Use of Energy Efficient Wood Structural Insulation Panels in Seismic Regions

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Abstract

The paper describes the use of Structural Insulation Panels (SIPs) as an energy efficient building material for walls, floors and roofs and their suitability in high seismic regions such as in California. SIPs are made out of a core of rigid form insulated plastic inserted between two structural skins of oriented strand board (OSB). The SIP system replaces a plywood shear wall system with vertical studs in residential and commercial buildings. In a plywood shear wall system there are vertical studs typically at 16 inches on center that helps to transfer the vertical loads to foundation. However in SIPs the vertical members are at least four feet apart and in some cases there are no dedicated vertical elements other than the OSB boards. While SIPs have widely been used in non seismic regions, questions remain their ability to sustain applied seismic loads. As a result the SIPs are not readily acceptable in high seismic regions.

The paper describes the use of SIPs as a structural material, and analytical studies conducted to evaluate suitability of SIPs in high seismic regions using structural simulations with SAP2000 and design calculations per the current design codes.

Keywords: Structural Insulated Panels, Energy Efficiency, Green buildings, Seismic regions, Splines, Hold downs, Structural Simulations

1. Introduction

There are Structural Insulated Panels in wood, concrete and steel construction. There are two environmentally friendly structural insulated panels that are increasingly becoming popular. One is based on timber material known as Structurally Insulated Panels (SIPs) while the other is based on concrete materials known as Insulated Concrete Forms (ICFs). These are typically used in floors, walls, and roofs in either residential or light commercial buildings.

1.1 Structural Insulated Panel (SIPs)

The SIPs are typically made of two structural panels (placed as inner and outer layers) structurally bonded to an inner foam core connected through various connectors. A timber SIPs are shown in Figure 1. The insulated shell reduces heating and cooling costs for the building. The thermal resistance is governed by insulation form core while structural strength of the panels is mainly governed by shear connections between the panels and inner core. The main component of a traditional timber home construction is a wood stud wall (normally studs placed 16 to 24 inches over centers) diaphragms with plywood sheeting either one side of the stud frame or both. The wood studs run from bottom of floor to the roof level. The frame is insulated with materials such as mineral wool in between studs. While this has been the standard practice for years for wood frame dwelling construction, SIPs are gaining popularity as an alternative due to their inherent energy savings (1).

The SIPs are made of a core of rigid foam plastic (EPS) insulated between two structural skins of oriented strand board (OSB a board similar to plywood). A typical sandwich panels are shown in Figures 1 and 2, below:

Figure 1: Structural Insulated Panels (www.sips.org)

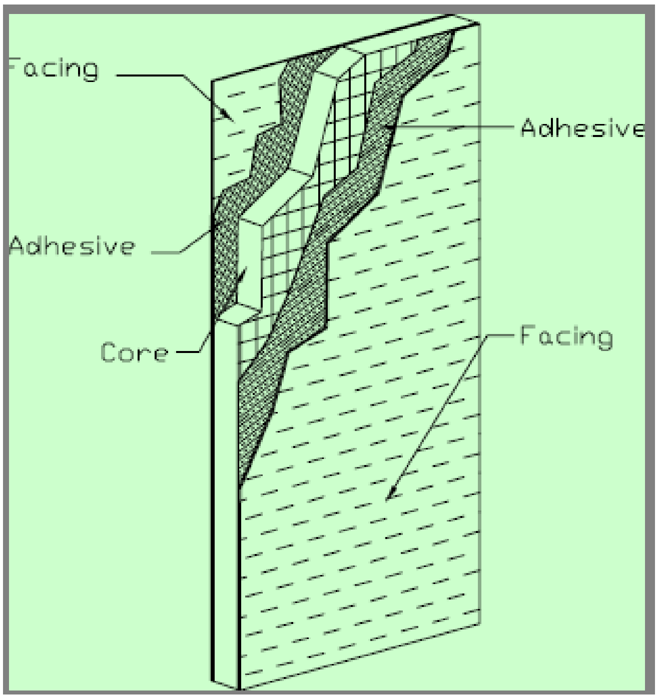

Figure 2: Timber Structural Insulated Panels (www.pathnet.org)

The figure 3 below is a comparison chart of the R-values for SIPs and typical wall panels.

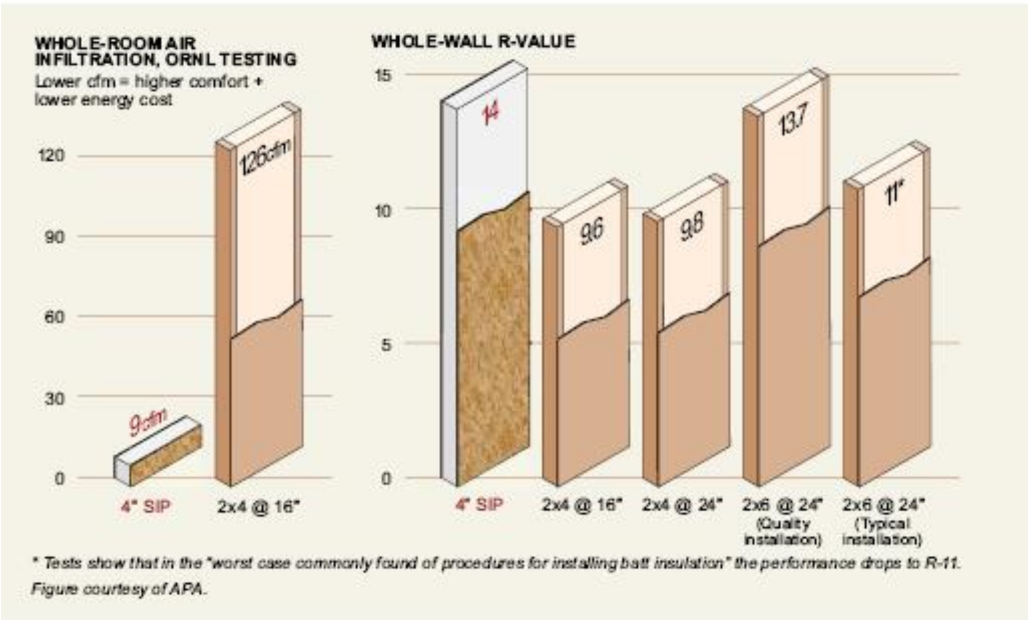

Figure 3: Comparison of R values of SIP panels vs. Conventional shear walls (Courtesy APA)

1.2. Insulated Concrete Forms (ICFs)

ICFs are a type of formwork used for insulating concrete walls, floors, and roofs. Plastic foams ICFs hold concrete in place during concrete curing and left permanently as a thermal insulating material for concrete. These foams are light weight and durable.

The figure 4 depicts a typical ICF configuration. The form planks are connected to each other by plastic ties. Normally steel rods are added as reinforcement before the concrete is poured.

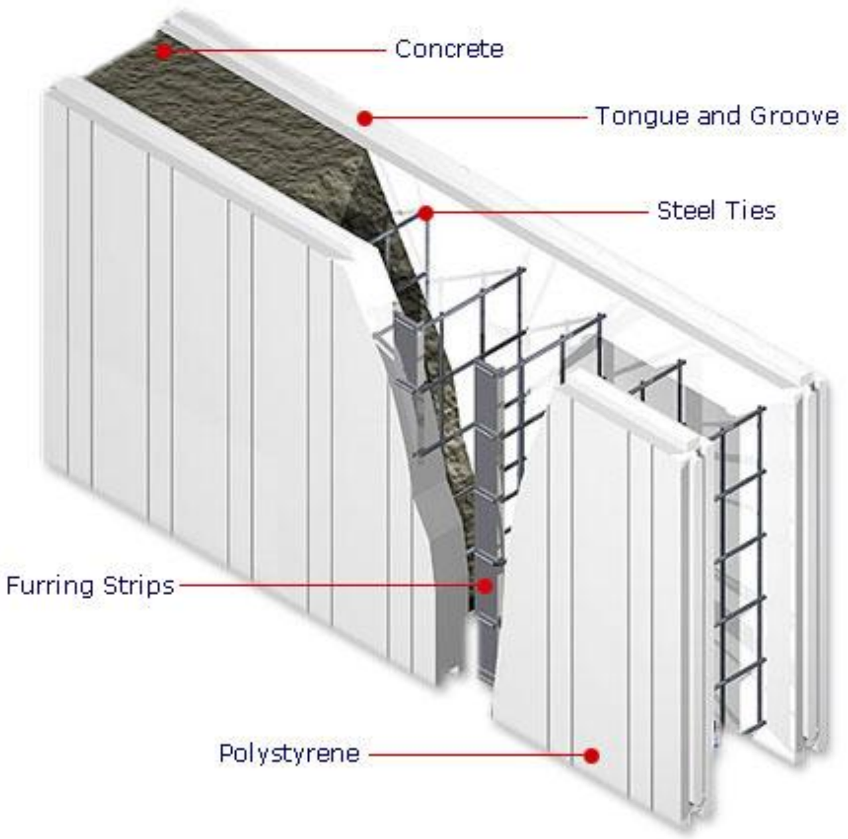

Figure 4: Structural Configuration of an ICF system (www.forms.org)

While Figure 4 depicts form planks, there are also ICFs with hollow form blocks.

Typical insulation values of ICFs are relatively high with a range from R-17 to R-26, as compared with wood-framed walls that have insulation values between R-13 and R-19, They are expected to have a 50% decrease in capacity of HVAC equipment comparing to conventional system. ICF walls are structurally designed in similar manner as reinforced concrete, thus it has higher wind and seismic resistance.

2.0 Suitability of Structural Insulated Panels in Seismic Regions

The current study is based on Structural Insulated Panels' suitability as a green structural material for sesimic regions.

The SIPs are a superior material for energy efficiency, and have been used very well in non seismic regions. However its structural performance in seismic regions is largely unexplored. The structural performance depends on the expected load path within the panel itself, which is based on how well the outer skin and the inner form are connected so that any possible slip between the two panels (inner and outer) is minimized and on how the panels are connected to each other and to the rest of the structure, Current practice often mimics conventional framing construction despite the differences in the component characteristics. Desirable structural performance often relies on not only strength, but also ductility.

The splines to connect one panel to another have different types. Currently accepted splines listed in the NTA listing report (2010) are Type S (Block or Surface Spline), Type I (Engineered Lumber Spline), and Type L (Dimensional Lumber Spline). For seismic design categories D, E, and F only Type S and L splines are allowed. They are shown in Figure 5.

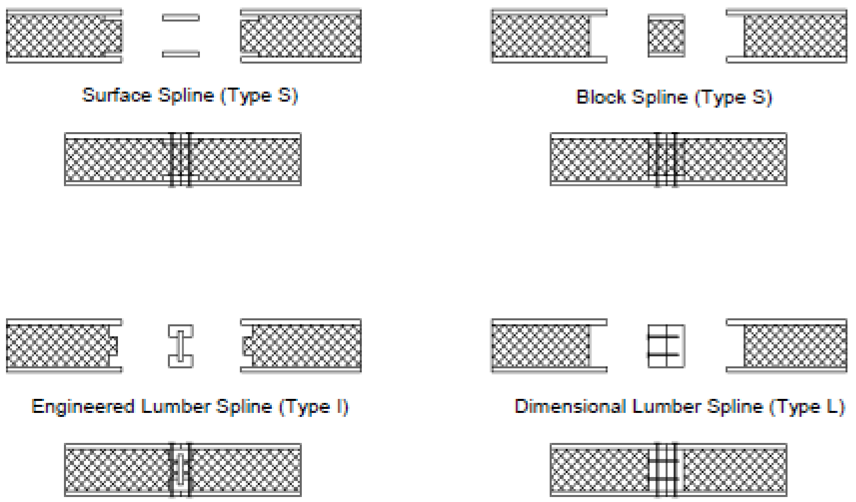

Figure 5: Splines types as connectors between SIPS (Courtesy NTA report PRS032808-3)

2.1 Design Examples based on current seismic design practice

The following are two examples of a code compliance check of a Structural Insulated Panel (SIPs) in a seismic region based on current design practice.

Example 1: Design check for hold downs, sill plate on a SIP panel

The figure 6 shows a SIP panel with static seismic and dead loads.

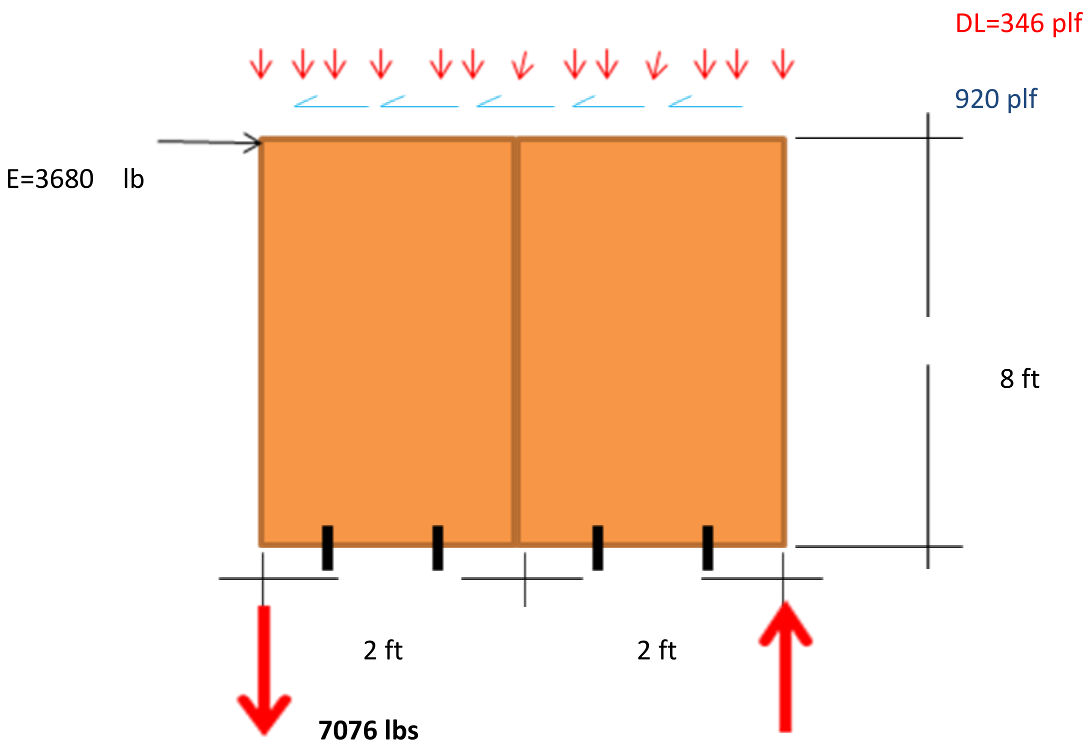

Figure 6: SIP panel with static seismic load and dead load

Hold Down Design:

Use a hold down HDU8-SDS2.5 –anchor bolt size 7/8 inch (per ICC Report ESR-2330)
Capacity 7870 lbs > 7076 lbs OK.

Sill Plate capacity check:

Sill Plate Capacity Per NDS 05

Demand and Design Info

Member size =	3 x 6 DF-L	CBC2010, Table 2306.3, foot note"i".	
Direction of loading =	Perp to grain		
Min reqd edge dist =	0.94	in	NDS'05 11.5.1A
Bolt diameter =	5/8	in	
ASTM grade =	A307		
P_u =	0	lb/bolt	
V_u =	920	lb/bolt = (920 plf * 4 ft)/4 bolts	

Wood Check for Dowel-type Fasteners per NDS '05

Z =	600 lbs	NDS '05 Table 11A
C_M =	1	NDS '05 Table 10.3.3
C_t =	1	NDS '05 Table 10.3.4
C_g =	n/a	NDS '05 eqn 10.3-1
C_Δ =	1.000	NDS '05 Section 11.5.1
C_{eg} =	1	NDS '05 Section 11.5.2
C_{di} =	n/a	NDS '05 Section 11.5.3
C_{tn} =	n/a	NDS '05 Section 11.5.4
C_D =	1.6	
Z' =	960	lb $= Z*C_M*C_t*C_g*C_\Delta*C_{eg}*C_{di}*C_{tn}*C_D$

Z' = 960 lb/bolt > Vu = 920 lb/bolt **OK**

Based on steel shear capacity, concrete breakout and pry out (ACI 318-08 Appendix D) shear capacity, 5/8 in diameter 8 inch length anchor bolts are adequate.

Design Summary

SIP Panel

2-2 x 8

HDU8-SDS2.5

Hold Down

Simpson's Hold-down or equal HDU8 -SDS2.5

Hold down anchor size 7/8 in

Note: All nailing shall be per manufactures

Standards.

Framing

Minimum boundary element	4 x 6	DF-L
Top plate	2 x 6	DF-L
Sill plate	3 x 6	DF-L
Spline	2-2 x 6	

All nailing except boundary elements shall be per manufacturer's standards.

Sill Plate Connections

Sill plate anchor diameter	7/8	in
Minimum conc. embedment	8	in

2 anchor bolts per panel with equal spacing (8' max)
Minimum of 4 anchor bolts per set-up

Example 2: This documents computer modeling and simulation of a SIP panels for seismic loads.

It is essentially a 2-D model using Computers and Structures Inc. (2010) SAP 2000 computer simulation program, consisting of thin shell elements which represent the structural sheathing and the insulated core; frame elements which represents the boundary members such as top plates and posts; and link elements which represents the tie down (hold down) and boundary nailing. The anchor bolts at the base of the shear wall has not been modeled since it is unlikely that a well design wood shear wall will experience pure shear failure at the base. Simpson HDU 8 has been used in the modeling scheme. The modeling scheme consists of three models RK-1, RK-2, and RK-3 as shown in Table 1 below.

Table 1: Computer model schematics

MODLE	***SIZE***	***PANELS***	***THICK-NESS***	***NAILING***	***H/W ratio***
RK-1	*8ft x 8ft*	*2-4ft x 8ft*	*7/16" OSB each face*	*3 inches o.c.*	*1:1*
RK-2	*4ft x 8ft*	*2-2ft x 8ft*	*7/16" OSB each face*	*3 inches o.c.*	*2:1*
RK-3	*4ft x 14ft*	*2-2ft x 14ft*	*7/16" OSB each face*	*3 inches o.c.*	*3.5:1*

The figure 7 depicts the displaced shape of the structural model under seismic loads.

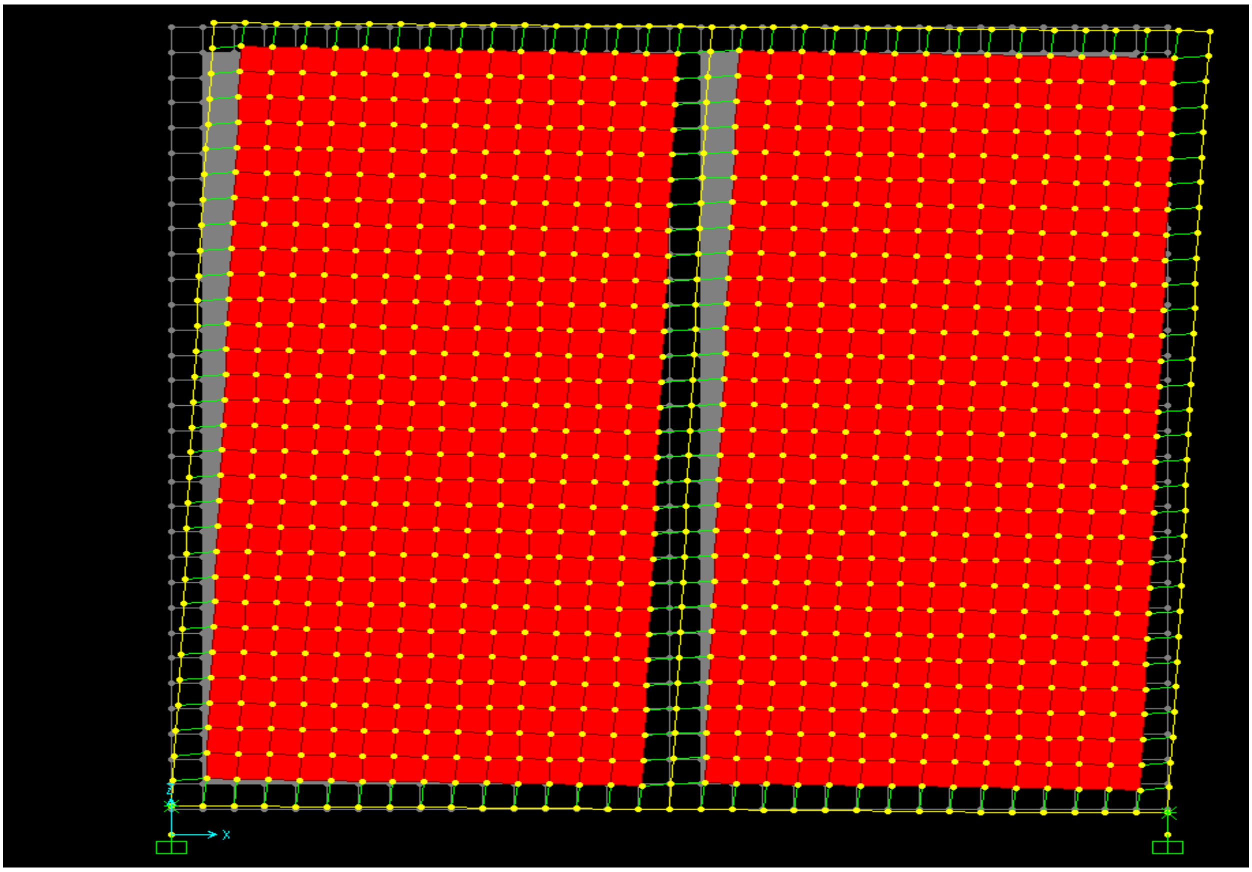

Figure 7: SAP computer model of SIP shear wall deflected shape

Using the results of the computer simulation, a code based seismic drift check has been performed for several lateral load values and results are shown in table 2 below.

Table 2: Design drift check for SIP panel under seismic load

Model RK-1						
Lateral Load (kips)	*Shear flow V (plf)*	*Nail Stiffness (kip/in)*	*Story displacement δ (inches)*	*Amplified displacement $=C_d*\delta$ (inches)*	*Allowable displacement = $0.025h_x$ (inches)*	*Remarks*
5.76	*720*	*19.2*	*0.586*	*2.93*	*2.40*	*N.G*
4.0	*500*	*26.67*	*0.392*	*1.93*	*2.40*	*OK*
3.0	*375*	*52.63*	*0.277*	*1.39*	*2.40*	*OK*
2.0	*250*	*52.63*	*0.184*	*0.92*	*2.40*	*OK*
1.0	*125*	*52.63*	*0.092*	*0.46*	*2.40*	*OK*

**Note: Linear link elements have been used to model the static load case. Nail stiffness were obtained by using values of fastener slip per table 2305.2.2(1) of the International Building Code.

2.2 Work in Progress

A desirable structural performance often relies on not only strength, but also on ductility. Since limited sources of ductility exist within the panel, one possibility is to connect SIP panels via ductile and replaceable connections similar in concept to the advances made in design and construction of precast structural components.

In green building technology, it is desirable to design to post-life of the building. In other words, designers need to ask the question, what will happen when this building reaches the end of its life or has a change in use. Instead of the current methods of demolition and disposal on a landfill, there are ways to design the building such that the components can be de-constructed and re-used; either in the same building to adopt for change in use, or for another building. As SIPs are an assembly of pre-made components, these structural components are a great candidate for use design to post-life of the building and the concept of using ductile connectors a suitable way of achieving the re-use goals.

A current connection based on current design practice is an interconnecting spline as shown in Figure 8 and in its current form would contribute very limited ductility. A current connection based on current design practice is an interconnecting spline as shown in Figure 8 and in its current form would contribute very limited ductility. Current research is underway to investigate alternatives to the current approach such that structural integrity of the panels is maintained.

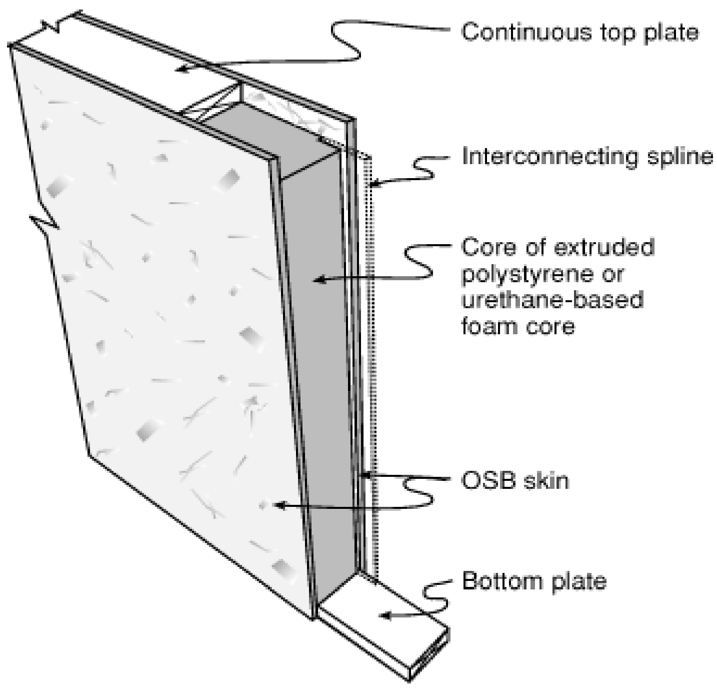

Figure 8: Structural Insulated Panel with a typical connector (Interconnecting Spline) between panels (www.sips.org)

Both the current approach and the alternatives will be tested using real-time full scale specimen earthquake simulation on a shake table.

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