# Laboratory Experiments conducted on Reinforced Concrete Pipes

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ABSTRACT: Tests were conducted on three concrete pipes to evaluate the potential of composite reinforcement to eliminate shear failure, when the composites are applied to the inside of the pipe. Pipe was used in the experiments to simulate the cylindrical structure of an intake tower. All three concrete pipes contained the least amount of steel reinforcement possible. The first test resulted in pure flexural failure of the pipe. As a result, pipes in the second and third experiments had to be retrofitted with glass laminates to prevent flexural failure. These laminates were positioned on the bottom third of both pipes. After reproducing shear failure of the pipe walls in the laboratory experiments, it was determined that composite reinforcement would not be effective if applied to the inside wall of the pipe. This is because the inside wall of the pipe crushed in compression and did not fail in tension like a typical shear crack. This mode of failure was due to the biaxial bending in the pipe cross section. This behavior is not expected to occur in pipes with a higher thickness to diameter ratio than the 1/10 ratio used in these experiments.

## 1.1 *Concrete Pipe Specimen Details*

Center-point load tests were conducted on three separate concrete pipes. The inner diameter of the pipe was 24” and the pipe wall was 3” thick, with a W2.0 x W2.0 inside wire cage. Each specimen was 7.5’ in length. All three pipes had the same dimensions and internal steel reinforcement. The manufacturer also specified that the pipes were made from 4000 psi concrete.

The first specimen was tested without any modifications, but the last two were strengthened flexurally with three layers of glass plates (Fig. 1). The laminates on specimen 2 were adhered over their full length, while the middle third of the laminates on specimen 3 were intentionally left unbonded (Fig. 2). The laminates covered the lower third of each pipe. Specimen 3 was also retrofitted with wood (2x4) vertical stiffeners (see figure 3) to prevent localized punching failure, which was observed in the second experiment. The middle one third of the glass laminates was not bonded to simulate the possible defects during installation. This imperfection, however, did not affect the results, thereby indicating certain redundancy in this structural retrofit system.

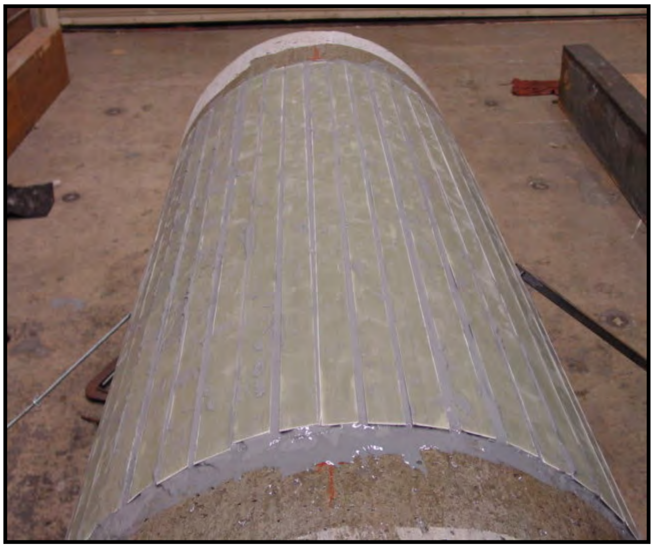

Figure 1. Glass laminates applied to lower third of specimen 2.

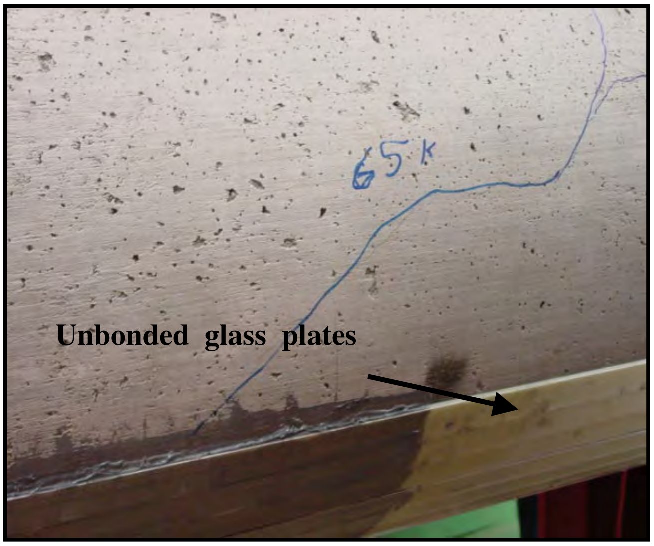

Figure 2. Partially bonded glass plates

Figure 3. Wood stiffeners used for specimen 3.

## 1.2 *Test Setup*

The beam test was conducted in the vertical load frame shown in Figure 4. This particular test frame is equipped with a 110 kip MTS actuator, which is supplied by a 30 gpm hydraulic pump. Load was applied at midspan with no lateral bracing. Pre-shaped supports were used at all load and reaction locations (Fig. 5). These supports were fabricated specifically to match the outer diameter of the pipes.

Figure 4. Test setup. Specimen 1 shown.

The span used for all three tests was 60”; however, the third specimen did not fail at that span. Hence, the span was then lengthened to 70” and specimen 3 was tested another two times. In the last test of specimen 3, all but four of the 2x4 wood stiffeners were removed (Fig. 6).

Figure 5. Pre-shaped supports.

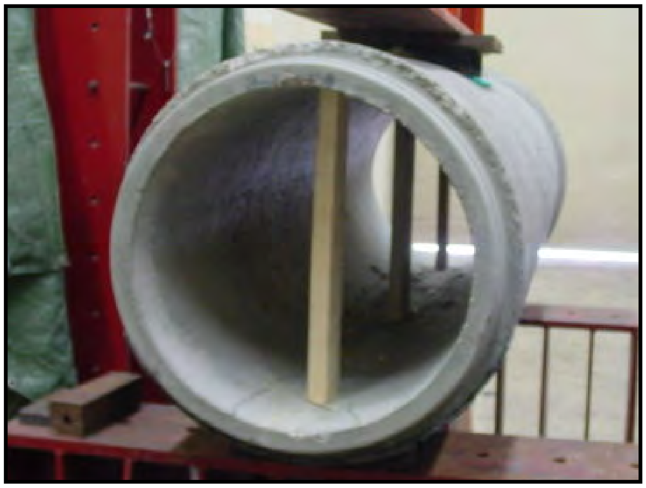

Figure 6. Test 3 of Specimen 3, with all but four vertical stiffeners removed.

## 1.3 *Testing Procedure*

Using a center-point load test setup, the retrofitted beam specimen was subjected to a continuous displacement by the 110 kip MTS actuator. Displacement control, as opposed to load control, was used because it is safer in a post-failure situation. The displacement rate for this test was 0.02 inch/minute, and was determined based on the desired 10-20 minute test duration. During the test, load and displacement was recorded from the actuator’s load cell and Linear Voltage Displacement Transducer (LVDT), respectively. This data can easily be plotted in Microsoft Excel or the like.

## 1.4 *Test Results*

**Specimen 1.** Without knowing the exact location and orientation of the internal steel reinforcement, it was assumed that the pipe would undergo a shear failure due to the short span. However, the minimal amount of longitudinal reinforcement was not sufficient to support this failure-mode, and the pipe failed flexurally (see figures 7 & 8). Specimen 1 achieved a 35.2 kip load before the failure, without any added reinforcement.

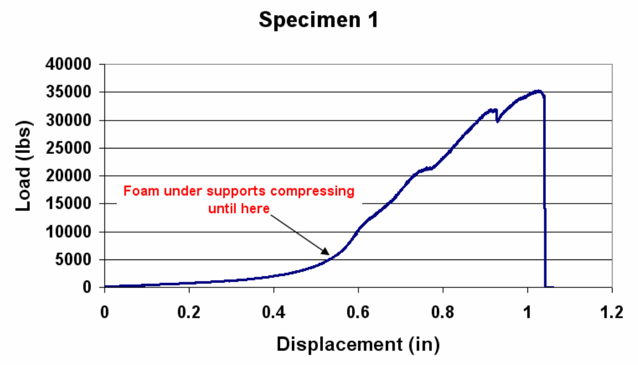

Figure 7. Load-Displacement Curve for Specimen 1.

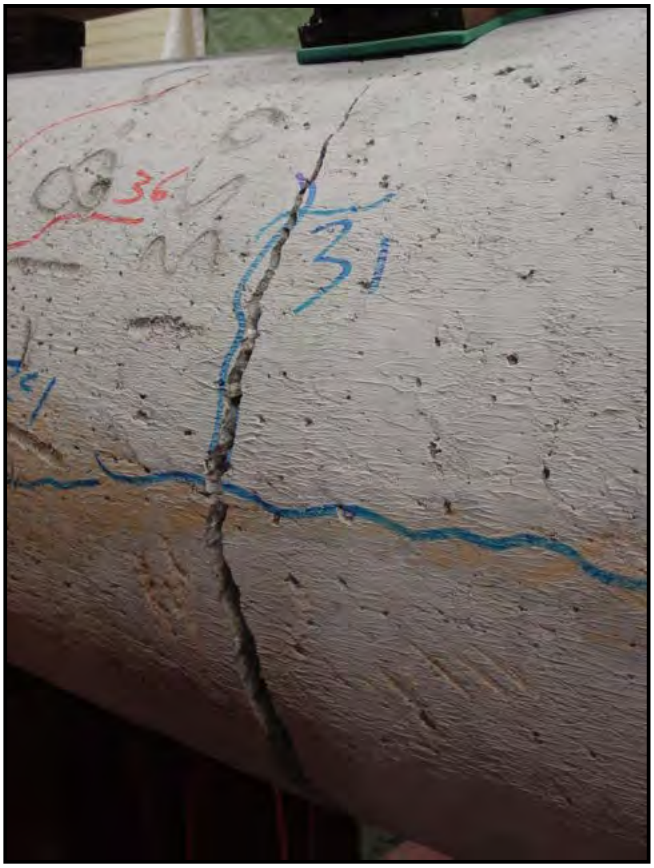

Figure 8. Flexural crack in Specimen 1.

**Specimen 2**. After witnessing the flexural failure in the first test, it was decided that the second pipe should be reinforced for flexure with glass plates to force a shear failure mode. The reinforcement proved to work well flexurally as shear cracks were developed in the second test (Fig. 9). Consequently, there was also a bearing failure at the point of applied load due to the increased flexural load capacity (Fig. 10). No delamination of the glass plates was observed. This specimen reached a maximum load of 50 kips, as shown in figure 11.

Figure 9. Shear crack in Specimen 2.

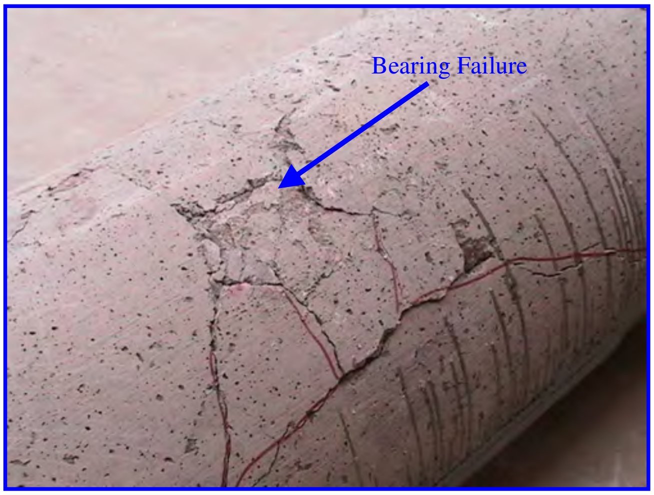

Figure 10. Bearing Failure under point of applied load.

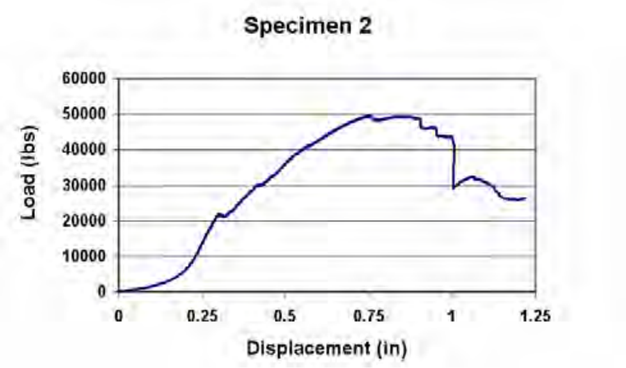

Figure 11. Load-Displacement Curve for Specimen 2.

**Specimen 3; Test 1.** Even after testing Specimen 2, the controlling failure mode was not well-defined. Because the intent was to develop a shear failure only, the third specimen was retrofitted to eliminate flexural, squashing and bearing failures. The third pipe was strengthened with the same glass plates to prevent flexural failure, except the middle third of the plates was left unbonded (Fig. 2). The pipe was also fitted with a row of vertical wood stiffeners, centered within the pipe in the plane of applied load (Fig. 3). Although these stiffeners may have been sufficient, another load plate was made and used to distribute the applied load over a larger surface area in an effort to prevent another bearing failure at that location. The first test of the third specimen showed that the pipe had been over-reinforced as it climbed to a maximum load of 104.6 kips with only minor cracking between 60 to 65 kips, as shown in figure 12.

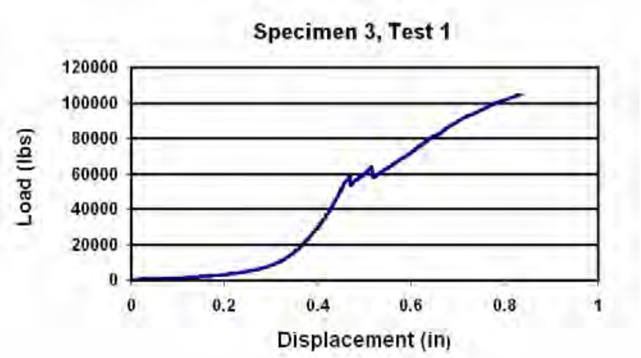

Figure 12. Load-displacement curve of Specimen 3, Test 1.

**Specimen 3; Test 2**. Because specimen 3 did not experience a shear failure and the actuator had reached its load capacity, the span was increased from 60" to 70" and the pipe was loaded again. All other parameters remained the same. Again, the results showed that the pipe was over-reinforced as it reached a maximum load of 105.2 kips with no drops in load capacity (Fig. 13).

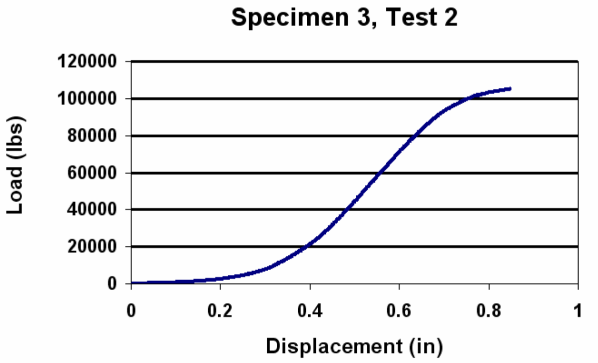

Figure 13. Load-displacement curve for Specimen 3, Test 2.

**Specimen 3; Test 3**. Based on the observations from the first two tests it was decided to remove all but four of the vertical wood stiffeners for the third test. The full row of stiffeners greatly enhanced the shear capacity of the beam and created an unrealistic model of the actual case. This proved to be true in the third test as the pipe reached a significantly lower maximum load of 78.4 kips (Fig. 14). A decreased load capacity was expected during the test because a dramatic widening of the shear cracks was observed (Fig. 15). Some localized punching failures were also observed at the locations of the vertical stiffeners (see figures 16 & 17).

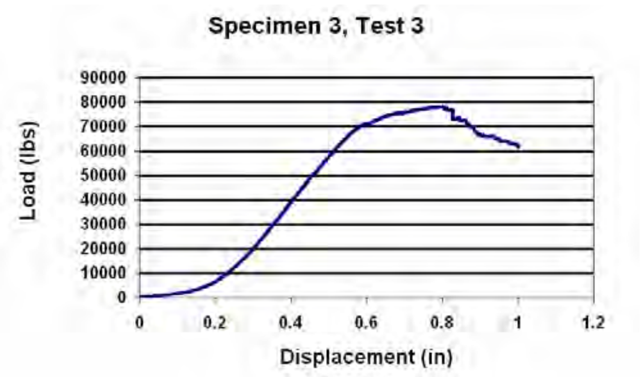

Figure 14. Load-displacement for Specimen 3, Test 3.

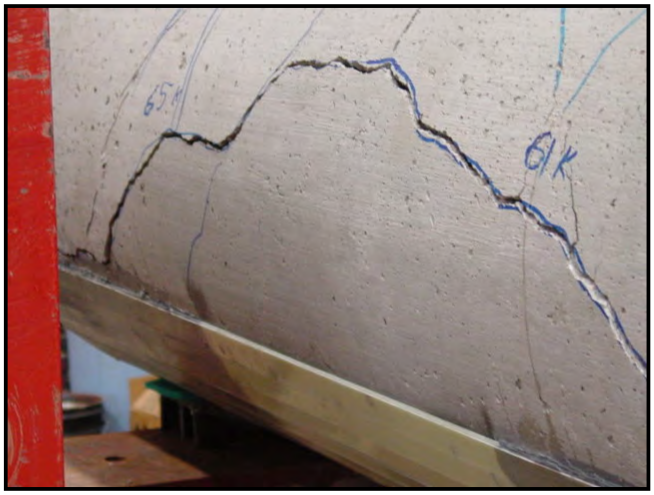

Figure 15. Enlarged shear crack in Specimen 3, Test 3.

Figure 16. Punching failure under vertical stiffeners of Specimen 3, Test 3.

Figure 17. Punching failure above vertical stiffener at the reaction support.

Figure 18. Spalling of concrete on inner wall of Specimen 3, along the shear crack.

## 2 CONCLUSIONS

The objective of this series of pipe tests was to determine the effectiveness of using composite reinforcement on the inside walls of concrete pipes to prevent shear failure. The first experiment revealed the primary failure mode of this particular pipe, while the results from experiments two and three were not as conclusive. The failure in specimens 2 & 3 was a combination of shear failure, local crushing failure and bearing failure at the support and load point locations.

Nevertheless, it was observed that the inner walls of the pipe were often in compression when the shear failures occurred. This was obvious for two reasons. First, the shear cracks were open on the outer wall and closed on the inner wall. Secondly, the spalling concrete on the inner wall along the shear crack appeared to buckle before dislodging (Fig. 18). It is the author's belief that this compression on the inner wall is primarily due to biaxial bending of the pipe section. For this reason, it can be concluded that reinforcing the inner wall of a concrete pipe with a thickness to diameter ratio of 1/10 or smaller will not be as effective as for pipes with larger thickness to diameter ratios. The reason being that if the inside wall fails in compression, the carbon fiber reinforcement must be designed for its compressive load carrying capacity which is roughly 1/3 of its tensile strength capacity. It is noted, however, that it is very likely that for higher ratios of thickness to diameter, the shear crack could open all the way through the section, resulting in tension crack failure on the inside surface. In these circumstances, the carbon laminate can be used very effectively. Additional tests would be required to confirm these conclusions.