Structural Breadth Analysis

Structural Redesign of Exterior Wall Panel Connections

Background Information

Campus Square's exterior wall assembly was constructed using a non load-bearing masonry façade system with metal stud backing, as well as a sizable curtain wall system on the north side of the building. The exterior walls were all constructed on-site, requiring scaffolding during masonry installation, as well as large numbers of craftsmen in order to complete the work. Using a prefabricated wall system will not only simplify the construction of the walls, but will also reduce the amount of workers on-site, mitigating safety risks. However, if a prefabricated wall system is implemented on exterior of the building, the structural connections which fasten the prefabricated panels to the steel structure would need to be designed. Campus Square currently supports the brick veneer with steel angles anchored in the composite deck system. Figure 30 below, illustrates the current steel angles used to support the masonry façade system. Properly designing the connections would be critical in ensuring the proposed prefabricated system is structurally anchored to the superstructure.

Figure 30 – Masonry Façade Steel Support Angles

Image courtesy Wohlsen Construction Company

Overall Goals

The goal of this analysis is to understand the connection design used for the current façade, and then redesign the connection detail in order to facilitate a prefabricated system. Furthermore, the connection locations along the wall system will need to be determined in order to efficiently design the quantity of connections needed. Proper spacing will be very important in the overall design because each connection point will require on-site craftsmen joining the walls to the structure, as well as adding to the amount of time it will take to install each panel.

Methods

- Understand current structural design of exterior masonry system
- Contact structural engineer of Campus Square about potential solutions of redesign
- Conduct literature review of prefabricated system
- Determine proposed prefabricated wall assembly and associated dead loads
- Establish schematic structural design of connections
- Analyze loads and determine proper connection spacing and connection type

Resources

- Dietrich Metal Framing (Connection Manufacturer)
- Wohlsen Construction Company (Project Manager for Campus Square)
- Structural AE faculty
- TEAM Panels International (Prefabricated Panel Manufacturer)
- KERR Interior Systems Ltd. & Composite Building Systems Inc. (Prefabricated Panel Manufacturer)
- *Mechanical and Electrical Equipment for Buildings (Textbook by Benjamin Stein)*
- AISC Design Guide 22, Table 2-1
- ASCE 7-05, Chapter 2: Combination of Loads

Expected Outcome

The new structural connection will be more complex than the original steel angles currently used to support the façade. The new connections will need to be stronger in order to support the added dead load of the entire wall assembly, compared to just the brick veneer. The added loads may involve additional reinforcing along the edges of the structure.

Existing Exterior Wall System

Campus Square was constructed using a high performance, brick veneer exterior wall system with galvanized steel stud backing for the exterior walls of the building. The wall assembly was implemented in order to achieve a higher thermal performance to reduce operating costs, as well as sustainability implications toward the building's LEED® Gold certification for core and shell. Supported by the foundation, as well as galvanized steel angles, the 4" brick veneer is typical throughout the façade of the building, with the exception of a small area along the entrances on the north side, which was made of an architectural stone. The 3/8" steel angles used to support the brick façade were connected to the edge of the concrete slab using a fillet weld connected to the 3/8" steel angle located along the slab edges. The angles also provide a moisture cavity between the sheathing and brick, as well as room for construction tolerances.

Each slab-on-deck is supported by the steel superstructure which acts as the main structural system for the building. The composite slab system overhangs the steel girders, requiring additional 2-way reinforcing at the slab's edge in order to resist the unsupported load. Additionally, the slabs are supported by a 3/8" bent plate attached to the steel girders.

The exterior wall assembly is rests on each slab, spanning the entire elevation for each floor, connecting once again at the bottom edge of slab of the next floor level. 14 and 16 gauge C-channel 6" metal studs are used as the primary framing material throughout the exterior of the building, coupled with 6" batting insulation with foil backing. 7/16" DensGlass® sheathing was attached to the exterior framing around the building. DensGlass® gypsum sheathing features a moisture-resistant core and enhanced fiberglass mats, instead of paper facings, to resist the effects of moisture exposure during and after construction. The drawings below, in Figure 31 depict the typical exterior wall assemblies and structural connections along the slab edges.

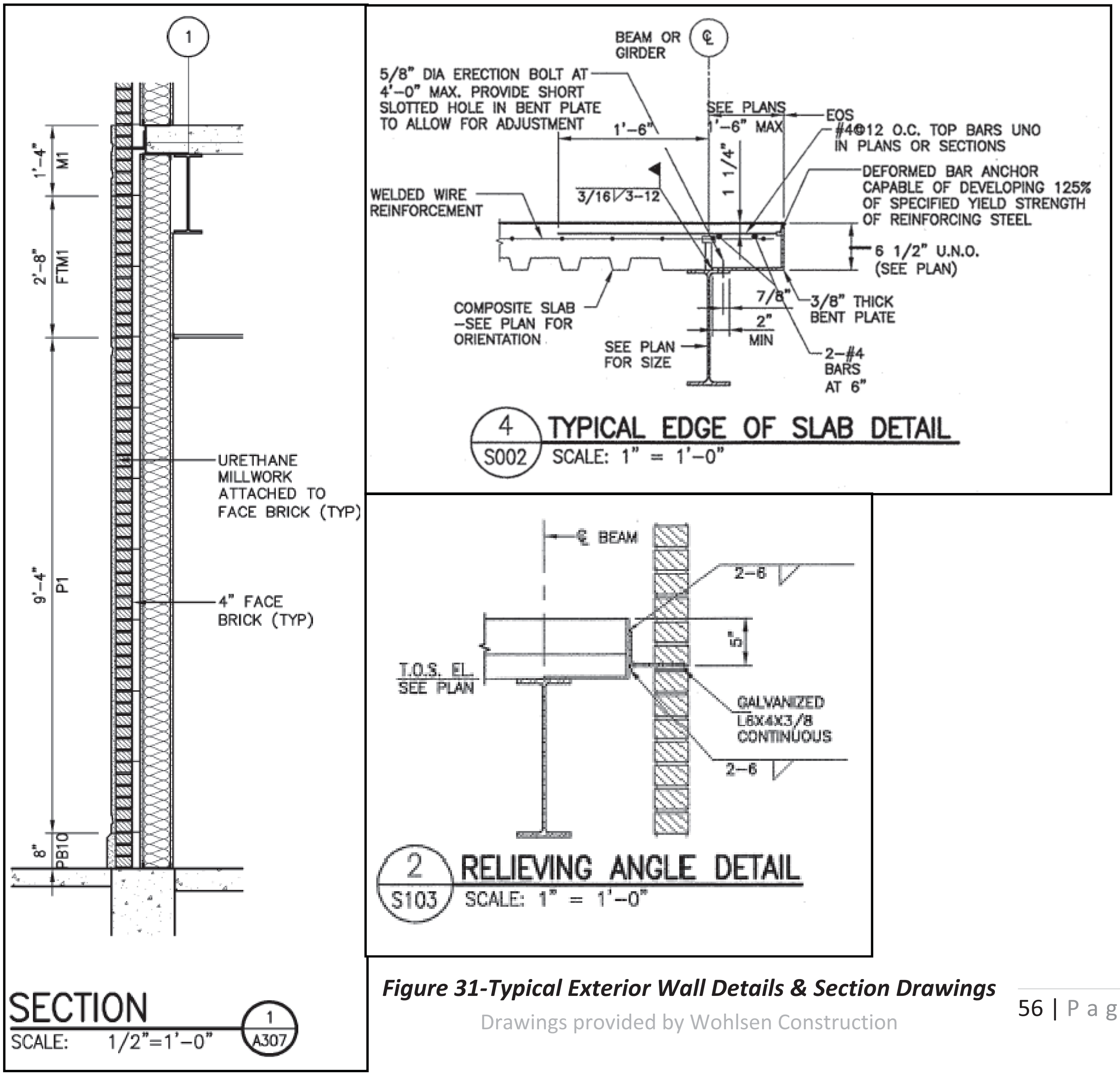


Figure 31-Typical Exterior Wall Details & Section Drawings

Drawings provided by Wohlsen Construction

Proposed Prefabricated System

After consulting with prefabricated wall manufacturers, including TEAM Panels International and KERR Interior Systems Ltd. & Composite Building Systems Inc., different wall assemblies were reviewed which could be implemented for Campus Square. It was important to identify complete panelized wall assemblies which could be manufactured in full, and installed on-site with the smallest amount of on-site installation. Furthermore, for the purposes of this report, the proposed system needed to be thermally more efficient than the as-built system, as discussed in the mechanical breadth of this report. Also, the proposed wall assembly needed to contain similar building materials as the original in order to meet aesthetic and sustainable requirements of Campus Square. By incorporating a prefabricated wall system for Campus Square, certain quality advantages may be achieved over the as-built methods due to the controlled environment of prefabrication. Such advantages include retaining aesthetic integrity and value by Eliminating problems relating to shrinkage, rotting, corrosion and cracks in the finishes; as well as pre-punched knockouts in the steel members, which decreases the time required from the other trades. Prefabrication also has LEED implications which are ideal for Campus Square and GreenWorks Development's sustainability mission. With respect to the LEED program's Materials and Resources (MR) Credits, Recycled Content, all of the cold-formed steel are produced from 90% recycled steel, comprised of 57% post-consumer recycled content and 33% post-industrial recycled content. Panel studs contain a high percentage of recycled steel comprised of both post-consumer and pre-consumer recycled content. In addition, depending upon the specific project location and manufacturer availability, opportunities may exist for credits under the Materials and Resources Credits for Regional Materials.

The wall system chosen for the proposed prefabricated system will contain 4" EIFS exterior insulation and simulated brick stucco. The simulated brick face will match that of the original design, but will provide for an improved insulating material over traditional batting insulation. The same 16" typical (unless noted otherwise on the drawings) stud spacing may also be kept the same in order to reduce the amount of framing required. Each panel is sized to span the typical bay width according to the panel's location. Utilizing this prescribed method will reduce the amount panel joints, as well as on-site time in seaming the panels together. Appendix C of this report lists the panel size and location schedule. Figure 32 on the following page shows a typical exterior wall assembly proposed for Campus Square, utilizing the EIFS system with metal stud backing.

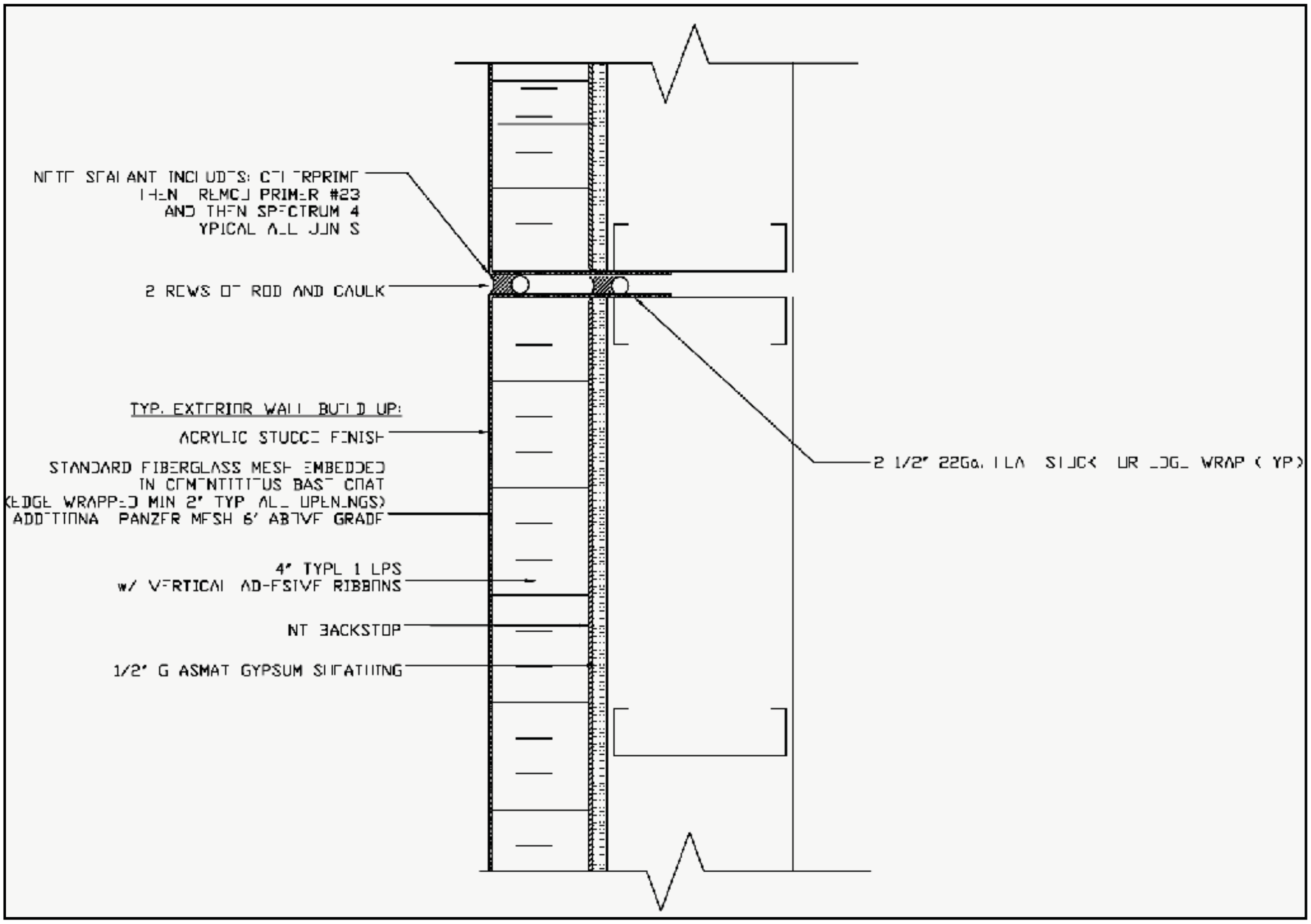


Figure 32– Typical Vertical Wall Assembly and Joint Detail

Drawing courtesy KERR Interior Systems Ltd. & Composite Building Systems Inc.

Proposed Structural Connection

For the purpose of this analysis, connections will be sized for a typical bay along the east side of Campus Square. The procedures and calculations used will mimic those which would be used to size the connections of the panels to the superstructure throughout the other elevations of the building. The bay which will be analyzed will be that of Panel #5, of erection sequence-4. This panel is located on the second floor of Campus Square, along 3rd Street. In order to determine the proper connection type to be used, gravity loads or dead loads, along with wind loads must be determined. With these values, the loadings onto the connections can be calculated, and sized appropriately. Figure 33 on the next page highlights the panel which will be analyzed.

Figure 33– Panel #5, Erection Sequence-4; Located Along 3rd Street

Drawing provided by Wohlsen Construction

The AISC Design Guide gives a common design assumption for an EIFS wall system (including gypsum sheathing, metals studs, and hardware), listing a gravity load of approximately 10 PSF. Using ASCE 7-05, an allowable load can be determined using strength design. Along with a dead load, a wind load will also need to be included into the design of the connections. Figure 34 lists the net wind uplift loads for Campus Square. Panel #5 will experience a net wind uplift of 26 PSF according to the diagram.

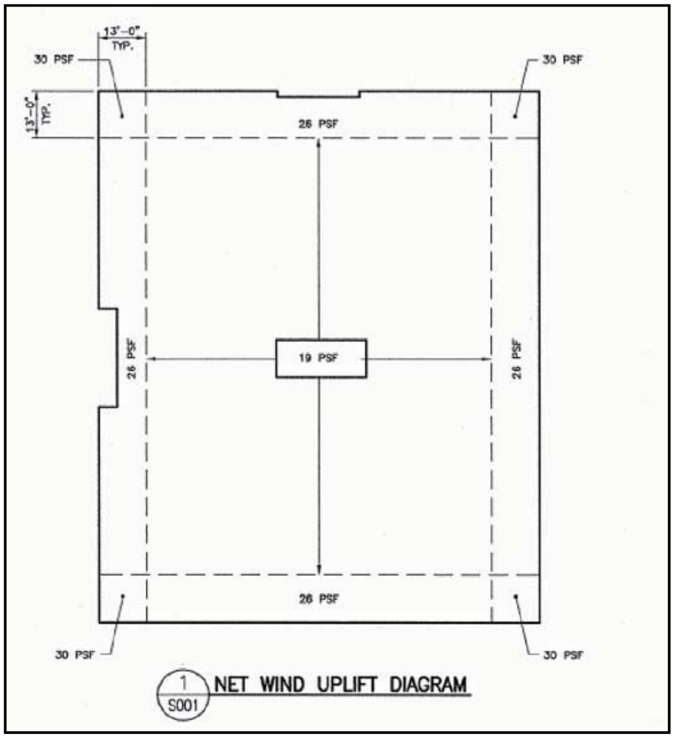


Figure 34-Net Wind Uplift Diagram

Drawings provided by Wohlsen Construction

Dietrich Metal Framing produces a series of connections used to attach curtain wall systems and wall sections to the superstructure. Using a QuickClip™ (QC-Series ™) in order to connect the proposed prefabricated wall sections to the steel and slab-on-deck of Campus Square, will provide the means to accomplish the proposed methods. The product allows for vertical building movement, restricts lateral movement, and provides up to 3" of horizontal standoff. Because the panels span each floor height, the wall sections will be attached at each 16" stud spacing at the floor and ceiling levels. Figure 35 below demonstrates how each steel stud will be attached the QuickClip™. Because the clips are installed vertically in line with another, it will negate a turning moment in design considerations.

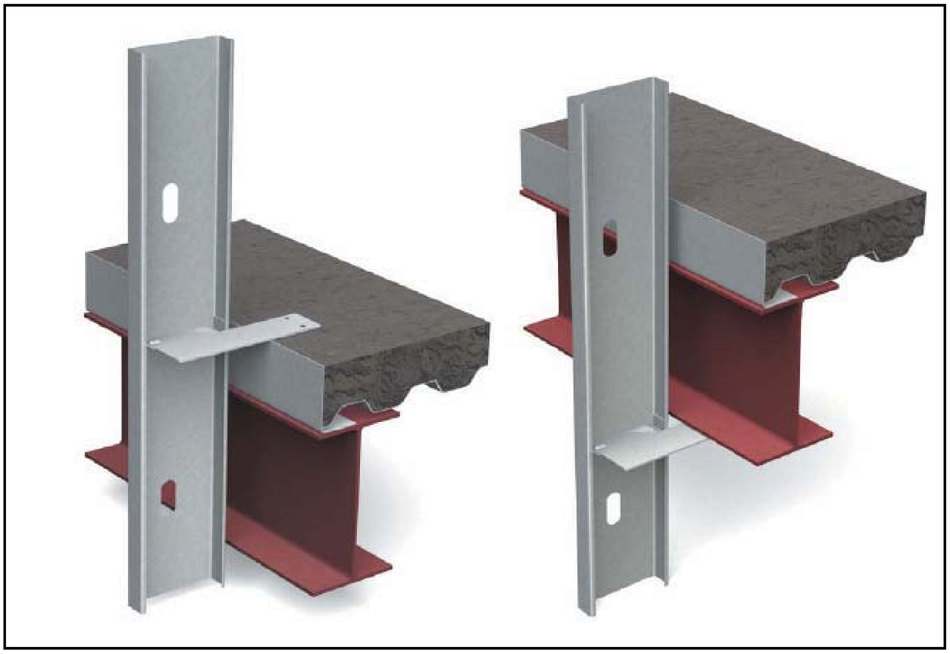


Figure 35– QuickClip™ (QC-Series™)
Left: Floor-to-Deck Connection (Typical). Right: Ceiling-to-Beam Connection (Typical).
Image courtesy Dietrich Metal Framing

Load Calculations
Chapter 2 of ASCE 7-05, Section 2.4 Combining Nominal Loading Using Allowable Stress Design, an allowable stress load can be determined using equation 5:

$$D + H + F + (W \text{ or } 0.7E)$$

Where:
D= Dead Load
H= Load due to lateral earth pressure, ground water pressure, or pressure of bulk materials
F= Load due to fluids with well-defined pressures and maximum heights
W= Wind Load
E= Earthquake Load

Equation 5 is used because this will result in the maximum design loading, ensuring worst case loading is met. The variables "H", "F", and "E" will not be needed in this calculation because those design elements do not contribute to the loading conditions of the proposed connections. Therefore:

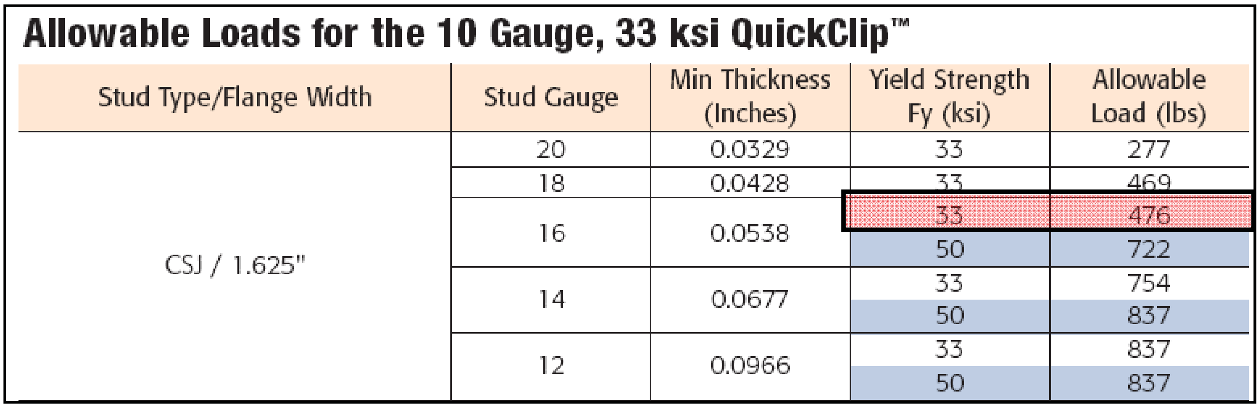
D + W = 10PSF + 26 PSF = **36 PSF**

Each steel stud will be placed at 16" O.C., resulting in (for this specific panel) an approximate tributary area of **20.31 SF**.

Load of each stud, based on calculated tributary area:

Stud Tributary Area * Dead Load = 23.31 SF * 10 PSF = **233.10 LBS**

Based off of the above value, 16 gauge, 33 ksi steel studs will be appropriate for the prefabricated wall, as designed by the manufacturer. Also, a 10 gauge, 33 ksi QuickClip™ will be able to support the tributary area of each stud. Figure 36 below depicts allowable loads for each QuickClip™



Allowable Loads for the 10 Gauge, 33 ksi QuickClip™

Stud Type/Flange Width	Stud Gauge	Min Thickness (Inches)	Yield Strength Fy (ksi)	Allowable Load (lbs)
CSJ / 1.625"	20	0.0329	33	277
	18	0.0428	33	469
	16	0.0538	33	476
			50	722
	14	0.0677	33	754
			50	837
	12	0.0966	33	837
			50	837

Figure 36- Allowable Loads for 10 Gauge QuickClip™

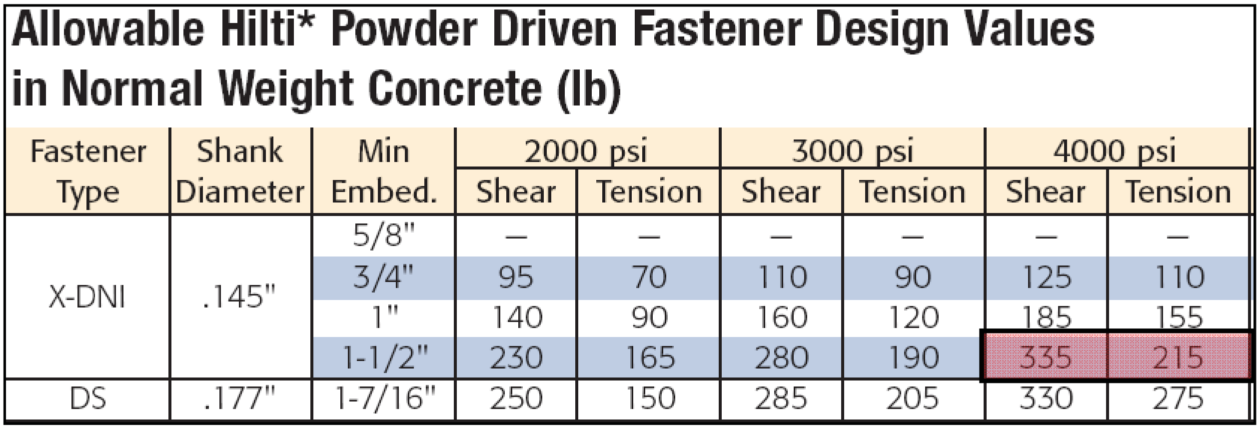
Image courtesy Dietrich Metal Framing

Each QuickClip™ will need to be welded to each stud, and fastened to either the concrete deck or steel beam. The Hilti™ powder-driven fasteners will to be designed for allowable shear and tension. In order to determine these values, the wind load must be incorporated into the shear stress.

Wind Load Shear:

Tributary Area * Wind Load = Wind Load @ Center of Tributary Area
20.31 SF * 26 PSF = **528.06 LBS**
(Wind Load @ Center of Tributary Area)/2 = Shear @ Each Connection
528.06 LBS / 2 = **264.03 LBS**

The Hilit™ fasteners will need to be embedded into the 4000psi concrete deck to a depth of 1-1/2", based off of the calculated allowable shear force. Figure 37 below lists the shear and tension forces for the Hilti™ fasteners in normal weight concrete.



Allowable Hilti* Powder Driven Fastener Design Values in Normal Weight Concrete (lb)

Fastener Type	Shank Diameter	Min Embed.	2000 psi		3000 psi		4000 psi	
			Shear	Tension	Shear	Tension	Shear	Tension
X-DNI	.145"	5/8"	—	—	—	—	—	—
		3/4"	95	70	110	90	125	110
		1"	140	90	160	120	185	155
		1-1/2"	230	165	280	190	335	215
DS	.177"	1-7/16"	250	150	285	205	330	275

Figure 37- Allowable Hilti™ Fastener Design Values In Concrete

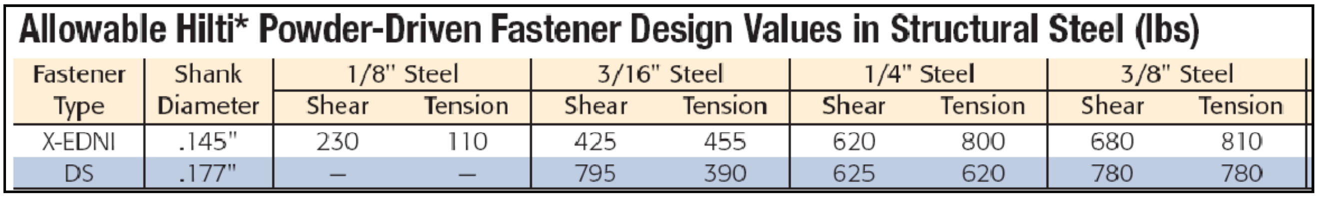
Image courtesy Dietrich Metal Framing

Shear and Tension through the steel beam also needs to be compared to the manufacturers design values to ensure the loads can be supported by the QuickClip™. Tension at the beam will be calculated because the fasteners will be installed at the bottom of the beam, directed upwards.

Tension at the steel beam:

Tributary Area * Dead Load = **233.10 LBS**

The tension value obtained does not exceed any design value listed in Figure 38 below; therefore, it will satisfy all beam types of Campus Square.



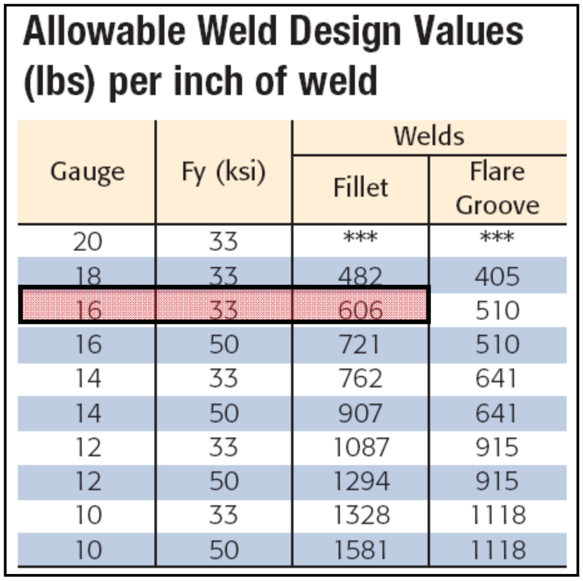
Allowable Hilti* Powder-Driven Fastener Design Values in Structural Steel (lbs)

Fastener Type	Shank Diameter	1/8" Steel		3/16" Steel		1/4" Steel		3/8" Steel	
		Shear	Tension	Shear	Tension	Shear	Tension	Shear	Tension
X-EDNI	.145"	230	110	425	455	620	800	680	810
DS	.177"	—	—	795	390	625	620	780	780

Figure 37- Allowable Hilti™ Fastener Design Values In Structural Steel

Image courtesy Dietrich Metal Framing

Lastly, the weld locations along the QuickClip™, which bonds the steel stud to the clip needs to be compared to allowable weld design values as listed by the manufacturer. As Figure 38 depicts, a 1" fillet weld connecting the clip and the 16 gauge stud will exceed the design conditions.



Allowable Weld Design Values (lbs) per inch of weld

Gauge	Fy (ksi)	Welds	
		Fillet	Flare Groove
20	33	***	***
18	33	482	405
16	33	606	510
16	50	721	510
14	33	762	641
14	50	907	641
12	33	1087	915
12	50	1294	915
10	33	1328	1118
10	50	1581	1118

Figure 38- Allowable Weld Design Values

Image courtesy Dietrich Metal Framing

Please review Appendix E of this report for the QuickClip™ product data used in this analysis.

Conclusion and Recommendation

The QuickClip™ connectors provide an excellent solution in attaching the prefabricated panels to the superstructure of Campus Square. They allow for construction tolerances in the field in their design by providing stand-off. Also, the clips can be manufactured and attached to the panels before they are delivered on-site. This will allow for less on-site welding which is costly, and allows for added risk during installation.

The redesign of the exterior wall system also eliminates the concrete slab overhang past the edge of the steel beams. This will ultimately reduce the amount of concrete needed during the pour of each floor, saving money in material costs, as well as time for installation.

Further study could be performed in determining the deflection differences the proposed panel system will have on the steel, compared to the as-built wall system. The original wall design created a distributed load along the concrete slab edge. However, the proposed system will incorporate point loads along the beams and the concrete slab. It can be assumed that because the prefabricated system will have a lesser dead load on the structure, deflection issues may be negated.

Prefabrication of the exterior wall system will result in carefully design details, construction joints, and sizing each panel due to the importance of mitigating gaps along the panels. Defects in the design and improper installation methods will result in a lesser performing system.