Utah State University
Systems, Materials, and
Structural Health Laboratory
1560 Canyon Road
Logan, UT 84322, USA
Director: Marc Maguire, Ph.D.
Tel: (435) 797-1139
Email: m.maguire@usu.edu

Double Shear Testing of Innovative Structural Solutions Concrete Sandwich Wall Assembly

SMASH LAB REPORT NO. SMASH.19.01

SUBMITTED: April 26, 2019

SUBMITTED BY: Marc Maguire, PhD

Standards Referenced

ICC-ES AC422	Acceptance criteria for semicontinuous fiber-reinforced grid connectors used in combination with rigid insulation in concrete sandwich panel construction, International Code Council Evaluation Service, 2016 (“AC422”).
ASTM C31	Standard practice for making and curing concrete test specimens in the field, ASTM International, 2018 (“ASTM C31”).
ASTM C33	Standard specification for concrete aggregates, ASTM International, 2013 (“ASTM C33”).
ASTM C39	Standard test method for compressive strength of cylindrical concrete specimens, ASTM International, 2014 (“ASTM C39”).
ASTM C150	Standard specification for portland cement, ASTM International, 2017 (“ASTM C150”).
ASTM C303	Standard test method for dimensions and density of preformed clock and board-type thermal insulation, ASTM International, 2007 (“ASTM C303”).
ACI 211.1	Standard practice for selecting proportions for normal, heavyweight, and mass concrete, American Concrete Institute, 1991 (Reapproved 2009) (“ACI 211.1”).

Scope of Report

This report presents the results of double shear testing of 4 in insulation version of the Innovative Structural Solutions (Innstruct) insulation and steel shear connectors system for concrete and rigid foam composite sandwich wall panels (SWP). This double shear testing provides a basis for comparison to other product on the market as well as providing shear strength and failure mode information. Testing is performed on a variation of AC422 testing which is the only testing procedure available for component testing of sandwich wall panel connector systems. Testing was performed at the Utah State University (USU) Systems, Materials and Structural Health Laboratory (SMASH Lab) for Innstruct. Per the contract, the scope of work was limited to:

1. Fabricate and test five total double shear specimens (based on a variation of AC422) for 4 in. insulation thickness at approximately 3500 psi to simulate lifting concrete strengths in a tilt-up application.
2. Report results of the proposed testing.

Product Description and Installation

This section details basic information about Innstruct panels with respect to the double shear testing and anticipated field fabrication. The panel assembly (Figure 1) comprises nominally 9 gauge wires connected through a 4 in. thick by 2 ft wide by 2 ft tall expanded polystyrene (EPS) sheet that are welded to a nominally 11 gauge wire mesh. Mesh properties were not provided by the manufacturer and not tested by the lab. The assembly is produced in Morgan, UT using an automated process that projects the wires through the insulation and welds these wires to both layers of facing wire mesh.

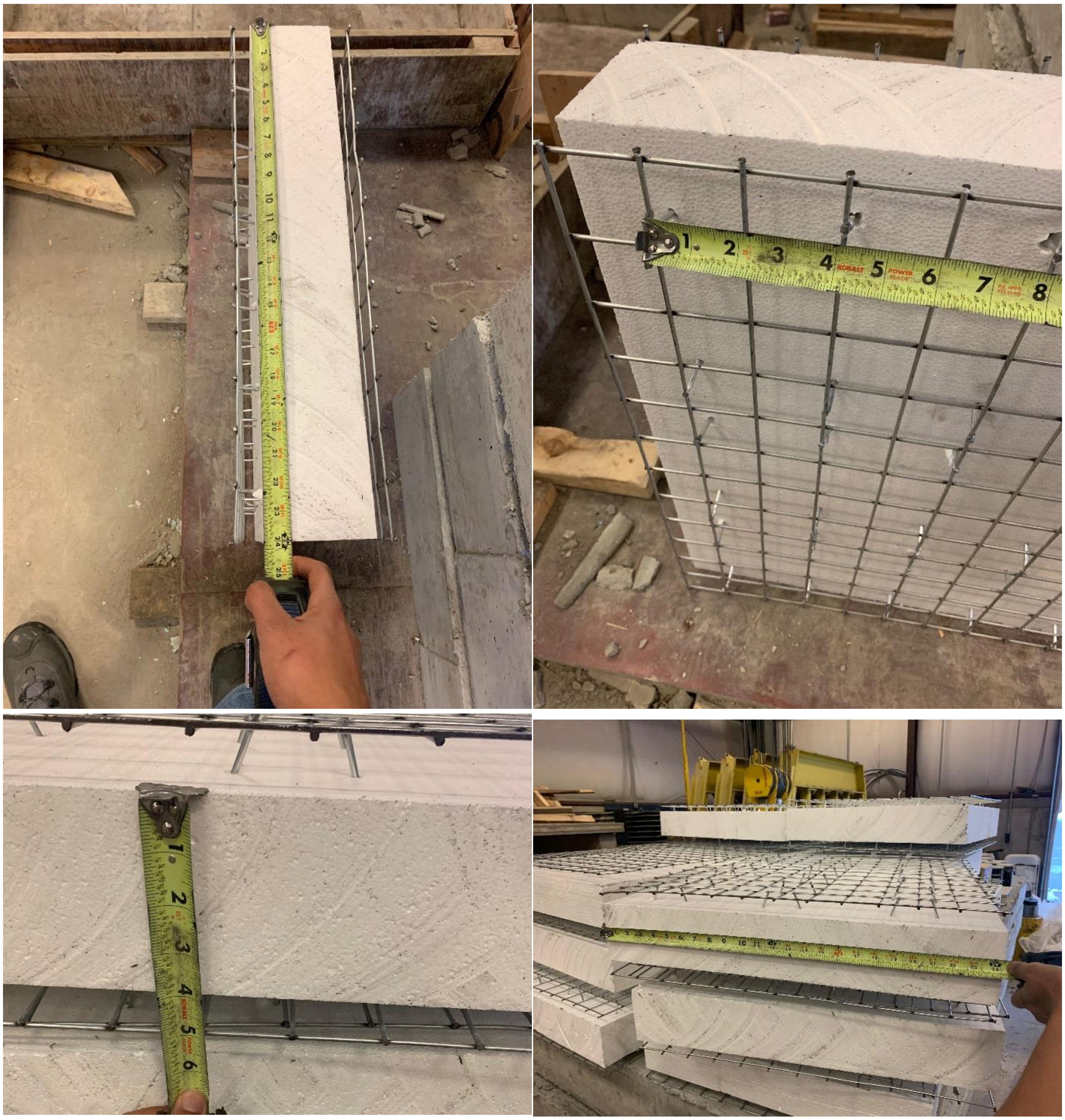


Figure 1. Innstruct 4 in. panel assembly

These and similar panels have been used routinely throughout the world since the 1960s in shotcrete – and other – applications, but rarely in the tilt-up application. For a tilt-up application, it is envisioned that the first layer of concrete is cast, then the panel is installed with appropriate splice mesh and any additional reinforcement required by the engineering design of the wall, then the second layer of concrete is cast with appropriate reinforcing to produce a three layer sandwich wall that can be tilted up into place upon reaching the required strength.

Sampling

All Innstruct panels used for the testing described herein were delivered by Hal Fronk of Innstruct to the SMASH lab.

Specimen Fabrication

Connector shear tests were performed using double-shear specimens similar to those described in Section 4.4.2 of AC422 and similar to those of other sandwich wall panel connectors in the literature. Double shear specimens consisted of three wythes of concrete and two wythes of rigid foam insulation, as shown in Figure 2. The thicknesses of the outer concrete wythes, the foam wythes, and the center concrete wythe were 3 in, 4 in, and 6 in, respectively. Each wythe measured 24 in wide and 24 in long. The completed specimen measured 20 × 24 × 24 in.

Specimens were prepared by casting a 3 in. layer of concrete, placing the insulation over it and casting the 6 in. center wythe, then placing the second insulation assembly followed by another 3 in. layer of concrete. Concrete was allowed to cure until reaching 3500 psi, a common lifting strength for tilt-up applications. The specimen setup allows the connectors to be evaluated in similar wythe strengths, thicknesses and maximum thickness insulation values to those in tilt-up sandwich construction.

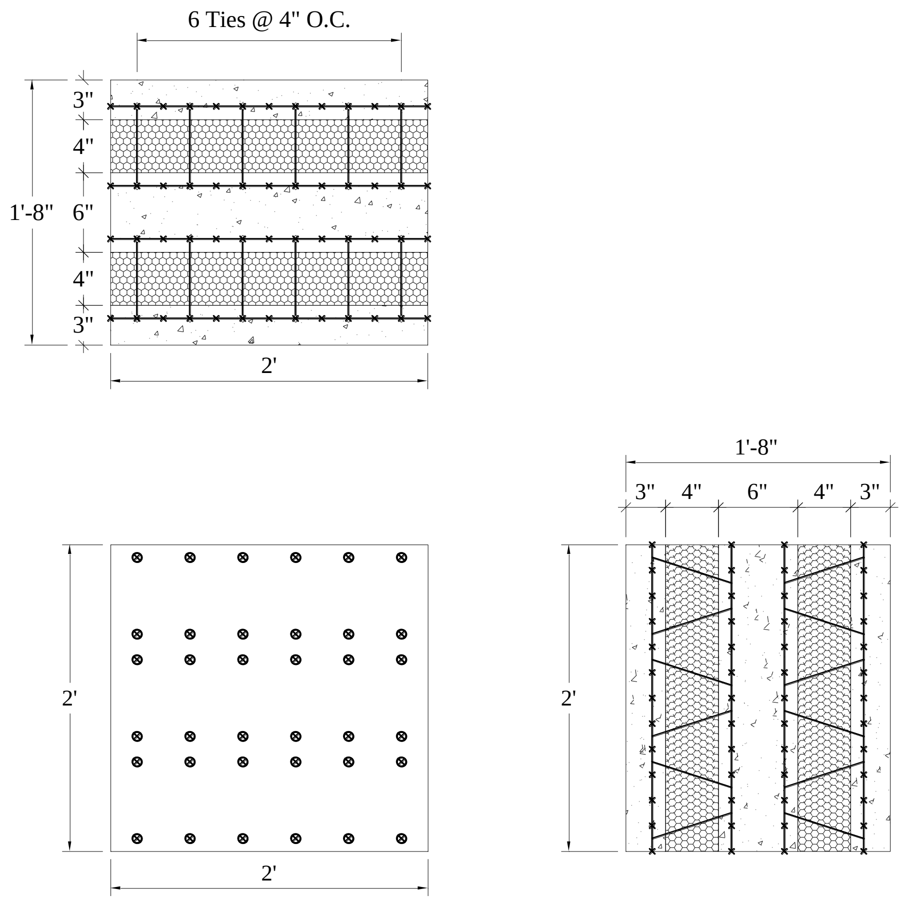


Figure 2. Double-shear specimen

Test Procedures

Double-shear specimens were tested as shown in Figure 3. The outer concrete wythes were supported on stainless steel bearing surfaces with low friction polytetrafluoroethylene (PTFE) pads. Specimens were instrumented with a load cell to measure the applied force, and with four linear variable differential transformers (LVDT)—two on each side of the specimen—to measure the displacement of each outer concrete wythe relative to the center concrete wythe. Load was applied parallel to the connector rows and concentric to the test specimen using a servo-hydraulic actuator with advance rate of 0.05 in/min. The applied force was measured using a load cell. Test specimens, supports, and loading were all symmetric about the center plane of the test specimen.

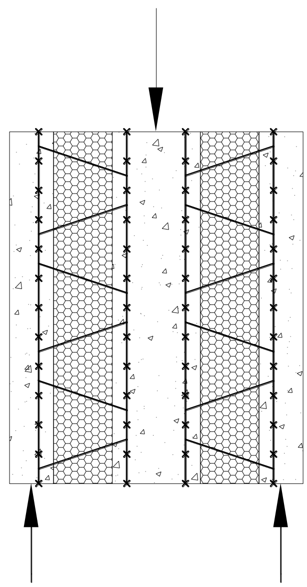


Figure 3. Connector shear test loading apparatus

Concrete

Concrete conformed to the requirements of Section 4.1 of AC422. Mixture proportions were in general accordance with ACI 211.1. Coarse and fine aggregates met the specifications of ASTM C33. Cement met the specifications of ASTM C150. Ready-mix concrete was delivered by Staker Parson (Smithfield, UT).

Cylindrical specimens were cast at the same time as double shear specimens for the purpose of compressive strength determination. Cylindrical specimens measuring 4 in in diameter and 8 in in length were cast and field-cured in accordance with the specifications of ASTM C31. Concrete compressive strength was evaluated in accordance with the specifications of ASTM C39 at the SMASH Lab. Three concrete cylinders were tested in compression on the day that connector shear tests were performed. The cylinder strengths were 3,240 psi, 3,810 psi, and, 3,790 psi, for an average concrete compressive strength of 3,610 psi for the five double shear tests.

Summary of Test Results

Double shear testing was performed on April 6, 2019. Specimens were loaded until the sensors maxed out at approximately 2 in. displacement. A photo of Specimen 1 after load was removed can be found in Figure 4 where large deformations are present.

Figure 4. Example Post-Failure Specimen 1

Load versus deformation relationships are presented in Figure 5 and Figure 6. The curves show a nearly linear portion followed by an initial peak and resulting drop in strength. Following this drop in strength, all specimens held considerable strength through large deformations and gain more strength until reaching a second peak that is often higher than the first after 1.5 in. of relative displacement.

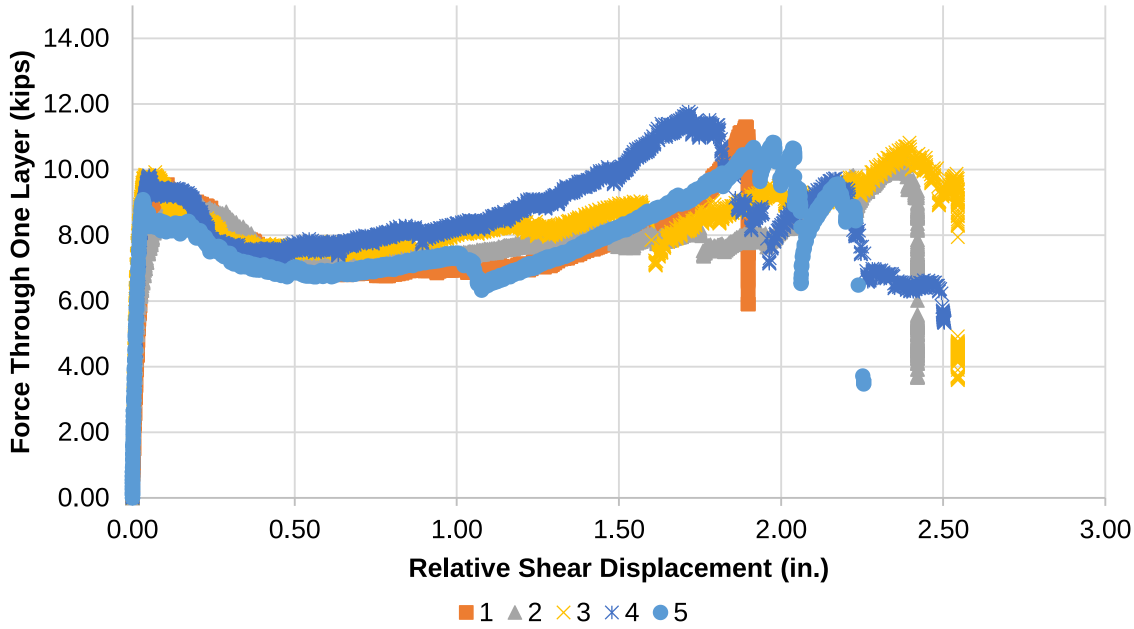


Figure 5. Full Load versus Displacement curve for all double shear specimens

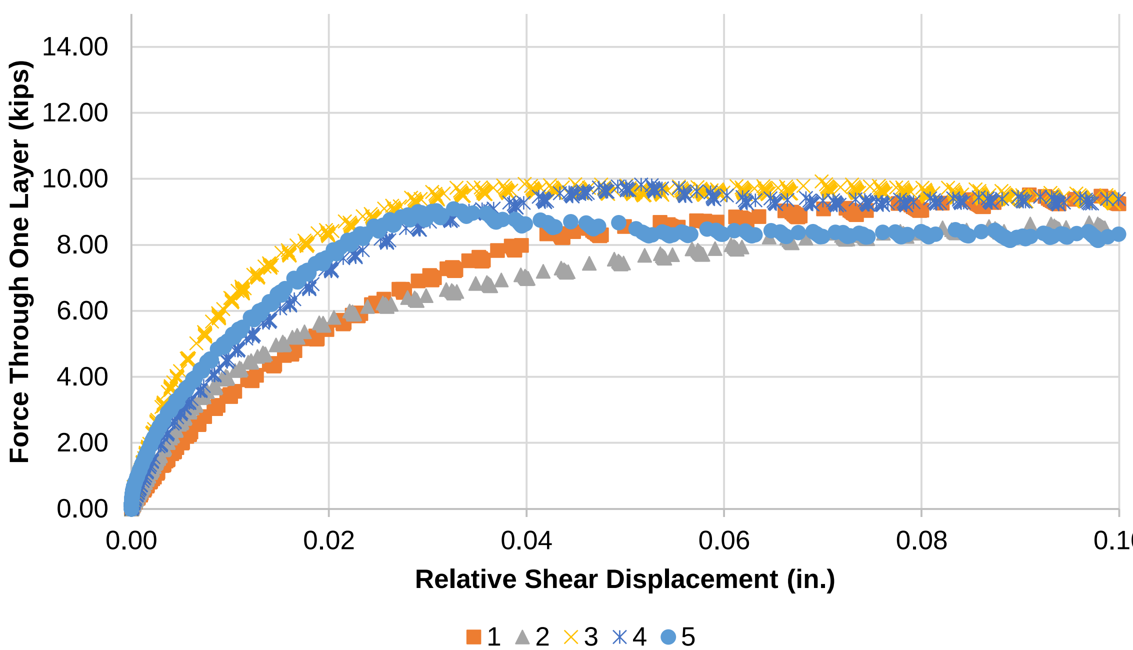


Figure 6. Small Displacement Load versus Displacement curve for all double shear specimens

Design values obtained from these tests are strength (F_{max}) and the secant stiffness to 0.5*F_{max} ($K_{0.5}$). These design values are summarized in Table 1. F_{max} is 9.4 kip on average with a 4.6% coefficient of variation (COV), which is very low. $K_{0.5}$ is 493 kip/in. on average with a COV of 36% which is high. A high COV is anticipated for this value because the insulation was allowed to bond to the concrete because of access and fabrication making it impossible to debond the specimen. Design strength and stiffness values presented herein can be used to design sandwich panels using the generalized methodologies for full size sandwich panels are outlined in Olsen et al. (2017). Verification that these measured shear deformation properties and methods can predict full scale behavior is recommended.

Table 1. Summary of Design Values

Specimen #	F_{max} (kip)	$K_{0.5}$ (kip/in)
1	9.5	294
2	8.8	396
3	9.8	764
4	9.7	448
5	9.1	562
Average	**9.4**	**493**
COV	**0.046**	**0.36**

Upon inspection of the specimen failure modes, it appears the peak occurs upon buckling of the compression wires which then were bent back the through large deformations, then contributed to strength through tension causing the second peak which seems to correspond to final tension failure (seemly at the weld) of the tension wires (see Figure 7).

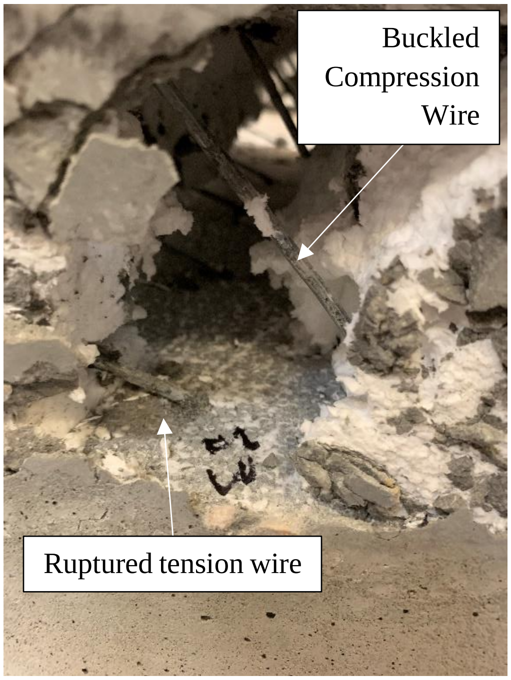


Figure 7. Specimen 1 failure mode typical of all double shear tests

Conclusion

Based on the tests and results described herein, the maximum strength per a 2ft x 2ft section of panel can resist an average of 9.4 kips shear force with a COV of 4.6%. The elastic stiffness of the same 2ft x 2ft section results in 493 kip/in. with a COV of 36%. While there are no codified design procedures for concrete sandwich wall panels exhibiting partial composite action, these values can be used in established analysis procedures in Olsen et al. (2017). A spreadsheet loading the values derived in this report along with several other systems can be found at the following link:

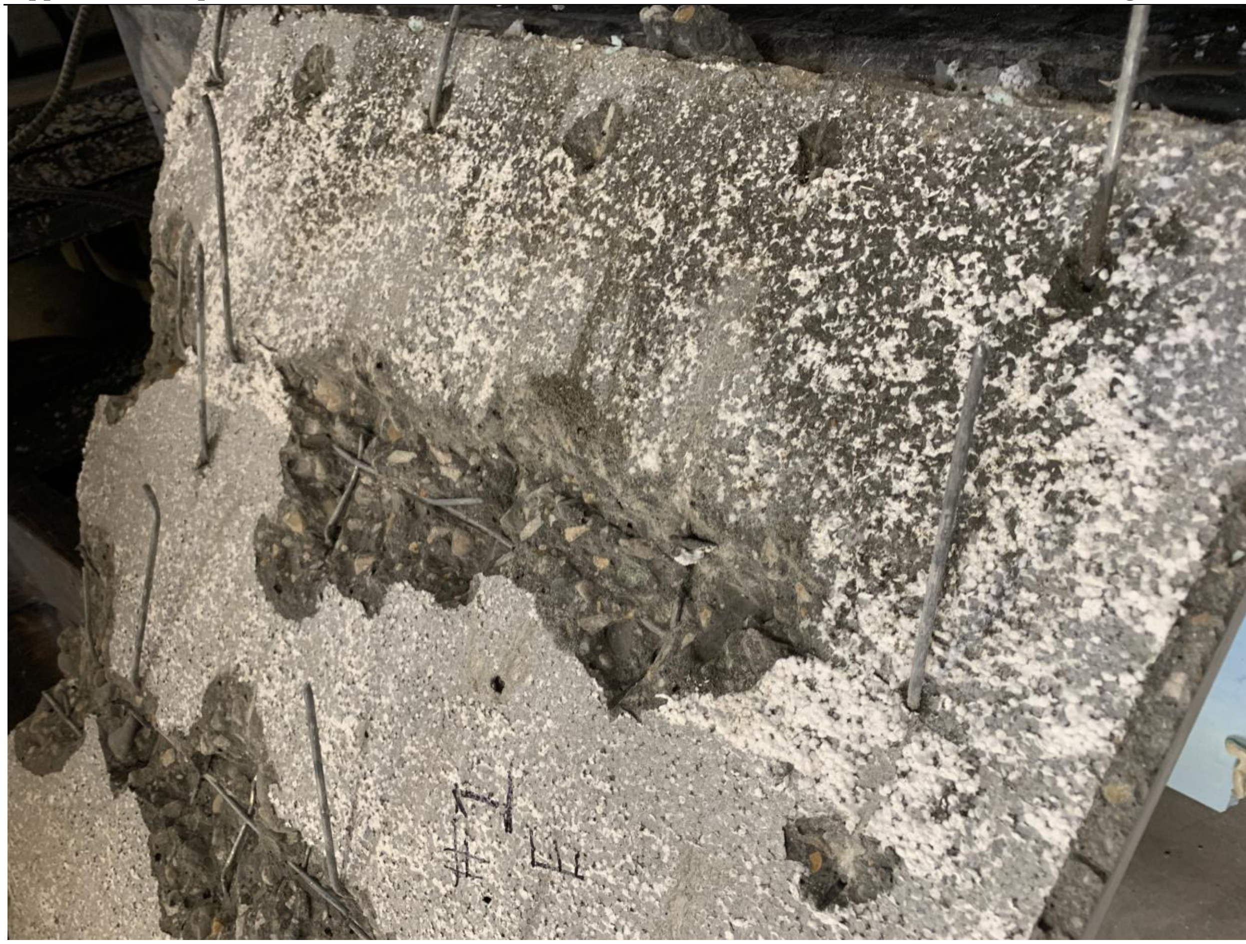
https://app.box.com/s/pligrbbc4niojvjdattnpiwteg9tg619

This spreadsheet can be used to obtain percent composite action for various limit states as well as cracking moment, deflection and ultimate strength prediction and is based on the fundamental mechanics-based methods outlined in Olsen et al. (2017). This spreadsheet is not intended for design purposes, but as a demonstration tool. This spreadsheet is also periodically updated as new connector information is gained and analysis methods modified.

References

Olsen, J., Al-Rubaye, S., Sorensen., T., Maguire, M., (2017) "Developing a General methodology for Evaluating Composite Action in Insulated Wall Panels. *Report to the Prestressed/Precast Concrete Institute*. Chicago, IL.

Specimen 1




#1 W

Specimen 2


XX2

Specimen 3

Specimen 4


#4 W

Specimen 5