October 4, 2022

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RE: Summary of Innstruct TIPS Panel Performance -TCA Testing, Rev 1
Tilt-Up Partially Composite Insulated Wall Panels (Report)

Introduction

This document reviews and summarizes research and testing completed by Marc Maguire, PhD, Assistant Professor, and Salam Al-Rudaye, PhD Candidate, Graduate Research Assistant at the Durham School of Architectural Engineering and Construction at the University of Nebraska-Lincoln. The full research and test report is titled **Tilt-Up Partially Composite Insulated Wall Panels** (Report), which was prepared for the Tilt-Up Concrete Association (TCA), and is available online at "Tilt-Up Partially Composite Insulated Wall Panels" by Marc Maguire and Salam Al-Rubaye (unl.edu). Periodic quotations and inclusion of report data or findings included in this summary are referenced to the applicable pages of the Report.

Forsgren Associates, Inc. (Forsgren) provided structural design and assistance to Innovative Structural Solutions (ISS) for the Innstruct TIPS test panels used in the tilt-up wall panel testing project and has consulted for ISS with the Innstruct product for the past eight years. Forsgren has been retained to prepare a summary report for general use and to present the Report information specific to the Innstruct TIPS product. This document does not and is not intended to present or comment on all aspects or details of the Report; nor does it address the performance or characteristics of other connector systems included in the research and testing program. Reasonable effort has been taken to include the appropriate level of context in the work summarized herein; however, the reader is encouraged to obtain and review the full Report at the appropriate level of detail in making decisions on use of the Innstruct TIPS product.

The Executive Summary of the Report states that the TCA and the five connector systems funded the study (Project) with the intent of better understanding second-order analysis for combined axial and out-of-plane loading on slender walls; and to verify the applicability of current ACI alternate slender wall analysis design for taller walls. To that end and as a control for the connector tests, solid concrete walls were tested with the concrete insulated wall panel (CIP) systems with test specimens. The research found that the solid concrete wall panels performed substantially in accordance with expectations using the tilt-up Slender Wall Design method (Report page ii).

Rather than naming the proprietary connector systems used in the study throughout the document, the Report lists the connector systems tested by letter, A through E. The Innstruct TIPS panel system is noted as “Connector A” or “Group A” in the Report. This naming convention is preserved in the summary when quotes or figures from the Report are included herein.

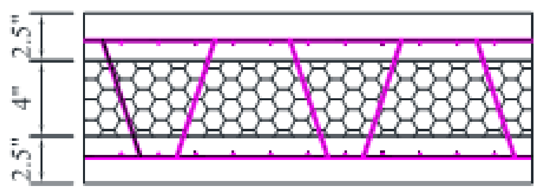
The Executive Summary states:

> “*Group A panels performed very similarly to solid walls, even matching closely an unmodified version of the Slender Wall Design Method. This behavior was likely due to the reduced and solid regions noted in the Group A panels that would be similar to their in-service construction.”* Report page iii.

Note: foam to foam construction without concrete at panel edges is not recommended. Even though the panels used for the tests did not have concrete on the edges, there were substantially solid concrete sections at the lifting inserts.

Experimental Program Setup

This section introduces the Innstruct wall panel section used for the Project and summarizes the general test process. The wythe connectors for the Innstruct TIPS product are the diagonal truss wires shown below extending through the EPS insulation and compositely connecting the reinforced concrete wythe on each side of the panel. For the Project a 2.5”-4”-2.5” panel was used with 2.5-inches of concrete on each side of the 4-inch insulation section as shown below. In addition to the flexure tests with an applied axial load, test specimens were prepared and tested in a double shear test apparatus to test shear slip between the concrete wythes. A photo from the Report of the Innstruct TIPS panel double shear test is shown below.



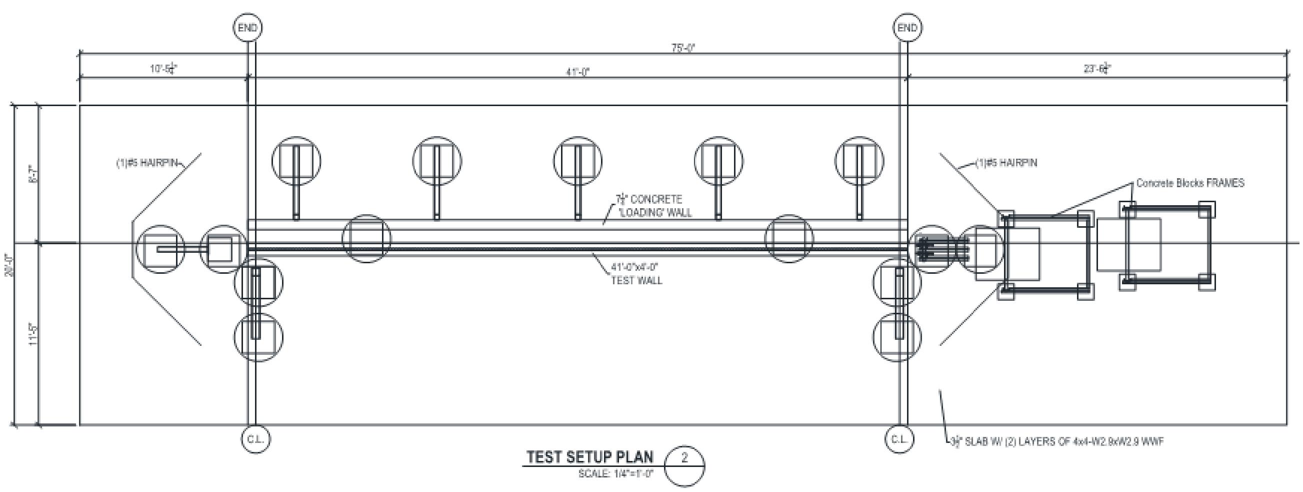
Report Figure 2-6, page 14.

Report Figure 4-2, page 96.

The double shear test provided axial load compared to the slip between concrete wythes on the test specimens. Double shear specimens for the Innstruct TIPS panels were fabricated with a 2.5-inch outer layer, 4-inch insulation, 5-inch central concrete wythe, 4-inch insulation, and 2.5-inch outer concrete wythe on the other side. Double shear tests were completed by applying load to the center wythe with the two outside wythes resisting the applied force. Results of this testing will be discussed later in the summary.

Flexural tests were conducted to simulate an in-situ condition for a tilt-up wall; however, the testing was completed with the panel oriented sideways instead of vertically. Terminology in the report, matches that of an in-place wall. During the test, an axial load was applied to one end, the “top”, the other end was the reaction or bearing end “bottom” of the panel. Out of plane load was applied through inflatable bags between the test panel and a reinforced concrete reaction wall.

Solid concrete control panel specimens were 8-inches thick, 41-feet long and 4-feet wide. The test length between reaction points for all specimens was 40-feet. Group A, the Innstruct TIPS specimens, were cast at 9-inches thick by 41-feet long, and 4-feet wide. The full Report can be referenced for additional details on the panel design criteria and apparatus setup for the testing.



Plan view of large-scale flexural test apparatus, Report Figure 3-24, page72.

Instrumentation monitored throughout the test process through a data collection system included the following components with data collectors providing near continuous records:

- Load applied to the panel through the air bags
- Applied axial load
- Reaction force
- Deflection measurement at several locations along the panel
- Inside/outside wythe slip at several locations along the panel
- Internal and external stresses were measured by strain gages cast integrally with the panels and placed on the exterior face
- Crack mapping and numbering throughout the test

Experimental Results Summary

Results from the double shear tests and large-scale panel flexural test are summarized in this section.

Double Shear Test Results

Six double shear tests were completed for the Group A, Innstruct TIPS, panels. The test applied a shear force to the connectors by loading the center wythe. Results for the Innstruct TIPS connectors are presented as pounds of shear force per square foot of panel face due to the close spacing or near continuous configuration of the diagonal truss wires, which comprise the connector system. Double shear test results for other connector systems are noted as pounds per connector in the Report.

Double shear test results and commentary about the test for the Innstruct TIPS system are presented below.

> *"For group A connectors, the load was reported per square foot due to the continuous nature of the connector. Connector A showed very ductile behavior during the test and obtained an average peak load of 2.82 kip with a standard deviation of 0.18 kip and maintained approximately 75% of its maximum load after failure, resulting in large displacements as shown in Figure 4-3a."* Report page 94-95.

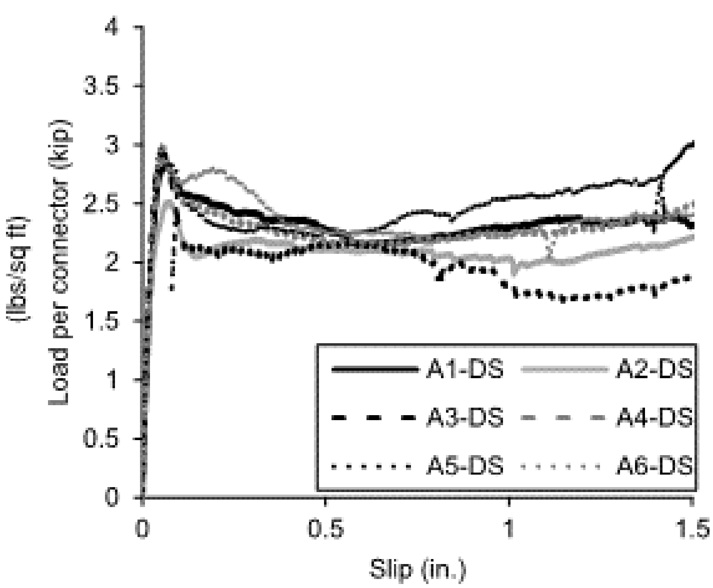


Figure 4-3a Load vs slip for double shear test (Connector A), Report page 97.

Data showing additional test results for the individual double shear tests are included in the Report. Consistency of the samples is noted in the low standard deviation and by observing the load/slip graph results. The average stiffness (K) at 0.50 Fu = 101.86 kips (Report Table 4-3, page 98).

Large-Scale Flexural Test Results

The following table shows the concrete material properties for the solid panels and the Group A, Innstruct TIPS panels. It is noted in the table that the Group A concrete has a substantially lower concrete compressive strength than the solid panel specimens. Concrete cylinders cast at the time the panels were poured were broken on the same day that the large-scale testing was completed. Therefore, the concrete properties noted herein should be representative of the tested panels. For comparison of the moment-deflection properties, the solid panel moment-deflection graph is included in the summary.

Table 4-1: Concrete material properties for all panels.

Panel ID	Truck	Concrete Strength (f'c) (psi)	Modulus of Elasticity (Ec) (psi)	Modulus of Rupture (fr) (psi)	(fr) ACI Eq. $7.5\sqrt{f'_c}$ (psi)
Solid Panel 4-6	1	5945	5,117,700	620	578
	2	5646	5,032,000	575	564
All A	1	3790	4,202,400	424	462

Table 4-1 (partial) Report Page 93.

The moments shown in the following moment-deflection curves for both the solid and Group A, Innstruct TIPS, panels reflect the total moment. Total moment includes the lateral moment from the out-of-plane load plus the P-δ moment. In the figure below the Response 2000 curves indicate the theoretical calculated upper and lower bound moment-deflection results for zero tension stiffening and full tension stiffening computer generated results.

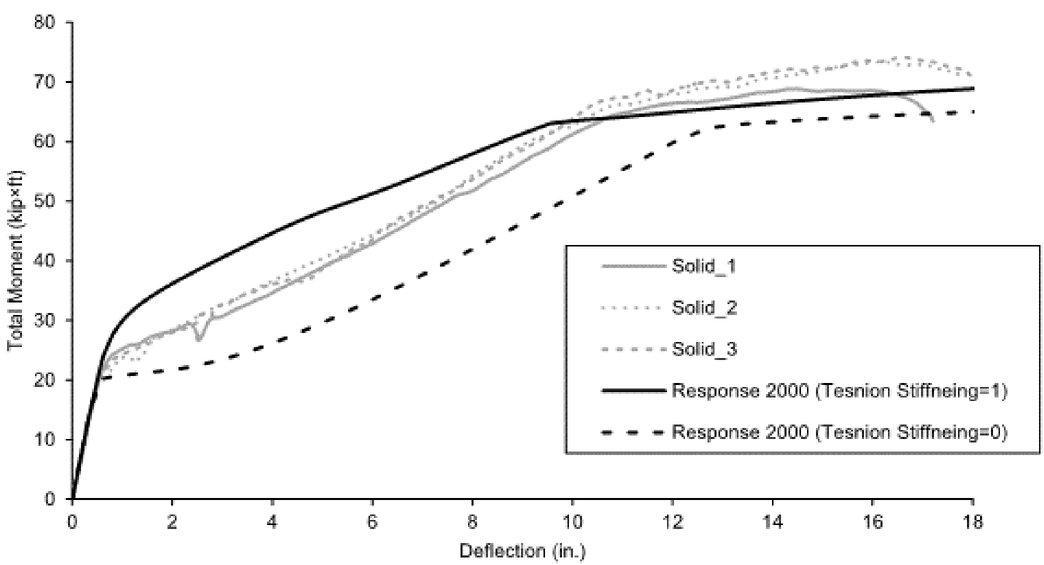


Figure 4-12: Total moment versus deflection for all solid panels, including Response 2000 with different tension stiffening rules.

Report page 106.

The following figure presents the moment-deflection curve for the three Group A, Innstruct TIPS, specimens. The FC and NC curves represent the theoretical (Response 2000) fully composite and non-composite responses, respectively. As is noted the actual tests performed very near or above the calculated fully composite response. Additionally, the tested response curves for Innstruct TIPS exhibit a bi-linear shape very much like the solid test panels; the Report addresses this as follows:

> *"Typically, when a CIP failed in flexure, the moment versus deflection curve was shaped like a trilinear curve when compared to solid panels that exhibited a bilinear curve.* ***The exception to this was the group A panels, which behaved very similar to the solid bilinear curve."*** Report page 109.

> *"It is not clear why the group A panels did not have a trilinear curve like the other CIPs. However, this is likely due to the very strong bond between the concrete and EPS insulation and the apparent solid sections at the lifting locations. The group A panels were intended to have drop zones (insulation reduced but not completely through the insulation) to accommodate the lifting device as shown in (Figure 4-16 and Figure 4-17) These drop sections were made on-site by burning through the foam. As a result, some foam was reduced through the entire thickness, resulting in solid zones. In practice, Group A panels are typically designed with solid zones at lifting locations and at the perimeter of the panel, which is part of standard construction, so this behavior is likely expected in the field."* Report page 112.

The Report indicates that the ultimate moment including P- δ for the design load was 33.2 kip-ft and the service level moment was 10 kip-ft for the Group A panels (Report page 107). The reinforcement ratio and concrete properties of the Group A, Innstruct TIPS, panels are different from the solid concrete panels, therefore, a direct comparison of moment-deflection capacity cannot be made, nor inferred.

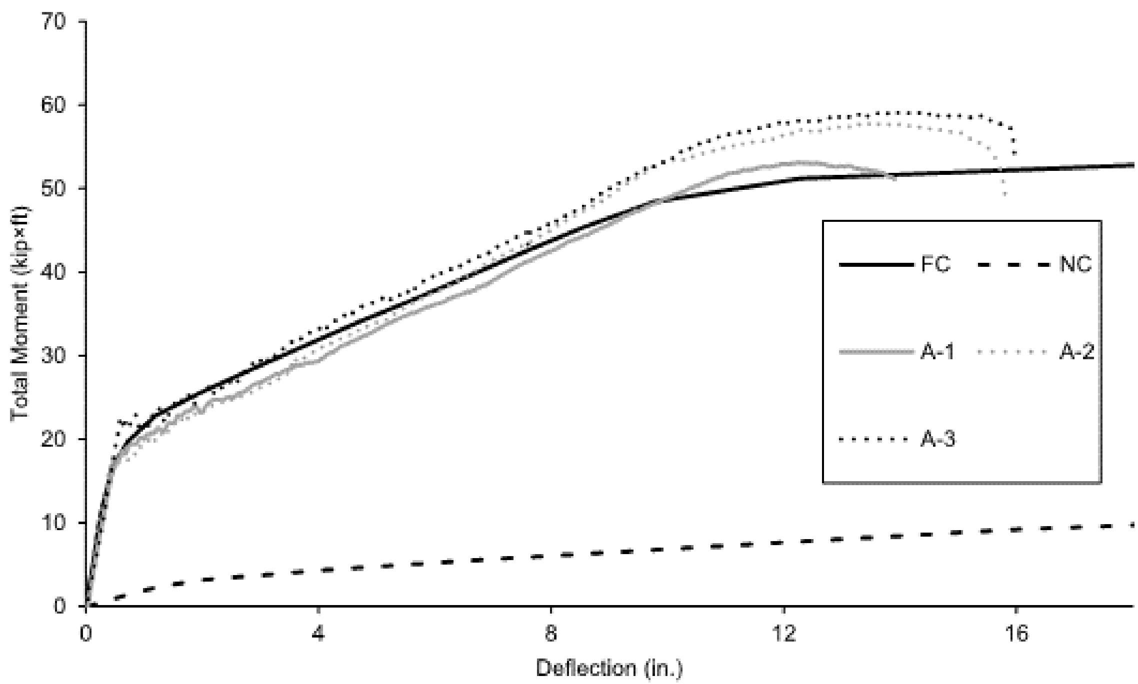


Figure 4-21: Total moment versus deflection for group A panels.

Report page 117.

The Report includes data for each respective test panel detailing the lateral moment, slip along the panel (between wythes), deflection, cracking conditions, and P- δ moments at the cracking load and at maximum load conditions. A summary table showing the cracking moment and subsequent deflection, and maximum moment and deflection is shown below.

Table 4-5: Summary of cracking and ultimate loads for CIPs.

Group		Cracking Moment kip * ft	Cracking Deflection in.	Maximum Moment kip * ft	Deflection at Maximum Moment in.	Age at Tested day
A	1	17.31	0.49	53.01	12.23	58
	2	18.61	0.50	57.77	13.48	59
	3	23.32	0.73	59.21	14.09	59
	Average	**19.75**	**0.57**	**56.66**	**13.27**	

Report page 108.

End slip is one of the important parameters measured during the large-scale flexural test of CIPs. A larger end-slip between the concrete wythes indicates a lower degree of composite behavior since the connector deflection or yielding allows the wythes to slip. Conversely, a very small end slip condition indicates a higher degree of composite behavior. Table 4-3 of the report notes that the average slip of the six double-shear tests for the Innstruct TIPS was 0.06 inches at the ultimate load and 0.014 inches at 0.5Fu or 50% of the ultimate load with a resulting stiffness factor, $K_{0.5Fu}$ = 101.86 kip/in (Report page 98). Table 4-6 of the Report shows the end slip for the Group A panels during the large-scale flexural test with the average end slip at the cracking point equal to 0.0029 inches. The average end slip at maximum load was determined to be 0.0095 inches (Report page 111). Significantly, the flexural test end slip at the maximum load was approximately 1/6 of the slip measured at the ultimate load from the double-shear test, and below the slip at 0.5Fu as well indicating minimal yielding of the connectors.

Conclusion

The Report should be consulted for a detailed description of the overall Project, including background and literature review, theoretical approaches to design, and a more information on the experimental program and results. The Report also addresses the tri-linear response model in more detail as applicable to most CIPs and presents an alternate design method for consideration that more closely matches the tri-linear response curve. However, that analysis method is not described herein since it was clearly observed and noted that the Group A, Innstruct TIPS matched the bi-linear response exhibited by the solid test panels.

The conclusion being that the Innstruct TIPS panels can be accurately designed using the Slender Wall Design Method as outlined in ACI 318, and ACI 551 for tilt-up panels within the provisions of UES Report 0593. Concrete edging around the panel perimeter and around openings in the wall panel should be provided, and additional manufacturer recommendations remain applicable.

Respectfully,

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