent publication of various design standards, specifications, and other guidelines providing design requirements in both high-seismic applications and wind and low-seismic applications (as will be reviewed in subsequent chapters).

1.1.1. Overview

This introduction provides a general description of steel plate shear walls (SPW) and the Special Plate Shear Wall (SPSW) system. This introduction also describes the format and organization of the Design Guide.

This Design Guide has been developed using:

- ASCE 7-05 *Minimum Design Loads for Buildings and Other Structures*, including Supplement No. 1
- AISC 360-05 *Specification for Structural Steel Buildings*
- AISC 341-05 *Seismic Provisions for Structural Steel Buildings*, including Supplement No. 1

Analytical and capacity-design methods presented in this Design Guide typically establish the seismic load effect on a member or connection; this load effect can be utilized in either LRFD or ASD load combinations. The design examples in this Design Guide illustrate the LRFD method.

The Design Guide addresses design for both high-seismic applications and wind and low-seismic applications. Certain provisions of AISC 341 are used regardless of the Seismic Design Category.

Throughout this Design Guide, standards are referred to by their number (e.g., ASCE 7, AISC 360, AISC 341, etc.). The document titles are listed in the bibliography.

1.1.2. Wall Types

Steel plate shear walls in building construction are of various types. By far the most popular in the United States is the unstiffened, slender-web steel plate shear wall. This type is the basis for the SPSW system, which is included as a "Basic Seismic Force Resisting System" in ASCE 7 and AISC 341. This type of web plate has negligible compression strength and thus, shear buckling occurs at low levels of loading. Lateral loads are resisted through diagonal tension in the web plate[1] (akin to tension-field action in a plate girder), rather than in shear. Boundary elements are designed to permit the web plates to develop significant diagonal tension; for high-seismic design, they are designed to permit the web plates to reach their expected yield stress across the entire panel.

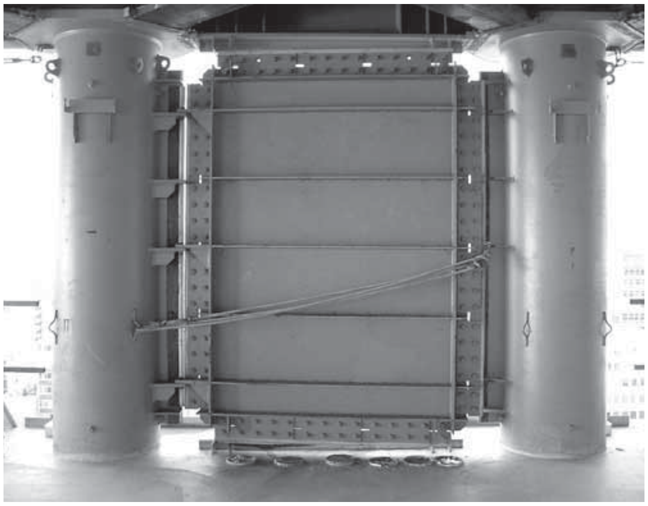
Stiffened web plates may also be used. Stiffening increases the shear-buckling strength of the web plate. Sufficient stiffening to permit the web plate to develop its shear yield strength may be added, or the stiffening may be partial. For partially stiffened web plates, the strength is a combination of the shear buckling strength and the additional strength gained from tension-field action. This available strength is calculated using methods developed for plate girders, as discussed in Chapter 3.

Composite steel plate shear walls have also been used in building design. In this system, steel web plates are stiffened by adding concrete on one or both sides of the web plate. Sufficient stiffening is typically provided to permit shear yielding of the web plate. Chapter 3 contains a treatment of composite steel plate shear walls, including the requirements of AISC 341.

Stiffening of the web plate has a moderate effect on the strength and stiffness of the wall. Additionally, it tends to reduce the flexural strength and stiffness required of the boundary elements. Stiffening of the web plates also results in hysteretic behavior that is significantly less pinched. However, it also substantially increases the cost of the construction and increases the thickness of the wall. It is generally preferred to achieve the required strength and stiffness by utilizing an unstiffened, slender web plate, rather than a stiffened web plate. Very high strength and stiffness can be provided by unstiffened steel web plates of moderate thickness. In high-seismic design, the hysteretic behavior can be improved with the use of rigid beam-to-column connections in the frame of the shear wall.

Steel plate shear walls with unstiffened, slender web plates are the focus of this Design Guide. Chapter 3 contains a design method for this type of steel plate shear wall.

[1] The term *web plate* is used to refer to the steel plate that resists the horizontal shear in the wall. A web plate connects to columns, called Vertical Boundary Elements (VBE), on either side, and beams, called Horizontal Boundary Elements (HBE), above and below.



(a)

(b)

Fig. 1–1. SPW panel in Japan: (a) wall with horizontal panel stiffeners (courtesy of Takanaka); (b) wall with horizontal and vertical stiffeners (courtesy of Nippon Steel).

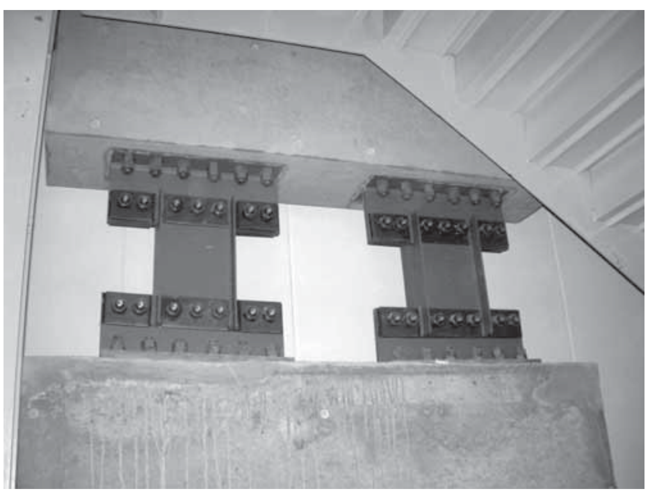


Fig. 1–2. Small shear yielding elements in Japan (courtesy of Shimizu).

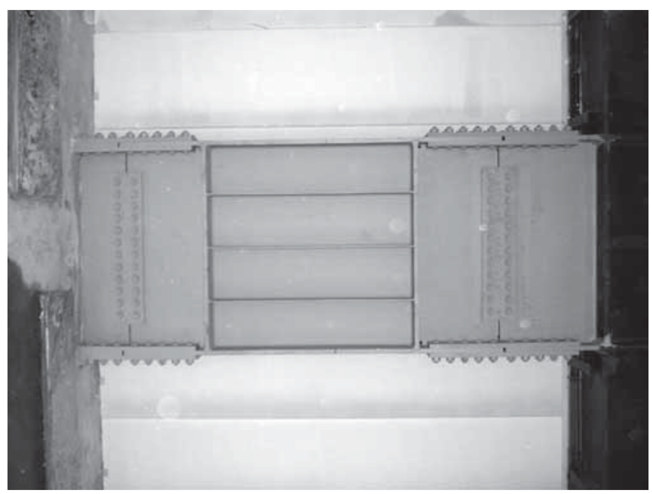


Fig. 1–3. Shear link connected between closely spaced columns (courtesy of Nippon Steel).

Chapter 4 uses this system in a design example for wind and low-seismic application, and Chapter 5 uses this system in a design example for high-seismic application. Chapter 6 addresses the design of openings in steel plate shear walls with unstiffened, slender web plates.

1.1.3. Applications

Steel plate shear walls have been used in a large number of buildings, including in the United States, Canada, Mexico, and Japan. Building types have ranged from single-family residential to high-rise construction. In addition to new construction, steel web plates have been added to retrofit existing frame buildings requiring additional strength and stiffness.

SPSW may be used wherever the building function permits walls of moderate length. Mid-rise and high-rise construction, with their repetitive floor plans and continuous building core, are especially well suited for SPSW.

Chapter 1 contains an extensive list of buildings utilizing steel plate shear walls.

1.1.4. Advantages

Steel plate shear walls, and SPSW in particular, offer significant advantages over many other systems in terms of cost, performance, and ease of design.

Compared to concrete shear walls, the reduced thickness (and thus plan area devoted to them) represents a substantial benefit. The reduced mass can also be significant in the design of the foundation. Most importantly, however, steel plate shear walls can be erected in significantly less time than concrete shear wall structures.

SPSW may be considered as an alternative to braced frames. They can provide equivalent strength and stiffness and require the same or less plan area.

The speed of construction of SPSW is comparable to that of braced frames as well. While there is typically a significant amount of field welding, most if not all web-plate field welding can be selected as single-pass fillet welds, and thus erection typically proceeds at a rapid pace.

The strength and stiffness of the system ensure good performance under moderate lateral loads. The ductility of steel web plates in SPSW results in good performance under severe seismic loading.

Because SPSW can provide significant strength and stiffness, shorter bays can be used. This results in greater flexibility for use of the space.

SPSW are relatively easy to design—the capacity-design calculations for the design examples in Chapters 4 and 5 were performed on a simple spreadsheet. As is discussed in Chapter 3, SPSW can be modeled with either membrane elements or truss elements using many of the structural engineering programs typically employed by design offices.

1.1.5. Limitations

SPSW may be used for structures ranging from one or two-story residential structures to the tallest high rise.[2] However, while the system is viable for both small and large structures, aspects of the design vary with building size.

Compliance with some requirements of AISC 341 for seismic design may prove to be more difficult or at least more tedious than typical detailing practice for smaller structures. The provisions that require the beams and columns of SPSW to form a moment frame (and comply with certain requirements for Special Moment Frames) may be especially onerous in structures that combine SPSW with light-frame construction.

For taller structures, drift control is much more difficult. While providing a steel plate with sufficient strength does not pose a problem, building drift may require longer bays of SPSW to reduce forces in columns. However, because SPSW bays with long horizontal proportions have not been studied, their use is restricted. Building drift control may require that SPSW be supplemented in some way, such as by coupling two SPSW to reduce the axial forces in columns, or by providing outrigger beams to deliver some of the overturning force to adjacent columns.

1.1.6. Design Guide Structure

This Design Guide is divided into seven chapters. Chapter 1 includes an extensive survey of buildings that employ the system. New construction and retrofits in Japan, Canada, Mexico, and the United States are presented, showing the extensive use of the system and a wide range of applications.

Chapter 2 includes a survey of the research (both analytical and experimental) into the system behavior. Chapter 2 also provides a brief treatment and comparison of the design provisions that have been developed for this system in Canada and the United States.

Chapter 3 includes a treatment of the mechanics of unstiffened, slender-web-plate shear walls. It also provides a discussion of stiffened and composite steel plate shear walls. Chapter 3 discusses methods of analysis, and both general requirements and seismic design methods are presented. For seismic design, the requirements of AISC 341 are illustrated, and equations for determining the required strength of elements are developed.

[2]ASCE 7 limits SPSW to 160 ft in Seismic Design Categories D, E, and F, unless a dual system is used.