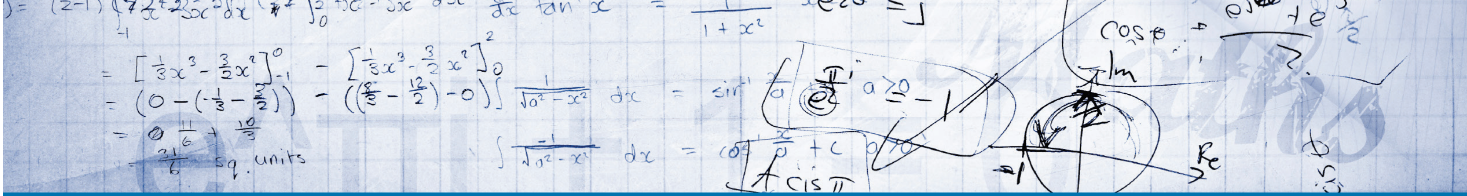
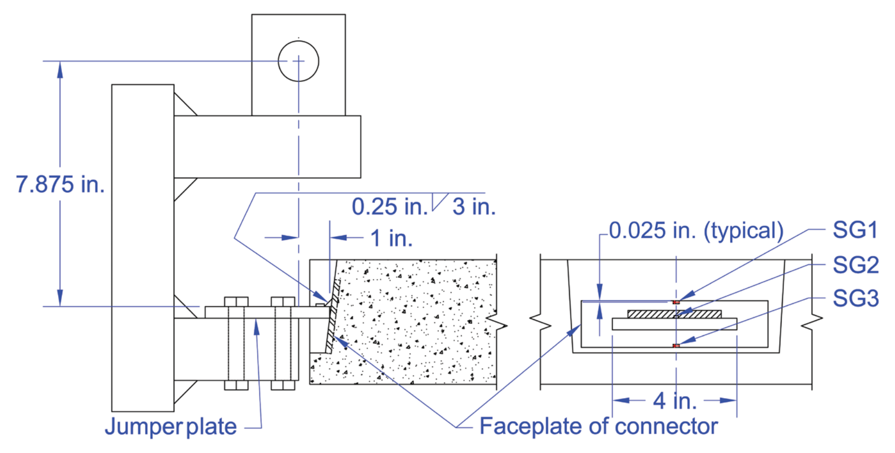


DISCUSSION

Flange-to-Flange Double-Tee Connections Subjected to Vehicular Loading, Part 1: Numerical Assessment Approach

The following comments relate to “Flange-to-Flange Double-Tee Connections Subjected to Vehicular Loading, Part 1: Numerical Assessment Approach,”[1] by R. Hendricks, C. Naito, and A. Osborn, which appeared in the July–August 2018 issue of *PCI Journal*.



Corrected Figure 3. Overall single connector test setup details. Note: 1 in. = 25.4 mm.

Figure 3 seems to contain a drafting error. The arrows associated with the distance 0.49 in. (12 mm) touch rather than being separated by 0.49 in.

There are several aspects of the behavior that deserved comment in addition to simply presenting the data in tables and graphs. In **Fig. 4**, it is perfectly logical for the stiffness under downward loading

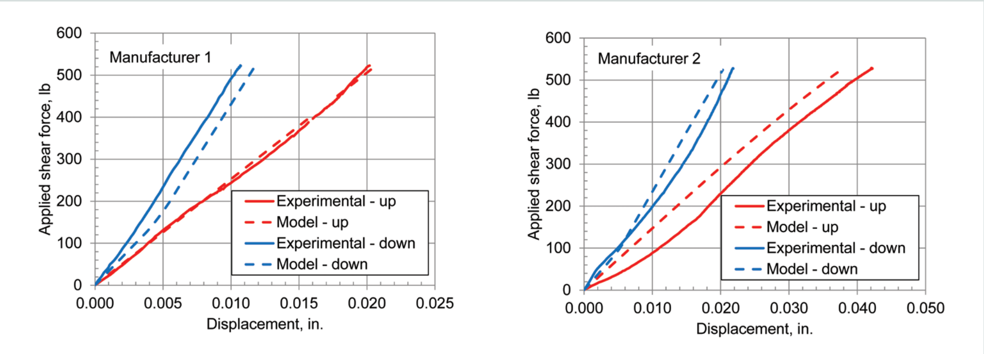


Figure 4. Comparison of numerical model with measured results for single-sided loading. Note: 1 in. = 25.4 mm; 1 lb = 4.448 N.

to be significantly higher than in upward loading. Under upward loading, the entire moment is resisted by bending of the weld metal. Under downward loading the weld metal obviously contributes in bending, but there is also another source of resistance. There is a couple consisting of a tension force in the weld metal and a compression force where the jumper plate contacts the faceplate of the connector, and this couple must add something to the stiffness.

I have other questions concerning Fig. 4. Were these for carbon steel or stainless steel? Were the base metal, jumper plate, and weld materials always the same, that is, either all carbon steel or all stainless steel? Were the yield stresses of the jumper plate materials determined? If they were quite different, it might explain some of the differences between the test results.

For the upward loading case, especially, the penetration of the weld metal into the jumper plate must be important. The fully plastic moment capacity of the weld should depend on the effective throat thickness squared, and the elastic stiffness should depend on the effective throat thickness cubed. **Figure 11** shows a couple of the weld penetrations measured. **Figure A12** is concerned with this aspect of the welds. Were most of the weld penetrations measured or only these few? Variation in weld penetration might explain some of the variations in failure forces shown in **Table 1**.

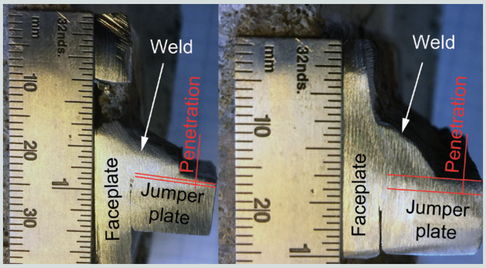


Figure 11. Weld penetration between jumper plate and faceplate.

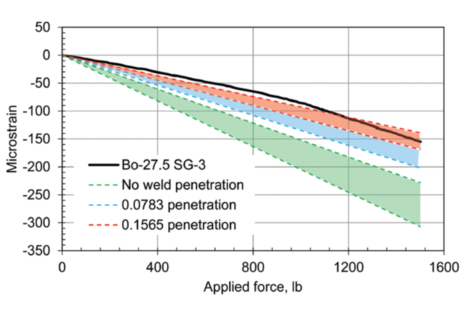


Figure A12. SG3 with comparison of modeled strains for varying levels of weld penetration. Note: 1 lb = 4.448 N.

Table 1. Summary of results

Connector	Direction	Estimated compressive strength, psi	Applied load at deformation of 0.010 in., lb	Maximum strength, lb	Deformation at maximum strength, in.
M1 carbon	Upward	5970	199	4418	0.119
	Downward	5980	398	7513	0.092
M2 carbon	Upward	6550	1040	6270	1.225
	Downward	5900	195	6573	0.123
M3 carbon	Upward	5900	294	7191	0.285
	Downward	5910	365	6828	0.118
M1 stainless	Upward	5900	287	5084	0.121
	Downward	5940	143	6681	0.148
M2 stainless	Upward	5800	259	8186	1.166
	Downward	5960	110	9174	0.564
M3 stainless	Upward	5950	773	8241	0.274
	Downward	5950	597	7674	0.138

Note: 1 in. = 25.4 mm; 1 lb = 4.448 N; 1 psi = 6.895 kPa.

The force variations in Table 1 seem to be so large that quite a few tests should be done to obtain information on averages and scatter. Both M3 upward tests achieved greater forces than the downward tests, and this deserved some comment, if not an explanation. Single tests tell something, but not enough. Yes, I know that they are expensive.

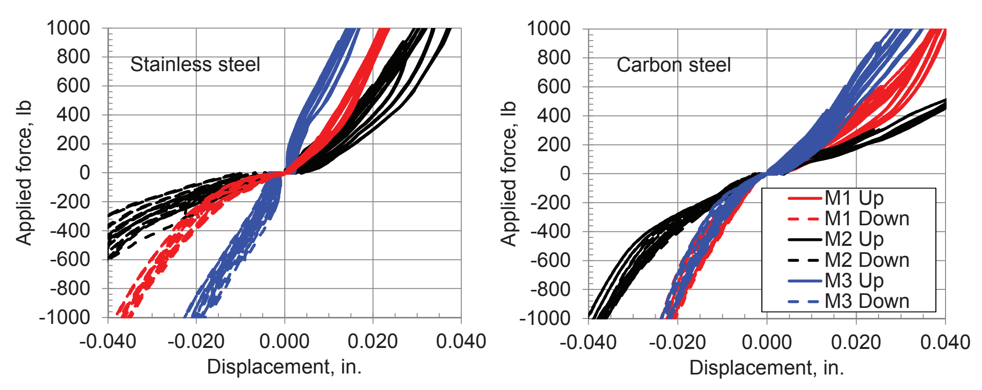


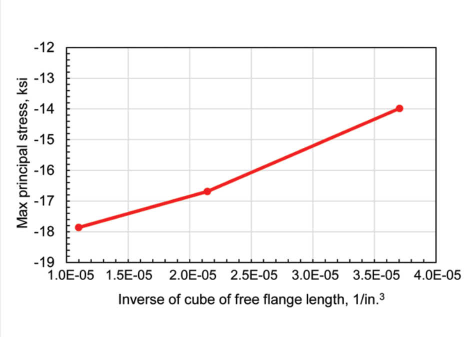
Figure A5. Vertical response of connectors: elastic range. Note: 1 in. = 25.4 mm; 1 lb = 4.448 N.

Figure A5 introduces several questions or puzzles. For the stainless steel cases, the upward deflections are smaller than downward deflections, often substantially so. Some comment was clearly needed because this behavior is quite the opposite that shown in Fig. 4. Was the scale of the graph inverted, or is the geometry of the stainless steel cases substantially different from that of the companion carbon steel cases?

A second puzzle from Fig. A5 is that the upward deflections for the carbon steel cases are significantly higher than for the stainless steel cases. This is in spite of the fact that the elastic modulus of typical stainless steel is about 10% lower than of carbon steel.

A third puzzle about Fig. A5 is that the M3 cases were significantly stiffer than the other two, especially for the stainless steel case. Figure 4 or something similar should have included the same data for M3 that was given for the other two cases.

The horizontal scale on **Fig. A13** is not correct. Three values are repeated. Should the second 2.0 be 2.5, for instance? In addition to the stiffness of the flange going down in proportion to the length cubed, the stiffness goes up in proportion to the thickness cubed. A 4 in. (102 mm) flange is 49% stiffer than a 3.5 in. (89 mm) flange on the basis of the uncracked section properties. The cracked section stiffness is more complex, but the difference should be similar.



Corrected Figure A13. Effect of free flange length on connection stress. Note: 1 in. = 25.4 mm; 1 ksi = 6.895 MPa.

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References

1. Hendricks, R., C. Naito, and A. Osborn. 2018. "Flange-to-Flange Double-Tee Connections Subjected to Vehicular Loading, Part 1: Numerical Assessment Approach." *PCI Journal* 63 (4): 41–53..

Authors' response

The authors appreciate that Dr. Gamble was able to provide an in-depth review of the paper.[1] The authors have addressed his comments and questions in the order in which they were written.

Figure 3 does indeed contain an error. The drawing was scaled, and the dimensions of the strain gauges were automatically dimensioned by the CAD program. The distance should be 0.025 in. (0.635 mm).

In Fig. 4, as noted, the couple consisting of a tension force in the weld metal and a compression force where the jumper plate contacts the faceplate of the connector adds to the stiffness. As a vehicle axle passes from one double tee to the next, each side of the connection is subjected to different stress demands. With the axle on the first double tee, the near weld will be subjected to positive bending resulting in prying at the root. The far weld would be subjected to negative bending, which would be resisted by the force couple as noted. In the experiments shown in Fig. 4, these tests were conducted independently with one case loading up and the other case down. As noted by Gamble, the downward loading would thus result in a greater stiffness, as observed. This is an important point to make and is discussed in more depth in part 2[2] of this paper and in the referenced papers. Keep in mind that the goal of the tests conducted and illustrated in Fig. 4 was to provide experimental data that could be used to calibrate numerical models of the connection and was not intended to fully model the complete connection. A complete connection is also subjected to axial constraint across the jumper plate as the flange is deformed. The constraint influences the weld stress and is dependent on the restraint provided by the remaining diaphragm. This issue is investigated in more depth in the full-scale testing presented in **Fig. 8** and **9** and in the referenced papers.

Figure 4 presents the carbon steel tests. Tests were conducted for both the stainless steel and carbon steel connections. The stainless steel connections were fabricated with ASTM A304 stainless steel jumper plates and ASTM E308 welding electrodes. The carbon connections were fabricated with ASTM A36 carbon steel jumper plates and ASTM E7018 welding electrodes. The focus of the experiments was the elastic response. Consequently, the yield strengths of the materials were not determined. Details on the connector tests can be found in "Precast/Prestressed Concrete Institute Fatigue Study: Experimental Evaluation of Double Tee Flange Connectors Subject to Out-Of-Plane Loading."[3]

Regarding weld penetration, the elastic response of the single connections with jumper plate and weld are indeed sensitive to the section modulus of the weld. The issue of concern for these connections, however, is that the stiffness of the completed connection is very complex. It is not as simple as a weld being pried open. Instead, the flexibility of the faceplate that the weld is attached to is a factor.

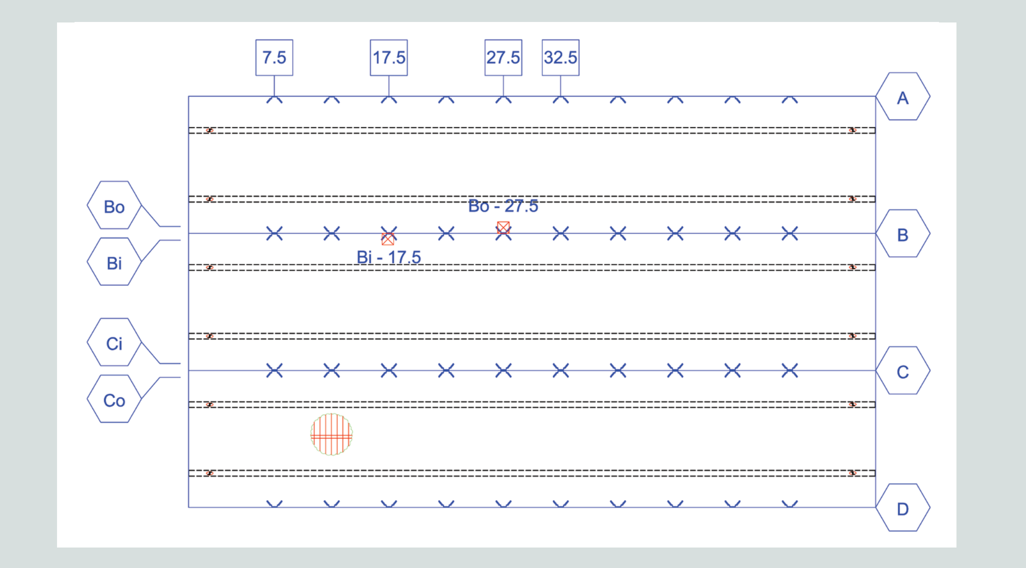

Figure 8. Full-scale double-tee setup. Note: All measurements are in feet. 1 ft = 0.305 m.

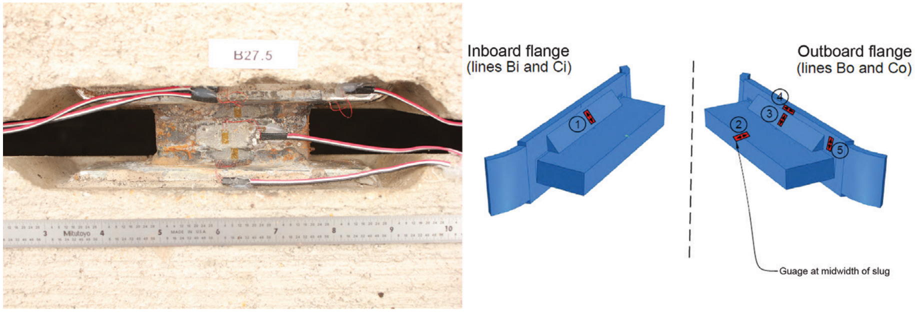

Figure 9. Photograph of connector B27.5 and schematic of strain gauge locations.

If the faceplate is very stiff, then it only minimally affects the stress in the weld. For most of the connections in common use, the faceplate is relatively thin and flexible; this results in a variation in stress distribution along the weld due to torsion and flexure of the faceplate. In addition, the jumper plate will tend to bear on both faceplates because it is subject to large vertical shears from vehicle loads. This results in axial transfer across the jumper plate that also affects the stress distribution in the weld. Consequently, the only viable method of accurately determining the stress in the weld is through numerical modeling.

With regard to the question on weld penetration, the samples shown in Fig. 11 were from the full-scale test. Weld penetration in the laboratory tests was not measured; however, similar levels are likely. The failure mode for laboratory tests was due to concrete breakout and not weld failure. Thus, the variability in the ultimate strength is likely associated with the concrete properties as opposed to the weld.

The authors agree that the variability in the maximum strengths in Table 1 was large. The goal of the testing was to model the elastic response, which had less variation. The maximum strengths are provided to give a sense of the capacity of the individual connectors and should not be used to assess their design capacity. Capacities in horizontal and vertical shear are also available from the manufacturers. The strengths of the connectors were controlled by concrete breakout in all cases. The variability is associated with the concrete material properties (in other words, concrete strength and aggregate distribution) and the presence of reinforcement crossing the failure plane.

Gamble makes a good point about the stainless steel cases versus the carbon steel cases in Fig. A5 and 4. One would expect that loading downward would provide greater stiffness given that the jumper plate and the weld act as a force couple, while loading upward, only the weld provides flexural resistance. The likely cause of the apparent variation is the weld placement. Standard welding recommendations were followed for all connectors. The typical weld is a ¼ in. (6 mm) fillet located above the centerline of the faceplate. (The top of the jumper plate was aligned with the center of the faceplate.) As previously mentioned, the faceplate of the connectors is thin and very flexible. Consequently, when loading upward there is more torsional resistance provided by the supporting faceplate, resulting in some cases having greater stiffness loading upward than downward. The secondary point that is made by Gamble on the change in behavior from the carbon to the stainless steel connectors is indeed puzzling. The data was compared with photos, and the results are correctly presented. The reason for the upward direction to be stiffer for one material and less stiff for another material is not clear. The carbon tests are correct and were used for the modeling. The stainless results were provided for general information and may need to be examined in more detail through additional testing. One additional thought pertains to the way we measured the displacements during the test. We only measured displacement on one side of the connection. If the connection were to rotate slightly as it deflected, the measured deflection would be off. This could have been solved by measuring vertical displacements on both sides of the connection, but unfortunately that was not done.

The variation in upward deflections for the carbon steel and stainless steel cases in Fig. A5 can again be associated with the complexity of the response. In addition, there were slight variations in the welding profile. While ideal conditions were attempted, the weld was manually installed using the shielded metal arc welding process. It is likely that this resulted in marginal variation from test to test.

Further, stainless steel has a greater coefficient of thermal expansion than mild steel. Cooling shrinkage of the welds, jumper plates, and faceplates could have created small gaps that led to an initial stiffness variation. We have no way to quantify any of these effects except though further testing.

Unfortunately, time and budget were only available to model two of the connectors in detail. As a result, M3 is not included in Fig. 4. As an aside, the comparison shown in Fig. 4 is from the second cycle for a given load step. This allowed for removal of any seating that may have occurred in the first cycle.

The horizontal scale on Fig. A13 is indeed the result of an error in the plot. The decimal values are missing. The horizontal axis should read 1.0E-05 to 4.0E-05 in increments of 0.5E-05. As mentioned, the response is complex. Note that for all connectors, the concrete section remains uncracked under vehicular loading and is essentially elastic up to a concentrated load of 3000 lb (13 kN) on one side of the joint.

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1. Hendricks, R., C. Naito, and A. Osborn. 2018. “Flange-to-Flange Double-Tee Connections Subjected to Vehicular Loading, Part 1: Numerical Assessment Approach.” *PCI Journal* 63 (4): 41–53.
2. Hendricks, R., C. Naito, and A. Osborn. Forthcoming. “Flange-to-Flange Double-Tee Connections Subjected to Vehicular Loading, Part 2: Fatigue Life Assessment.” *PCI Journal*.
3. Naito, C., and R. Hendricks. 2016. “Precast/Prestressed Concrete Institute Fatigue Study: Experimental Evaluation of Double Tee Flange Connectors Subject to Out-Of-Plane Loading.” ATLSS report 16-07, ATLSS Center, Lehigh University.

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