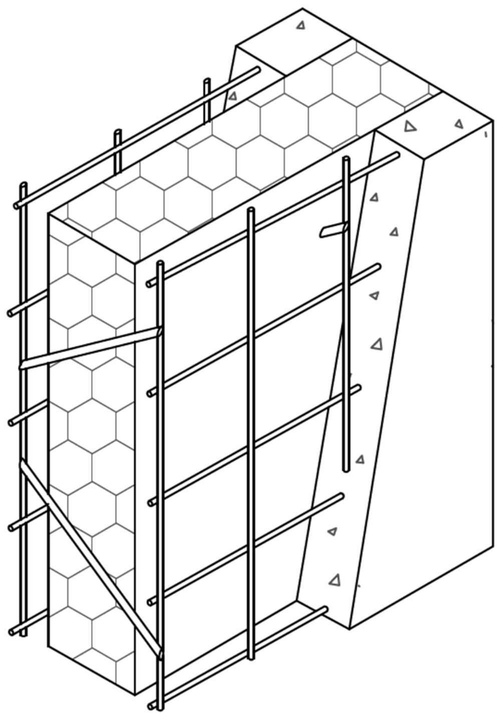
Innovative Structural Solutions

Introduction to the

Total Integrated Panel System

March 2021



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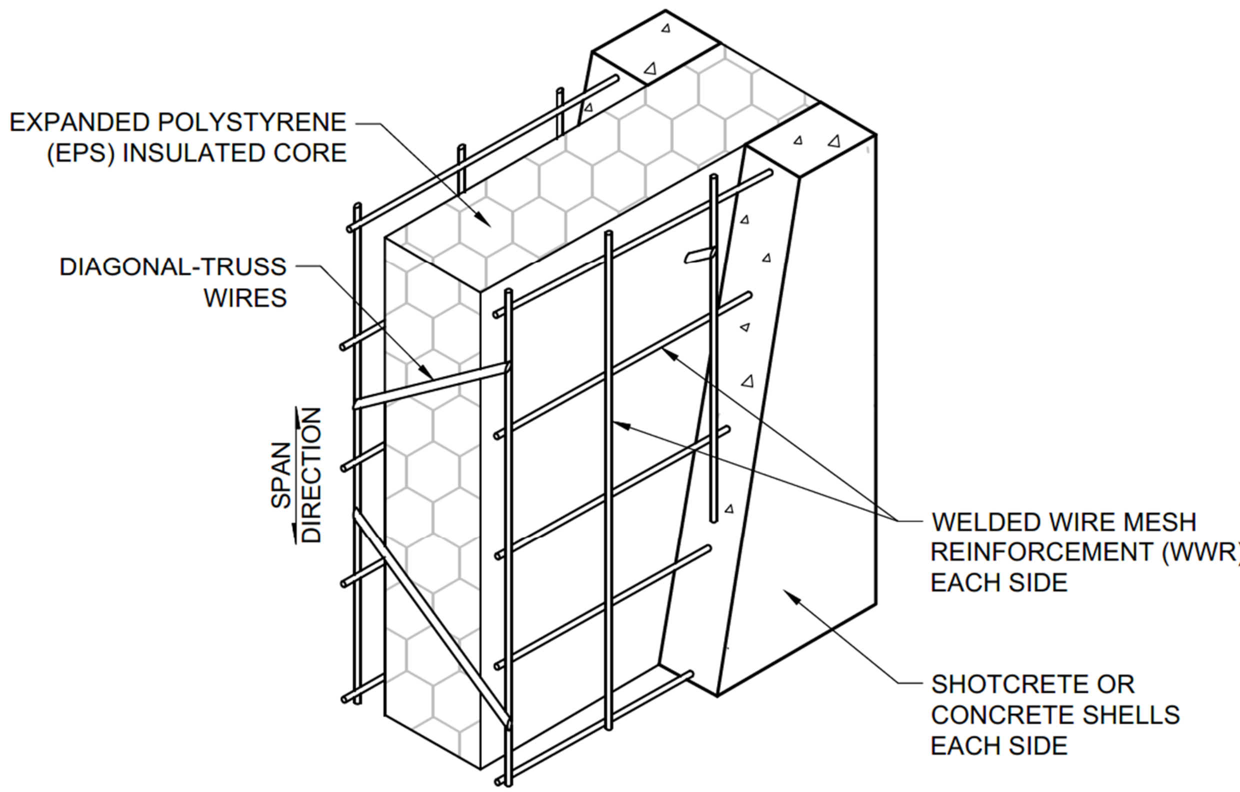
1.0 Introducing Innstruct Total Integrated Panel System

1.1 Product Description

Innovative Structural Solutions hereby introduces the Total Integrated Panel System (TIPS), a building and construction technology system based on a Structural Concrete Insulated Panel (SCIP or Sandwich Panel) system. This sandwich panel system consists of four components: an Expanded Polystyrene (EPS) insulation core, Welded Wire Mesh Reinforcement (WWR), diagonal-truss-wires, and the shotcrete or concrete shells (wythes). The diagonal-truss-wires pass through the EPS and are welded to the outer WWR reinforcement to create a wire-truss-system. The field-applied concrete shells encases the WWR to create the top and bottom chords of a truss type system, which spans in the truss-wire direction. This configuration creates a 3-Dimensional, composite sandwich panel system. The system is shown in the following figure.



Innstruct* TIPS - *Isometric

Innovative Structural Solutions (Innstruct) manufactures this composite sandwich panel system with a product name of TIPS. Innstruct Panels are produced with certified EVG manufacturing equipment. EVG is a global mechanical engineering company that specializes in the development and construction of equipment for processing wire and reinforcing steel. With this state-of-the-art equipment, Innovative Structural Solutions is committed to providing precise panels in conformance with quality control requirements to offer a modern, safe, and economical building option.

1.2 Development & Manufacturing of Innstruct Panel

In the early 1960's, the idea of using Structural Concrete Insulated Panels (SCIP) or 3-Dimensional panels with insulation material between two layers of reinforced concrete was developed. While the idea was sound, the technology to economically mass produce the panels did not yet exist. There were many attempts to automate the manufacturing process of a SCIP system, but efforts were largely unsuccessful until EVG developed, and subsequently patented, the specialized machinery (or welding line) to mass-produce the panel system. EVG is an Austrian company known worldwide for designing and manufacturing machinery to automate the production (including welding) of fine mesh, light mesh, industrial mesh, reinforcing steel, and more.

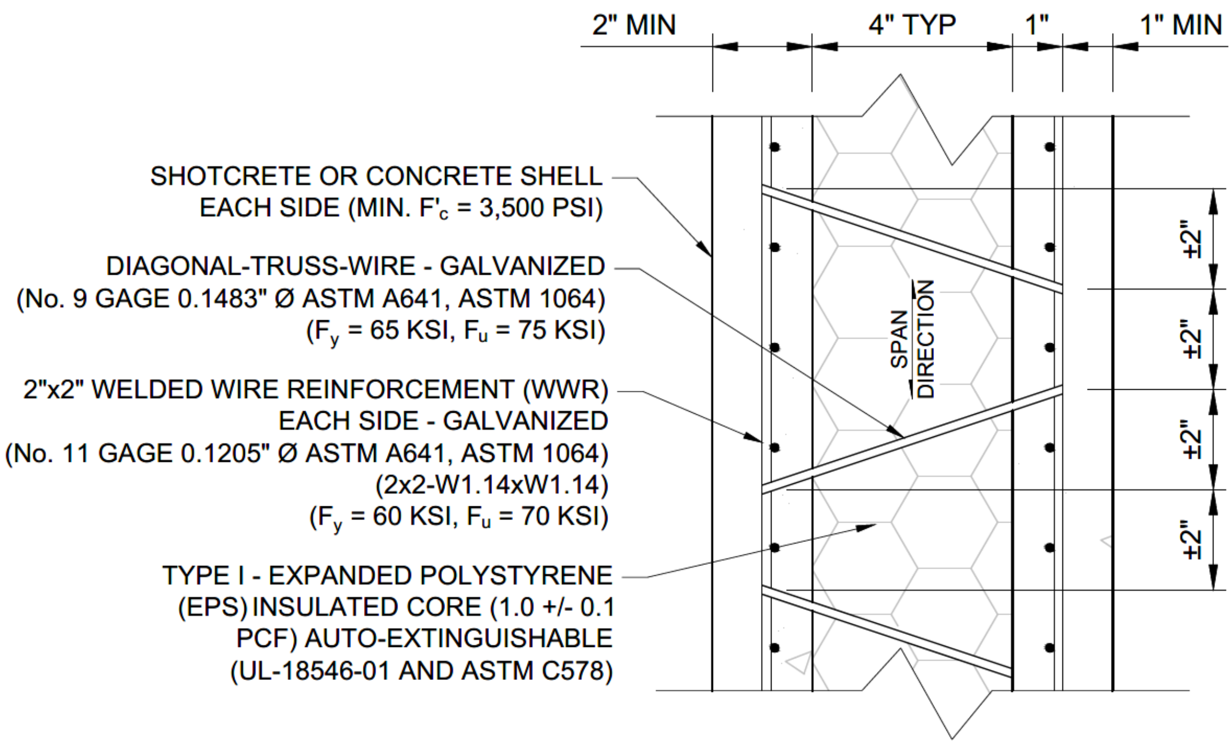
Innstruct Panels are produced on fully automatic, high-speed welding lines. The EVG machinery spaces and punches the diagonal-truss-wires through the EPS foam core and welds the truss-wire to the WWR at each side. The diagonal-truss-wires are used to accurately place the WWR and to firmly hold the EPS foam during concrete placement. The diagonal-truss-wires are cut flush with the WWR to avoid injuries in handling and to maintain concrete cover over all reinforcement. The truss-wire system combined with the EPS foam core is extremely rigid, is held to the highest dimensional accuracy, and is ready for field installation. A manufacturing line is shown in the following figure:

With the development of this efficient machinery, Innovative Structural Solutions is able to manufacture the featured TIPS to meet a unique set of design needs.

1.3 *The Standard* TIPS *Geometry*

The standard Innstruct Panel uses the following materials and geometry:

- Insulation Core – 4" Type I – Expanded Polystyrene (EPS) Insulation that complies with UL-18546-01 and ASTM C578 specifications. The EPS foam has a nominal density of 1.0 +/- 0.1 pcf.
- Welded Wire Mesh Reinforcement (WWR) – A smooth, 11 gage (0.1205" Ø) galvanized wire at a 2" spacing is used in each direction of the WWR (2x2-W1.14xW1.14). The same WWR configuration is used on each side of the panel. The wire in the WWR complies with ASTM 641 and ASTM A1064 specifications with the *Yield Strength* (F_y) of 60 ksi and the *Tensile Strength* (F_u) of 70 ksi.
- Diagonal-Truss-Wire – A smooth, 9 gage (0.1483" Ø) galvanized wire complies with ASTM 641 and ASTM A1064 specifications with the *Yield Strength* (F_y) of 65 ksi and the *Tensile Strength* (F_u) of 75 ksi. See the following figure for truss wire placement.
- Exterior Shotcrete Shells – Concrete shells shall be constructed with a minimum 28-day (f'_c) of 3,500 psi concrete compressive strength. A 2" minimum structural shell thickness is required at all locations.



Standard* Total Integrated Panel System *Configuration – Cross Section in Span Direction

2.0 Innstruct General Information

TIPS Panels can provide a flexible and cost effective building system for commercial, industrial, institutional, and residential requirements. While traditional building systems only partially fulfill these benefits, TIPS Panels provide all of these listed benefits. General design and construction information is also provided herein.

2.1 Total Integrated Panel System Benefits

- TIPS Panels are made from non-combustible materials and may be used in any *Construction Classification* (Type I through V).
- The following *Fire Resistance Ratings* are calculated using Equation 7-4 of the IBC-2015 Section 722.2.1.2:

Fire-Resistance Rating - *IBC 2015 Section 722.2.1.2 (Equation 7-4)*		
Concrete Facing Thickness (Equal on both sides)	Fire-Resistance Rating (Hours)	
	Carbonate Aggregate	Siliceous Aggregate
2.00 inches	2.0	1.75
2.25 inches	2.4	2.1
2.50 inches	2.8	2.4
2.75 inches	3.1	2.75
3.00 inches	3.5	3.1
Note: Fire-Resistance Ratings for alternate material types and thickness can be determined based upon IBC 2015 Section 722.2.1.2 Multi wythe walls.		

Fire-Resistance Rating (Fire-Rating)

- *Energy Efficiency* – The TIPS, constructed with EPS foam inside concrete shells, provides an insulated system with mass concrete. Energy Code compliance shall be verified on a project specific basis using COMcheck or other methods acceptable to the Building Official. COMcheck calculations can be completed by selecting the “Other U-Factor Option” category for the Assembly and selecting “Mass Wall” or “Other Roof” for the wall and roof, respectively. The U-Factor for the standard TIPS Panel system to be used in COMcheck is 0.0263 Btu/hrft^2 °F.
- The Total Integrated Panel System provides excellent noise control by effectively blocking airborne sound transmission and absorbing noise. The system can serve as common wall or floor system between occupancies and are predicted to provide the following *Sound Transmission Class (STC)* according to the calculation approach of Standard Method for Determining Sound Transmission Rating for Masonry Walls – TMS 0302-
12. The calculation approach of TMS 0302-12 is often conservative based on actual performance.

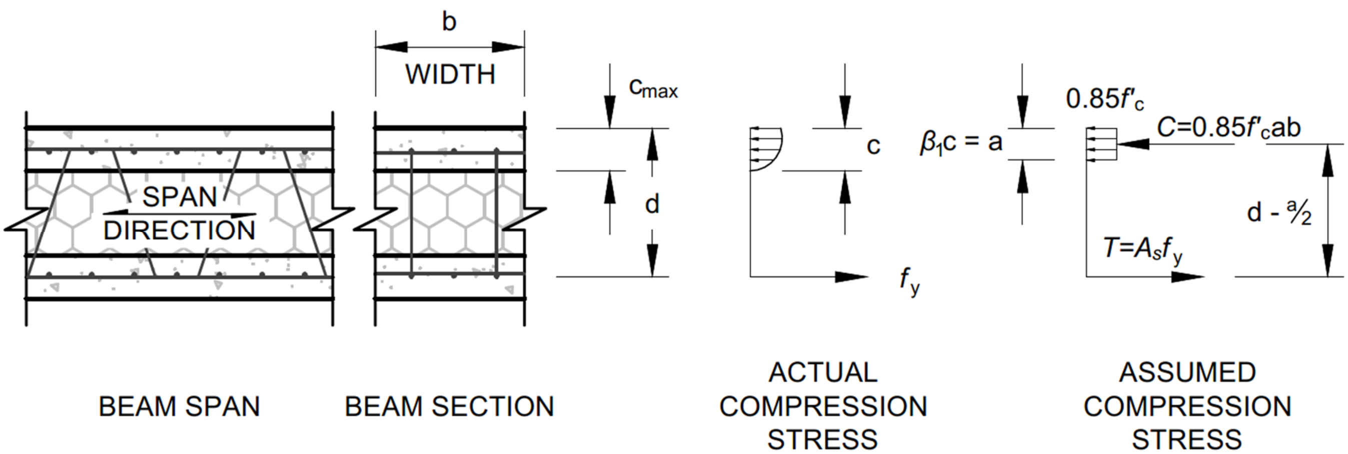
Sound Transmission Class (STC) *TMS 0302-12 & NCMA (TEK 13-1C)*				
Description	Wall Weight (psf)	STC Concrete	ΔSTC Void Space	STC Value
Standard 8" Panel	50.0	51.2	10.1	61
8 1/2" Floor Panel	56.3	52.6	10.1	63

Sound Transmission Class Values from Calculation Method of TMS 0302-12

3.0 Structural Design Information

Structural calculations of TIPS Panels shall be completed in accordance with ACI 318-14 or the currently adopted version of the standard. Additional ACI recommendations are located in ACI 318.2R-14 – Building Code Requirements for Concrete Thin Shells and ACI 533R-11 – Guide for Precast Concrete Wall Panels. The PCI Design Handbook and a PCI Committee Report titled, “State of the Art of Precast/Prestressed Concrete Sandwich Wall Panels” also have beneficial design information for sandwich panels. Shotcrete requirements can be found in ACI 506.2-13 – Specification for Shotcrete and ACI 506R-16 – Guide to Shotcrete.

Numerous compressive tests with walls and bending tests with floor slabs constructed with the TIPS have verified the composite nature of the panels and that reinforced concrete engineering principles apply to this building system. The configuration of the diagonal truss wires, solid concrete end sections, or developed longitudinal reinforcement contribute to the composite condition. Reinforced concrete end sections at slab bearing locations and at the top and bottom of walls are required as shown in WS and FN TIPS Typical Details. In design, the solid cross-section is reduced by the EPS core so that shear forces are only transferred through the diagonal-truss-wires. All pertinent and mandatory design methods and standards for reinforced concrete, i.e. ACI 318-14,



are still followed. Since the panels are composite, the typical stress block seen with concrete design principles is shown below with the limiting compression block labeled (*c*) located within the concrete shell.

Compression and Tension Couple at Nominal Moment

Some aspects of hand design of TIPS can be more complex, but are possible. Finite-element software programs, e.g. SCIA Engineer (developed by the Nemetschek Group), are capable of modeling the panel’s unique properties to accurately predict deflections and stresses. These programs are commonly used in design, especially in more complex structures, and are highly recommended for design of TIPS structures due to the nature of the fully composite system with a reinforced concrete shell at each face of the panel. The following 2D modification factors should be used to correctly model TIPS properties in finite-element software programs; and are applicable to an 8” solid concrete wall or slab for the Innstruct Panel. ACI 318-14 requires additional checks which shall also be verified (e.g. compression zone geometry limitations, in-plane shear forces, out-of-plane shear forces, etc.).

	2D Property Modifiers (f'_c = 3.5 ksi)														
Description	Thickness (inches)			Selfweight Factor	Mass Factor	D_{11}	D_{12}	D_{22}	D_{33}	D_{44}	D_{55}	d_{11}	d_{12}	d_{22}	d_{33}
	Shell	EPS	Shell												
Standard 8" Panel	2.00	4.00	2.00	0.500	0.500	0.875	0.165	0.031	0.165	0.010	0.010	0.500	0.500	0.500	0.500
8 1/2" Roof Panel	2.50	4.00	2.00	0.529	0.529	0.887	0.185	0.038	0.185	0.010	0.010	0.529	0.529	0.529	0.529

2D Modification Factors for Innstruct Panel

The 2D property modifiers have the following meanings in the SCIA Engineer software:

D_{11} and D_{22} – Flexural Stiffness in the x and y directions
D_{12} – Lateral Contraction Resistance
D_{33} – Torsional Stiffness
D_{44} and D_{55} – Shear Stiffness in the x and y directions
d_{11} and d_{22} – Axial Stiffness in the x and y directions
d_{12} – Lateral Contraction Resistance
d_{33} – Shear Stiffness

ACI 318-14 and other technical requirements must be followed in designing with TIPS Panels. This “Structural Design Information” section is not a comprehensive list of code or technical literature requirements for all structures. However, this section does provide common design information and a general background to make panel design more straight forward and give the engineer a better perspective of how to design with TIPS Panels in conformance with the ACI 318-14 requirements. The Structural Design Information Section is divided into the three main sections: *Material Property Concepts*, *Gravity Design Requirements*, and *Seismic or Wind Design Requirements*. Each have their own sub-section.

3.1 Material Property Concepts

Material Property Concepts, specifically relating to shotcrete/concrete and reinforcement, are presented in this section. The concepts include *Concrete Strength* and *Concrete Durability* requirements, No *Cold Joints* in Shotcrete Layers, Reinforcement Design Properties (*Specified Yield Strength*), *Concrete Cover* Requirements, and *WWR Development and Lap Lengths*. Shotcrete sequencing procedures are located in the *Construction & Quality Control Process* section.

3.1.1 Shotcrete – Concrete Strength & Concrete Durability Requirements

All shotcrete shall meet the *Concrete Strength* requirements of ACI 318-14 §19.2.1, which includes *Concrete Durability* requirements (ACI 318-14 §19.3.2-Table 19.3.2.1). In addition, all shotcrete shall meet ACI 318.2R-14 §4.1.1 which has a single minimum strength requirement. Innovative Structural Solutions has also specified a minimum 28-day concrete strength (f'_c) of 3,500 psi to ensure the Innstruct Panel system meets or exceeds the typical strength and durability requirements. More corrosive conditions may require an increase in the shotcrete/concrete compressive strength or shell thickness. The designer should follow ACI 318-14 Chapter 19 and ACI 318.2R-14 Chapter 4 requirements for *Concrete Strength* and *Concrete Durability*. Proper external coatings and maintenance procedures shall also be considered in design.

	Concrete Strength & Durability Requirements:	
Panel Application	Minimum Specified 28-day Concrete Strength (f'_c)	Referenced Section
Interior Partition, Load Bearing Walls, Shear Walls & Slabs	3000 psi	ACI 318.2-14 §4.1.1 & ACI 318-14 §19.2.1.1(a) - Table 19.2.1.1
Exterior Walls	3500 psi	ACI 318-14 §19.2.1.1(b) - Table 19.3.2.1
Innovative Structural Solution's Minimum	3500 psi	Innstruct Panel Minimum
Exterior Roof or Slab	4500 psi	ACI 318-14 §19.2.1.1(b) - Table 19.3.2.1
Exterior Walls or Slabs exposed to De-icing Compounds & Special Structural Walls	5000 psi	ACI 318-14 §19.2.1.1(a) - Table 19.3.2.1 ACI 318-14 §19.2.1.1(a) - Table 19.2.1.1

Concrete Strength & Durability Requirements for ACI 318-14 §19.2.1.1 and ACI 318.2-14 §4.1.1

3.1.2 Shotcrete – No Cold Joints in Shotcrete Layers

Questions sometimes arise with respect to *Cold Joints* forming between applications of shotcrete. In December 2014, Concrete International published an article entitled, “Shotcrete Placed in Multiple Layers does NOT Create Cold Joints” by Charles S. Hanskat. The article can be found online and provides the concepts behind the self-explanatory title and the applicable references of ACI 309R-05 (Guide for Consolidation of Concrete) and ACI 506.2-13 (Specification for Shotcrete). Thin concrete layers are sensitive to dry-out. A thorough after-treatment including regular wetting in the first week, or applying a curing agent after application is recommended.

All applicable shotcrete specifications of ACI 506.2-13 and ACI 506R-16 should be followed; including but not limited to, shotcrete properties, applying shotcrete, layering procedure, working sequence for multi-story buildings, etc. When placing shotcrete against a previous shotcrete surface, it is important to hydrate to a saturated surface dry condition the existing shotcrete to achieve proper bonding and curing.

3.1.3 Reinforcement – Design Properties

ACI 318-14 §20.2.2 provides the *Design Properties* for reinforcement; a broad range of reinforcement types with variable *Specified Yield Strength* are included in this section. ACI 318.2R-14 §4.1.2 requires that the *Specified Yield Strength* of non-prestressed reinforcement shall not exceed 60 ksi. The panels WWR for flexural reinforcement meets this requirement. Any additional reinforcement for flexural strength used with this system shall also conform to ACI 318.2R-14 and have a yield strength equal to or less than 60 ksi.

3.1.4 Reinforcement – Concrete Cover

Concrete Cover is given in ACI 318-14 §20.6.1. According to §20.6.1.1 of ACI 318-14, alternative methods of protecting reinforcement may be approved by the building official under the provisions of §1.10. This provision is used to establish concrete cover requirements between cast-in-place and pre-cast concrete systems as follows:

- Precise panel manufacturing provides for a well-defined reinforcement condition for placement in the concrete shell; thereby making the system more like a precast process than traditional cast-in-place construction. Tables 20.6.1.3.1 and 20.6.1.3-3 of ACI 318-14 §20.6.1.1 refer to concrete cover requirements.

Cast-in-Place Non-Prestressed Concrete Members: ACI 318-14 (§20.6-Table 20.6.1.3.1)		
Concrete Exposure	Member Type	Specified Cover
Exposed to weather or in contact with ground	All	1.50"
Not Exposed to weather	Slabs, Joists, and Walls	0.75"

Precast Non-Prestressed Concrete Members Manufactured under Plant Conditions: ACI 318-14 (§20.6-Table 20.6.1.3.3)		
Concrete Exposure	Member Type	Specified Cover
Exposed to weather or in contact with ground	Walls	0.75"
	Others	1.25"
Not Exposed to weather	Slabs, Joists, and Walls	0.625"

Concrete Cover Requirements for ACI 318-14 §20.6

- The field applied shotcrete has a lower water-to-cement ratio than typical poured cast-in-place concrete giving the shell a lower water permeability which further protects the reinforcement.

- The WWR and diagonal-truss-wires are galvanized which provides additional protection to the reinforcement.

Given these additional protective measures, the 1” minimum concrete cover (outside the WWR) is appropriately justified for the Total Integrated Panel System for above grade construction. Uncertainties associated with soil types and permanent moisture conditions warrant an increased cover for below grade construction. Therefore thickening the concrete shell below grade is recommended to provide the minimum 1.5” cover (outside the WWR) specified by ACI 318-14 Table 20.6.1.3.1 for concrete in contact with ground. Project specifics or engineering requirements may call for additional concrete cover or treatments.

3.1.5 Reinforcement – Development and Lap Lengths

Development Length and *Lap Length* of WWR is given in ACI 318-14 §25.4.7 and §25.5.4. Matching WWR rolls are used for these connections. The development and lap lengths for the manufacturer’s WWR are given in the table below.

Development Length & Splice Length		
ACI 318-14 Section	(#) of Cross-Wires[1]	Length[2] [L_d or L_{lap}]
Development Length §25.4.7	(2) minimum	6"
Lap Splice Length §25.5.4	(2) minimum	6"

Notes:
1. (#) of Cross-Wires must be 2" from critical section
2. Lengths are from critical section

Development and Lap Lengths of WWR according to ACI 318-14 §25.4.7 and §25.5.4, respectively

3.2 Gravity Design Requirements

TIPS *Gravity Design Requirements* described in this section include: *One-Way Slab*, *Slender Wall & Moment Magnification*, and *Integral Beam and Column*. TIPS Panel design in other gravity scenarios are straightforward once these items are understood.

3.2.1 One-Way Slab – ACI 318-14 Chapter 7

TIPS Panels can be considered a One-Way Slab system as described in ACI 318-14 Chapter 7. Chapter 7 principles are described and referenced herein; nevertheless, this section is comparable to Beam Design – ACI 318-14 Chapter 8. The Design Strength requirements of §7.5 must be met for flexural ($ØM_n \geq M_u$) and out-of-plane shear ($ØV_n \geq V_u$) design of TIPS Panels. The applicable *Reduction Factors (Ø)* are determined in §21.2. The *Factored Moment (M_u)* or *Factored Shear (V_u)* are determined by the loading conditions. The *Design Flexural Strength ($ØM_n$)* and the *Design Shear Strength ($ØV_n$)* are determined with §22.3 and §22.5, respectively. This section discusses the *Nominal Flexural Strength (M_n)* and the *Nominal Shear Strength (V_n)* and provides additional design requirements. The other applicable requirements of Chapter 7 shall be followed in addition to the following requirements:

- Minimum slab thickness of §7.3.1 is assumed to be superseded by minimum and maximum shell thickness, strength requirements, and deflection requirements. It should be noted that the panel's WWR meets *Minimum Flexure Reinforcement* (ACI 318-14 §7.6.1) and *Minimum Temperature and Shrinkage Reinforcement* (ACI 318.2-14 §6.1.3) with shells 3.125" or less. Typically a 2" bottom shell and a 2" to 3" top shell are recommended as minimum and maximum thicknesses to ensure an efficient design and to accommodate various flooring materials, radiant heating, etc. In all cases the neutral axis shall be located within the EPS core. The minimum and maximum shell thickness are summarized below:

Panel Shell Thickness		
Location	Required Minimum	Recommended Maximum
Top Shell	2"	3"[1]
Bottom Shell	2"	

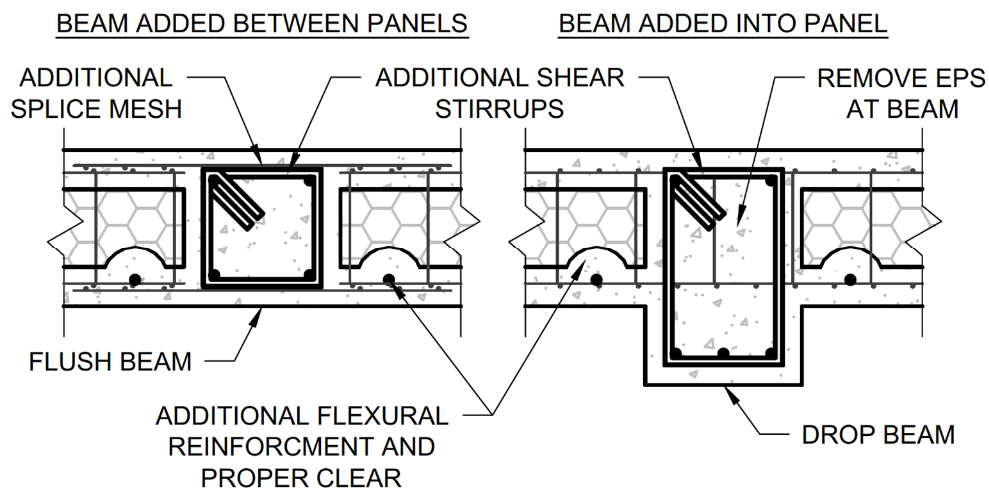
Notes:
1. Additional temperature reinforcement required with shells greater than 3"

Shell Thickness Requirements

- Compression WWR is neglected in the *Design Flexural Strength ($ØM_n$)*
- The flexural compression zone (*c*) must be within the concrete shell
- It is recommended that additional reinforcement located inside the bottom WWR layer be a smaller bar diameter; i.e. #4 bars are the largest recommended size for flexural design of slabs
- The out-of-plane *Design Shear Strength ($ØV_n$)* must be limited to the buckling strength and the welded joint strength of the diagonal-truss-wire

The *Design Flexural Strength* ($\O M_n$) of the standard TIPS Panel is typically calculated with the bottom WWR mat and additional reinforcement (where required by design) placed between the bottom WWR and the EPS core. Respectively, additional reinforcement may be added between the top WWR and EPS core for a cantilevered slab or negative moment conditions over supports. The EPS is melted away at rebar locations to provide proper concrete cover. It should be noted that the standard panel typically has a compression zone (*c*) well within the concrete requirement and is a tensioned controlled section (Ø = 0.9). The figure found in the *Design Shear Strength* section below shows how proper cover is provided for the additional reinforcement. This figure also shows solid shotcrete strips with additional reinforcement (integral beams) which may also be considered for increased flexural capacity.

The out-of-plane *Design Shear Strength* ($\O V_n$) can include additional shear reinforcement added between panels or by removing the EPS foam at regular intervals. Where shear stirrups are added between panels, splice mesh or transverse bars (with proper clearance) are added to provide continuity of reinforcement and to transfer shear forces to the shear stirrups. The solid shotcrete pockets with additional reinforcement may also be used to increase moment capacity in slab design. The additional flexural reinforcement (with minimum 1”cover required) is also shown in the figure. The shear stirrups are to be designed in according with ACI 318-14 §22.5.10 and may be added to the panels as shown below.



Additional Shear Stirrup – Beam Cross-Section

3.2.2 Slender Wall & Moment Magnification – ACI 318-14 Chapter 11 & §6.6.4

TIPS Panel walls can be load bearing or non-load bearing walls and can be designed per Chapter 11 of ACI 318-14. According to §11.3.1.1, walls that demonstrate adequate strength and stability can be thinner than those listed in Table 11.3.1.1. The required strength is calculated according to Chapter 6 of ACI 318-14, which includes the ability to use the Finite Element Analysis of §6.9. Finite-element software programs with the applicable 2D modification factors can be beneficial in this design area. Stability is taken into account through slenderness effects which are required by §11.4.1.3. Additional strength is required for eccentric loads according to §11.4.1.4. Where the applied wall moments are minor, it may be beneficial to ensure that shell thickness are the same to produce a concentric self-weight loading. Where applied moments are more significant, varying the shell thicknesses may be beneficial to compensate for the applied moments. It is highly recommended that both panel shells be loaded evenly to eliminate eccentric load conditions.

The Design Strength requirements of ACI 318-14 §11.5 must be met for the axial ($ØP_n \geq P_u$), flexural ($ØM_n \geq M_u$), and both in-plane and out-of-plane shear ($ØV_n \geq V_u$). The applicable *Reduction Factors (Ø)* are determined in §21.2. The *Factored Axial (P_u), Factored Moment (M_u),* and *Factored Shear (V_u)* are determined by the loading conditions and structural analysis requirements of Chapter 6. The in-plane *Nominal Shear Strength* (*V_n)* is discussed in the *Seismic or Wind Design Requirements* section, but is found in ACI 318-14 §11.5.4. Out-of-plane shear is found in ACI 318-14 §22.5. ACI 318-14 provides the following three methods to show adequate *Nominal Flexural* (*M_n) and Axial* (*P_n) Strength*s:

- §11.5.2 - *Combined Flexural and Axial Strength (Compression Member Design)*
- §11.5.3 - *Simplified (Empirical) Design Method*
- §11.8 - *Alternative Method for Out-of-Plane Slender Wall Analysis*

The simplified method is not applicable for the design of TIPS Panels since it applies only to solid, rectangular wall sections. The alternative method may be used for design in limited situations. Refer to ACI 318-14 §11.8 commentary for limitations on use. The compression member design method is referring to ACI 318-14 Chapter 10 with §6.6.4 which is applicable for the Total Integrated Panel System. Finite element software programs use deflections (modified by the property modifiers) to solve for internal stresses; then, design reinforcement according to these stresses.

Chapter 10 refers to §22.4 and §22.3 to calculate the *Nominal Axial Strength (P_n)* and the *Nominal Flexural Strength (M_n)* for load-bearing walls. For non-load bearing walls §22.3 is referenced for calculating the *Nominal Flexural Strength (M_n)*. TIPS Panels typically fall into the slender reinforced concrete column category. ACI 318-14 §11.4.1.3 specifies that slenderness effects must be taken into consideration by using §6.6.4, §6.7, or §6.8 unless the exception of §6.2.5 is met. The three options listed may be used, but §6.6.4 titled *Slenderness effects* [by the] *Moment Magnification Method* is commonly used in design. The moment magnification method can be calculated for nonsway (§6.6.4.5) or sway (§6.6.4.6) frames. The nonsway equations (§6.6.4.5) for amplifying the first-order factored moment (M_2) by the moment magnification factor (δ) to the factored moment used for wall or column design (M_c) are shown below.

$$M_c = \delta \times M_2 \qquad (6.6.4.5.1)$$

Where:

$$\delta = \frac{C_m}{1-\left(P_u/_{0.75P_c}\right)} \qquad (6.6.4.5.2)$$

$$1.0 \leq \ \delta \ \leq 1.4 \qquad (6.6.4.5.2\ \&\ §6.2.6)$$

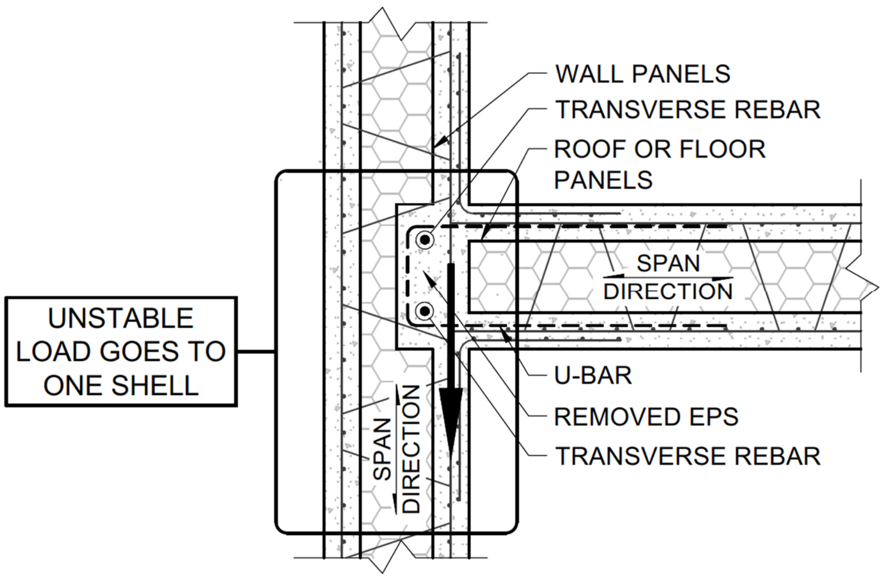
$$C_m = \left(0.6 - 0.4\left(M_1/_{M_2}\right)\right)\ or\ (1.0) \qquad (6.6.4.5.3a\ \&\ b)$$

$$P_c = \left(\pi^2 \times (EI)_{eff}\right)/_{(k \times l_u)^2} \qquad (6.6.4.4.2)$$

$$(EI)_{eff} = 0.25E_cI_g \qquad (6.6.4.4.4.a)$$

The moment ratio (M_1/M_2) is described in §6.6.4.5.3a with limitations on (M_2) found in §6.6.4.5.4. The Jackson and Moreland Method for determining the *Effective Length Factor* (k) in different conditions is given in §6.2.5. Simplified options for the effective length factor are shown in Table 11.5.3.2. Two additional options for calculating the *Effective Flexural Stiffness* $(EI)_{eff}$, are given in §6.6.4.4.4.a.

An additional consideration arises when a continuous thermal barrier is desired. Typically, the wall design and detailing should ensure both concrete shells are loaded and supported equally. Instability may occur where only one shell is loaded (as shown in the following figure). If similar detailing is used, the designer is responsible for designing for the eccentrically loaded wall such that the loaded shell shall carry the entire applied load.

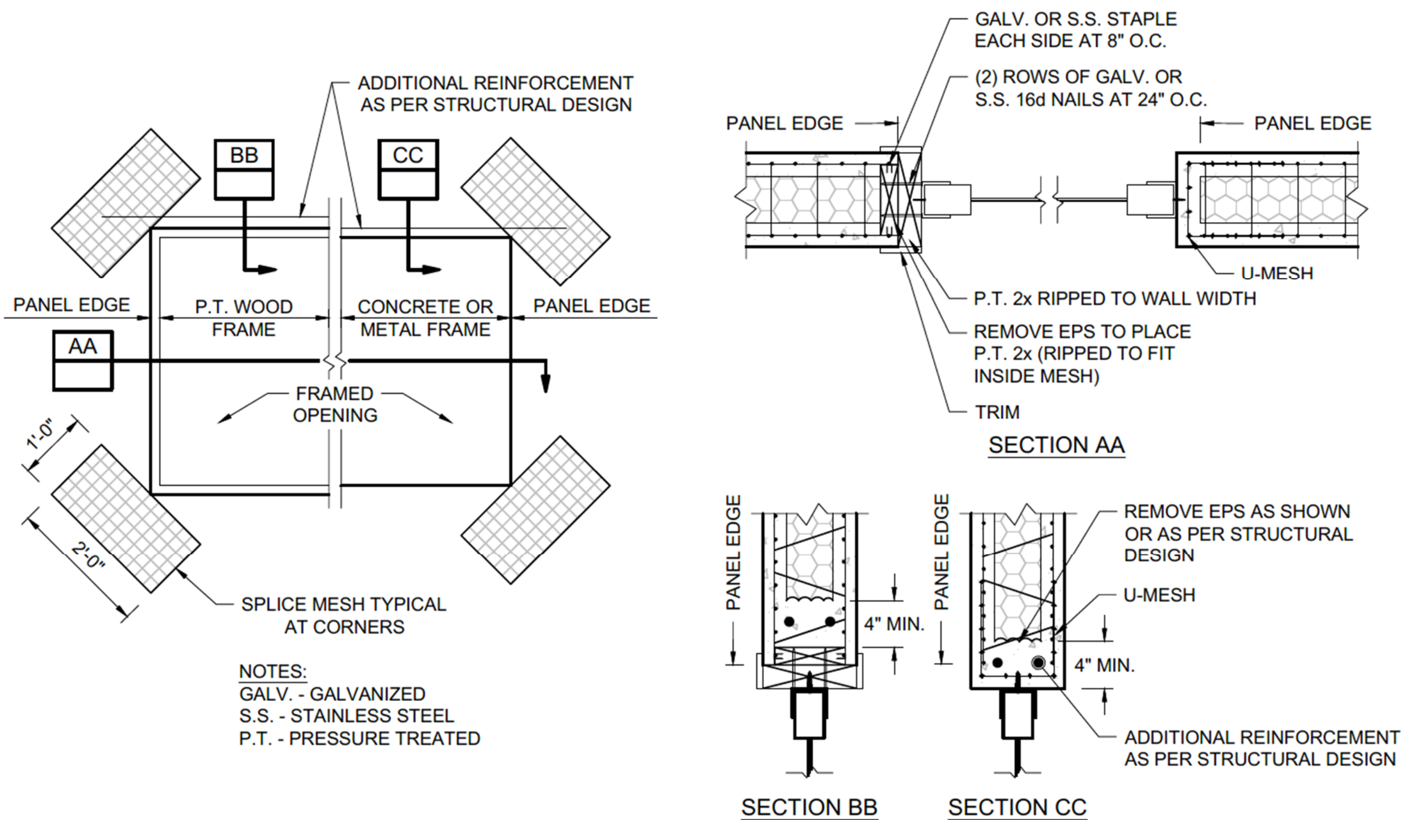


Unstable Wall Connection – One Shell Loaded

All applicable requirements of Chapter 11 of ACI 318-14 shall be followed for bearing walls designed as a compression member.

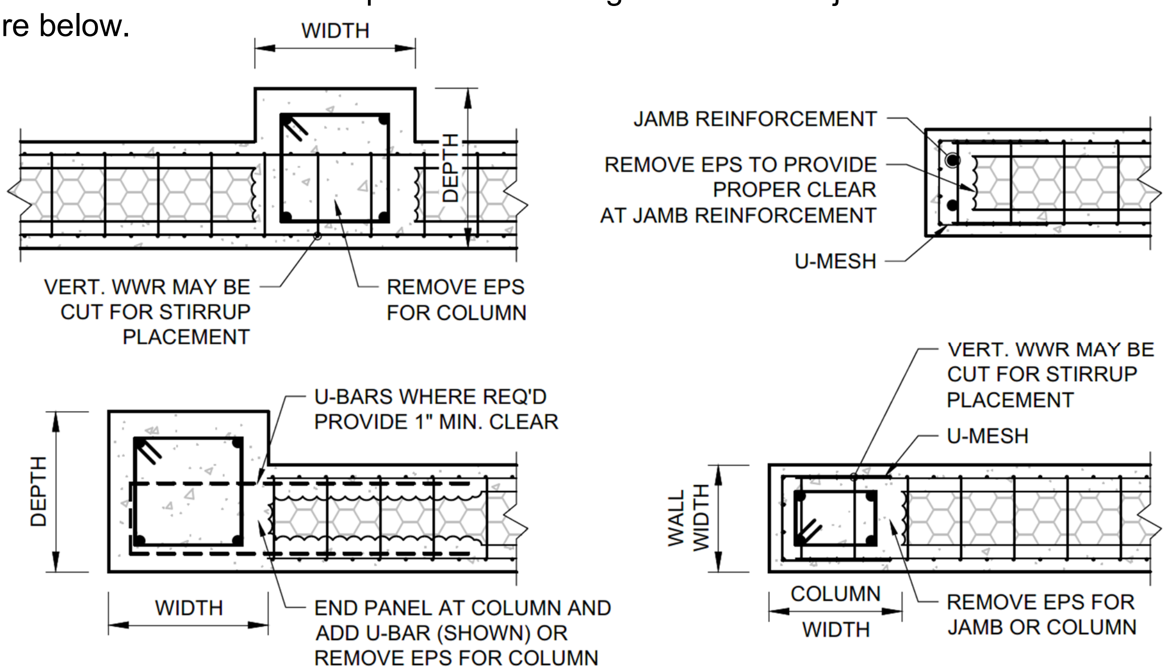
3.2.3 Integral Beam and Column – ACI 318-14 Chapter 9, Chapter 10, & §6.6.4

The typical beam or deep beam procedures from ACI 318-14 – Chapter 9 can be applied for beams, T-beams, or framed opening headers. For headers, a web width of 4" (two shells each 2" thick) can be used with the WWR acting as stirrups. Additional rebar reinforcement clearances may be met by removing the EPS foam. The typical WWR on the panels may also act as additional reinforcement required for deep beams. Welded wire splice mesh (1'-0" x 2'-0") are also place at the corner of openings to fulfil Innstruct detailing requirements for corner reinforcement. An example is shown in the following figure.



Framed Opening Header Reinforcement and Trim

ACI 318-14 – Chapter 10 with §6.6.4, where applicable, can be used for columns or jamb design. Design examples of beams and columns can be found in structural concrete design literature and will not be given here. Removing EPS foam and cutting the WWR or diagonal-truss-wires at these locations may be required to place the necessary reinforcement and ties. Example details of integral columns or jambs are shown in the figure below.



Columns Integral or Adjacent to Panels

3.3 Seismic or Wind Design Requirements

The three lateral design concepts described in this section include the following:

- Description of the *Lateral Force-Resisting System* which includes the *Seismic Design Coefficients and Factors*
- Typical shear wall layout
- Discussion of the In-Plane *Nominal Shear Strength* of Innstruct Panels.

TIPS Panel design for most lateral load conditions are generally straightforward when these concepts are properly applied.

3.3.1 Lateral Force-Resisting System and Seismic Design Coefficients and Factors

TIPS Panels may be used as the *Lateral Force-Resisting System* with the structural shells (or wythes) resisting in-plane shear forces. These shells or wythes act the same as a concrete or shotcrete shear wall. The concrete requirements of IBC 2015 - Chapter 19 must be followed along with ASCE and ACI requirements. In calculating the seismic forces according to ASCE 7-10, the force is dependent on the resisting system. The Total Integrated Panel System is classified as an Intermediate Precast Shear Wall as in ASCE 7-10 Table 12.2-1. In accordance with sample test results, the *Design Coefficients and Factors* for *Seismic Force-Resisting System* of ASCE 7-10 Table 12.2-1 are required to be modified to the following:

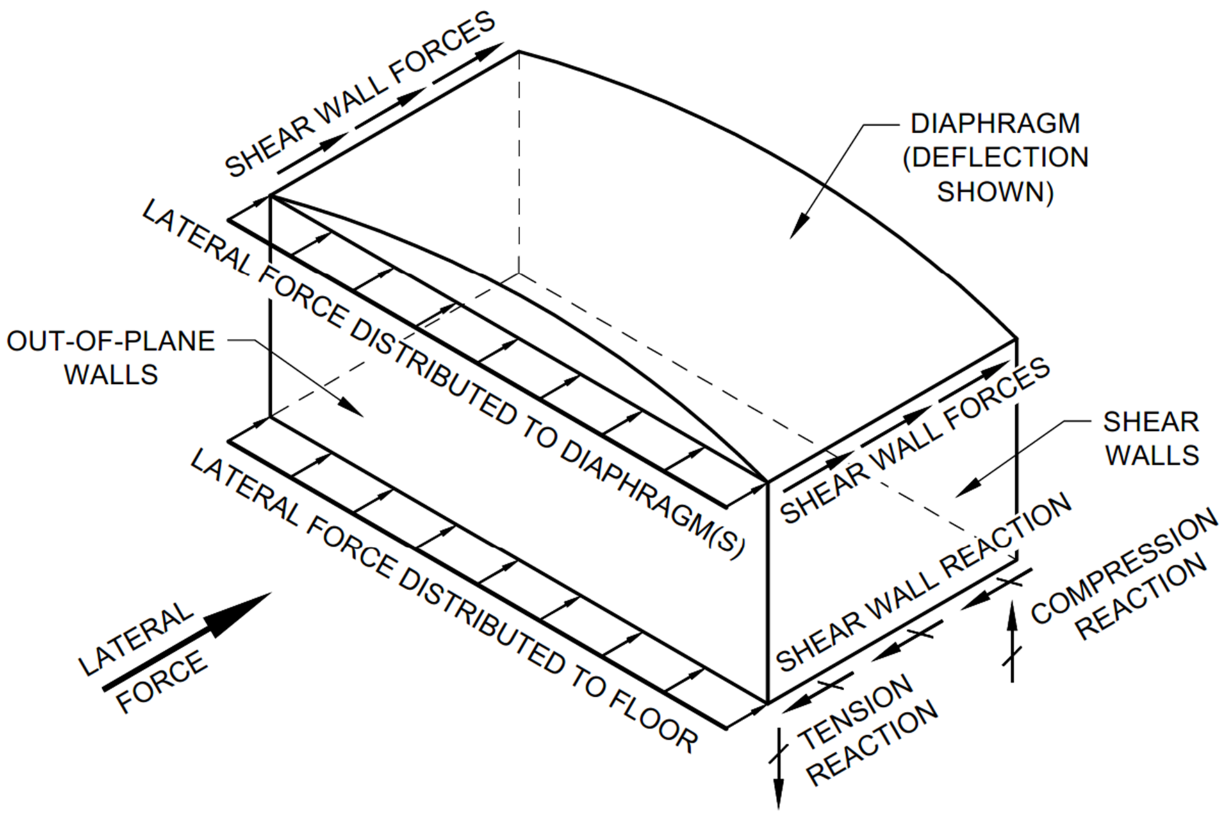
Design Coefficients and Factors for Seismic Force-Resisting Systems				
Seismic Force-Resisting System	Detailing Requirements of ASCE 7-10	Response Modification Coefficient (R)	Overstrength Factor (Ω_o)	Deflection Amplification Factor (C_d)
Innstruct Panels - Intermediate Precast Shear Walls	14.2	3.5	3	3.5

TIPS *Panel - Design Coefficients and Factors for Seismic Force-Resisting Systems*

It is also required to follow the detailing requirements of the lateral system and other respective elements (boundary elements, coupling beams, and wall piers) according to Special Structural Wall provisions of ACI 318-14 §18.10 which are more restrictive than the Intermediate Precast Shear Wall requirements. The exception to this section is that the panel's WWR meets the Intermediate Precast Shear Wall requirements instead of the special wall requirements.

3.3.2 Shear Wall Layout

Seismic or wind design forces acting on buildings are transferred most effectively by using the TIPS Panels as shear walls. The respective "box-like" layout of shear walls can provide the required lateral resistance. A layout using moment frames with the panels requires heavy reinforcement and is typically not necessary. Unlike most moment frames, shear walls typically stay flush with the architectural walls, making them less intrusive when this space is utilized in the aesthetics design. Typically, the "box-like" layout of shear walls is the best solution to meet both the strength and architectural requirements. An example of the "box-like" layout of shear walls is shown on the next page.



Shear Wall Layout – "Box-Like"

3.3.3 In-Plane Nominal Shear Strength of TIPS Panel Walls

The *Nominal Shear Strength* (V_n) for walls with in-plane shear is found in ACI 318-14 §11.5.4. The total nominal shear strength contains the *Nominal Shear Strength* provided by *Concrete* (V_c) and the *Nominal Shear Strength* provided by *Reinforcing* (V_s). In the case of TIPS Panels, the in-plane concrete shear strength includes the sum of the two concrete shells as the total wall thickness (h) in the appropriate ACI formulas, provided the diaphragm is connected to both wythes via a bond beam or edge beam at the diaphragm level. The in-plane *Nominal Shear Strength* (V_n) for the standard TIPS Panel is calculated below with the most basic ACI formulas. Other options for these formulas are available in ACI 318-14. The *Design Shear Strength (ØV*$_n$*)* also uses a *Reduction Factor (Ø)* of 0.75, but ACI 318-14 – Chapter 21 may modify this according to design requirements.

$$V_n = V_c + V_s \quad (11.5.4.4)$$

$$V_c = 2\sqrt{f'_c}\, hd \quad (\text{Table } 11.5.4.6)$$

$$V_s = (A_s f_y d)/s \quad (11.5.4.8)$$

Where:

$$h = \sum th_{shells} \quad (\text{Appended})$$

$$d = 0.8\, l_w \quad (11.5.4.2)$$

As described in the Lateral Force-Resisting System section, TIPS Panels may be considered Intermediate Precast Shear Walls with the seismic coefficients and factors as listed in that section. The Lateral Force-Resisting System section explains that special shear wall detailing requirements must be met (i.e. boundary elements, coupling beams, and shear piers) and each design must take into account any specific shear wall configuration and wall anchorage requirements.

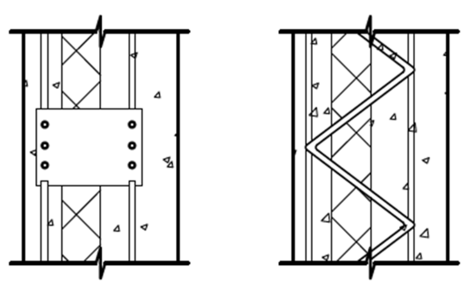
3.4 ABBREVIATED DESIGN SUMMARY

3.4.1 Total Integrated Panel System Design According to ACI 318

The purpose of this document is to present design requirements for TIPS Panels for design conformance with the International Building Code (2015 IBC), ASCE 7-10, and ACI 318-14. The following summary outlines the basis of building code design, and provides the applicable code/standards sections recommended to be addressed in the design and detailing of TIPS Panel projects. Non-structural information applicable to the panel is also shown in the subsequent document, as it may be pertinent to the building official and designer.

Structural design shall conform to the minimum requirements of the adopted Building Code and referenced standards. The Engineer of Record is responsible for meeting this requirement in design as per the Building Code. Typically structural design includes the following:

1. Loads and load combinations per 2015 IBC and ASCE 7-10
2. ASCE 7-10 Lateral Force-Resisting System (Table 12.2-1)
   a. Intermediate Precast Shear Walls with seismic parameters amended as follows:
      i. $R = 3.5$, $C_d = 3.5$, $\Omega_0 = 3.0$ (These values are more stringent than the building code, and are supported by the product patent holder – EVG, and multiple research tests are available upon request)
3. Structural design per ACI 318-14 including the recommendations from ACI 318.2R-14 (Building Code Requirements for Concrete Thin Shells) and ACI 533R-11 (Guide for Precast Concrete Wall Panels).
   a. TIPS Panels are composite sandwich panels:
      i. “Sandwich Panels – A precast panel consisting of two layers [wythes or shells] of concrete separated by a nonstructural insulating core.” (ACI 533R). These can be connected with different types of shear connectors as given by PCI below:



PCI – Welded Wire Truss Shear Connectors in Sandwich Panels

      ii. A composite system is provided by connecting the two reinforced concrete shells with the diagonal-truss-wires welded to the WWR. This provides rigidity and shear transfer for fully composite behavior.
      iii. PCI also states the following, “**Composite for full life cycle of panel** – The two wythes act as a fully composite unit for the full life of the structure. In order to provide for composite behavior, positive measures must be taken to ensure shear transfer between the wythes in the direction of panel span. This may be accomplished by rigid ties, longitudinal welded-wire trusses,

regions of solid concrete that join both wythes, or other tested methods." *PCI Design Handbook, Seventh Edition, Paragraph 5.11.2.2*.

- iv. ACI 533R-11 Section 5.6.2.3 states, "Steel trusses with thin wires have been used in the construction of structurally composite wall panels. Steel trusses, like steel ties, have a high thermal conductivity."

b. Structural Design – Composite Panels with the following:
- i. ACI 318-08 Provisions (ACI 318-14 references also listed) for applicable member design per ACI 533R-11 Section 3.2.3
  1. Flexure – Chapter 10 (ACI 318-08)
     a. ACI 318-14 – Chapter 9
  2. Shear – Chapter 11 (ACI 318-08)
     a. ACI 318-14 – Section 22.5 with additional information below:
        - i. Out-of-Plane Shear – Modified by ACI 533R-11, Section 3.3.1.4 by using the effective depth [h_{eff}].
        - ii. In-Plane Shear – ACI 318-14 – Section 11.5
  3. Bearing – Sections 10.14 and 15.8 (ACI 318-08)
     a. ACI 318-14 – Sections 22.8 and 16.3
  4. Combined Bending and Axial Load – Section 10.3 (ACI 318-08)
     a. ACI 318-14 – Chapters 10 or 11 with Sections 6.2, 6.6, & 6.6.4

c. Material Properties:
- i. Concrete/Shotcrete
  1. ACI 318-14 – Section 19.2.1
  2. ACI 318.2R-14 – Section 4.1.1
  3. TIPS Panel Manufacturer's Minimum – 3,500 psi
- ii. Reinforcement
  1. ACI 318-14 – Section 20.2.2
  2. ACI 318.2R-14 – Section 4.1.2

d. Reinforcement Information:
- i. Reinforcement Cover
  1. ACI 318-14 – Section 20.6 subject to approval per Section 1.10.
     a. Adequate cover must be decided per ACI tables 20.6.1.3.3 vs. 20.6.1.3.3 and accepted by building official per Section 1.10.
     b. Welded wire mesh and diagonal-truss-wires are galvanized.
     c. Field shot shotcrete has a lower water-to-cement ratio providing a lower water permeability than typical concrete.
- ii. Reinforcement Development and Splice
  1. ACI 318-14 – Sections 25.4.7 and 25.5.4.
- iii. Temperature & Shrinkage
  1. Applicable ACI 318-14 Chapters 9, 10, 11, and 12 for the respective portions of the structure.
- iv. Minimum & Maximum Reinforcement
  1. Applicable ACI 318-14 Chapters 9, 10, 11, and 12 for the respective portions of the structure.

e. Detailing Requirements in Seismic Design Categories (SDC) B through F: TIPS Panel structures shall conform to the Detailing Requirements of ACI 318-14 Chapter 18.

4.0 Construction & Quality Control Process

This document addresses two specific stages of *Construction & Quality Control Processes* for the Total Integrated Panel System. The first stage is before shotcrete or concrete is applied. This pre-shotcrete or pre-concrete inspection is termed a “Rough-In” inspection and is similar to a Rough-In inspection for wood or light gage steel framing inspections that take place before the covering materials are installed. The Rough-In inspection can be readily accomplished just prior to shotcrete application. The second stage addresses Special Inspection and Test (IBC 2015 – Chapter 17) requirements of the shotcrete process itself. Both parts are described herein. The last concept described in this section is the *Working Sequence* which describes the typical order that shotcrete is applied to the panels.

4.1 Rough-In Inspection

At this Rough-In stage, the panels should be placed and braced true and plumb. Items that should be observed as part of this Rough-In or pre-shotcrete or pre-concrete inspection include the following:

- All splice mesh used to join panels together should be placed at seams, corners, and where the mesh reinforcement may have been cut for utility or electrical system installation. Splice mesh should be attached to the main reinforcing mesh using hog rings, e-clips or tie wire.
- Welded wire splice mesh (1’-0” x 2’-0”) should be placed diagonally at window and door openings. Corner mesh should be attached to the main reinforcing mesh using hog rings, e-clips or tie wire.
- Starter reinforcing bars and additional starter bars extending from the foundation system for shear wall systems should be verified according to the structural plans. Starter bars must be placed inside the reinforcing mesh of the panel. If starter bars are epoxied in place, a report from the special inspector as per the IBC requirements should be provided.
- Additional reinforcing at headers, jambs, beams, columns, walls, slabs, roof systems, connections, and in other locations indicated on the structural plans should be observed and verified according to the structural documents. Reinforcing should be placed behind the mesh to meet concrete cover requirements except as may be detailed for basement walls where concrete cover is increased.
- Verify that the EPS has been removed to provide a minimum of 1” clearance around additional reinforcing bars and starter bars. Verify that the EPS is properly removed at beam, column, or other member locations to provide the designated sized members as per the structural drawings. Melted EPS should be removed from the area to receive shotcrete.
- Conduit or other items placed inside the walls should be observed to ensure that the conduits are set back behind the mesh flush with the face of the insulation panel to provide concrete placement for the shell. Concrete blocks, short sections of rebar, or standard reinforcing chair systems can be used to hold conduit in place to provide concrete cover.

- A guide wire (also called a screed or shooting wire) is stretched across the face of the wall system and used as a screed in the shotcrete application process. This guide wire establishes the shotcrete shell thickness and shotcrete/concrete cover over the panel's mesh reinforcement. The guide wire location is used in the quality control process to measure each. Measuring from the insulation to the guide wire gives the shotcrete shell's total thickness. Measuring from the mesh reinforcement to the guide wire gives the shotcrete/concrete cover over reinforcing. If panels are not placed true to line, the shotcrete thickness may be slightly thicker than the shell's design thickness, but should not be less than the design thickness (Note that the product's minimum shell thickness is 2"). The shotcrete/concrete cover over reinforcement should not be less than the design cover (Note that the product's minimum shotcrete/concrete cover is 1"). Contractors may elect to use other methods for establishing concrete panel thickness. Spacers can also be used that are inset in the wall. It is the contractor's responsibility to provide an acceptable method of constructing and verifying the thickness of the concrete shell.
- Additional observation items may be required in regards to the seismic resisting system according to IBC Section 1704.6.1-Condition 5 and the building official.

4.2 Special Inspection and Tests (IBC 2015 – Chapter 17)

As with other types of construction completed under the requirements of the IBC, Section 1704.3 requires a Statement of Special Inspection. This is applicable for Innstruct Panel projects and should be shown on construction documents. The Statement of Special Inspection should be in conformance with IBC Section 1705 which covers the requirements for quality control prior to and during the shotcrete application. IBC Section 1908, ACI 506.2-13, and ACI 506R-16 also indicate shotcrete requirements. Section 1705.3 Concrete Construction - Table 1705.3 indicates the requirements of special inspection for concrete work as summarized herein, and found more completely in Section 1705 of the IBC:

- Inspect reinforcement – Periodic Special Inspection
- Inspect anchors cast in concrete – Periodic Special Inspection
- Inspect anchors post-installed in hardened concrete as applicable to the design location and requirement. Generally, anchors are not designed to resist sustained tension loads, and Periodic Special Inspection is appropriate as indicated by the anchor manufacturer per Table 1705.3 footnote b.
- Verify use of required design mix – Periodic Special Inspection
- Prior to concrete placement, fabricate specimens for strength tests, perform slump and air content test, determine the temperature of the concrete – Continuous Special Inspection
- Inspect concrete and shotcrete placement for proper application techniques – Continuous Special Inspection. The Special Inspector should refer to ACI 506.2-13 Specification for Shotcrete, and ACI 506R-16 Guide to Shotcrete, for proper shotcrete placement techniques and items applicable to the special inspection.

- Verify maintenance of specified curing temperature and technique – Periodic Special Inspection. Generally curing temperatures are not controlled. However, application of curing compounds may be applicable to the work.
- Inspect formwork for shape, location and dimension of the concrete members being formed – Periodic Special Inspection. Observation of construction elements to verify beam sizes, shotcrete shell thickness, etc. should be included as part of the special inspection plan.

While there are certainly other items associated with construction that require inspection such as electrical, plumbing components, etc. The structural items noted herein are intended to assist the Building Department in establishing field observation objectives by presenting the requirements already included in the IBC that are applicable to the Innstruct Panel system.

4.3 Working Sequence

As described in the *Shotcrete – Cold Joint* section, thin concrete layers are sensitive to dry-out. A thorough after-treatment to provide proper curing is recommended. All applicable shotcrete specifications of ACI 506.2-13 and ACI 506R-16 must be followed along with technical literature in shotcrete properties, applying shotcrete, layering procedure, working sequence for multi-story buildings, etc.

4.3.1 Shotcrete Layering

Shotcrete can be applied the full shell thickness (typically 2”) in one layer, or can be applied in two layers. If two layers are used, then the first layer must just cover the reinforcing mesh and shall be left rough. Curing agents should not be placed on the first layer due the effect of limiting bonding of the second or finish shotcrete layer. Water curing and/or wrapping with plastic sheeting should be applied to the first shotcrete layer until curing is complete or until the second layer is applied. Regardless of curing status, immediately prior to applying the second shotcrete layer the first layer must be conditioned to a saturated surface dry status to ensure proper adhesion of the second shotcrete layer. Shotcrete applied in two layers shall follow the same placement sequence as for a single layer application.

4.3.2 Shotcrete Application Order

The recommended shotcrete application order for typical TIPS Panel buildings is as follows:

1. Apply shotcrete to exterior walls.
2. Apply shotcrete to interior wall surface.
3. Apply shotcrete to lower side of slab. See Section 4.3.3 for Innstruct Panel shoring or support requirements.
4. Place shotcrete to upper side of slab either by shotcrete or pumped concrete methods.
5. Place panels and continue with upper levels of multi-level systems in the same shotcrete application order as for the lower level for the first layer of shotcrete.

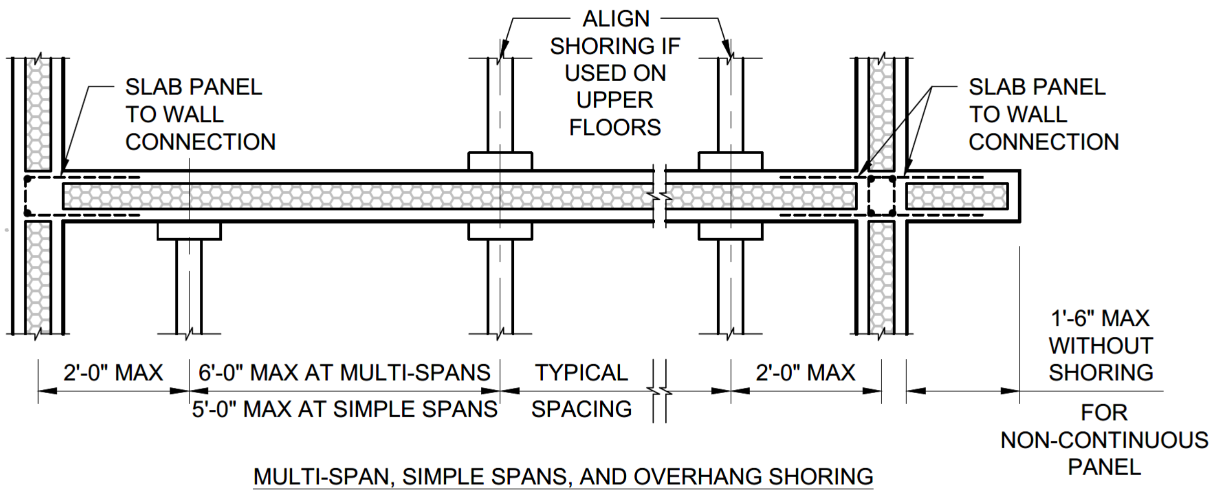
6. If shotcrete is applied in two layers, the second layer can be placed concurrently on the walls and bottom of slab elements. It is recommended to remove the shoring element adjacent to walls in accordance with Section 4.3.3, prior to the placement of the second layer of shotcrete

4.3.3 Slab Shoring Requirements

Proper support (shoring) of TIPS Panel floor and/or roof systems is essential to ensure structural stability and performance of the structure. Limiting construction loads and providing adequate shoring is necessary during the construction process. Slab shoring shall run perpendicular to the strong direction of the panel (parallel to the primary support walls). Shoring for upper levels shall stack above lower level shoring, and in no cases shall lower level shoring be removed prior to removing the shoring above.

Edge shoring for floor systems shall be placed no further than 2 feet from the support wall. Spacing of interior shoring shall be no greater than 6 feet, and is limited to 5 feet without an overhang condition.

Edge shoring can be removed 2 to 3 days (longer in cool weather or if unusual conditions exist) after placement of the first layer on the underside of the floor slab. However, shoring shall not be removed at lower levels of multi-story buildings until upper floor shoring is removed first. Spacing from support walls to interior shoring shall not exceed 8 feet.



Recommended Minimum Shoring Requirements

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