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Effect of Connection Details on the Cyclic Behavior of Nestable Screw Sidelaps

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Effect of connection details on the cyclic behavior of nestable screw sidelaps

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Abstract

The connection strength and stiffness sensitivity of screwed sidelaps in nestable steel decks to screw installation details has been experimentally explored via cyclic testing. The cyclic behavior of sidelaps has been recently incorporated in the high fidelity modeling and seismic evaluation of the steel deck diaphragm in rigid wall - flexible diaphragm buildings, where "unzipping" a sidelap (loss of a significant number of sidelap connections along a deck edge) could significantly reduce the seismic performance of the whole diaphragm. A total of 24 monotonic and cyclic sidelap tests have been performed in the Thin-Walled Structures Laboratory at Johns Hopkins University. Two different screw edge distances, three different deck thicknesses (i.e. 18 gauge 20 gauge, and 22 gauge), and two different screw sizes were included in the test matrix. The screws were installed either "close to the edge" or "far from the edge". For the "close to the edge" condition the typical 1.5d edge distance limitation in the design specification was not satisfied. Both monotonic and cyclic test results show that the strength of the sidelap connection can be correlated to edge distance and screw installation details. A maximum 25% and 19% difference in the ultimate strength of the screw sidelaps were observed in monotonic and cyclic tests, respectively. The rest results were compared to sidelap strengths in the literature, and potential changes to sidelap strength predictions and installation methods are discussed.

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Introduction

The main objective of this paper is to study the effect of the screw installation location on the performance of nestable screw sidelaps for steel decks. This study is motivated by the observation of relatively high variation in the behavior of nestable screw sidelaps throughout a former testing program on a wide variety of sidelap and frame connections (Torabian et. al 2018). The current and the former experimental program are directed at improving knowledge of the performance of steel deck diaphragms, particularly in seismic applications such as in rigid wall – flexible diaphragm buildings where diaphragm inelasticity plays a prominent role in structural response.

It has been hypothesized that the location of screw installation in a nestable steel deck sidelap can notably influence connection strength and stiffness. A screw in a nestable sidelap can be installed in a variety of valid configurations, largely according to the practice of the installer. As shown in Fig. 1a, the screw can be in the flat part of the deck lip, or close to the corner and web of the deck (Fig. 1b), or even at the middle of the curved corner, as shown in Fig. 1c. By installing the screw closer to the corner, the strength of the deck is increasing due to the cold-forming effects and also the out of plane stiffness of the deck will increase due to the curved geometry of the deck. Both of these parameters can potentially increase the strength of a screw connection and could result in an increase in the capacity of a nestable sidelap connection.

To study the effect of the screw installation details, the Cold-Formed Steel Research Consortium (CFSRC) has funded and performed a total of 24 sidelap connection tests in the Thin-Walled Structures Laboratory at Johns Hopkins University. Two installation configurations: Fig. 1a and Fig.1b, have been examined and the configuration in Fig. 1c is currently undergoing testing.

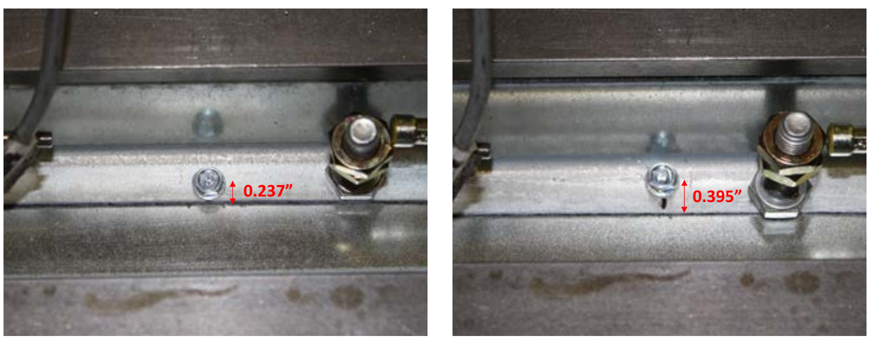
Test Matrix of the Nestable Screw Sidelap connection

The screw sidelap conditions in the testing program are summarized in Table 1 and shown in Fig. 2. For each condition, three specimens have been tested cyclically and one monotonically. Three different deck thicknesses (i.e. 18 gauge 20 gauge, and 22 gauge), and two different screw sizes (#10 for 22 gauge and #12 for 20 and 18 gauge decks) are included in the test matrix. Two different screw edge distances, 1/4 in. and 3/8 in., are also included. The screws are installed close to the edge (1/4 in. as shown in Fig. 1a) and far from the edge (3/8 in. as shown in Fig. 1b), where the typical 1.5d edge distance limitation in the design specification was not satisfied for the screws installed close to the edge (i.e. 1/4 in. edge distance). The edge distance of 1/4 in. is approximately 1.3d for the #10 screw and 1.2d for the #12 screw and the edge distance of 3/8 in. is 2d for the #10 screw and 1.8d for the #12 screw.

Table 1: Sidelap connection test matrix

Specimen*	Thickness (gauge)	Screw	Nominal screw edge distance (in)	Loading
S22-10-1/4”	22	#10-16-¾"	0.25	3 Cyclic -C1~3 1 Mono. -M1
S20-12-1/4”	20	#12-14-1"	0.25	
S18-12-1/4”	18	#12-14-1"	0.25	
S22-10-3/8”	22	#10-16-¾"	0.375	3 Cyclic -C1~3 1 Mono. -M1
S20-12-3/8”	20	#12-14-1"	0.375	
S18-12-3/8”	18	#12-14-1"	0.375	

* All decks are 1.5 in WR



S20-12-1/4”-C1   S20-12-3/8”-C1

Fig. 2. Measured screw edge distances for two of the test specimens in two edge screw configurations

Test Setup and Instrumentation

The test setup is motivated from the lap-joint shear setup in AISI S905-13, recent commercial testing, and a companion testing program (Torabian et. al 2018). As shown in Fig. 3, the test setup consisted of a moving part on a longitudinal linear motion system and connected to a dynamic actuator, and a stationary part connected to the support beam.

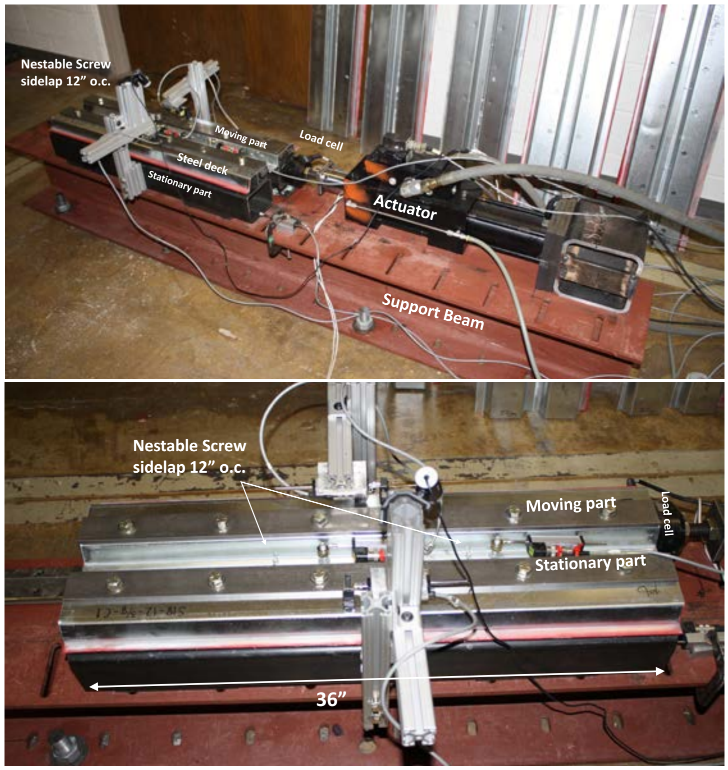


Fig. 3. Sidelap testing rig and at the Thin-Walled Structures Laboratory - Johns Hopkins University

A load cell installed between the actuator and the moving part of the rig records the force response of the specimens and the position transducers (PTs) record the rig displacements. The internal LVDT of the actuator provides the overall actuator displacements. Seven other PTs are installed to measure relative displacement at different points on the testing rig, as shown in Fig. 4. Note: PT1 and PT7 are selected to be short position transducers (length = 1 in.) to increase the accuracy of the displacement measurements. The results are combined to provide a full history of displacement records for the moving part.

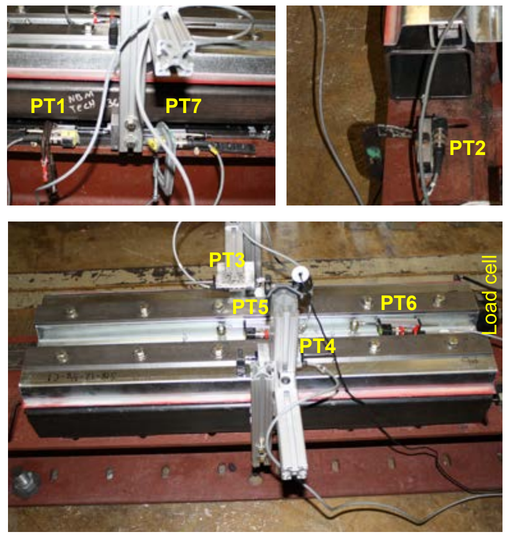


Fig. 4. Position Transducers (PTs)

Loading protocol

The FEMA 461 cyclic loading protocol has been adopted here. Notably, recent and extensive CFS-based cyclic fastener tests (Tao et al. 2016) and recent extensive experimental program on the sidelap and framing connections; (Torabian et al. 2018) also employed the FEMA 461 protocol. The loading rate in the testing program is assumed to be 0.01 in./sec throughout all cycles. However, the loading rate has been decreased to 0.0033 in./sec in the initial cycles (first 3 steps in the loading) to increase the displacement resolution for the small displacement amplitudes at the beginning of the testing.

Test Observations

The failure mode of all screw sidelaps was screw tilting and bearing as shown in Fig. 5. However, the plate deformation around the screw was different for the two different screw edge distances. As shown in Figs. 5a and 5b, when the edge distance is about 1/4 in., more edge deformation and plate out-of-plane deformation were observed throughout the tests.

It should be noted that in large cyclic displacements, the screw started to back out of the hole to accommodate the large tilting angle and the back out was irreversible and ultimately ended up in a complete removal of the screw.

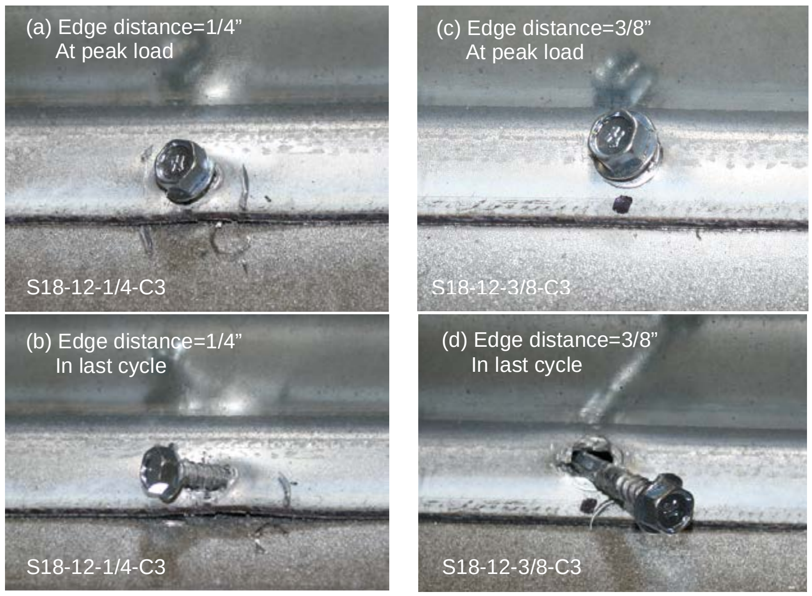


Fig. 5. Screw and deck deformations at the peak load and in the last cycle for 18 gauge deck sidelap with #12 screw

In the following figures (Figure 6-11), the cyclic response of all specimens is provided. Comparing the results of the same gauge steel deck can show the effect of the screw edge distance on the behavior of the screw sidelap. As shown in the figures, the larger edge distance can typically provide higher strength and slightly higher ductility for the nestable screw sidelap.

Table 2 summarizes the mean peak strength and stiffness of the cyclic tests in the 1st (positive) and 3rd (negative) quadrants. The strength degradation from reducing the edge distance is clear from the results, but the effect on the stiffness is not well correlated with the edge distance and the stiffness variations are quite high in the cyclic response.

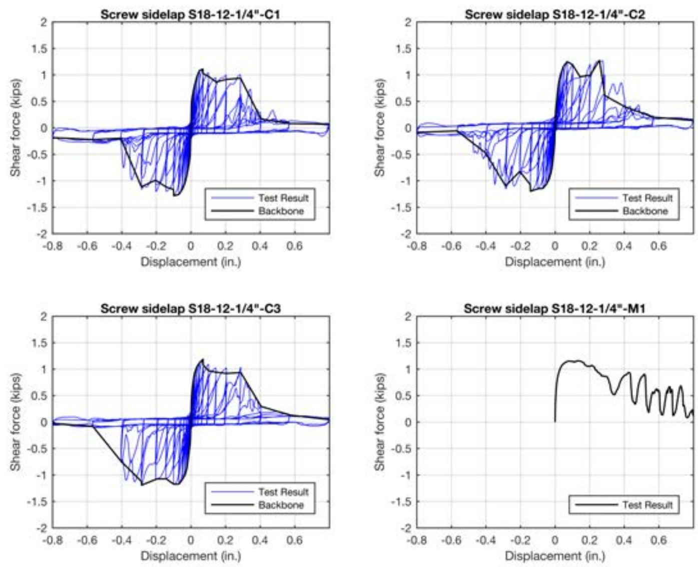


Fig. 6. Screw sidelap 18 gauge deck, edge distance=1/4 in.

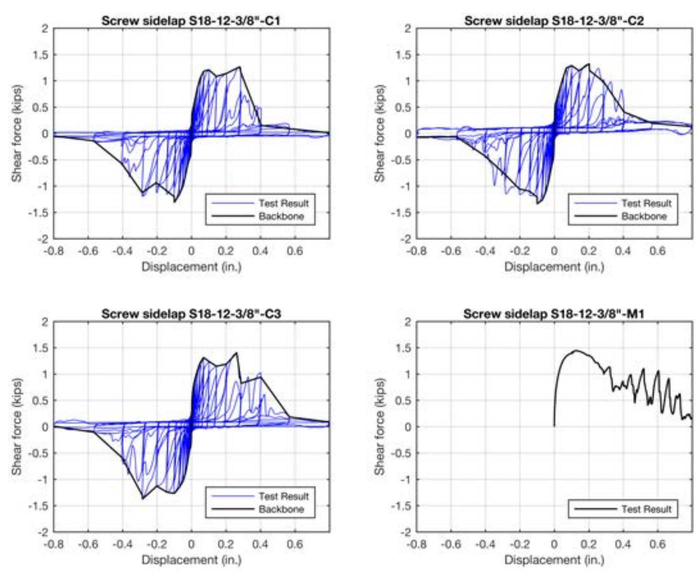


Fig. 7. Screw sidelap 18 gauge deck, edge distance=3/8 in.

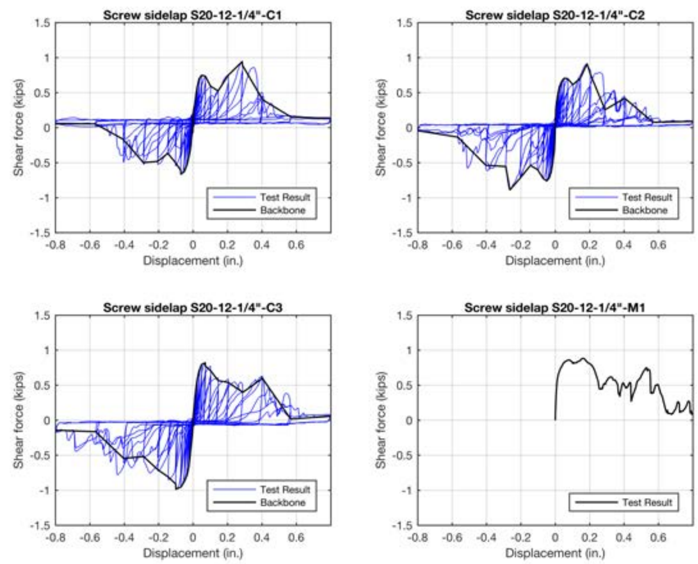


Fig. 8. Screw sidelap 20 gauge deck, edge distance=1/4 in.

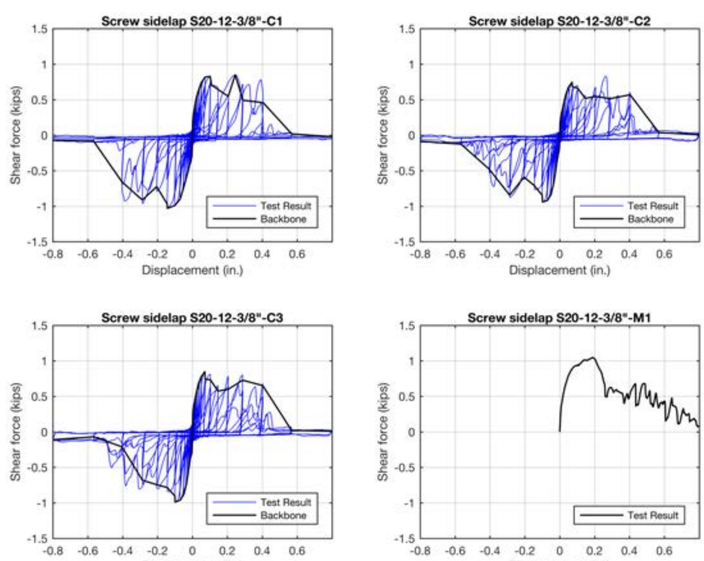


Fig. 9. Screw sidelap 18 gauge deck, edge distance=3/8 in.

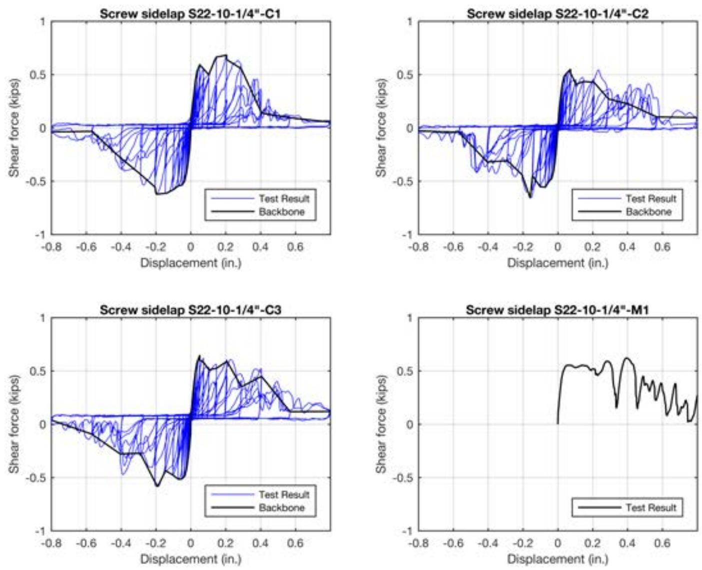


Fig. 10. Screw sidelap 22 gauge deck, edge distance=1/4 in.

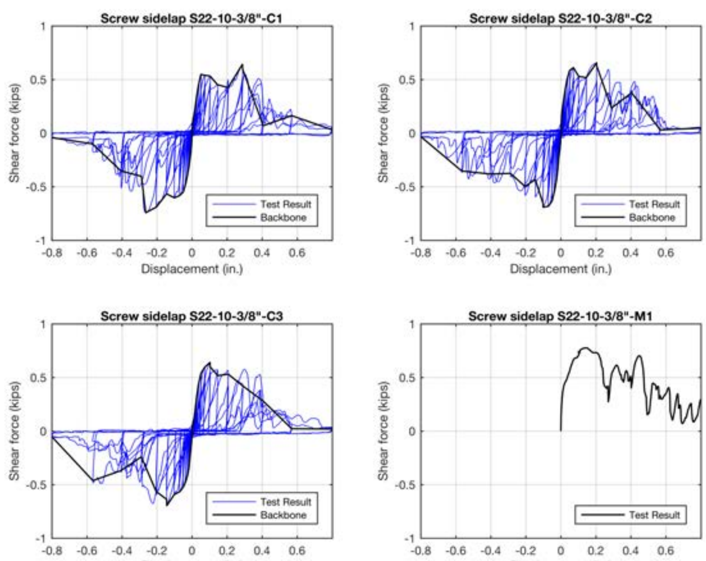


Fig. 11. Screw sidelap 22 gauge deck, edge distance=3/8 in.

Table 2. Mean peak strength and stiffness of the cyclic test results

Specimen	Data	Peak Strength		Stiffness (@ 0.4 P_{max})	
		Positive	Negative	Positive	Negative
		lb	lb	kip/in	kip/in
S18-10-1/4"	Mean	1180	-1220	100.3	82.7
	c.o.v	6%	5%	40%	41%
S18-10-3/8"	Mean	1280	-1304	102.7	41.3
	c.o.v	5%	3%	53%	32%
S20-10-1/4"	Mean	826	-804	37.5	37.5
	c.o.v	10%	20%	22%	52%
S20-10-3/8"	Mean	808	-986	45.3	26.8
	c.o.v	7%	5%	33%	11%
S22-10-1/4"	Mean	624	-621	21.7	23.6
	c.o.v	11%	6%	13%	9%
S22-10-3/8"	Mean	612	-690	16.2	20.0
	c.o.v	9%	1%	38%	3%

Cyclic back-bone and comparison to AISI-S310-16

The backbone of the cyclic tests has been compared in Fig. 12. The "Average" results are the mean of 3 cyclic tests, and "Minimum" results are the minimum of the averaged results in the 1st and 3rd quadrants. The "4-point" backbone curve is a 4-point curve fit to the minimum data by equilibrating the area under the curve for the test and model (energy balance). The peak strength and stiffness of the 4-point curve are shown on the plots in Fig. 12 and summarized in Table 3 along with the monotonic test results and AISI-S310-16 strength and stiffness predictions.

The strength of the sidelap connection in cyclic tests are always lower than the monotonic test results, due to cyclic strength degradation throughout the cyclic loading. The same conclusion on the stiffness is not always valid, due to high variation in the stiffness of the connection. Comparing the results of sidelap specimens with edge distances of 1/4 in. and 3/8 in. shows that the strength of the 3/8" in. edge distance specimens are higher than the 1/4 in. edge distance specimens, but again the same conclusion for the stiffness is not always valid.

Comparing the results of both 1/4 in. and 3/8 in. edge distance specimens to the AISI-S310-16 predictions reveals that the S310 prediction is closer to the results of the smaller 1/4 in. edge distance specimens and the predictions are conservative for monotonic loading and the 3/8 in. edge distance specimens. Although AISI-S310 does not include the deck strength in the screw sidelap equations, it is worth mentioning that the average yield strength of the decks are about 54 ksi for the tested specimens.

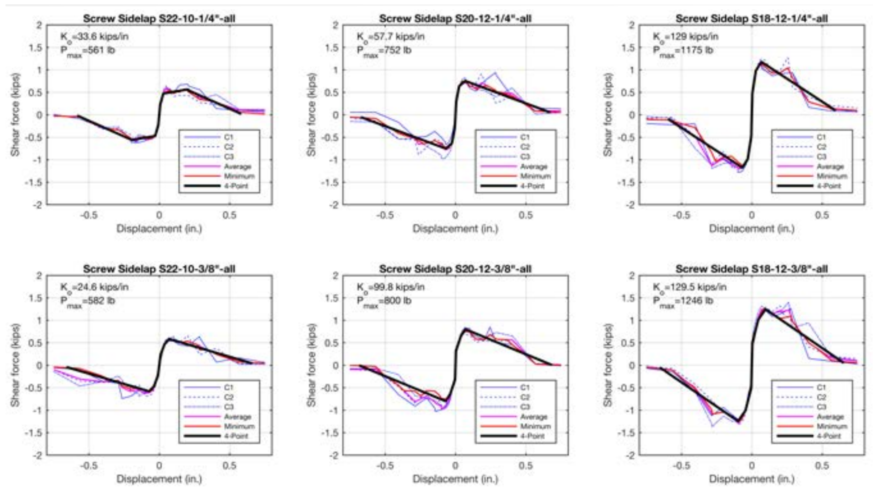


Fig. 12. Average backbone curves of the cyclic tests

Table 2. Mean peak strength and stiffness of the averaged cyclic test results and comparison to the AISI-S310-16 screw sidelap

	Loading	Peak Strength	Stiffness*
		lb	kip/in
S18-10-1/4"	Cyclic	1175	129.5
S18-10-1/4"	Monotonic	1155	124.4
S18-10-3/8"	Cyclic	1246	129.5
S18-10-3/8"	Monotonic	1443	90.5
AISI-S310-16	N/A	1151	72.4
S20-12-1/4"	Cyclic	752	57.7
S20-12-1/4"	Monotonic	882	68.1
S20-12-3/8"	Cyclic	800	99.8
S20-12-3/8"	Monotonic	1046	33.3
AISI-S310-16	N/A	869	62.9
S22-12-1/4"	Cyclic	561	33.6
S22-12-1/4"	Monotonic	621	26.2
S22-12-3/8"	Cyclic	582	16.2
S22-12-3/8"	Monotonic	775	41.3
AISI-S310-16	N/A	633	57

* Initial stiffness K_o of the cyclic tests is associated with secant stiffness @ 0.2Pmax

Summary and Conclusions

A total of 24 nestable screw sidelap specimens including three different steel deck gauges (18 ga., 20 ga., and 22 ga.), two different screw fastener sizes (#10 and #12), and two different screw edge distances have been tested in this study. In monotonic tests, placing fastener at 3/8 in. from the edge versus 1/4 in. could result in 20~25% increase in shear strength. In cyclic tests, placing fasteners at 3/8 in. from the edge versus 1/4 in. could result in a 7~19% increase in the strength. Effect of fastener edge distance on the sidelap stiffness does not have a clear pattern in the tests. The fastener secant stiffness includes high variability in the tests. The variability could be related to the mechanics of the fastener as well as the load level at which the secant stiffness is calculated. AISI-S310-16 strength predictions are found to be consistent with the 1/4 in. edge distance results in this testing program.

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