Introduction
- History, examples
- Benefits
- Disadvantages

Plate Girder Analogy

Behavior of Special Plate Shear Walls (SPSW)

Design of SPSW
- Important considerations
Special Plate Shear Walls (SPSW)

Prior to 1980s

- Limit State considered to be out-of-plane buckling
- Result: heavily stiffened steel plates
  - Not competitive with reinforced concrete shear walls

Since then...

- Experimental studies have demonstrated significant post-buckling strength, tension field action

- Canadian Standards Association and AISC 
  *Seismic Provisions for Structural Steel Buildings* 
  2005 implemented design standards for SPSW
Steel plate shear wall with horizontal and vertical stiffeners (Japan)

Courtesy of Nippon Steel
Kobe Office Building

Typical Floor Plan

North

134'-6" (41 m)

119'-5"
(36.4 m)

N-S Frame

424'-7"
(129.4 m)

E-W Frame
Kobe Office Building

(Photo by M. Kanada, from Kanada and Astaneh-Asl, 1996),

(From: Fujitani et al., 1996) and (AIJ, 1995)
Olive View Hospital

Courtesy of ENR
Olive View Hospital

Courtesy of Naeim and Lobo
U.S. Federal Courthouse, Seattle

Courtesy of John Hooper, MKA Seattle
U.S. Federal Courthouse, Seattle

Courtesy of John Hooper, MKA Seattle
Steel plate shear walls in residential construction

Courtesy of Jon Brody Structural Engineers

Courtesy of Matt Eatherton, GFDS
Steel plate shear walls and details at base of SPW, ING building

Courtesy of Louis Crepeau and Jean-Benoit Ducharme, Groupe Teknika, Montreal, Canada
Advantages

- Ductility, energy dissipation
  → *if detailed properly, up to 4% drift without damage*
- Thinner walls
  → *<18” with furring+finishes, savings in gross square footage*
- Light weight
  → *Lower total building weight; reduced foundation and overall building seismic loads*
- Fast construction time
  → *e.g. shop-welded, field-bolted; no curing time*
  → *"Easier than ... concentrically braced frames."

- Easier retrofit
X-bracing

V-bracing / K-bracing

Eccentric Bracing

Steel Plate Shear Wall (Unstiffened)

Stiffened Shear Walls with Openings
Fin Plate

Fillet Welds

Erection Bolts
Disadvantages

- **Stiffness**
  - Stiff, but more flexible than reinforced concrete shear walls

- **Construction Sequence**
  - Need to avoid pre-compression of SPSW due to dead loads?

- **Unfamiliarity**
  - Currently, relative unfamiliarity with SPSW might result in higher costs for fabrication/erection (this is becoming less of an issue)
Single Bay

Coupled Bays

Coupled Bays & CFT Columns
“Nabih Youssef Associates ....suggested replacing the heavy 30-in. concrete shear walls with light 1/4-in. to 3/8-in. steel-plate shear walls to free valuable real estate space; eliminate 35% of the weight of the structure; and reduce seismic design forces and foundation sizes. ...compressed the construction schedule and budget while allowing for more simplified and efficient construction.”

http://www.modernsteel.com/SteelInTheNews/?p=181
L.A. Live

SPSWs at 45th floor

Box column fabricated in Japan

Buckling-restrained braces at 28th floor (transition from hotel to condo)

http://blogdowntown.com/2008/10/3756-la-live-tower-structure-hailed-at-steel-industry
http://www.aisc.org/content.aspx?id=16012

Links to full presentation, videos of site tour (2008), etc.
Project Description

Architectural

Upper Tower

Pool Deck

Lower Tower

Podium

Variable Floor
Project Description

Structural

- Thin Steel Plates
- BRB Outrigger
- Variable Floor
- Upper Tower
- Pool Deck
- Lower Tower
- BRB Outrigger
- Podium
Boundary elements (HBE and VBE) are designed to allow the web plates to develop significant diagonal tension and reach their expected yield stress across the entire panel to dissipate the seismic energy.
L.A. Live – SPSW at Foundation
Project Goals/Achievements

- Enhanced & Confirmed Performance
- Uncompromised Architectural Vision
  - No Deep Spandrel at Perimeter
- More Sellable Floor Area for Ownership
- Lighter Building Weight
  - 30% lighter without Concrete Walls
  - Reduced Foundation Pressures
- Early Completion of Structural Frame
  - Erected 3 Floors Per Week
Plate Girder Analogy

Plate Girder

Shear Wall
Behavior

- Behavior *similar* to that of a vertical plate girder
  - Boundary columns act as flanges
  - Story beams act as stiffeners
  - Infill plate acts as web
- Infill plate allowed to buckle in shear
- Then diagonal tension field forms and the infill plate dissipates energy through yielding in tension

Courtesy of Jeff Berman, UW
Shear wall vs. Plate girder

- **Axial load**: Taken by boundary columns. \( P-\Delta \) effects must be considered.

- **Flanges**: Boundary columns = flanges. Affect inclination of tension field.

- **Stiffeners**: Floor beams provide very good anchors for tension field. Also affect angle of tension field!!!

- **Loading**: Shear walls expected to see large inelastic cyclic loading.
Behavior of Shear Walls

Shear Wall Within a Simple Frame

Shear Wall Within a Moment Frame (Dual System)
Tests of Steel Plate Shear Walls

Test Specimen

Load vs. Displacement
(Curves from: Timler and Kulak, 1983)
Tests of Steel Plate Shear Walls

(Photo: Courtesy of C. Ventura)

(Curves from: Lubell, 1997)
Testing for US Federal Courthouse (Seattle)
SPSW Test for US Federal Courthouse

Courtesy of Astaneh-Asl and Zhao
SPSW Test for US Federal Courthouse

At 2% Drift

End of Test, Fracture of Coupling Beam

Force-drift Relation for Second Floor

Courtesy of Astaneh-Asl and Zhao
Plate Buckling, multi-story SPSW

Courtesy of Robert Driver, University of Alberta, Edmonton, Canada
Local buckling and fracture of column

STEEL PLATE SHEAR WALL
WEST COLUMN SOUTH FACE
MAY 29, 1995

Courtesy of Robert Driver, University of Alberta, Edmonton, Canada
Fracture of steel plate shear wall web plate corner at 3.07% Drift

Courtesy of Berman and Bruneau
Perforated steel plate shear wall

Courtesy of Vian and Bruneau
SPSW with corner openings

Courtesy of Vian and Bruneau
Shear wall vs. Plate girder

- Implications for design
  - AISC specifications for plate girders will underestimate capacity
  - Different considerations for design of boundary elements
  - Web slenderness limit (related to vertical flange buckling of plate girders) does not apply to SPSW
Expected Yield Mode

Development of tension diagonals

Shear buckling

Frame flexure
Progression of yielding across strips
Buckling of steel plate shear wall web plate at 1.82% Drift

Courtesy of Berman and Bruneau
Design

\[ A_c \]
\[ I_c \]

\[ A_b \]
\[ h \]
\[ L \]

\[ \alpha \]
Design

\[ \tan^4 \alpha = \frac{1 + \frac{t_w L}{2 A_c}}{1 + t_w h} \left[ \frac{1}{A_b} + \frac{h^3}{360 I_c L} \right] \]

AISC Seismic Provisions 2010 Eq. F5-2
Design
Design

- Top and Bottom of SPSW?
  - Need stiff horizontal boundary elements (HBE) to anchor the tension field!
Design

\[ V = \frac{1}{2} tLF_y \sin 2\alpha \]

- Same basic equation for TFA only for Plate Girders
- Equivalent to \( \gamma \) for Plate Girders, but much different value

- Note: buckling strength negligible for SPSW
Design

- AISC Seismic 2010 – PANEL Design Shear Strength

\[ \phi V_n = (0.9)0.42t_wF_yL_{cf}\sin 2\alpha \]

- Clear distance between column flanges
- 0.5 divided by system overstrength, defined by FEMA 1.2 for SPSW (Berman and Bruneau, 2003)
Boundary elements designed for expected capacity of plate
Vertical Boundary Elements (VBE) have minimum stiffness requirement to prevent excessive deformations under tension field action
• AISC 2010 requires HBE and VBE remain elastic (except plastic hinging expected at ends of HBE)

• Additional requirements for HBE and VBE including width-thickness limits
Expected Yield Mode

- Multi-story shear mode
- Hinging at base
Multi-story steel plate shear wall

Courtesy of Behbahanifard
Inward Flexure of Boundary Elements

Required stiffness for VBE

\[ I_c \geq 0.0031 \frac{t_w h^4}{L} \]
Inward Flexure of Boundary Elements

Required stiffness for HBE

\[ I_b \geq 0.0031 \frac{(t_i - t_{i+1})L^4}{h} \]

Distributed load on HBE

\[ w_u = R_y F_y (t_i - t_{i+1}) \cos^2(\alpha) \]
Inward Flexure of Boundary Elements

Courtesy of Carlos Ventura, University of British Columbia, Vancouver, Canada