Seismic Design and Detailing Requirements of Coupled Composite Plate Shear Walls/Concrete Filled According to ANSI/AISC 341-22 and ASCE/SEI 7-22

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Composite Plate Shear Wall / Concrete Filled (C-PSW/CF), also known as the SpeedCore system, is an efficient seismic force-resisting system for buildings, which was already addressed in ASCE/SEI 7-16. Coupled C-PSW/CF are more ductile and have more redundancy than uncoupled composite plate shear walls, but ASCE/SEI 7-16 did not assign them seismic design coefficients in Table 12.2-1. A FEMA P695 study was conducted to substantiate the design coefficients that should be used for such coupled C-PSW/CF structures. Adding this as a separate category in Table 12.2-1 was important because modern high-rise buildings often have elevator core wall systems; many of these core walls could utilize the coupled C-PSW/CF systems. Two line items featuring this system are now added to ASCE/SEI 7-22 Table 12.2-1 under Building Frame Systems and Dual Systems with Special Moment Frames. R = 8, Cd = 5.5, and Ω0 = 2.5 are the design coefficients in both line items. The height limits are the same as for corresponding uncoupled isolated wall systems.

A definition for the coupled C-PSW/SF system and design and detailing requirements for it are so far not given in ANSI/AISC 341-16 (AISC, 2016a) or ANSI/AISC 360-16 (AISC, 2016b). A new Section 14.3.5 in ASCE/SEI 7-22 (ASCE, 2021) includes specific provisions for the definition and application of this coupled C-PSW/CF system, including details on the design philosophy and limits on applicability. It is anticipated that the provisions in Section 14.3.5 will ultimately end up distributed in ANSI/AISC 341-22 (AISC, 2022a) and AISC 360-22 (AISC, 2022b). Rather than construct the requirements in Section 14.3.5 to modify the applicable sections of ANSI/AISC 360-22 and ANSI/AISC 341-22, it is presented as a completely new comprehensive section in ASCE/SEI 7-22 for clarity.

This course outlines the above developments and presents a ***detailed design example*** illustrating the coupled C-PSW/CF seismic force-resisting system.

1. Introduction

Functional and often structural requirements make the use of shear walls desirable in many buildings. Functionally, shear walls are useful in buildings because they serve as partitions between spaces. Structurally, they make buildings laterally stiff, thereby helping to keep lateral deflections within acceptable limits. Often, such walls are pierced by numerous openings for windows, doors, and other purposes. Two or more walls separated by vertical rows of openings, with beams at every floor level between the vertically arranged openings, are referred to as coupled shear walls. When a coupled shear wall system is subject to lateral loads due to wind or earthquake forces, shear forces generated at the ends of the coupling beams accumulate into a tensile force in one of the coupled wall piers and into a compression force in the other wall pier. The couple, due to these tension and compression forces, resists a part of the overturning moment at the base of the wall system, with the remainder of the overturning moment being resisted by the wall piers themselves (Figure 1). The ratio of the overturning moment resisted by the tension-compression couple to the total overturning moment at the base of the coupled wall system is often referred to as the degree of coupling. The shorter and deeper the coupling beams, the higher the degree of coupling. When the degree of coupling is very low, the two wall piers tend to behave like isolated walls, and when the degree of coupling is very high, the entire coupled wall system tends to behave like a shear wall with openings. It should be noted, however, that as and when inelastic displacements develop in the coupling beams, the degree of coupling tends to lose its significance.

A coupled shear wall system can be designed such that a considerable amount of earthquake energy is dissipated by flexural yielding in coupling beams before flexural hinge formations (typically) at the bases of the wall piers. Coupling beams are required to have length-to-depth ratios between three and five. Wall piers are required to have height-to-length ratios larger than or equal to four. Although such coupled wall systems are highly suitable as the seismic force-resisting systems of multistory buildings, they are not recognized as distinct entities in Table 12.2-1 of ASCE/SEI 7-16. Therefore, such systems need to be designed using *R*-values that essentially ignore the considerable benefits of having coupling beams, which can dissipate much of the energy generated by earthquake excitation. This course reports on a successful effort to remedy this situation.

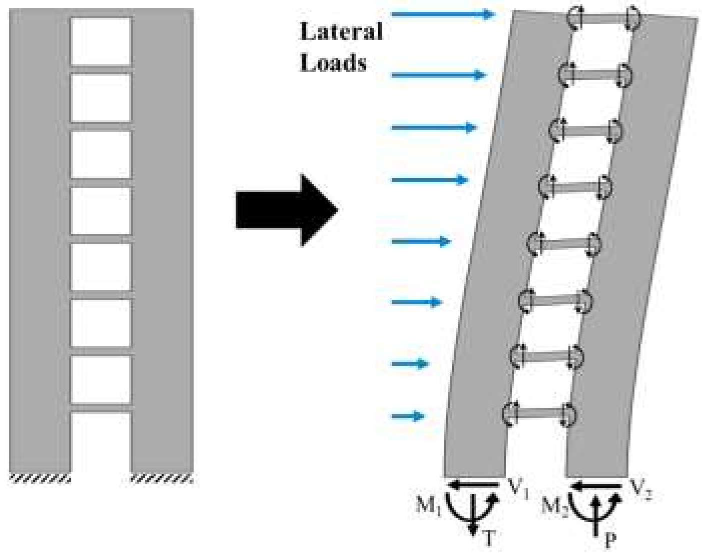

Figure 1- A Coupled C-PSW/CF Subjected to Lateral Loads

2. Coupled Composite Plate Shear Wall / Concrete Filled (C-PSW/CF) Systems

C-PSW/CFs are an alternative to conventional reinforced concrete (RC) shear walls and core wall structures in building structures. Similar to RC walls, composite walls provide the stiffness, strength, and deformation capacity needed to serve as the primary lateral force-resisting system. C-PSW/CFs may be used as the elevator core structure or as individual shear walls in building structures. Two versions are possible: uncoupled and coupled. In a given building structure, it is possible to have a coupled system in one direction and an uncoupled system in the orthogonal direction.

The coupled C-PSW/CF system consists of (i) composite C-PSW/CFs and (ii) composite coupling beams. Both the composite walls and composite coupling beams consist of a concrete core sandwiched between two steel plates that serve as the primary reinforcement, completely replacing conventional rebars. Figure 2(a) shows a typical C-PSW/CF with its components. Tie bars connect the two steel plates and provide stability during transportation and construction activities. After concrete casting, the tie bars become embedded in the concrete infill and provide composite action between the steel and concrete. The coupling beams are built-up steel box sections with concrete infill. Figure 2(b) shows a composite coupling beam. Similar to the composite walls, the built-up steel section provides primary reinforcement to the coupling beam. The empty steel modules, including both the walls and the coupling beam components, are typically fabricated in the shop, transported to the site, erected, and filled with concrete. The composite walls can be planar, C-shaped, or I-shaped, following the typical geometric configurations of conventional concrete core walls.

It is important to note that there are no additional reinforcing bars needed in either the C-PSW/CFs or the composite coupling beams. The empty steel modules are filled with plain concrete, which is usually self-compacting concrete (SCC). There are no temperature and shrinkage concerns related to strength. The effects of concrete cracking due to locked-in shrinkage strain are included in the stiffness equations. The steel plates provide all the reinforcement needed to resist forces. The steel modules, including the plates, tie bars, and shear studs (if used), are prefabricated in the shop and shipped to the field for assembly and erection. The modular steelwork serves as formwork for the concrete infill and falsework for construction activities. Generally, the steel parts come without painting, but after assembly, they might be painted or fireproofed if needed (Anvari et al., 2020). Commercial interest in the coupled C-PSW/CF system is motivated by these potential advantages of modularity, construction schedule, and overall project economy. In addition, another benefit of using C-PSW/CFs is that they are thinner than corresponding reinforced concrete shear walls, providing more available floor area.

The composite walls are required to have a height-to-length (hw/Lw) ratio greater than or equal to 4.0. This requirement is specified to ensure that the walls are flexure critical, i.e., flexural yielding and failure govern behavior rather than shear failure. Calculations can also be performed to show that the wall is flexure critical, i.e., plastic hinges (with expected flexural capacity) form at the base of the walls before shear failure occurs. The shortest archetype structure that was evaluated using the FEMA P695 approach for this system was three stories with two 45-foot tall composite walls with 10- 10-foot length (Bruneau et al., 2019), corresponding to a height-to-length ratio equal to 4.5 for each wall.

The composite coupling beams are also required to be flexure critical, i.e., flexural yielding and failure govern behavior rather than shear failure. Calculations can be performed to show that the composite beam is flexure critical, i.e., plastic hinges (with expected flexural capacity) form at the ends of the beams before shear failure occurs. For at least 90% of the stories of the building, composite coupling beams are also required to have clear length-to-section depth ratios greater than or equal to 3.0 and less than or equal to 5.0, i.e., $3.0 \leq L/d \leq 5.0$. This requirement is specified based on the range of parameters included in the FEMA P695 studies conducted to establish the seismic factor (*R,* etc.) for the system.

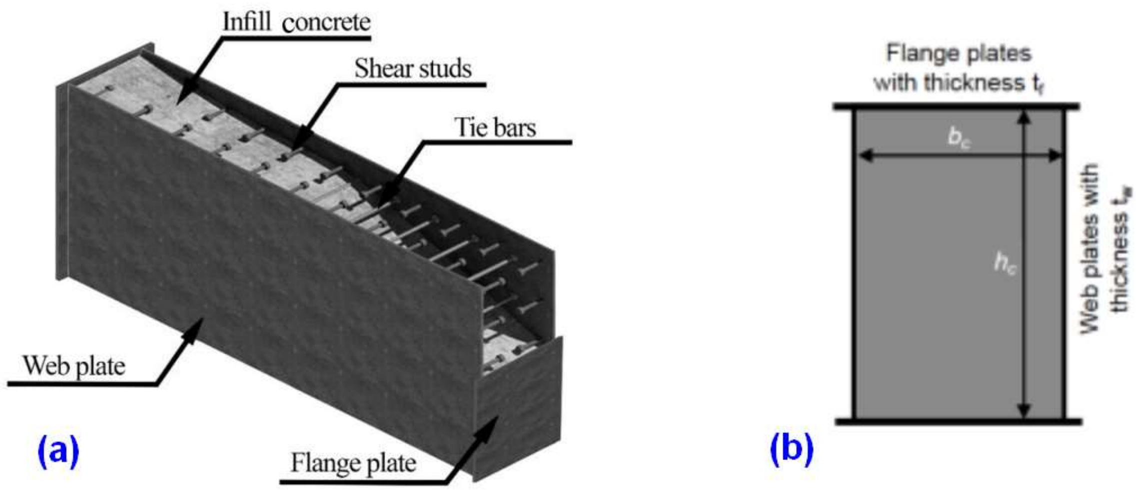

Figure 2. Components of: (a) C-PSW/CF (Shafaei et al., 2021b), and (b) Composite Coupling Beam

3. Coupled C-PSW/CF System in ASCE/SEI 7-22

Issue Team (IT) 4 of the Provisions Update Committee (PUC) of the Building Seismic Safety Council (BSSC) developed a proposal that led to the addition of two line items to ASCE/SEI 7-22 Table 12.2-1, Design Coefficients and Factors for Seismic Force-Resisting Systems, featuring the steel and concrete coupled composite plate shear walls (Table 1). The line items will be under B. Building Frame Systems, and D. Dual Systems with Special Moment Frames.

Note: The coupled C-PSW/CF system is called "Steel and concrete coupled composite plate shear walls" in ASCE/SEI 7-22; however, "Coupled Composite plate shear walls/concrete filled" (coupled C-PSW/CF) name is used for this coupled system in ANSI/AISC 341-22 and AISC Design Guide 37.

Table 1. Addition of Coupled C-PSW/CF to ASCE/SEI 7-22 Table 12.2-1

Seismic Force-Resisting System	ASCE/SEI 7-22 Section Where Detailing Requirements Are Specified				Structural System Limitations Including Structural Height, (ft) Limits[d]				
					Category				
								E[e]	F[f]
...									
B. BUILDI									
...									
26. Steel sp plate shear w									100
27. Steel and concrete coup composite plat shear walls									100
...									
D. DUAL SYSTEM PRESCRIBED SEIS									
...									
13. Steel special plate shear walls					NL	NL	NL	NL	NL
14. Steel and concrete coupled composite plate shear walls	14.3	8	2½	5½	NL	NL	NL	NL	NL

Based on a FEMA P695 study, R = 8, Cd = 8, and Ωo = 2.5 have been adapted in all the line items. The height limits are the same as for corresponding uncoupled isolated wall systems, eccentrically braced frames, steel special concentrically braced frames, steel buckling-restrained braced frames, and steel special plate shear walls. It will be possible to increase the 160-ft height limit to 240 ft for buildings without significant torsion because ASCE/SEI 7-22 Section 12.2.5.4 has been made applicable to these systems.