NISTIR 6829

Strength of an Interlocking FRP Connection

Dat Duthinh
Kunwar Bajpai

U.S. DEPARTMENT OF COMMERCE
Technology Administration
Building and Fire Research Laboratory
National Institute of Standards
and Technology
Gaithersburg, MD 20899

1901-2001
NIST CENTENNIAL

NIST
National Institute of Standards
and Technology
Technology Administration
U.S. Department of Commerce

NISTIR 6829

Strength of an Interlocking FRP Connection

Dat Duthinh
Kunwar Bajpai

U.S. DEPARTMENT OF COMMERCE
Technology Administration
Building and Fire Research Laboratory
National Institute of Standards
and Technology
Gaithersburg, MD 20899

November 2001

U.S. DEPARTMENT OF COMMERCE
Donald L. Evans, Secretary

TECHNOLOGY ADMINISTRATION
Phillip J. Bond, Under Secretary
of Commerce for Technology

NATIONAL INSTITUTE OF STANDARDS
AND TECHNOLOGY
Karen H. Brown, Acting Director

ABSTRACT

The strength of an interlocking fiber-reinforced polymer (FRP) connection was measured in bending, and in-plane and out-of-plane shear. This connection allows the rapid assembly of FRP panels into houses, and can be used in interlocking mode only, or interlocking and adhesively bonded mode. An additional mode was tested, where the connection was adhesively bonded only, without an interlocking toggle. The complete characterization of the behavior of the connection allows rational prediction of the performance of a building assembled with such panels.

Keywords: adhesive, bending, building technology, composite, connection, fiber-reinforced polymer, interlocking, joint, panel, shear strength.

DISCLAIMER

Contents

Strength of an
Interlocking FRP Connection

1. Introduction

FRP (fiber-reinforced polymer) structural members are increasingly used in civil engineering applications, such as in bridge decks and girders. One promising application is in residential housing, where FRP panels can be assembled quickly on site, without the need for additional framing. The speed of erection is particularly important for emergency and military shelters. Further advantages are the light weight of the material, the possibility of fabricating standardized panels and connections in the factory, thus potentially leading to lower cost and improved quality control. Furthermore, the shelter being designed according to engineering principles rather than tradition may lead to a greater resistance against natural disasters.

This work evaluates the strength of a particular type of interlocking joint used to assemble double-skinned panels (Fig. 1). The panels can be used in walls, floors and roofs of shelters and are assembled by driving a toggle into the jaws of the end cells (Head and Churchman, 1989). Foam can be injected into the cells formed by the panel skins and stiffeners for insulation. For permanent structures, adhesive bonding can also be used in addition to mechanical interlocking. If no adhesive is used, disassembly and reuse are possible.

Several interlocking composite joints are commercially available (Duthinh, 2000a). They all are proprietary designs, however, and their performance is not generally known to the engineering community. To facilitate the use of this promising technology, NIST is undertaking a series of tests to measure the performance of this type of joint and to make the results available in the public domain. It is our hope that more companies will participate in this program, which enables innovation to modernize and ensure the safety of construction, in conformance with the Advanced Construction Technology goals of the **NIST** Building and Fire Research Laboratory.

2. Panel Tests

A previous report (Duthinh, 2000b) investigated the performance of this connection under tension. The present work aims at fully characterizing the performance of the connection under flexure, in-plane shear, and out-of-plane shear. Knowledge of the connection behavior under various loads is necessary to predict the strength and behavior of a structure built with such elements, when subjected to gravity loads and lateral loads such as wind or earthquake.

All tests used panels and connectors of width 150 mm in three possible configurations: toggle only, adhesive only, and toggle and adhesive combined. For the interlocked and bonded specimens, we followed the manufacturer's bonding recommendations: First, we lightly sanded and wiped the mating surfaces clean. Next, we applied to *only* ***one*** of the two pieces to be joined a **3** mm diameter bead of adhesive in each of two grooves on the sides of the toggle cavity. **We** then aligned and mated the two parts together and inserted the toggle, making sure that no adhesive was applied to the toggle or toggle cavity. The specimen was left undisturbed to cure for at least 16 hours. For the bonded only specimens, the procedure was similar, except that adhesive was applied to *both* mating surfaces, which were subsequently clamped together.

3. Flexural Tests

Nine panels were loaded in flexure under four-point loading (Photo 1, Fig. 2). The panel webs were stiffened with a cementitious grout to prevent them from buckling under the applied loads. LVDTs (linear variable differential transformers) measured the deflections at midspan and the gap between the mating flanges 12 mm from the bottom face of the flange as the connection opened up. In general, the connection remained engaged until failure, which occurred by cracking of the jaws (Photo 2). Table 1 gives the bending moments and deflections at the first peak and at ultimate. Figures 5 to 13 show the curves of moment versus deflection and opening.

Results show the flexural strength per unit width of the connector joined with a toggle only to have a mean of 471 N·mm/mm with a standard deviation of 65 N·mm/mm. Specimen BT1 behaved linearly up to the first peak, which was fairly close to the ultimate moment. The joint opening of BT1 was an order of magnitude smaller than that of BT2 and BT3, probably due to the high sensitivity of this measurement to the location of the extensometer. Also, BT2 and BT3 behaved much more non-linearly than BT1, with major jumps in loads before ultimate.

In the bonded configuration, and the toggle plus adhesive configuration, the connection was stronger than the junction between web and flange, at least in this test geometry. Moment-deflection behavior ending with failure at the junction between flange and intermediate web was fairly reproducible, but the joint opening varied over a factor of five (BG1 and BG3), probably

Table 1: Flexural Tests Results

Test	M_l	D_l	M_u	D_u	Comments
Toggle only					Significant opening at loads much less than ultimate.
BT1	518	10	540	25	Large deflection, connection remained engaged.
BT2	370	7	412	12	Connection opened up at failure.
BT3	320	5	460	25	Jaws cracked and caused failure.
Mean			471		
St. Deviation			65		
Adhesive onlv					Very little opening until final failure.
BG1	680	12	850	20	Rupture of upper junction of flange and intermediate web (circled region in Fig. 2). Connection held.
BG2	925	18	1070	26.5	
BG3			850	24	
Mean			923		
St. Deviation					
Toggle and adhesive					Very little opening until final failure.
BTG1			625	11.8	Sudden cracking of jaws caused failure.
BTG2	740	13	840	21	Rupture of upper junction of flange and intermediate web. Connection held.
BTG3	760	16	860	23	
Mean			775		
St. Deviation			130		

M_l = first peak, N·mm/mm
D_l = Deflection at M_l, mm
M_u = ultimate moment, N·mm/mm
D_u = Deflection at M_u, mm

for the same reason as mentioned previously. Test BTG1 (toggle and adhesive) failed by cracking of the jaws of the connection at an ultimate moment of 625 N·mm/mm.

4. In-Plane Shear Tests

Photo 3 and Fig. 3 show the double-shear test configuration designed to test the in-plane shear strength of the connection. An LVDT measured the relative slip of the panels at each connection. The load bearing blocks were slotted to allow the toggles to clear. Since the tests with toggles only, resulted in no permanent damage, the toggles were sometimes reinserted and the test repeated (a and b). It was difficult to achieve the same slip at both connections of each test, due to manufacturing tolerance (some toggles were easier to insert than others) and the inevitable slight eccentricity of the load.

Table 2 gives the in-plane shear strengths for the three joint configurations. Figures 14 to 27 are plots of shear force per unit width versus the relative slip across the joint. For the tests with adhesive only, or toggle and adhesive, the loads achieved were much higher than for toggle only. For these tests, it was difficult to achieve pure shear loading. If the loading blocks at the top and bottom were too far apart, then significant bending occurred. If, on the other hand, the loading blocks at the top and bottom were too close together, then the load path did not go through the

Table 2: In-Plane Shear Test Results

Tests	Shear Strength N/mm	Comments
Toggle only		Friction and slip, but reusable.
IPST1a	1.97	
IPST1b	1.80	
IPST2a	2.00	
IPST2b	1.92	
IPST3	2.97	
IPST4	2.25	
IPST5a*	0.66*	Test stopped because loads appeared too unbalanced.
IPST5b	1.85	
Mean (without 5a)	2.11	
St.Dev.(w/o 5a)	0.41	
Adhesive only		
IPSG1	320	Shear failure at comer, between web and flange (Photo 4).
IPSG2	160	Debond failure of connection.
IPSG3	310	Bearing failure.
Toggle and adhesive		
IPSTG1	160	Sudden failure along bond line.
IPSTG2	150	
IPSTG3	220	
Mean	177	
Standard Deviation	38	

connection and bearing failure occurred by longitudinal crushing of the cross section. **As** well, failure can occur by shearing of the junction between web and flange, and not of the connection (Photo 4). For these reasons, only the result shown in Table 2 for IPSG2 (160 N/mm) is indicative of the joint in-plane shear strength for the adhesive only condition. For the toggle only configuration, the mean shear strength is only 2.11 N/mm, with a standard deviation of 0.41 N/mm; and for the toggle plus adhesive configuration, the mean shear strength is 177 N/mm, with **a** standard deviation of 38 N/mm.

5. Out-of-Plane Shear Tests

Photo 5 and Fig. 4 show the test configuration. The test procedure is similar to the in-plane tests, except that the test specimen is rotated 90° so that the shear force is perpendicular to the toggle. Since the corners of the panel were curved, a fast setting cement (Hydrocal) was used to ensure good bearing over the entire corner. The difficulties mentioned previously about obtaining pure shear loading applied here as well.

For test OPST3b, we reused parts from previous tests that exhibited no visible damage. (Usually, only one of two connectors would be visibly damaged in any one test.) This test produced the highest load and the only instance of shearing failure of the toggle (Photo 6). Since specimens

Table 3: Out-of-Plane Shear Tests Results

Tests	Shear Strength N/mm	Comments
Toggle only		
OPST1a	155	One side of connection disengaged. Reused in OPST1b.
OPST1b	110	Same side opened up and disengaged.
OPST2a	113	No sign of damage at small load drop after peak.
OPST2b	114	Failure of upper junction between web and flange (as in Photo 4).
OPST3a	120	
OPST3b	162	Used parts from earlier tests. Failure by shearing of toggle! (Photo 6)
Mean w/o 2b and 3a	135	
St. Dev. w/o 2b. 3a	27	
Adhesive only		
OPSG1	75	Failure by cracking of jaws. (Photo 7)
OPSG2	59	
OPSG3	76	
Mean	70	
Standard Deviation	10	
Toggle and adhesive		
OPSTG1	148	Failure by shearing of junction between web and flange (as in Photo 4).
OPSTG2	180	
OPSTG3	186	
Mean	171	
Standard Deviation	20	

OPST 2b and 3a failed by shearing of the upper junction between web and flange, in a manner similar to what is shown on Photo 4, they do not represent the strength of the connection. These two test results were not included in the calculation of the mean out-of-plane shear strength for the toggle only configuration (135 N/mm) and the standard deviation (27 N/mm).

The specimens that were bonded (with adhesive only) all failed in the same manner, by cracking of the jaws of the connection, and produced a mean strength of 70 N/mm with a standard deviation of 10 N/mm (Table 3). For the toggle plus adhesive configuration, all three specimens failed outside the connection. The mean transverse shear strength of the web-flange junction is 171 N/mm, with a standard deviation of 20 N/mm. Figures 27 to 39 show plots of load versus deflection, and Photos 5 to 7 show the experimental set-up and two of the failed connectors.

6. Uncertainty

According to the current calibration sheet of the testing machine, for the relevant range of loads, the load displayed by the testing machine is less than 0.3 % lower than the calibrating device. Loads and displacements were stored directly by the testing machine, and also recorded at a rate of 10 Hz by a data acquisition system. The peak loads varied from 650 N for in-plane shear tests with toggle only, to 90 kN for in-plane shear tests with adhesive only. The maximum load indicated by the data acquisition system was less than 18 N lower than the machine load at the higher range. At the lower range, the noise of the data acquisition system is noticeable, but the smoothed out loads acquired by the system agree with the test machine reading within 5 %. The widths of the specimens were 150 mm ± 1 mm.

7. Conclusion

The goal of this work was to fully characterize the mechanical behavior and strength of the connection under static loads. The measurements can be used in designing structures and predicting their performance. This goal was largely achieved, but not completely, because some of the test specimens failed outside of the connection. That in itself is significant, because it shows that the connection is stronger than the rest of those specimens. It would also have been desirable to conduct more tests to obtain greater confidence in the mean strength and standard deviation.

This work is a step in developing the technical basis for standards for this new type of construction. The continued research and testing from industry, academia and government will lead to standards that can potentially have an impact on the construction industry.

8. References

Duthinh, D. (2000a), "Connections of Fiber-Reinforced Polymer (FRP) Structural Members: a Review of the State of the *Art*," NISTIR 6532, NIST, Gaithersburg, MD.

Duthinh, D. (2000b), "Tensile strength of an Interlocking Composite Connection," NISTIR 6565, NIST, Gaithersburg, MD.

Head, P.R. and Churchman, Q.E. (1989), "Design, Specification and Manufacture of a Pultruded Composite Construction System." *Proc., BPF Symposium on Mass Production Composites,* Imperial College, London, Sep., pp. 117-162.

9. Acknowledgments

This study was made possible by a grant from the Advanced Technology Program of NIST (Felix Wu, Program Manager, Composite Materials). Strongwell (Bristol, VA) provided test samples, Maunsell (Beckenham, UK) technical data and Ashland Chemicals (Columbus, OH) the adhesive and applicator. Frank Davis and Mark Kile assisted with the experiments. To all, the authors are grateful.

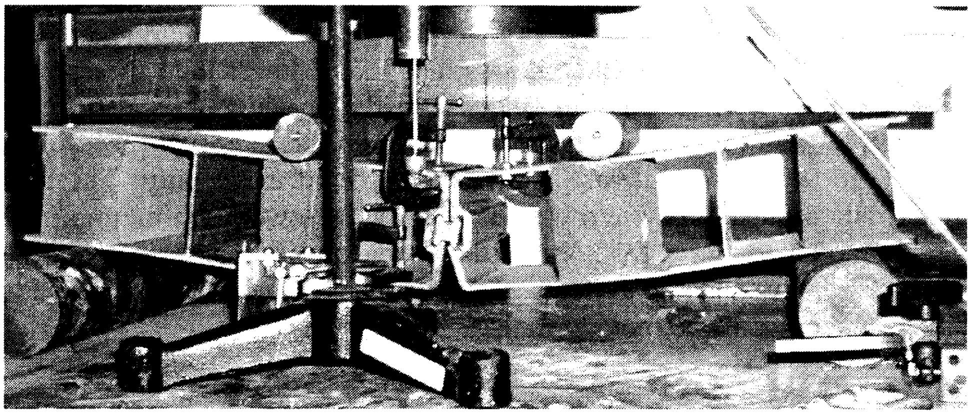


Photo 1: Bending Test

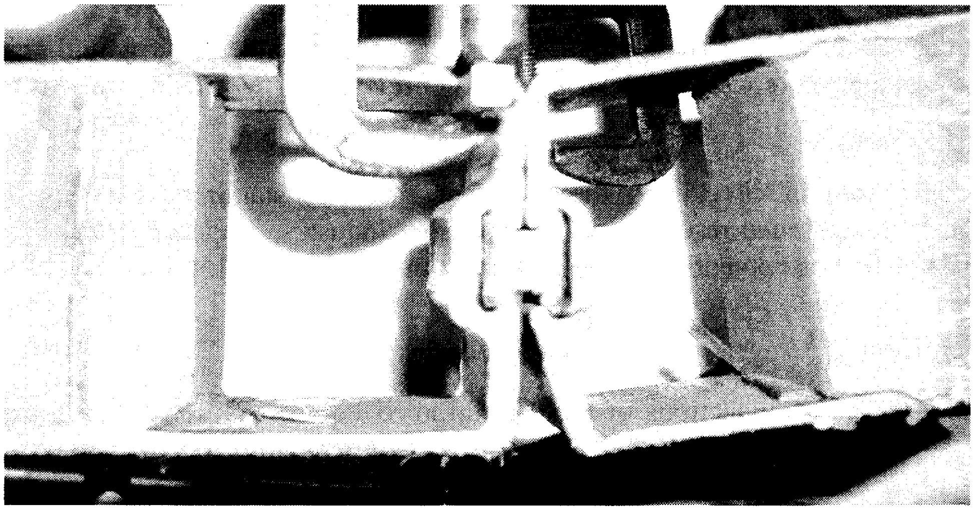


Photo 2: Bending Test, Toggle only.
Failure of jaws controlled bending strength.

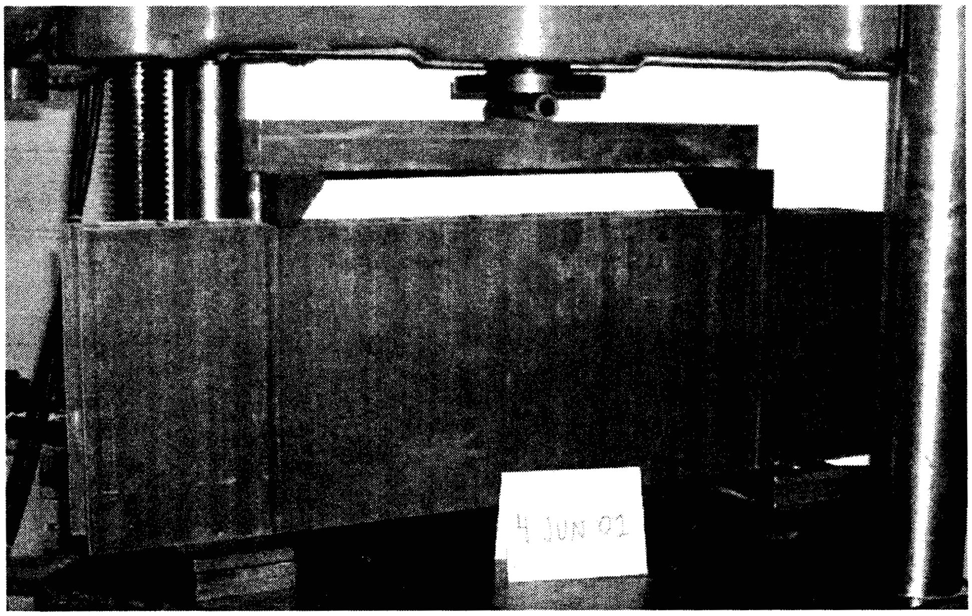


Photo 3: In-Plane Shear Test

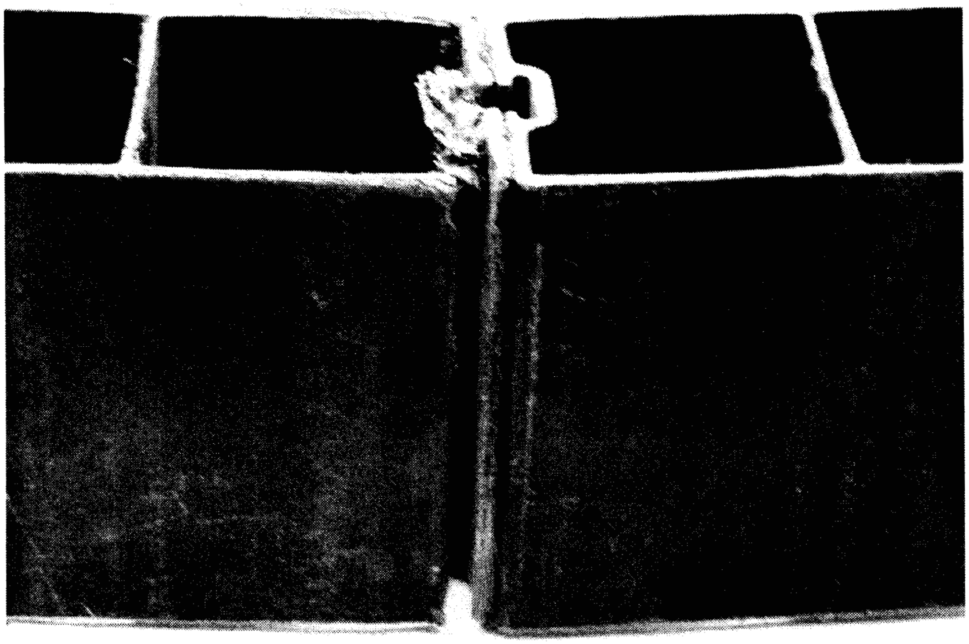


**Photo 4: In-Plane Shear Test (IPSG1).
Failure at flange-web junction, probably
caused by placement of loading block.**

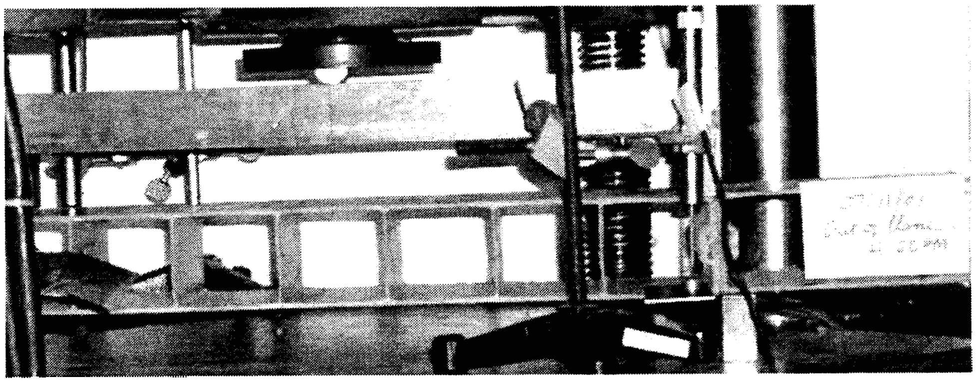


Photo 5: Out-of-Plane shear Test

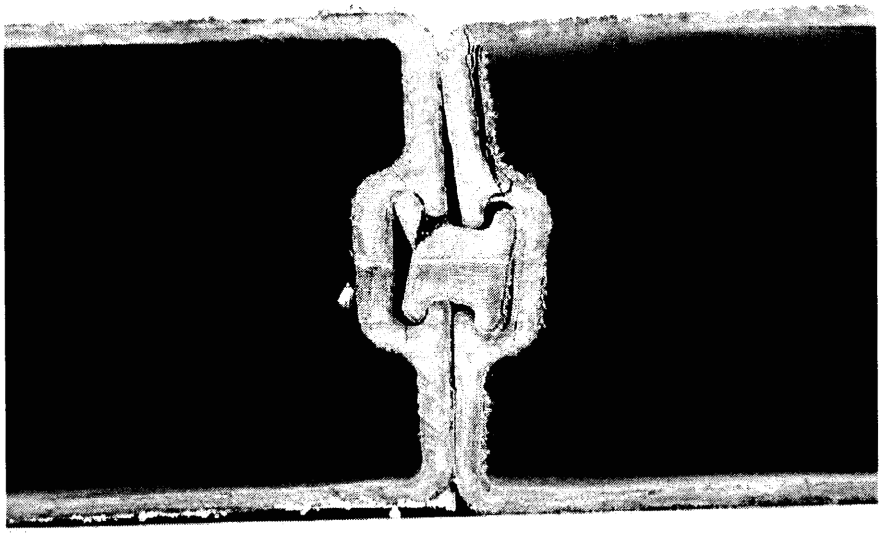


Photo 6: Out-of-Plane Shear Test, Toggle only (OPST3b)

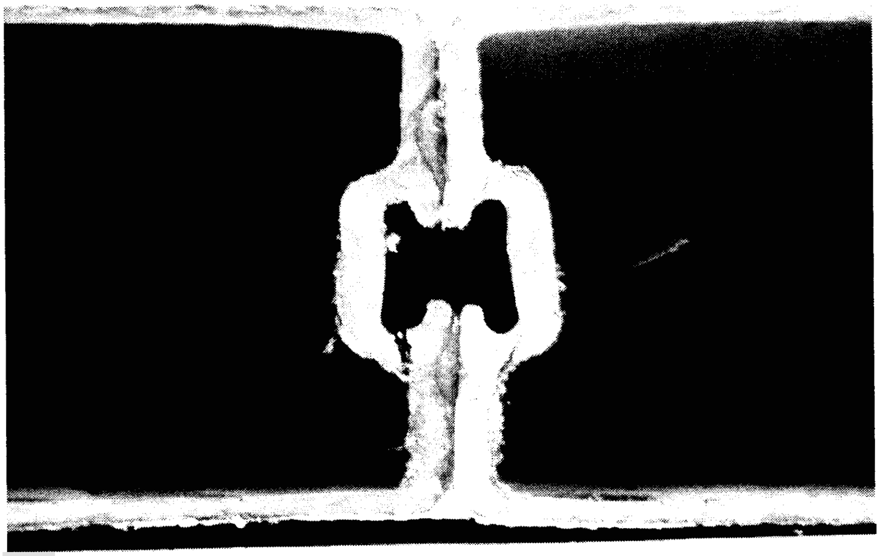


Photo 7: Out-of-Plane Shear adhesive l)PSG1

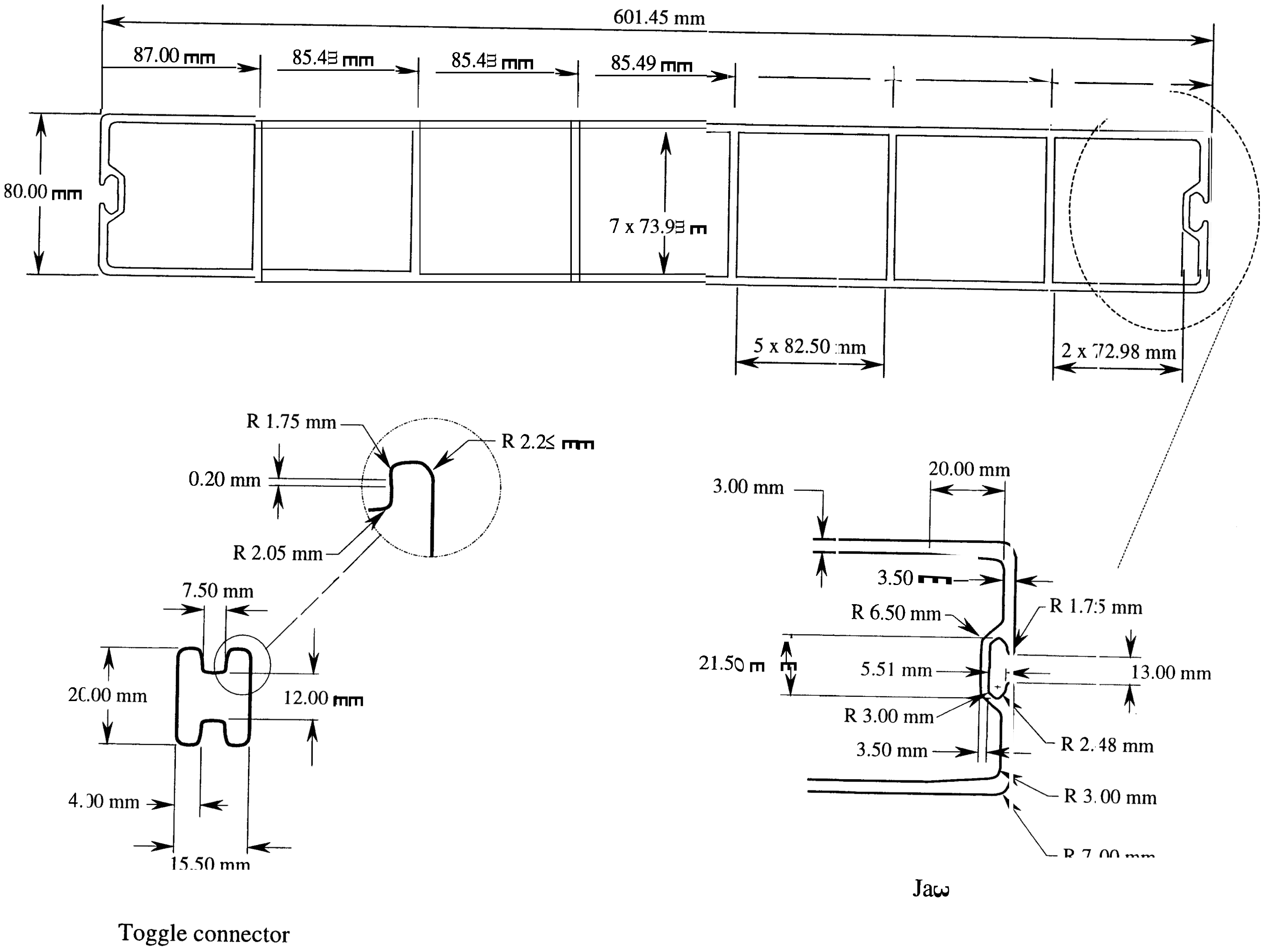
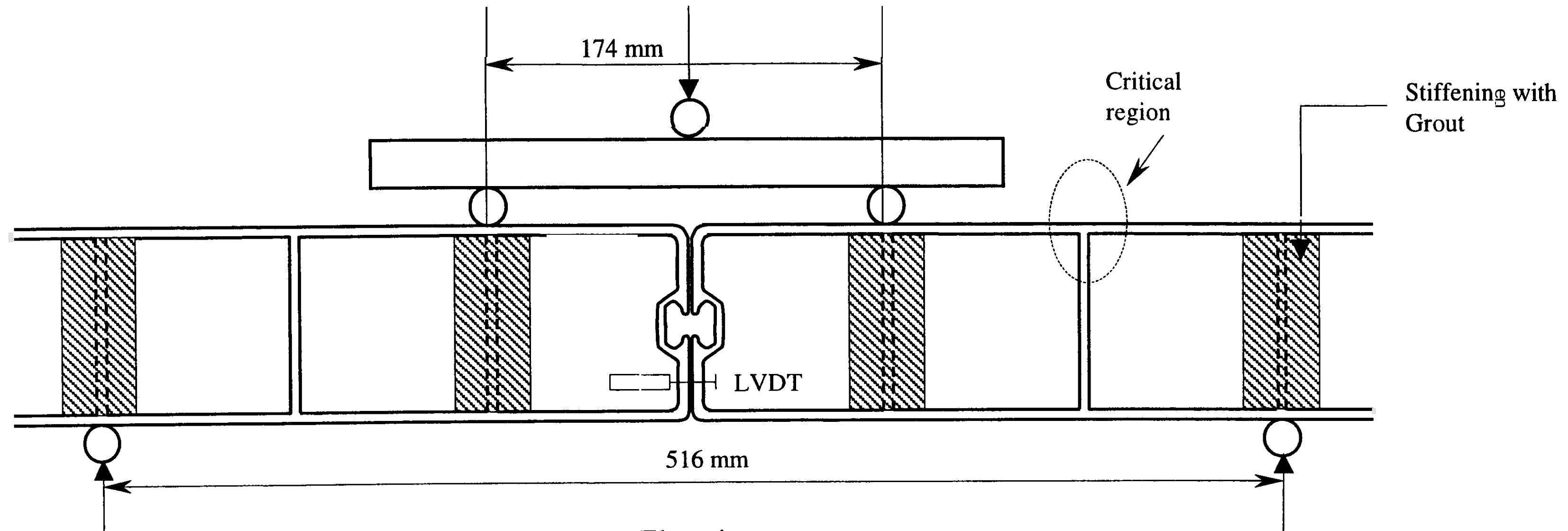
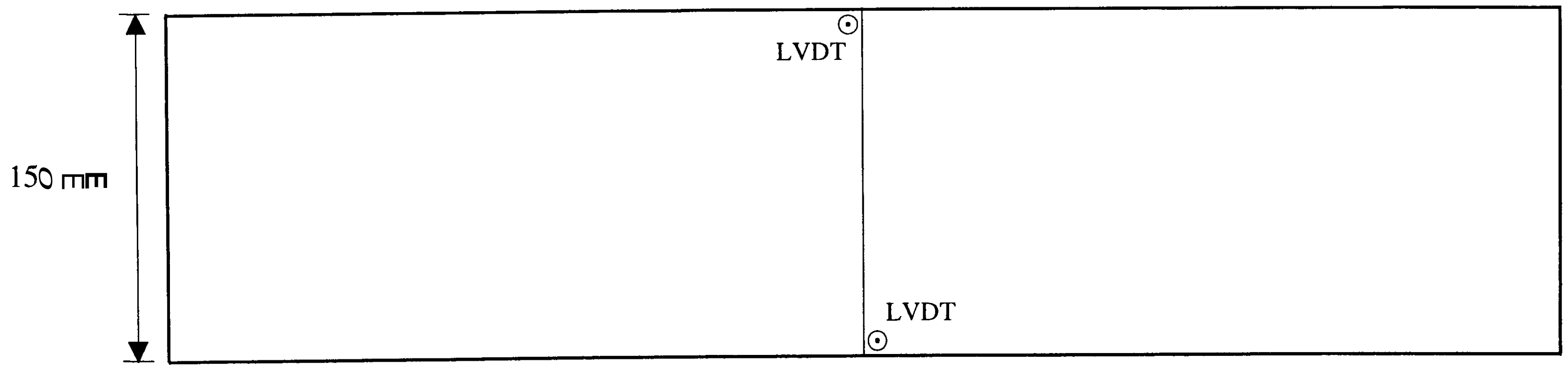


Fig. 1 Panel and Toggle Connector

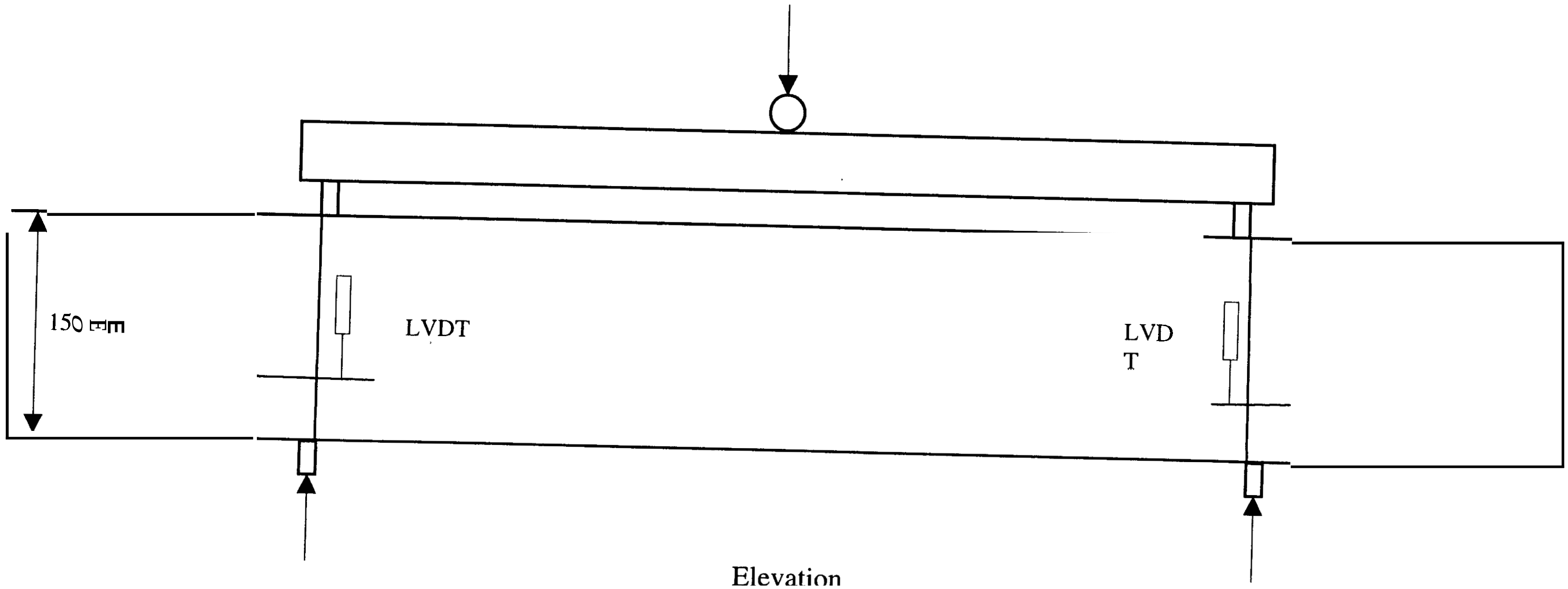


Elevation

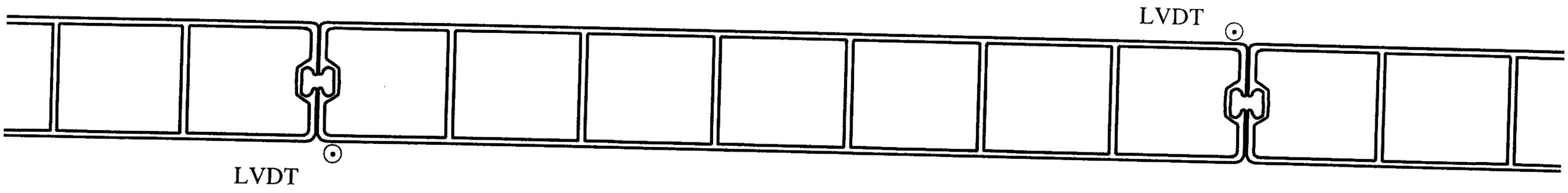


Top

Figure 2 Four-Point Bend Test

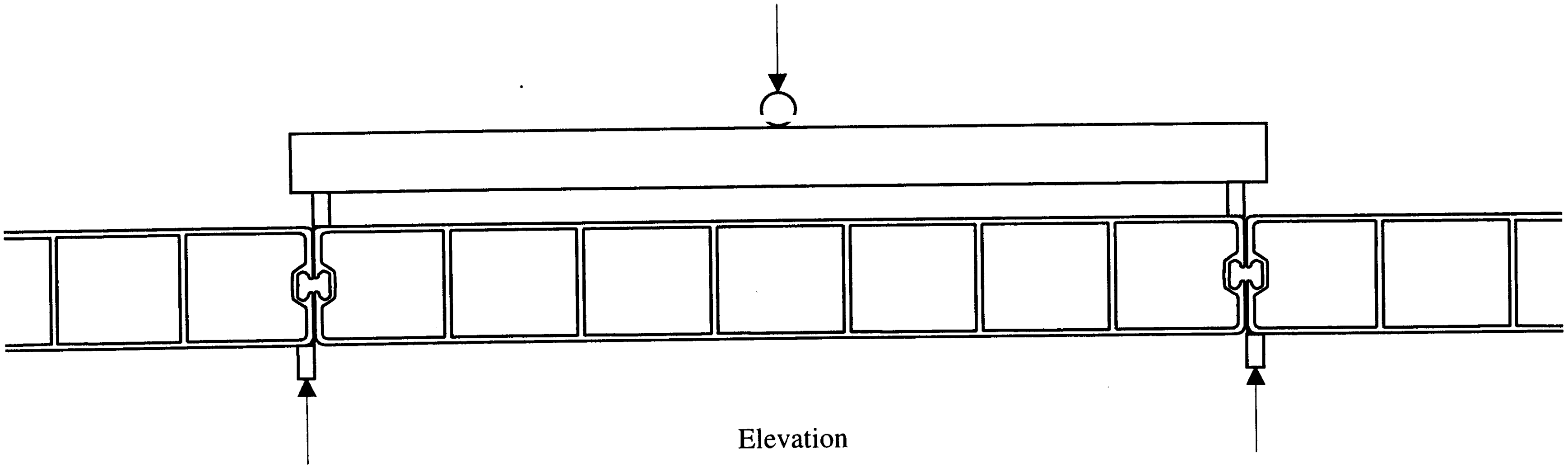


Elevation

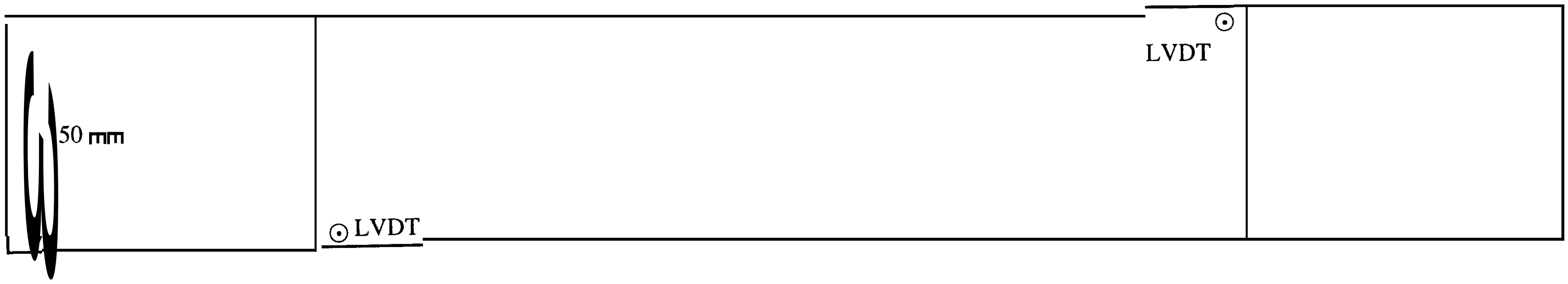


Top

Figure 3 In-Plane Shear Test



Elevation



Top

Figure 4 Out-of-Plane Shear Test

Fig. 5: Test BT1, Bending, Toggle only

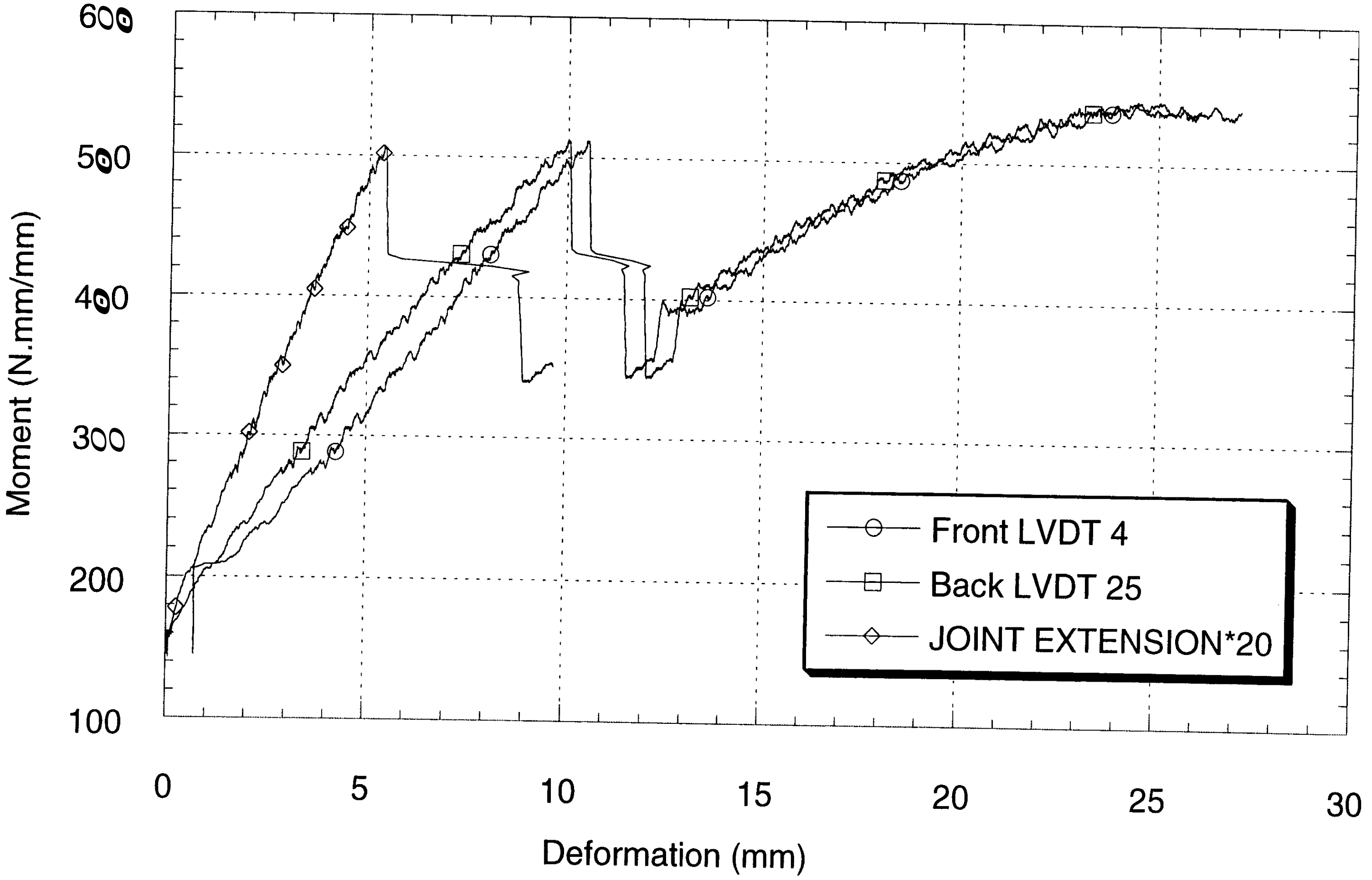


Fig. 6: Test BT2, Bending, Toggle only

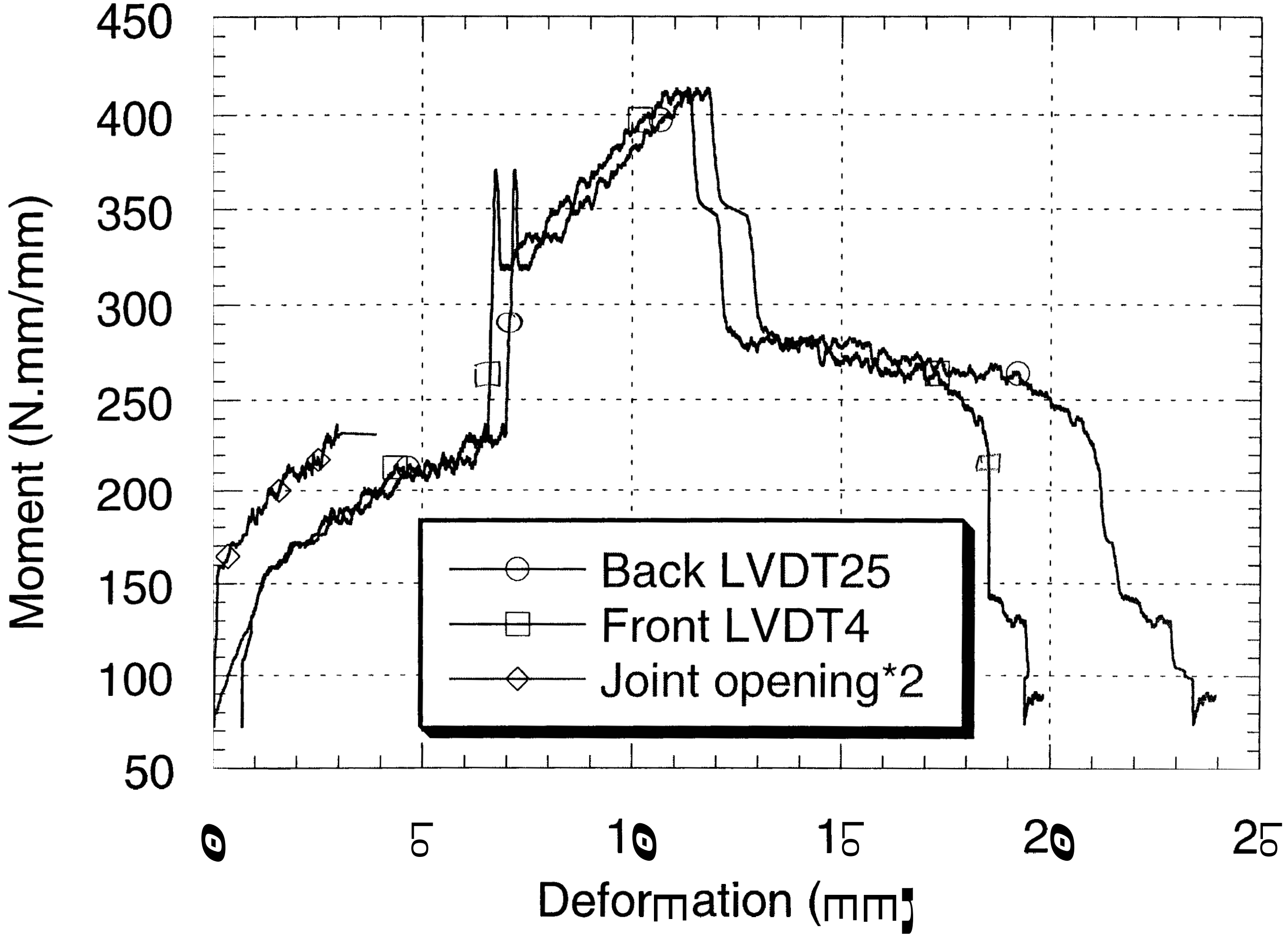


Fig. 7: Test BT3, Bending, Toggle only

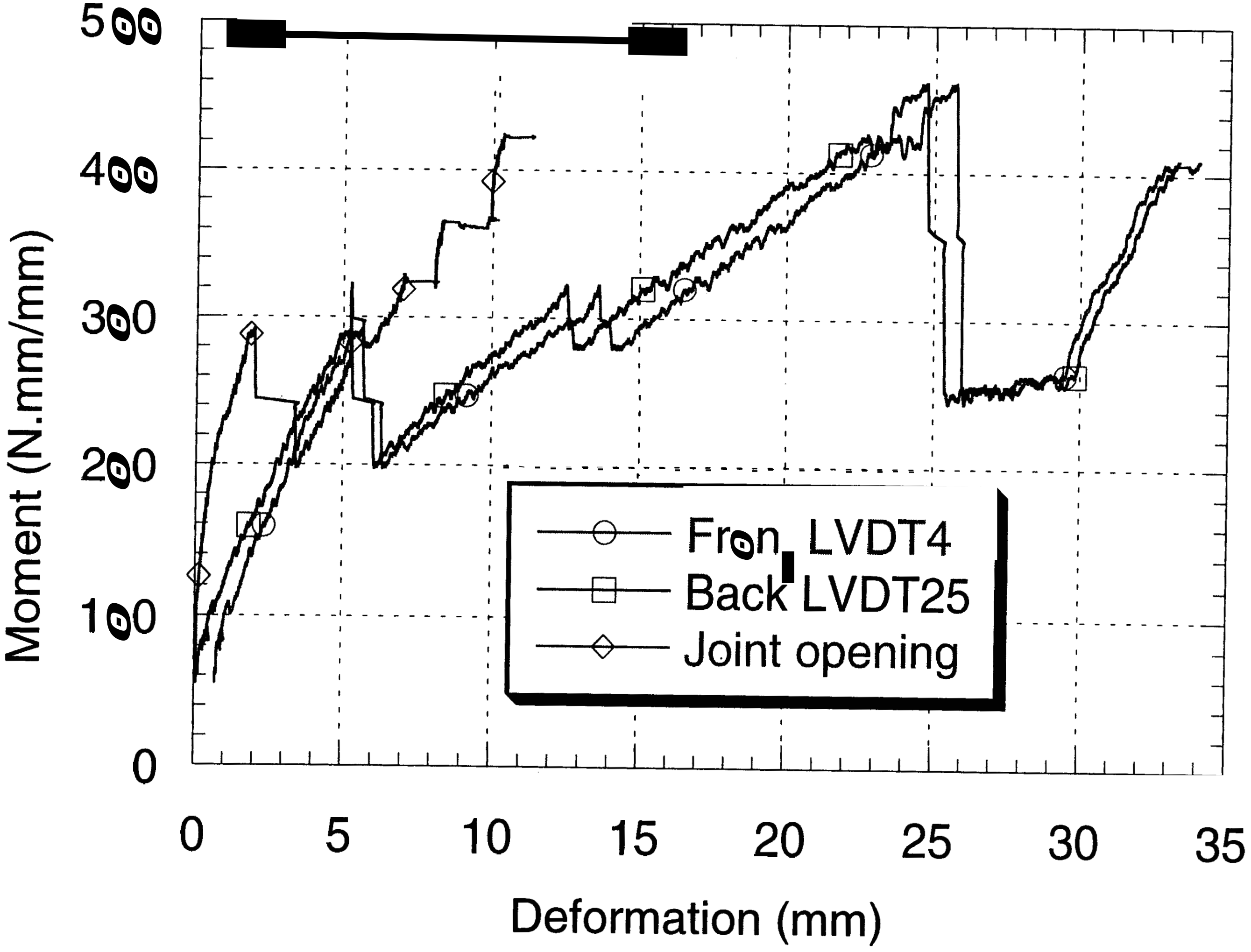


Fig. 8: st BG1, Bending, Glue only

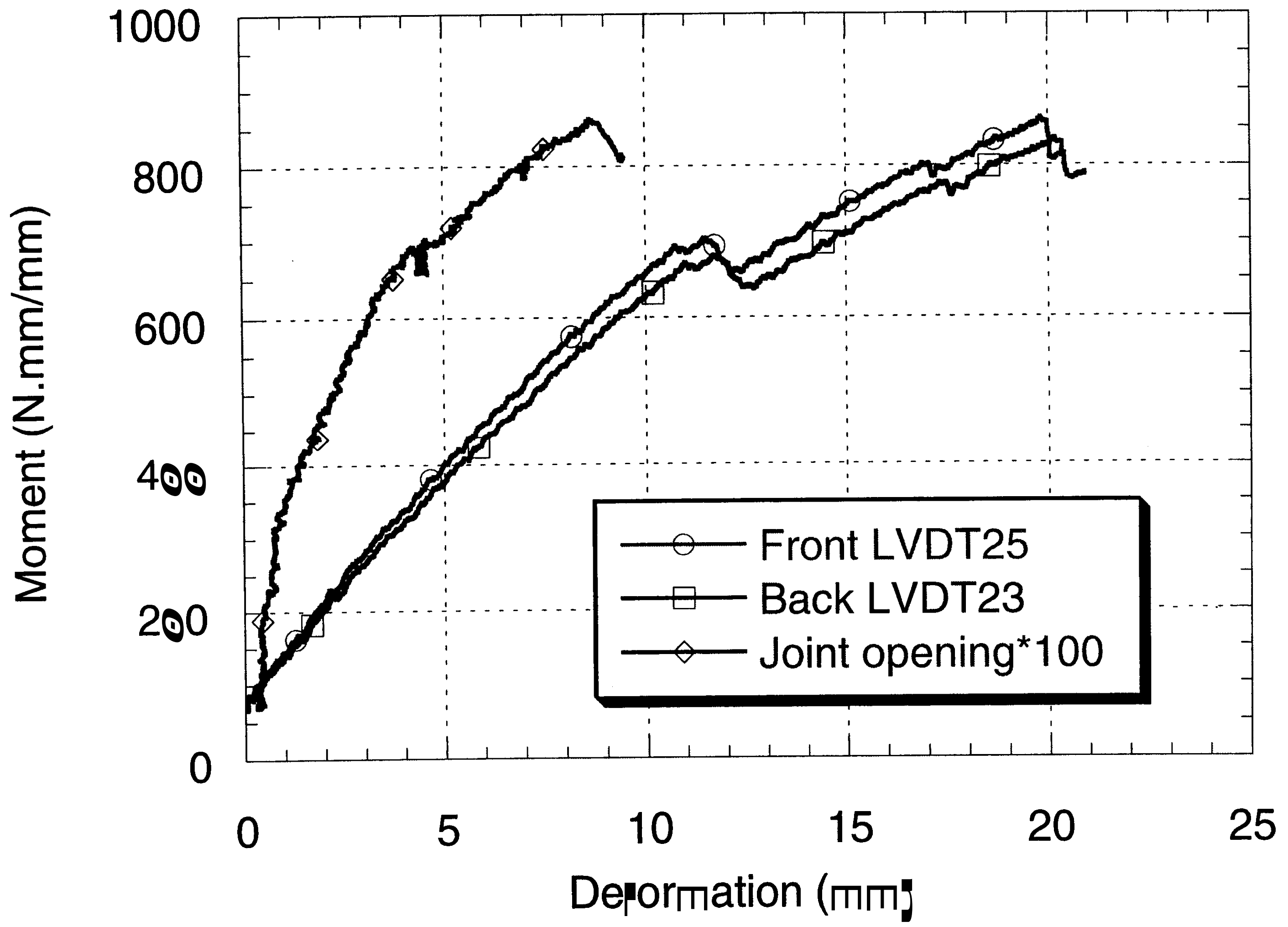


Fig. 9: Test BG2, Bending, Glue only

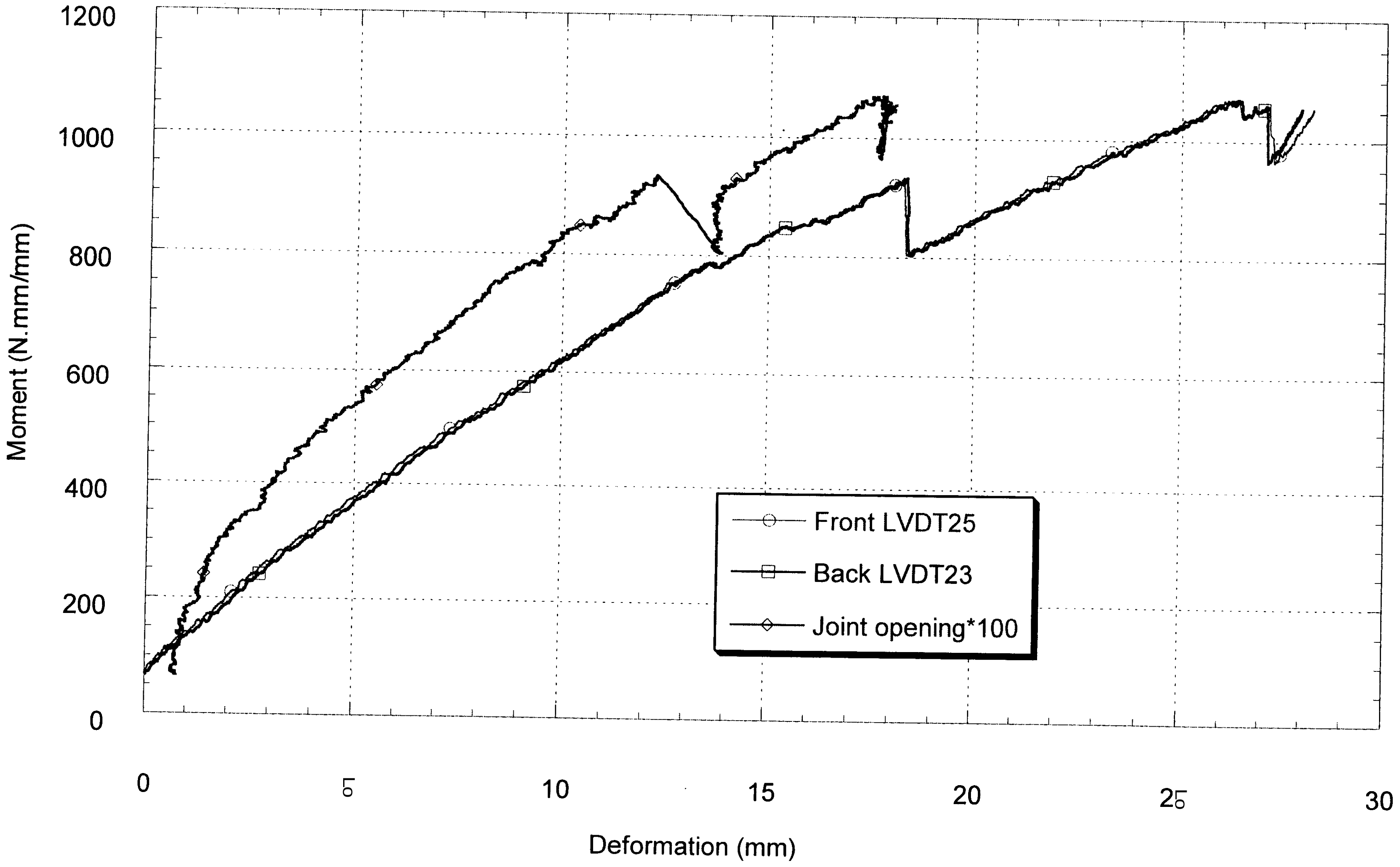


Fig. 10: Test BG3, Bending, Glue only

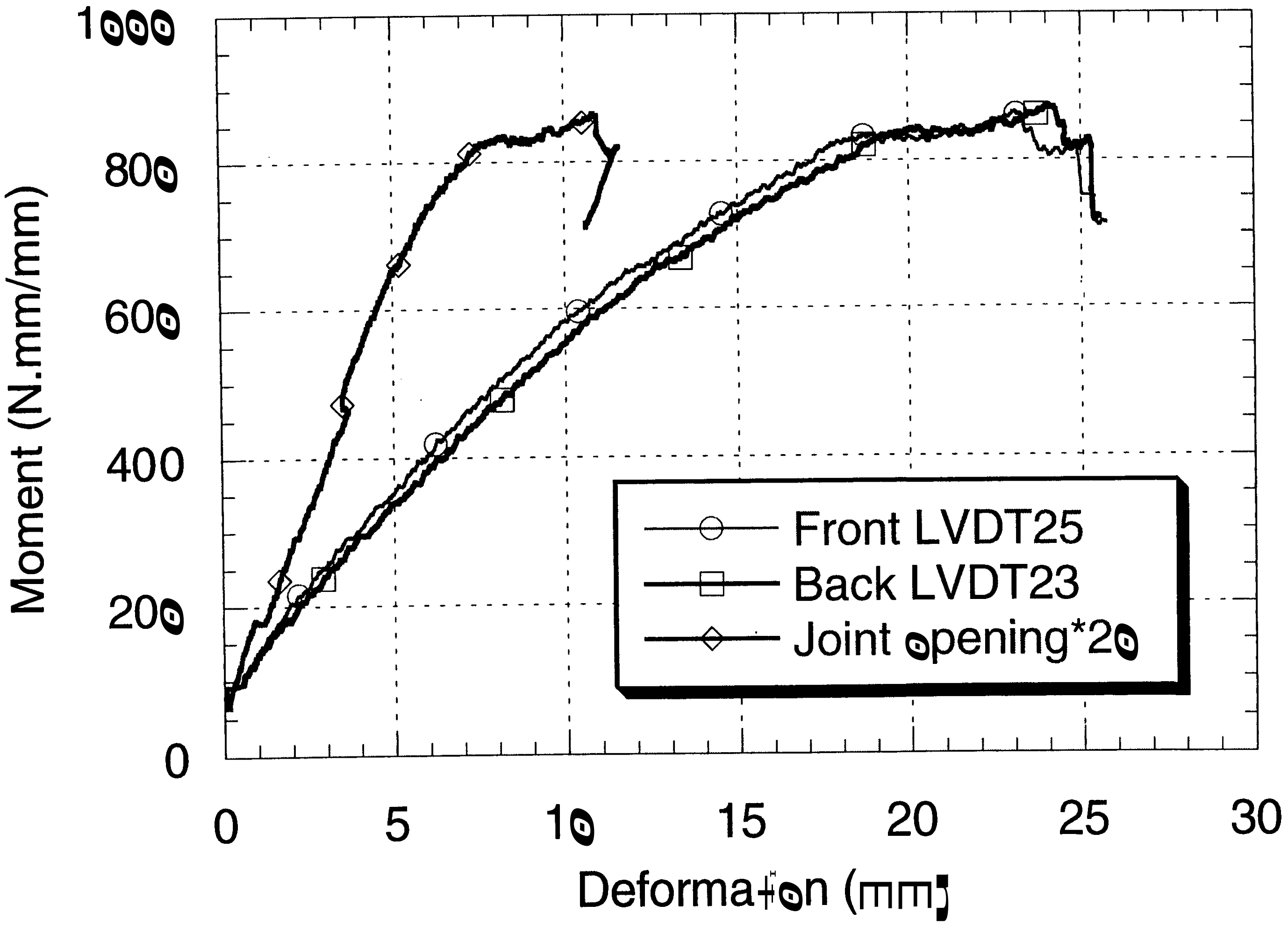


Fig. 11: Test BTG1, Bending, Glue and Toggle

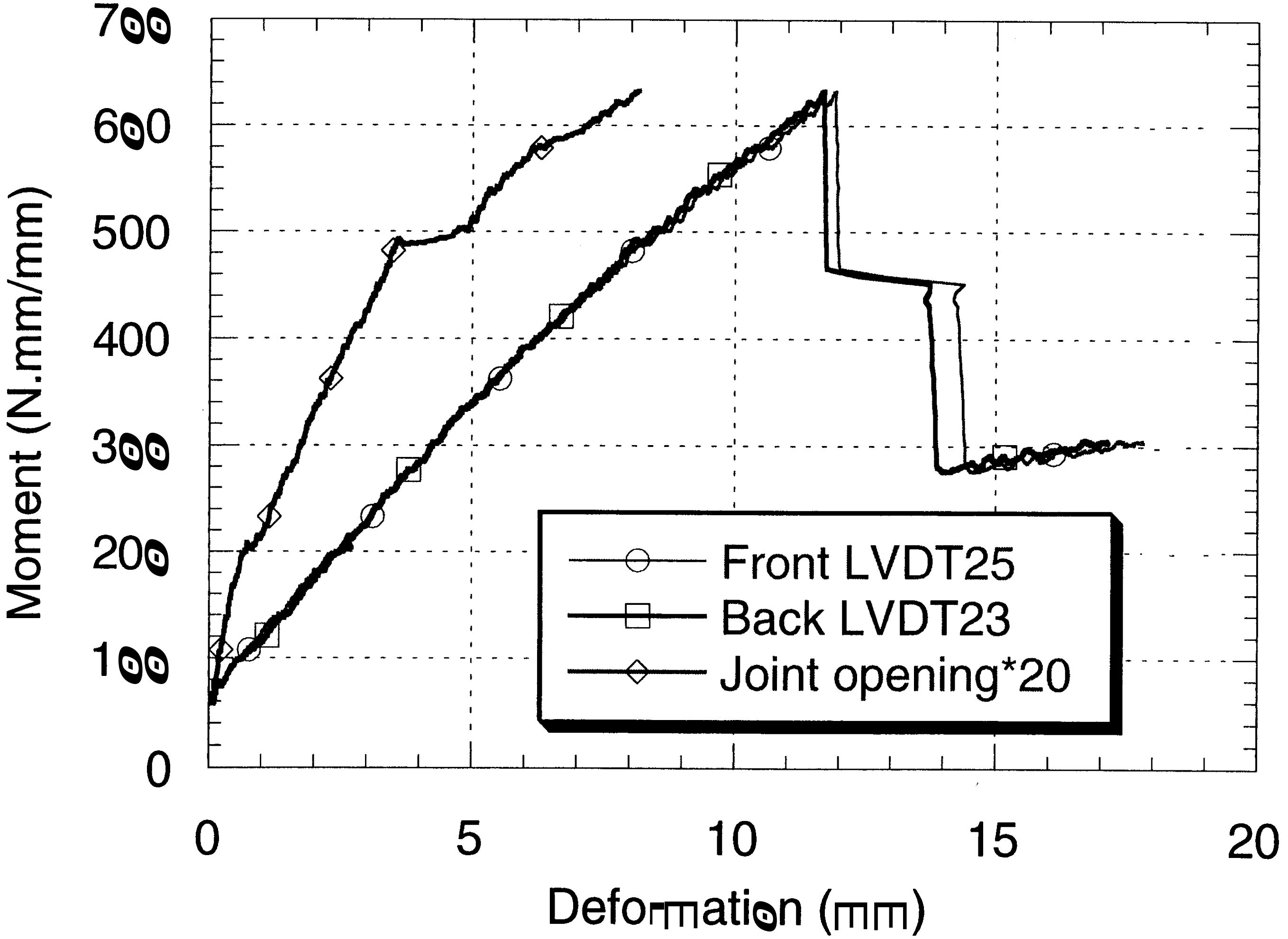


Fig. 12: Test BTG2, Bending, Glue and Toggle

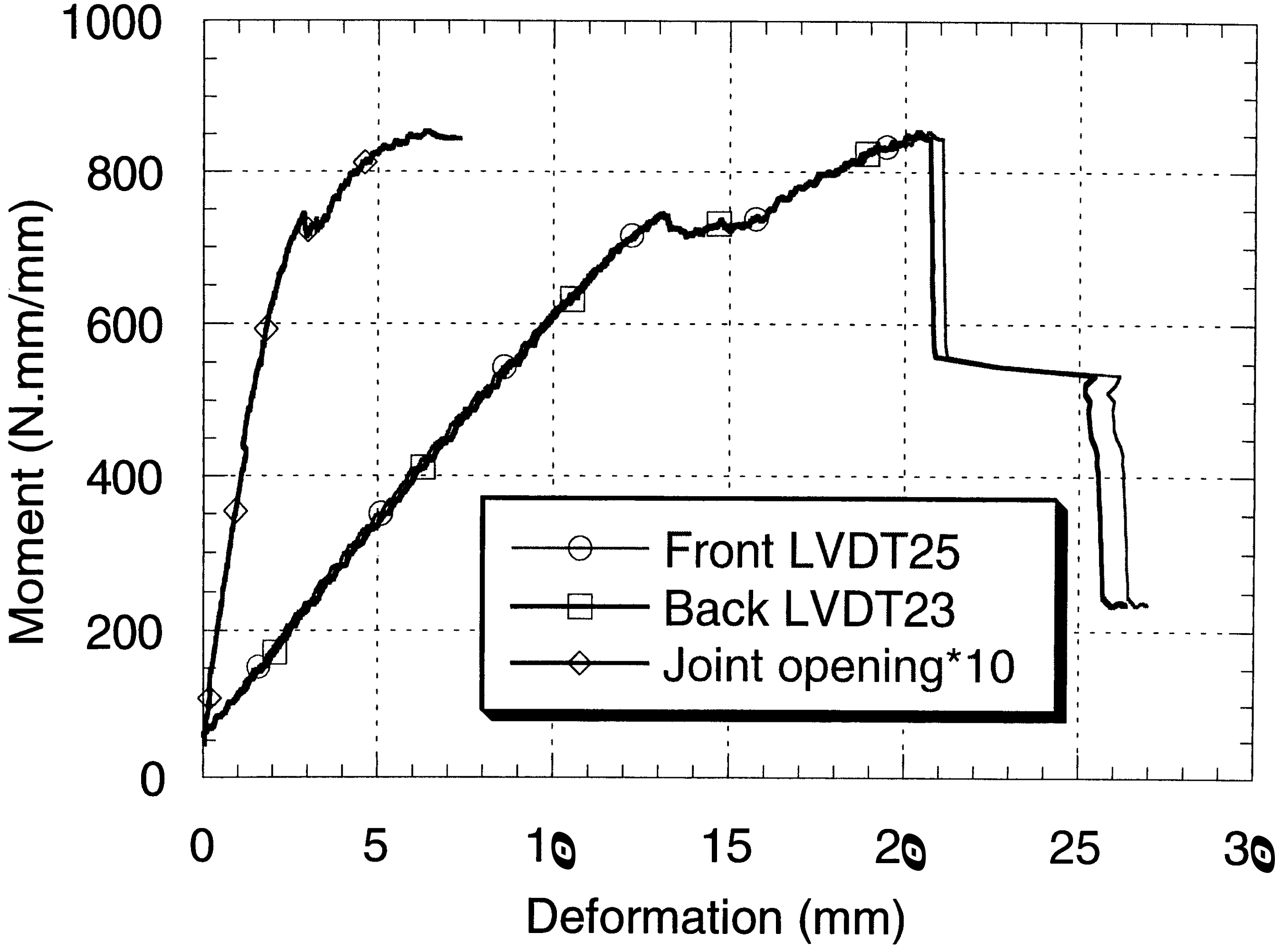


Fig. 19: Test BTG3, Bending, Glue and Toggle

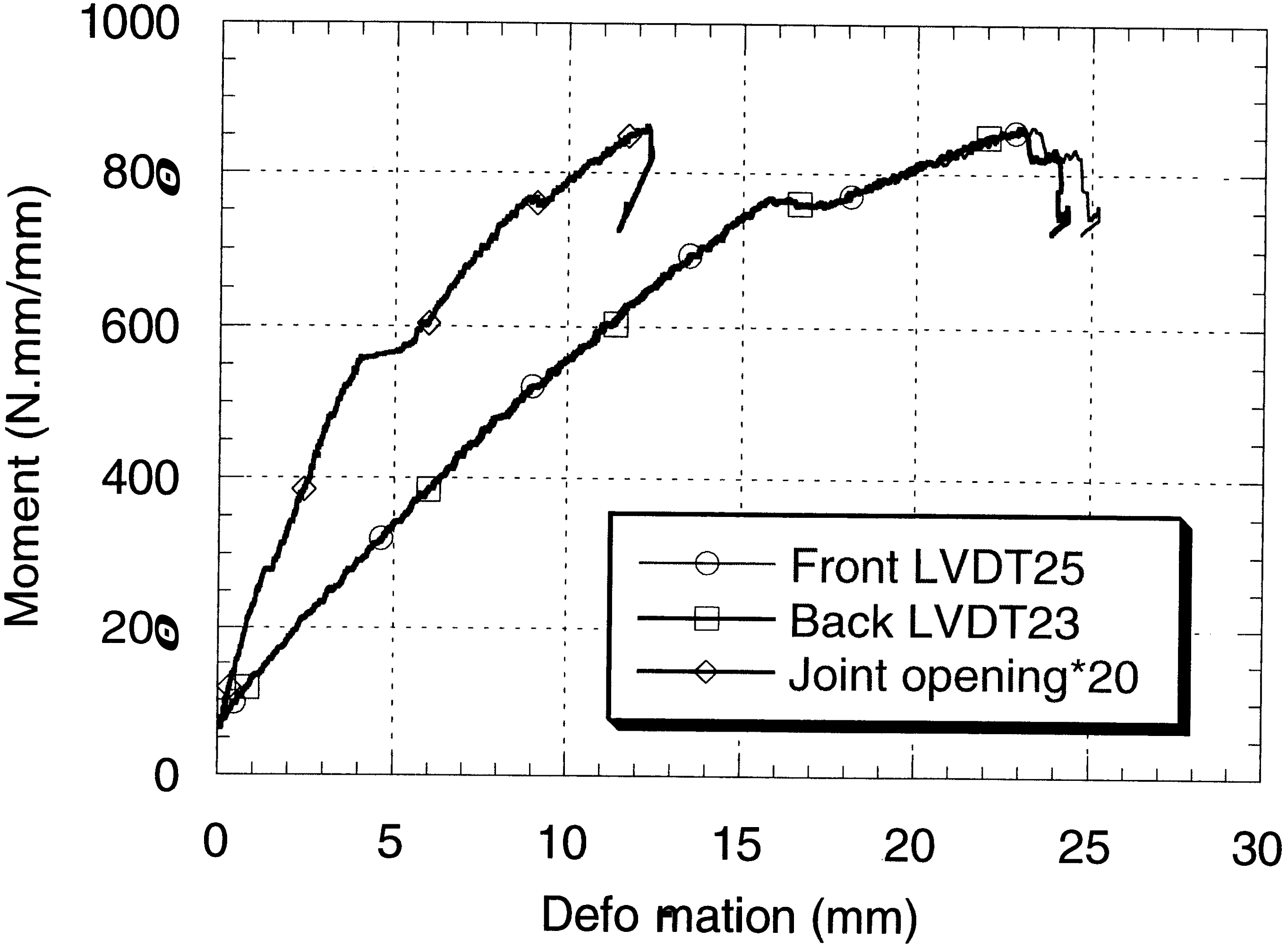


Fig. 14: Test IPST1a, In-Plane Shear, Toggle only

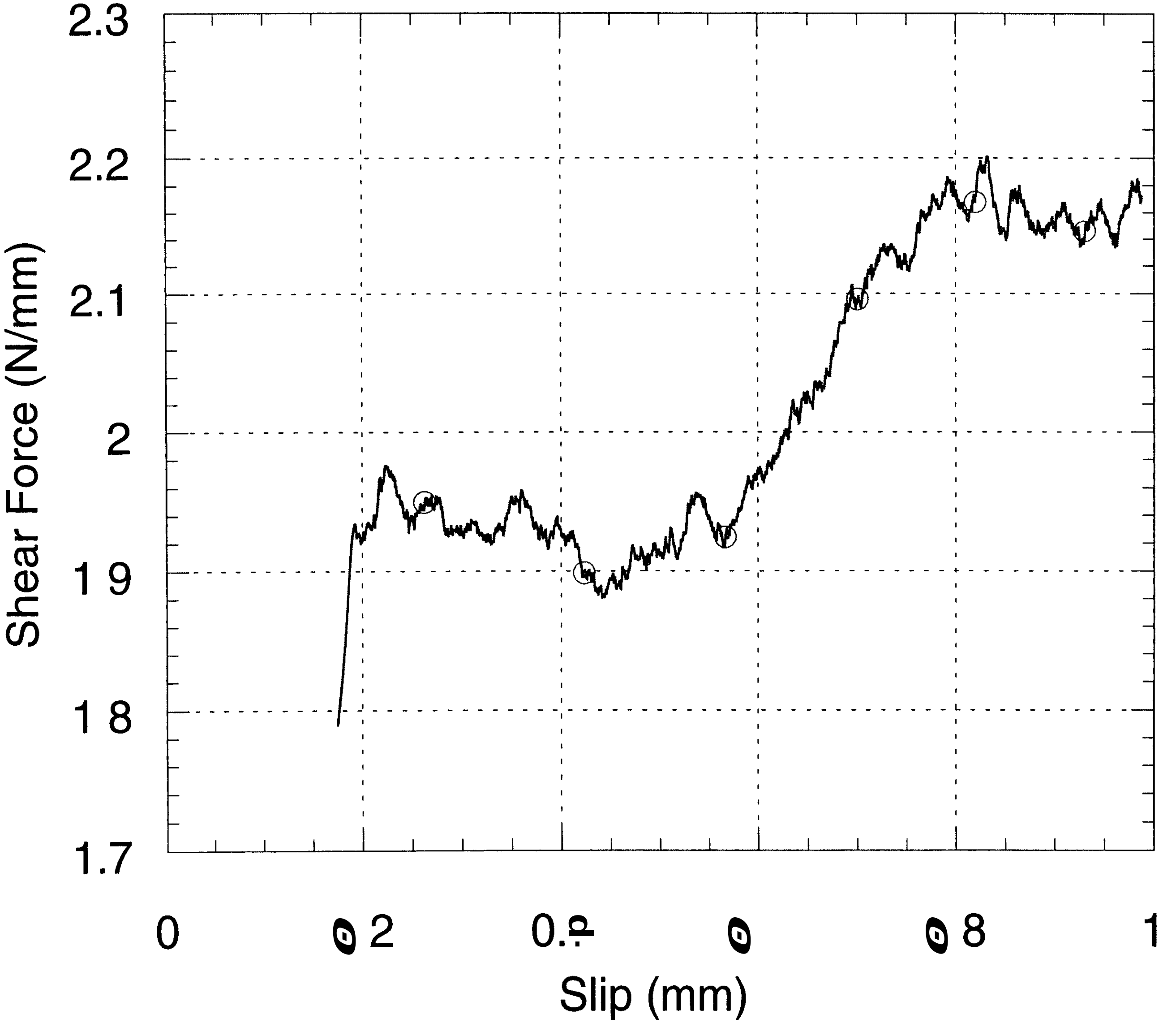


Fig. 15: Test IPST1b, In-Plane Shear, Toggle only

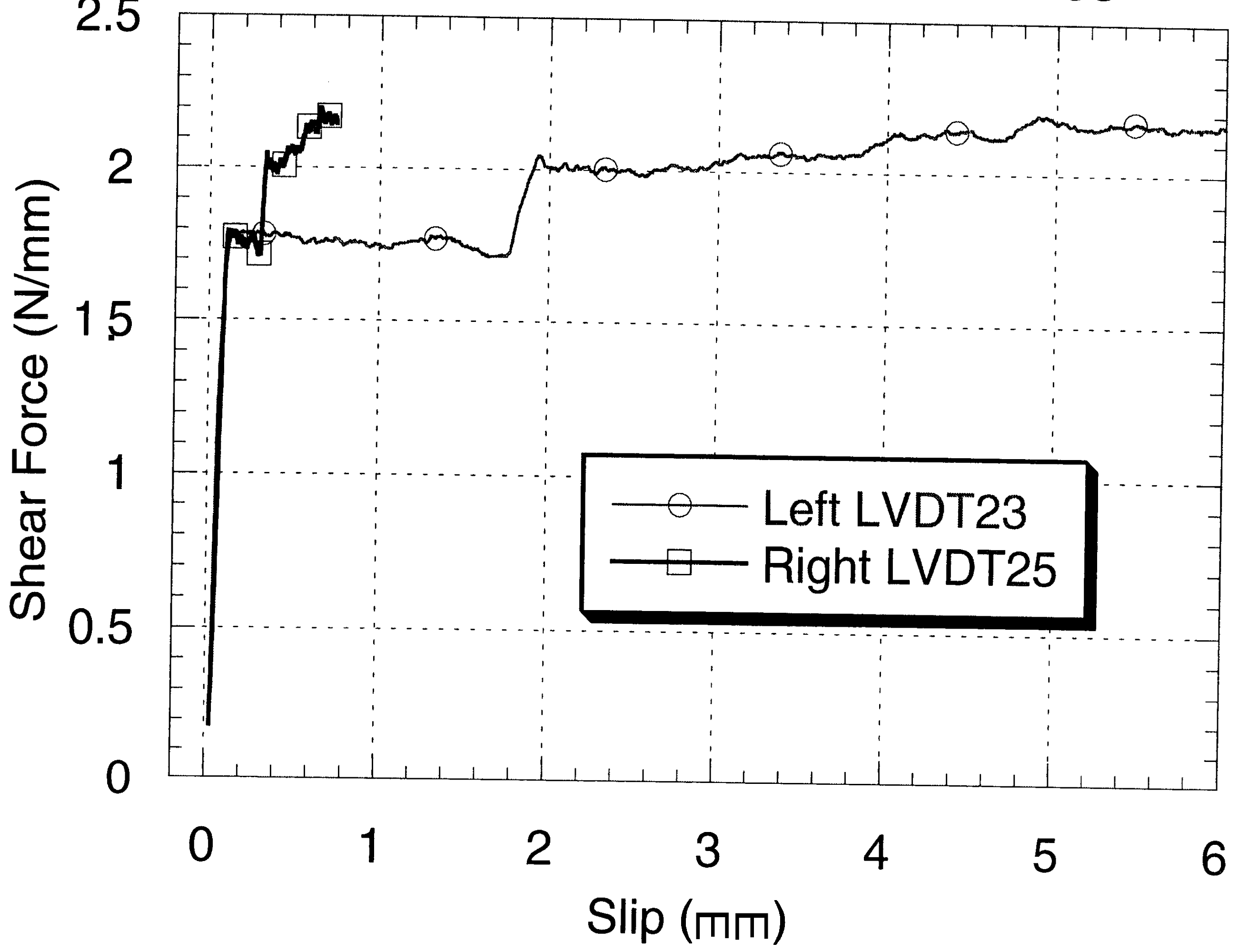


Fig. 16: Test IPST2a, In-Plane Shear, Toggle only

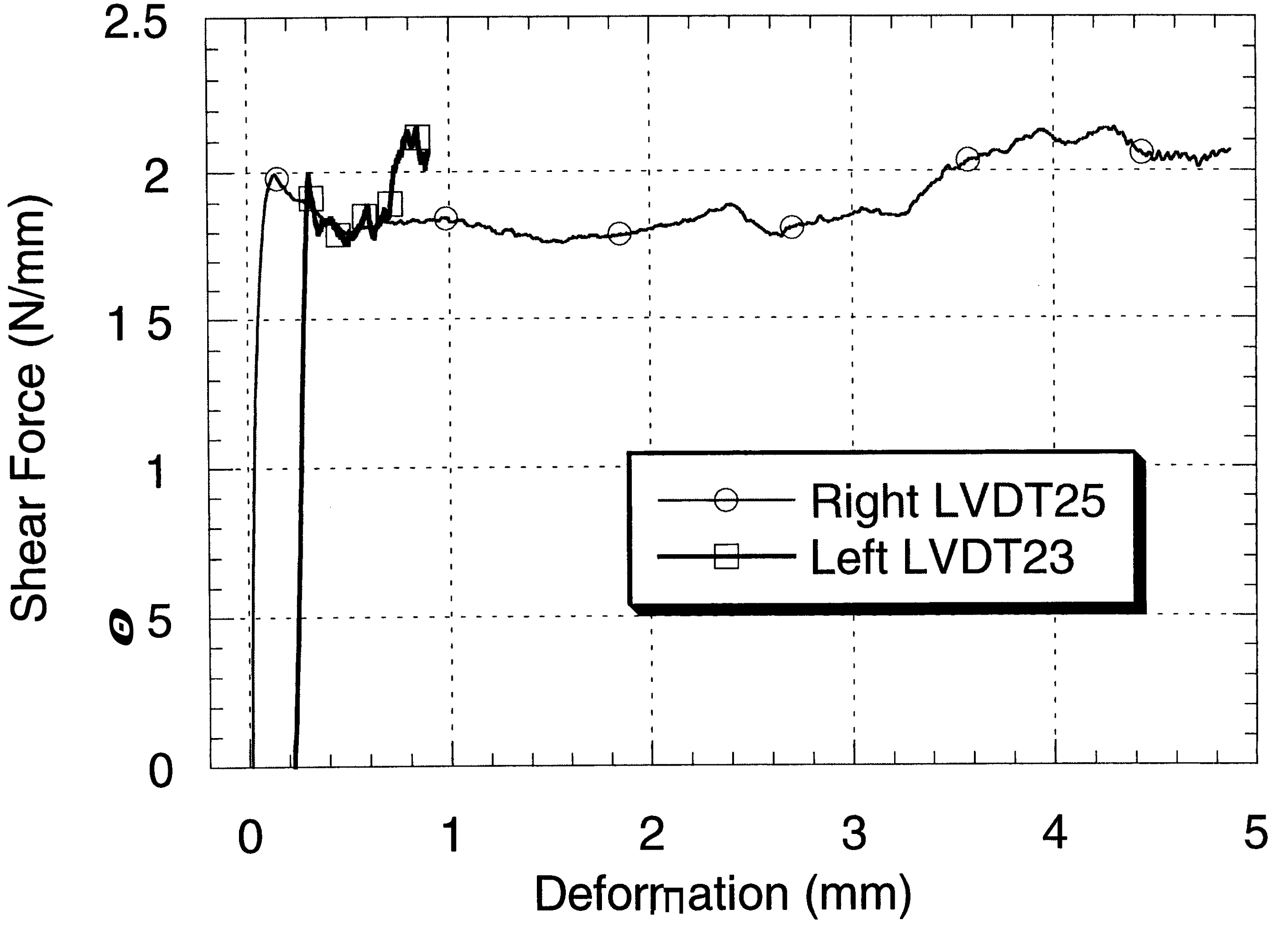


Fig. 17: Test IPST2b, In-Plane Shear Test, Toggle only

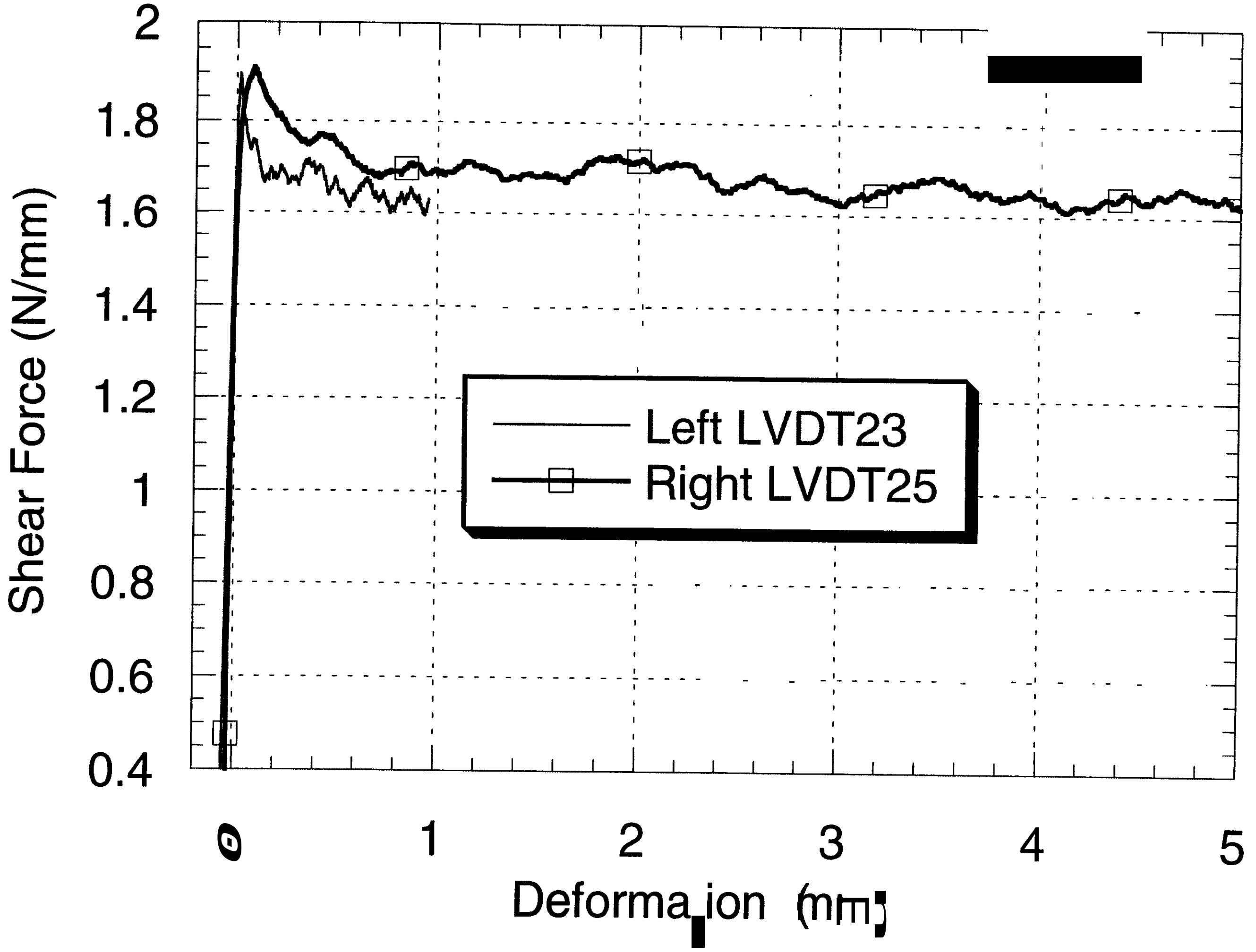


Fig. 18: Test IPST3, In-Plane Shear s&i Toggle only

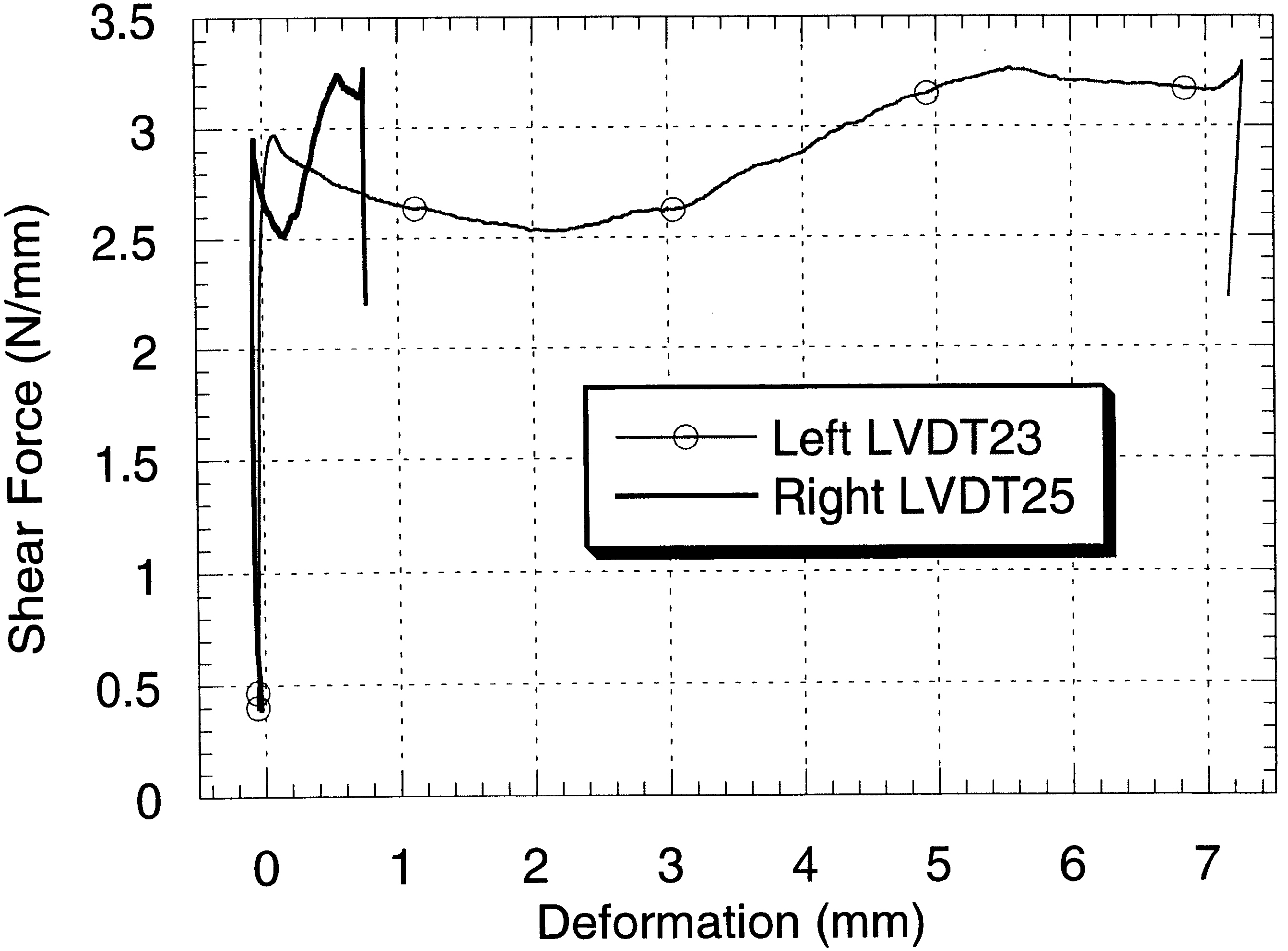


Fig. 19: Test IPST4, In-Plane Shear Test, Toggle only

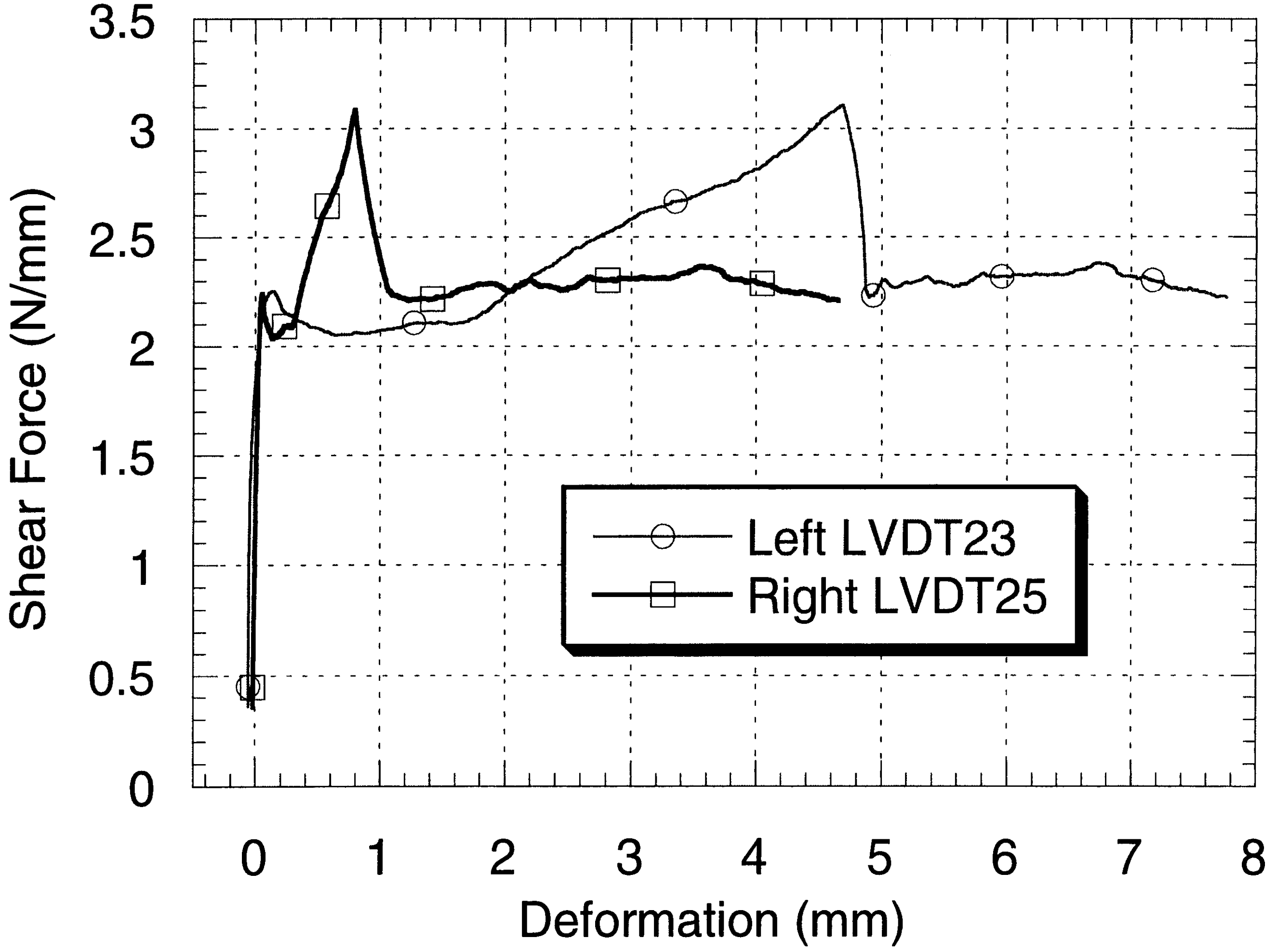


Fig. 20: Test IPST5a, In-Plane Shear Test, Toggle only

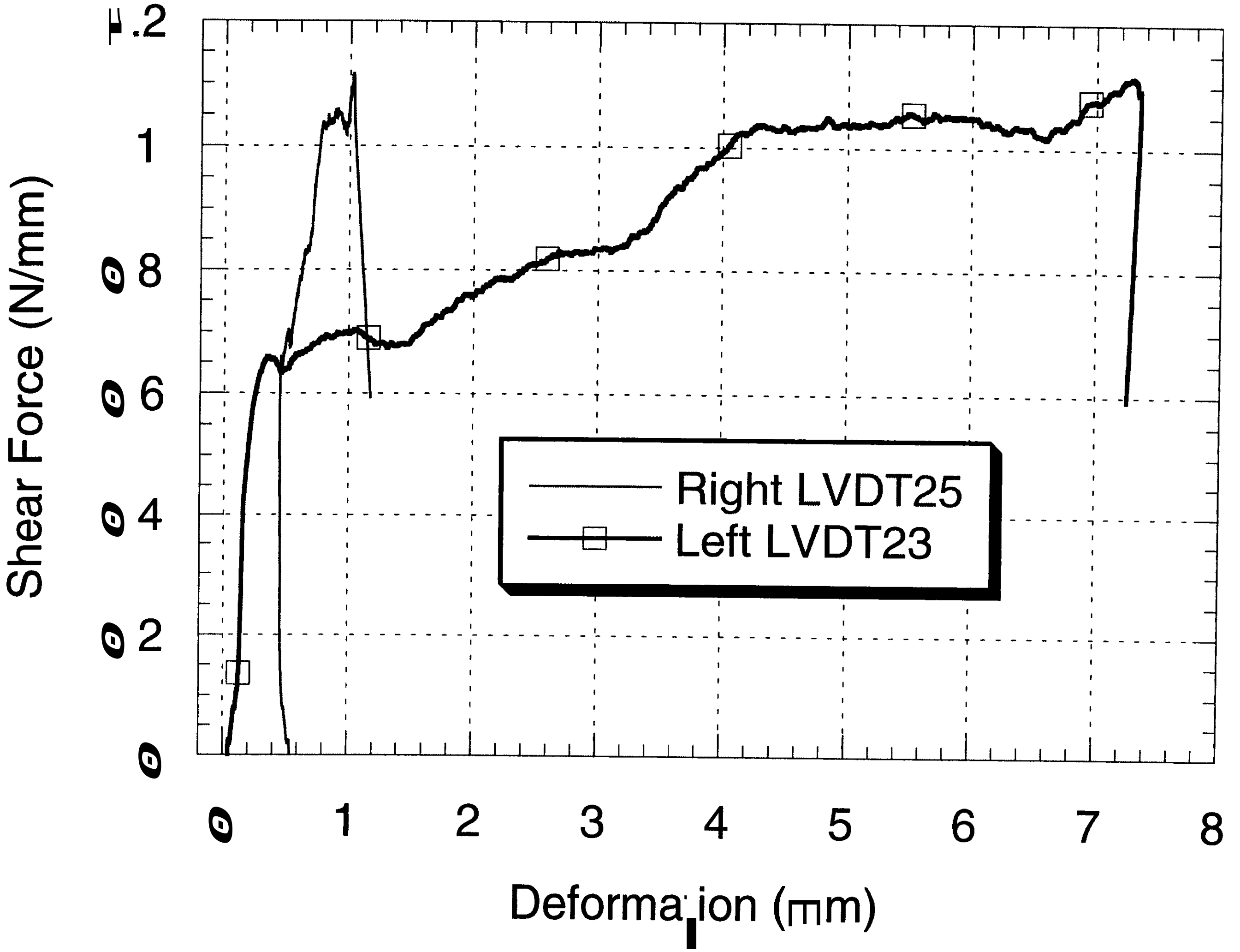


Fig. 21: st IPST5b, In-Plane Shear Test, Toggle only

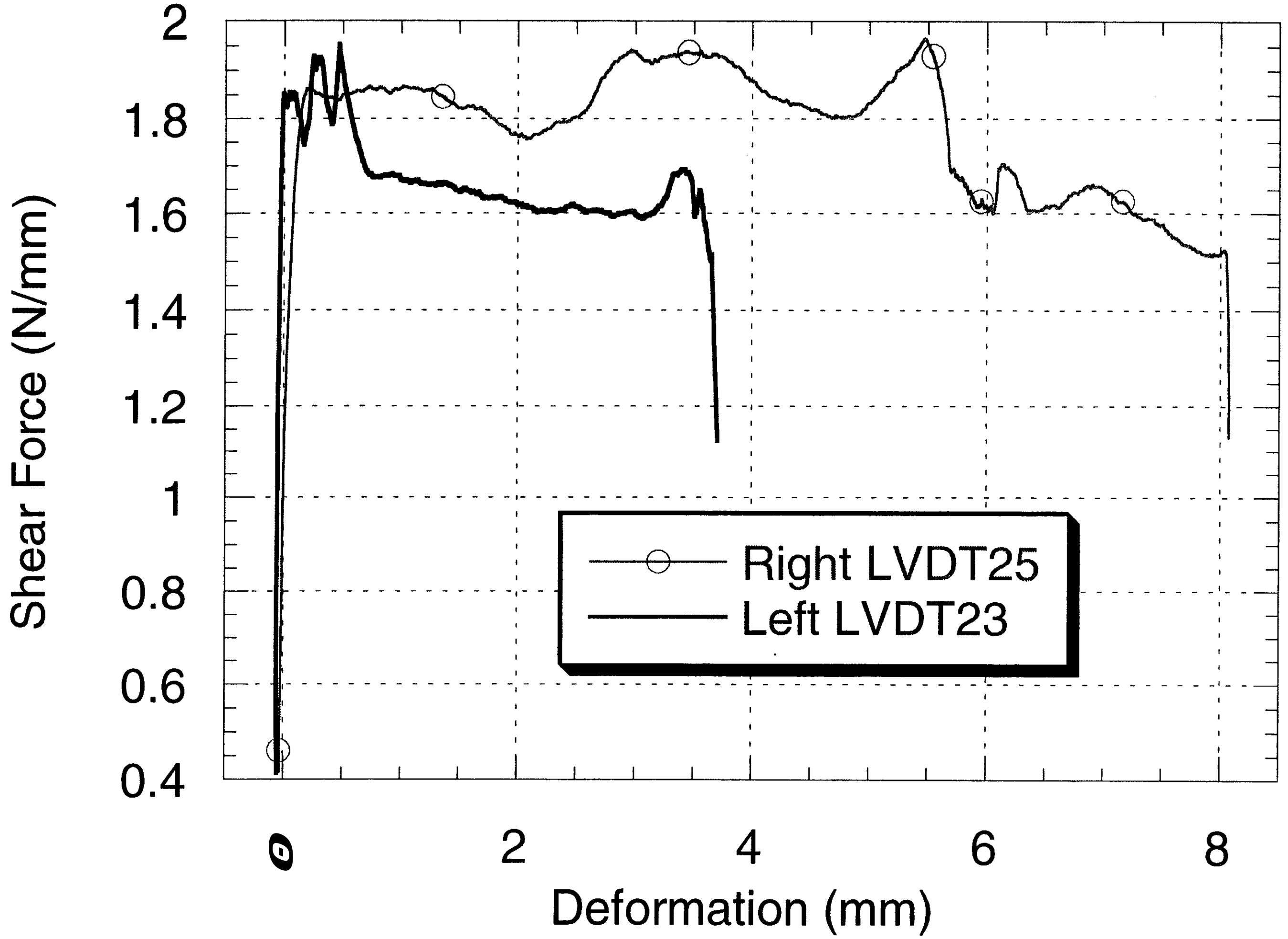


Fig. 22: Test IPSG1, In-Plane Shear Test, Glue Only