COMPOSITE REPAIR OF RAILROAD CROSSTIES THROUGH THE PROCESS OF SHEAR SPIKING

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DISCLAIMER

ABSTRACT

COMPOSITE REPAIR OF RAILROAD CROSSTIES THROUGH THE PROCESS OF SHEAR SPIKING

Investigations into the effects Z-spiking with fiber reinforced polymer (FRP) rods have on the flexural stiffness and repair of deteriorated railroad crossties were conducted. These tests were conducted to provide a pilot study for an ultimate goal of repairing full-scale bridges. This report presents the results found from flexural load testing conducted on deteriorated Douglas fir railroad crossties reinforced with FRP shear spikes; epoxy-resin shear strength testing; and finite element modeling of repaired crossties. Reinforcement was provided by installing 12.7mm (0.5in.) diameter polyglass polyester resin fiberglass rods bonded in place using epoxy-resin. The rods were inserted into the deteriorated railroad crossties perpendicular to the primary bending axis to provide horizontal shear reinforcement and improve flexural stiffness. Shear spikes were installed in pairs starting at each end of the crosstie specimen and moving inward. Load tests were conducted to determine the gain in effective stiffness as the number of spikes increased. A total of ten rows were sequentially inserted into each crosstie specimen with load tests performed after each successive row installation. Results from load tests show an average increase in flexural stiffness of 58 percent with all ten rows of shear spikes inserted into the crossties. The results show the use of FRP shear spikes as a reinforcement method dramatically increased the flexural stiffness of railroad crossties and helped to offset the deterioration present from decay. In addition, the shear spikes and epoxy-resin show a strong possibility for repairing decay voids present on the surface of the deteriorated crossties as well as their interior portions.

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EXECUTIVE SUMMARY

In many installations timber railroad bridges that are 50-100 years old are necessary for daily operation. Numerous timber-based highway bridges exist too, primarily for secondary roads. The latter are often in jurisdictions where new construction funds are very limited. Hence, economical repair of bridges is vital to the nation's infrastructure. Fiber-reinforced composites are extremely popular for infrastructure and in situ infrastructure repair. Common approaches are fiberglass wrap (bandages) or adding reinforced plates (patches) to the sides of the members. These require the members be removed from the bridge for the repair to be made. They also degrade with time because of exposure. Alternatives to these techniques that do not require member removal and are embedded in the member are invaluable to low-cost, long-lasting repair.

A prior research project explored an innovative alternative to fiberglass wrap and patch repair techniques, termed z-spiking. Adapting this method, fiberglass rods (shear spikes) are inserted from the bottom to the top of a wood member passing through the areas of damage. Pre-drilled holes and an injected adhesive are used to bond the spikes to the wood. They serve to tighten the member to restore overall stiffness and add horizontal shear resistance, among other benefits. This procedure proved very successful in rejuvenating small wood specimens (based on nominal 2 x 2 and 2 x 4 dimension lumber). Repairs to layered and split members resulting in strong recovery of the flexural strength and stiffness comparable to undamaged control specimens. The work described is the outcome of a pilot study in which the technique was applied to larger wood members. A set of 35 deteriorated wood railroad crossties were incrementally reinforced with shear spikes. Load tests were conducted to asses the gain in stiffness (related to the non-reinforced condition) as the number of shear spikes increased. On average the gain after all spikes were inserted was 58 percent, with the range being 32 percent to 98 percent. An empirically-based analytical model was developed to determine the benefit to be gained by reinforcing a given crosstie if its non-reinforced stiffness is known.

Z-spiking provides a fundamentally new, more structurally effective, low-cost alternative to presently limited repair methods based on fiber composites. This project shows promise of leading to an invaluable technology for repairing aged timber bridges on short- and main-line railroads and on secondary roads. Continuation of the research to full-size bridge members is warranted.

1. INTRODUCTION

1.1 Introduction

Since its inception, the timber trestle railroad bridge has been a mainstay in the infrastructure of the United States. Although there has been a wide range of bridges that vary in design, size, and shape, these timber bridges have many features that are the same. These similarities include construction using solid sawn timbers, steel spikes and mechanical fasteners for connections, all are expected to carry the ever-increasing loads of the rail industry; and exposure to varying weather conditions. However, low shear strength parallel to the grain, shrinkage and swelling due to moisture variation, and the susceptibility to decay are drawbacks.

Loads carried by the rail cars and the speed at which they travel have significantly increased in the past 50 years. Double-stacked container trains have increased their loads to 32 Mg (35.7 tons), with an additional 10-20 percent increase projected for the near future.[5] The standard axle load for trains has remained constant at 27 Mg (30 tons) during that time but increased requirements are being considered. Although each bridge is essentially proof tested each time a train crosses, the actual consequence of heavier and faster trains to the safety of those bridges is of concern. Consequently, there has been extensive research performed to investigate the possibility of increasing the strength and stiffness of timber bridge elements. Existing strengthening techniques included replacing the worn or deteriorated members with new timbers,[3] installing fiber reinforced polymers (FRP) rods in the longitudinal direction near the tension face,[2] and complete encasement of deteriorated members with a fiberglass or carbon fiber sheet.[1]

Extensive research on improved ways to construct timber bridges and to prevent deterioration caused by decaying fungi has also occurred. The deterioration or decay of wood requires the presence of four conditions: sufficient oxygen, a favorable temperature range [0^{o}C to 32^{o}C (0^{o}F to 90^{o}F)], adequate food supply, and moisture content greater than the fiber saturation point of the wood.[3] Without all of these factors present the decaying fungi will not thrive and therefore will not deteriorate the timber members. Despite extensive research developments, in practice it is very difficult to completely prevent decay from occurring in a timber bridge. The key to making wood structural material last long is to make it unpalatable to decay fungi and microorganisms.[3] The most common approach is the use of various liquid preservatives that are applied to the exterior faces of a wood member. The preservative is either sprayed on, brushed on, or pressure injected and provides an outer layer of treated wood fibers that is toxic to the decaying fungi and other microorganisms. Figure 1 gives a visual illustration of a pressure-preservative-treated Douglas fir crosstie and the resulting depth of penetration.

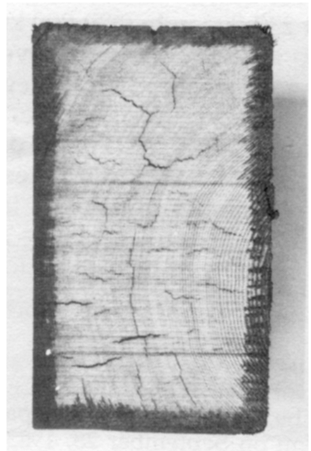

Figure 1. Solid sawn pressure-preservative-treated Douglas fir crosstie.[3]

Liquid preservatives remove the food component of the four conditions required for decay. One problem is that many existing timber bridges were pressure treated before they were constructed.[3] As a result, cracking and splitting can develop from transporting the members from a high moisture region to a lower one. Also, fasteners used to interconnect the members can penetrate the preservative layer and enter the non-treated core. This allows a path for the decay fungi to access the inner food supply. Muchmore suggests prefabricating as much of the bridge as possible before pressure treatment in order to eliminate any required field drilling or fabrication. Ref # 12 Figure 2 gives a visual representation of how fasteners allow moisture and decay fungi to migrate into the wood core and deteriorate the members from the inside.

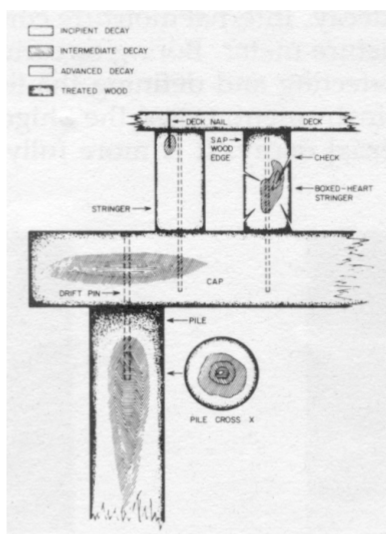

Figure 2. Schematic predicting where decay may occur.[3]

Where decay is present it can be assumed that loss of stiffness is proportional to the loss of sound wood in the section.[3] Since preservative treatment of the wood prevents surface decay and splitting along with mechanical fasteners allows decaying fungi entrance to the timber core, the decay process starts in the center of the cross-section. Therefore, the loss in stiffness for each deteriorated member can be attributed to the loss of sound wood in the interior regions. This loss of sound wood may also contribute to a decrease in horizontal shear performance in a flexural test along with a decrease in vertical shear performance in a pure shear situation.

The only method that can completely remedy the problems posed by a highly deteriorated bridge member is to replace the member. However, this is time consuming and expensive. Replacing members may require closing the bridge. It is also increasingly difficult to obtain larger size solid sawn timbers.

Present repair methods also only reinforce the exterior faces, and providing no direct effect on the interior decay voids present. An innovative alternative repair method called Z-spiking was recently devised. In this method small FRP rods are vertically (perpendicular to the primary bending axis) inserted through the sound wood of the exterior face into the deteriorated wood and then again into the sound wood on the opposite face.[7] Z-Spiking has evolved from aerospace-style laminated composites as it enhances the interlaminar shear performance of laminated sheets.[16] Thus, it offers the potential to reconnect fibers of separated material of a deteriorated timber beam.

The most common type of crosstie currently used in the United States railroad system (93 percent) consist of wood ties.[1] Advantages include, being lightweight, easily manufactured and installed, and having good energy absorption properties. However, wood crossties are susceptible to mechanical degradation such as splitting, checking, and damage from spikes and rail plates. Harsh environmental conditions increase the potential for rot and decay.[1] Various methods have been introduced to reduce these problems. These include the use of preservative treatments to control moisture absorption and decay fungi growth, and the use of anti-splitting devices to control splitting stemming from the crosstie ends under severe loads.[6]

1.2 Objective of the Study

The objective of this study is to examine the potential use of fiberglass pultruded rods (Z-Spikes) as a method to stiffen deteriorated railroad crossties. Z-spikes or shear spikes were used in conjunction with an epoxy resin and inserted into the crossties. The anticipated result was added horizontal shear strength to increase the flexural stiffness of the original deteriorated members. The technique was also expected to provide rehabilitation to the voids created by the decay fungi. Load tests were conducted to assess the effectiveness of the strengthening method. A prior study by Radford et al[7] demonstrated the effectiveness when used in much smaller members. The study described herein is a further step toward an ultimate goal of using it in very large members such as those used in timber railroad bridge stringers or piles.

2. SCOPE OF STUDY

2.1 Scope

Load testing was performed on repaired creosote-treated Douglas fir railroad crossties. The Z-spiking repair procedure was done using FRP shear spikes bonded in place by an epoxy resin. FRP shear spikes were inserted vertically, perpendicular to the primary bending axis, and bonded to the deteriorated crossties. The intent was to increase flexural stiffness, horizontal shear capacity, and repair local decay voids present near the shear spike insertion point. A statistical sample set of 35 crossties was used in this investigation. Twenty of the specimens were repaired incrementally. A three-point bending test was conducted on each crosstie. Load and deflection readings were recorded for each load test. An effective stiffness was calculated for each crosstie as a measure of the resulting gain in stiffness. Effective stiffness was taken as the product of the modulus of elasticity (MOE) and the cross-sectional moment of inertia and has units of force-length squared. This product, rather than the MOE value alone was used to denote stiffness because the crosstie specimens in this study had varying dimensions and varying surface conditions along their length. Thus, it was not feasible to accurately measure the moment of inertia for each specimen.

Specific values of increase were not the goal, as this study is a preliminary step in the ultimate goal of repairing and rejuvenating stiffness and strength in full-scale timber bridges. Instead, general trends of effective stiffness increase were examined. The sorting of material, load testing, and data acquisition methods chosen along with the data obtained from the thirty-five non-reinforced crossties and the twenty reinforced specimens are described. Separate load testing was also conducted to determine the shear strength of the epoxy-resin bond itself to determine how well the epoxy-resin bonded the FRP shear spikes to the wood fibers of the crossties. Finally, an empirical-based analytical model was developed using commercially available structural engineering software. Using this model, a reference chart was created to more easily predict how much effective stiffness could be attained if a crosstie was to be repaired.

2.2 Material Properties

The materials used included an available stock of timber railroad crossties, 12.7 mm (0.5 in.) diameter fiberglass pultruded rods, and the epoxy resin. The railroad crossties were solid sawn creosote-pressure-treated Douglas fir timbers of the dimensions listed in Appendix I. The average cross-section size was 165 mm X 213 mm (6.50 in. X 8.37 in.), as measured at their midpoint, and the average length was 258 cm (102 in.). For comparison with test results, strength properties were taken from the 1997 National Design Specifications (NDS) for Wood Construction Supplement Table 4D.[4] The tabulated values range from 6895 MPa to 11720 MPa (1,000,000 psi to 1,700,000 psi) and the flexural bending strength ranges from 4.5 MPa to 13 MPa (650 psi to1900 psi).

The pultruded rods are comprised of thin strands of fiberglass oriented in a unidirectional (longitudinal direction) manner and bonded with polyglass polyester resin. The Polyglass polyester resin used is a general-purpose resin for use with in-place temperatures up to 155°C.[6] The FRP bonded rods exhibit an average ultimate tensile strength of 483 MPa (70,000 psi), and a lengthwise compressive strength of 276 MPa (40,000 psi). For the 12.7 mm (0.5 in.) diameter FRP rods used herein, these tensile strength stress values correspond to a maximum tensile force of 61 kN (13.7 kips) and a maximum compressive force of 35 kN (7.85 kips), respectively. When subjected to bending, the fiberglass pultruded rods exhibit an average flexural modulus of 20,680 MPa ($3x10^6$ psi) at room temperature [21°C (70°F)] and an average value of 13,790 MPa ($2x10^6$ psi) at 100°C (212°F). The polyglass polyester resin fiberglass rods were chosen for this application because of the good corrosion resistance provided by the composite. The epoxy-resin used to bond the fiberglass pultruded rod to the railroad ties was developed by West Systems.[8] A wide variety of hardeners can be added to the liquid resin that vary the pot life and workability. The 105-epoxy resin product was used along with the 206-hardener product. This combination was chosen because of the ability of the components, when mixed, to effectively bond wood fibers as well as fiberglass and other polymer products. This epoxy and hardener combination has a longer resulting pot life and workability compared to the 205-hardener offered by West Systems. A mix ratio of 5 to 1, epoxy resin to hardener, allows for a pot life of 20-25 minutes with a cure to solid-state time of 10-15 hours. Final cure at maximum strength is achieved in 1-4 days. The time values stated above have variability due to temperature effects. The surrounding air temperature has a significant effect on the pot life and cure time. If ambient air temperature is lower than specified by the manufacture, the cure time can greatly increase due to the reduced heat available for the exothermic reaction to occur between the epoxy resin and the hardener. For all tests conducted in this investigation, the surrounding air temperature was monitored and ranged from 21°C to 30°C (70°F to 87°F) and was within the manufacturer's specification of 15°C to 32°C (60°F to 90°F).

2.3 Sorting

Prior to any drilling or shear spike insertion, the railroad ties were sorted into five general categories by the following procedures. These were established as high (H), medium-high (MH), medium (M), medium-low (ML), and low (L) and are based upon the physical condition of the crossties and their initial flexural stiffness.

The first sorting criterion, physical appearance, reflected the surface conditions of the crossties, how much material was present on each side, the extent of surface cracking present, and the general size of the surface cracks. It did not reflect the unknown quality of the interior wood fibers. To quantify these surface physical features, three sorting limits were established:

1. High quality appearance - Three faces with little or no cracks or deterioration. Cracks or splits of 127 mm (5in.) or less in length and less than 12.7 mm (0.5 in.) in width.

2. Medium quality appearance - Two faces with little or no cracks or deterioration. Cracks or splits of greater than 127 mm (5 in.) in length but not wider than 38.1mm (1.5 in.).

3. Low quality appearance – Significant cracks or deterioration on multiple faces Cracks or splits of greater than 127mm (5 in.) in length and wider than 38.1mm (1.5 in.).

Using these criteria the 35 crosstie specimens were sorted and the results were:

Table 1. Sample size for physical appearance sorting

Sample Sizes		
High	Medium	Low
5	17	13

The second sorting criterion utilized the initial effective stiffness values determined from a non-destructive load testing performed on each crosstie specimen in its original condition. This criterion reflected the quality of the timber fibers inside the crosstie section. The testing procedure for determining the initial effective stiffness is discussed subsequently. For sorting of the initial effective stiffness values, three criteria were established based upon the average value found from the sample set.

1. High quality stiffness – Greater than 10 percent above the average initial effective stiffness value.
2. Medium quality stiffness- Not more than 10 percent above and not more than 10 percent below the average initial effective stiffness.
3. Low quality- Greater than 10 percent lower than the average initial effective stiffness value.

Determination of the average value is discussed subsequently. These three criteria divided the 35 beam specimens into three smaller sample sets shown below:

Table 2. Sample size for initial effective stiffness sorting

Sample Size		
High	Medium	Low
8	15	12

Based on the combined results of the above sortings each crosstie was placed into a single final category. This was done by comparing and combining the sorted results for appearance and effective stiffness. The majority of the sample set did not have the equivalent sorted results for each case, so they were combined. As an example, if a high value was assigned for the appearance criterion and a high value was assigned for the effective stiffness criterion, then the final sorted value is high-high (H). A final sample size was then developed which was then used to determine which beam specimens were to be subjected to the shear spike tests. Table 3, below shows the samples sizes for each of the final grade categories.

Table 3. Final sorted sample size

Sample Size				
H	MH	M	ML	L
1	7	10	12	4

The selection of crossties to be subjected to reinforcement is discussed subsequently.

2.4 Shear Spike Installation

The shear spike installation process was started after the initial effective stiffness value of each of the 35 crosstie specimens was determined. A sample size of 10 specimens was taken from the medium- to high-quality range. To reduce the amount of epoxy resin to be mixed during an installation sequence, this group was then sub-divided into two subgroups of five each. To start the installation process, a row of two holes was drilled into the crossties near the ends. They were spaced at the one-third points across the crosstie width and located 18.3 cm (7.2 in.) from either end. Additional spikes were then incrementally added, working from each end toward mid span. Figure 3 illustrates the final shear spike layout along half of the specimen. Since each end had the shear spikes installed simultaneously the reinforced crosstie specimens were symmetric about their centerline after each increment. After each addition of shear spikes a load test was conducted.

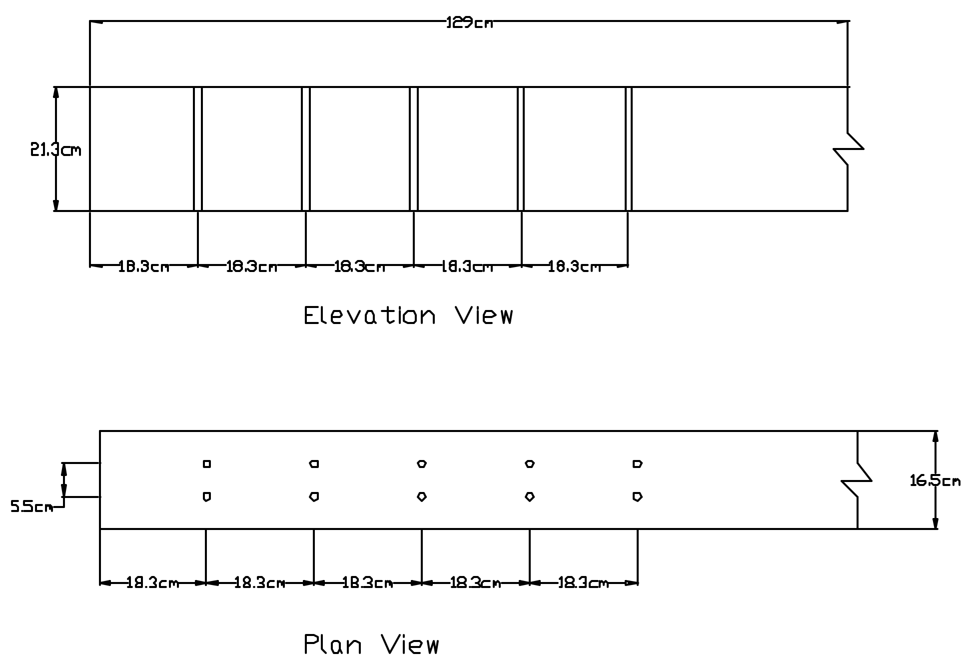

Figure 3. Shear spike layout

Spacing and layout of the shear spikes was based on past work done by Radford et al.[7] They used 12 shear spikes over a span of 1.22 m (4 ft) with a spacing of 88.9 mm (3.5 in.). The average total length of the railroad crossties used in the present study was 2.58 m (8.45 ft). This length is 2.11 times greater than the length of the nominal 2x4 specimens used by Radford et al.[7] Thus, the center-to-center distance between shear spikes used herein was a spacing of 18.3 cm (7.2 in). The value was obtained by multiplying the spacing used by Radford et al by 2.11.

Before proceeding to actual test specimens, four practice tests were performed by drilling and filling holes in a sacrificial Douglas fir crosstie. This enabled a determination of a preferred drilling technique and establishing a method and timing for mixing the epoxy resin. The practice holes consisted of two 12.7 mm (0.5 in.) diameter holes, one with 12.7 mm (0.5 in.) diameter constant throughout the depth of the crosstie and the other with a 14.3 mm (0.5625 in.) countersunk hole to a depth of 25.4 mm (1 in.). An example of a crosscut section is shown in

Figure 4. The third hole drilled was of 14.3 mm (0.5625 in.) constant diameter. The fourth hole was of 12.7 mm (0.5 in.) constant diameter. Epoxy resin and a shear spike were then inserted into three of the four holes. As shown in Figure 5, the fourth hole was only filled with epoxy resin to observe how well the epoxy resin coated the surface of the hole, as shown in Figure 5. The epoxy-resin was allowed to cure and each of the four holes was then cut cross-wise for a visual inspection.

Left - Constant 12.7mm (0.5 in.) diameter hole throughout the depth of the beam
Right - Constant 12.7mm (0.5 in.) diameter hole throughout the depth of the beam with14.3mm (0.5625 in.) diameter countersink.

Figure 4. Cross cut shear spikes

Constant 12.7mm (0.5 in.) diameter hole throughout the depth of the beam with no shear spike present.

Figure 5. Cross-cut with no shear spike

From the two cross-sections shown in Figures 4 and 5, it was determined that the epoxy resin bonds along the full length of the shear spike whether the hole was countersunk or not. However, a 14.3 mm (0.5625 in.) countersink provided an easier starting position to insert the shear spike into the specimens. Thus, a 12.7 mm (0.5 in.) diameter hole through the depth with a 25.4 mm (1 in.) deep, 14.3 mm (0.5625 in.) diameter countersink was used in all the actual specimens.

Initially, holes were drilled to half the depth of the specimen using a 9.5 mm (0.375 in.) diameter drill bit. This provided a relatively straight pilot hole for the more flexible 12.7 mm (0.5 in.) diameter drill bit. After the pilot holes were drilled, a 12.7 mm (0.5 in.) diameter auger drill bit was used to achieve the desired diameter. This was followed by a 14.3 mm (0.5625 in.) diameter paddle drill bit, which made the countersunk hole. Finally, a 12.7 mm (0.5 in.) diameter paddle drill bit was used to clean any wood fiber debris from the interior of the hole.

After preparing the holes, the shear spike rods were cut to length. Due to large variation in the crosstie depth dimension, each shear spike had to be custom cut to the actual depth at each location. This insured that the full depth of the hole was filled with the shear spike. After cutting the spikes to their desired length, the leading edges of the spikes were beveled to a sharp point using an angle grinder. This allowed the shear spikes to be driven into the beam specimens with less force and prevented the epoxy resin on the side of the hole from being scraped off by the sharp edge of the original straight cut spikes.

After cutting and beveling the shear spikes, the epoxy resin was mixed and injected into the drilled holes. As stated earlier, the mix ratio for the epoxy resin was five parts resin and one part slow hardener. This mix design was strictly monitored to ensure the quality and strength of the epoxy resin was consistent throughout the installation process. To start the mixing process the resin was poured into a large bowl and then the hardener was added. Using a paint stir stick, the liquids were then stirred to a milky-white consistency. Silica thickener was then added to increase the viscosity of the epoxy resin. This was done by general visual inspection as the liquid was mixed, thus the exact amounts of thickener added are unknown. The final viscosity was similar to that of whipped cream or baker's frosting. The viscosity of the resin was very important because it had to be thick enough to allow the resin to remain in the drilled hole without dripping out until the shear spike was driven. It also had to be thin enough to be injected into the hole using a refillable caulking tube.

The mixed epoxy resin was poured into the refillable caulking tube and injected into the drilled holes of the beam specimens. Upon filling the holes, the shear spikes were driven into the holes using a large block of wood instead of a hammer. This prevented the shear spikes from splintering because of the impact. Upon installation of an increment of spikes, the railroad crossties were left in place for 2 days to allow the epoxy resin to fully cure and bond the shear spikes to the wood fibers. Figure 6 shows two crossties with all ten pairs of shear spikes installed.

Figure 6. Crossties with shear spikes installed

2.5 Load Limit

Load tests determined the effective stiffness values of the crossties. To insure loading was within the elastic range of the specimens, a safe upper limit on the applied load was determined. By keeping the applied load below the upper limit, the possibility of causing damage to the crossties was reduced. A load value of 28.9 kN (6.5 kips) was applied to each of the beam specimens and was calculated using equation (1), the Euler beam equation for a single span beam with a concentrated load at the midpoint. In equation (1), P is the load applied at mid span, L is the clear span between the two supports, E is the modulus of elasticity, I is the moment of inertia and ? is the vertical deflection.

$$\Delta = \frac{PL^3}{48EI} \qquad \text{Equation (1)}$$

A clear span length of 208 cm (82 in.) and an imposed deflection of 25.4mm (1 in.) were used in the tests. The average moment of inertia of the 35 specimens, 13,400 cm^4 (322 in^4) (measured at the midpoint) was used for all specimens. Specimens were of an unknown location of origin; therefore an MOE value of 8270 Mpa (1,200,000 psi) was used and was taken for the Douglas Fir Larch (South) listing in the 1997 NDS wood design specifications.[4] Using equation (1) a calculated required load of 150 kN (33.6 kips) resulted. An arbitrary reduction of this value of about 80 percent resulted in a value of 28.9 KN (6.5 kips) being adopted. This 28.9 kN (6.5 kips) was then substituted into equation (2), the extreme fiber-bending stress equation, to calculate the corresponding bending stress. In equation (2), $M = \frac{PL}{4}$ and C is the distance from the centroid of the section to the extreme bending fibers. The stress calculated from the 28.9 KN (6.5 kips)

$$f_b = \frac{M_{\max} C}{I} \qquad \text{Equation (2)}$$

applied load is 12.3 Mpa (1.79 ksi and is close to the 10.6 Mpa (1.55 ksi) allowable stress value tabulated in the NDS, therefore deemed acceptable.

2.6 Load Testing Procedure

2.6.1 Initial Effective Stiffness

Before installing any spikes, the 35 beam specimens were each load tested to the 28.9 KN (6.5 kips) load level. This provided a base effective stiffness value for each of the crossties to later be compared with the values determined after each increment of shear spikes was installed.

A schematic of the test setup is shown in Figure 7. A ramp loading in a three-point bending test, using an MTS hydraulic actuator, was used. The test specimen was supported at its ends by two 35.6 cm (14 in.) diameter concrete cylinders topped with steel half cylinders. It had a clear span length of 208.3 cm (82 in.).

Deflection was recorded at the mid span location, using a single string potentiometer fixed to the bottom side of the specimen. The load rate was 0.0381mm/sce (0.0015 in/sec). Deflection readings were taken at 4.45 KN (1 kip) intervals during the ramp loading process; with a final reading taken at the maximum load level of 28.9 KN (6.5 kips).

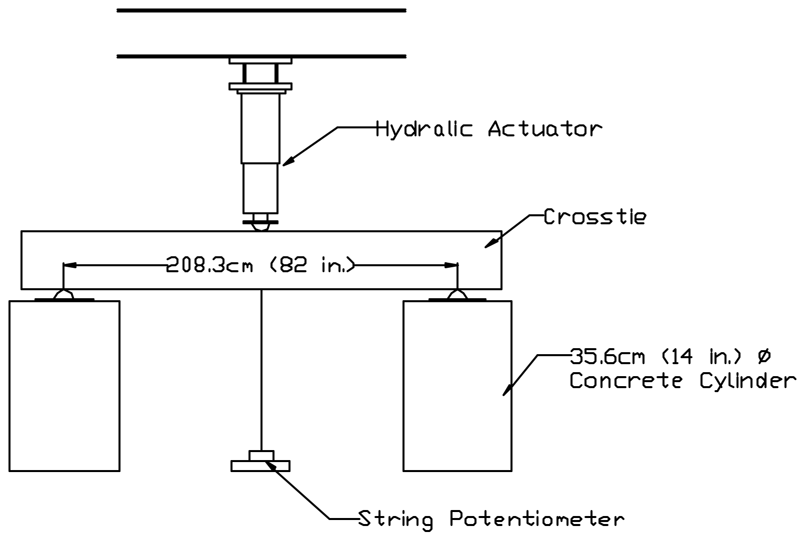

Figure 7. Crosstie load test setup

The specimen was unloaded in the same manner, taking deflection readings at the same load intervals in reverse. Before removal from the load frame, the specimen was marked for orientation to insure that for the subsequent shear spike tests it would be placed in the same orientation. Its moisture content was also measured at eight points near the midpoint of the span using a Delmhorst electrical resistance meter and recorded. The moisture content of the 35 specimens ranged from 7 percent to 12 percent and the mean value was 9 percent. The individual crosstie moisture content results are documented in Appendix I.

The load-deflection data were stored in an Excel spreadsheet and subsequently plotted graphically. The slope of the load-deflection plot was taken, as P/? in Equation 1. Equation 1 was then solved for the initial effective stiffness value [EI].

2.6.2 Shear Spike Testing

After the epoxy cured for two days, the specimen was ramp loaded in the same manner as the initial testing procedure. Care was taken to insure the placement of the crosstie was essentially the same as in the initial testing position. After the beam specimen was load tested, it was removed from the load frame and prepared for the installation of the next row of shear spikes. The following installation and loading process was followed for each of the five rows (per half span): install the shear spikes, allow to cure for two days, and ramp load to the specified 6.5 kips. Testing was first performed on the set of 10 beam specimens classified as medium- to high-quality since they had the best quality material present. The lower-quality beams were left to allow the researchers, if necessary, to modify the installation method or alter the shear spike locations to improve the stiffness rejuvenation process. Upon completing load tests on the medium- to high-quality specimens, the set of 10 lower-quality specimens were subjected to the same shear spike installation and load-testing procedures.

3. TEST RESULTS

3.1 Initial Effective Stiffness

As stated earlier, the 35 crosstie specimens were tested to determine their initial effective stiffness. Tables 4 and 5 show these individual measured values along with the sorting categories assigned to the corresponding specimens. A significant variability in initial effective stiffness was observed, i.e. values ranged from 562 kN-m^2 to 1388 kN-m^2 (1359 k-ft^2 to 3360 k-ft^2). Average values within each sorting grade are listed in Table 6. The overall average value of initial effective stiffness was 837 kN-m^2 (2025 k-ft^2) with a standard deviation of 192 kN-m^2 (464 k-ft^2). Further results are presented in Appendix II.

Table 4. Initial effective stiffness and corresponding overall sorted-quality of non-reinforced crossties

Specimen	EI (kN-m^2)	Quality
1	861	M
2	872	M
3	828	M
4	1182	H
5	968	MH
6	1116	MH
7	714	L
8	1388	MH
9	694	L
10	799	MH
11	647	M
12	762	M
13	879	ML
14	947	MH
15	598	ML
16	986	MH
17	561	ML
18	919	M

Specimen	EI (kN-m^2)	Quality
19	741	ML
20	884	M
21	582	ML
22	909	ML
23	616	ML
24	827	MH
25	1060	M
26	778	M
27	1254	M
28	642	M
29	755	ML
30	804	ML
31	758	ML
32	615	L
33	831	ML
34	750	L
35	753	ML

Average (kN-m^2)	837
Standard Deviation (kN-m^2)	192
Coefficient of variation	0.23

Table 5. Unreinforced crosstie specimens sorted by quality

Specimen	EI (kN-m^2)	Quality	Specimen	EI (kN-m^2)	Quality
4	1182	H	28	642	M
8	1388	MH	22	909	ML
6	1116	MH	13	879	ML
16	986	MH	33	831	ML
5	968	MH	30	804	ML
14	947	MH	31	758	ML
24	827	MH	29	755	ML
10	799	MH	35	753	ML
27	1254	M	19	741	ML
25	1060	M	23	616	ML
18	919	M	15	598	ML
20	884	M	21	582	ML
2	872	M	17	561	ML
1	861	M	34	750	L
3	828	M	7	714	L
26	778	M	9	694	L
12	762	M	32	615	L
11	647	M			

Table 6. Average non-reinforced EI by quality

Grade	Average EI (kN-m^2)
H	1182
MH	1005
M	864
ML	831
L	693

3.2 Medium- to High-Quality Group

In the next stage of the study, the group of 10 medium- to high-quality crossties was subjected to the shear spike reinforcement and load test procedures. Results are presented in Table 7 which shows the effective stiffness and percent increase corresponding to each shear spike row installation. The installation of one row of spikes at each end of the specimens increased the average effective stiffness of the ten specimens to 1178 kN-m^2 (2852 k-ft^2), with a standard deviation of 383 kN-m^2 (927 k-ft^2). This constitutes an average 20.3 percent increase above the initial average effective stiffness value of 973 kN-m^2 (2354 k-ft^2) observed for the 10 medium- to high-quality specimens. With all five rows of shear spikes present, the resulting average value was 51 percent above the initial effective stiffness. Thus a dramatic increase in the effective stiffness occurred, overall.

Table 7. Effective stiffness increase for reinforced medium- to high-quality specimens

Specimen	Quality	Initial EI (kN-m²)	Row 1		Row 2		Row 3	
			EI (kN-m²)	% Change from Initial	EI (kN-m²)	% Change from Initial	EI (kN-m²)	% Change from Initial
2	M	872	942	8.0%	1489	70.7%	1545	77.1%
3	M	828	788	-4.9%	1192	43.9%	1294	56.2%
4	H	1182	1592	34.7%	1563	32.3%	1638	38.6%
5	MH	968	1345	38.9%	1276	31.8%	1341	38.5%
6	MH	1116	1073	-3.8%	1700	52.3%	1704	52.7%
8	MH	1388	2019	45.5%	2127	53.2%	1856	33.7%
16	MH	986	1184	20.1%	1353	37.2%	1456	47.6%
18	MH	919	968	5.3%	1213	31.9%	1218	32.4%
20	M	884	1065	20.5%	1179	33.4%	1149	30.0%
21	ML	582	807	38.6%	763	31.1%	814	39.9%
	Average	973	1179	20.3%	1386	41.8%	1401	44.7%
	Standard Dev.	219	383	0.186	365	0.132	305	0.143

Specimen	Quality	Row 4		Row 5	
		EI (kN-m²)	% Change from Initial	EI (kN-m²)	% Change from Initial
2	M	1363	56.2%	1567	79.6%
3	M	1024	23.6%	1285	55.2%
4	H	1597	35.1%	1843	56.0%
5	MH	1307	34.9%	1346	39.0%
6	MH	1668	49.4%	1523	36.4%
8	MH	2148	54.7%	2648	90.7%
16	MH	1435	45.6%	1426	44.6%
18	MH	1124	22.2%	1237	34.5%
20	M	1160	31.2%	1171	32.5%
21	ML	800	37.5%	822	41.2%
	Average	1363	39.1%	1487	51.0%
	Standard Dev.	381	0.121	489	0.199

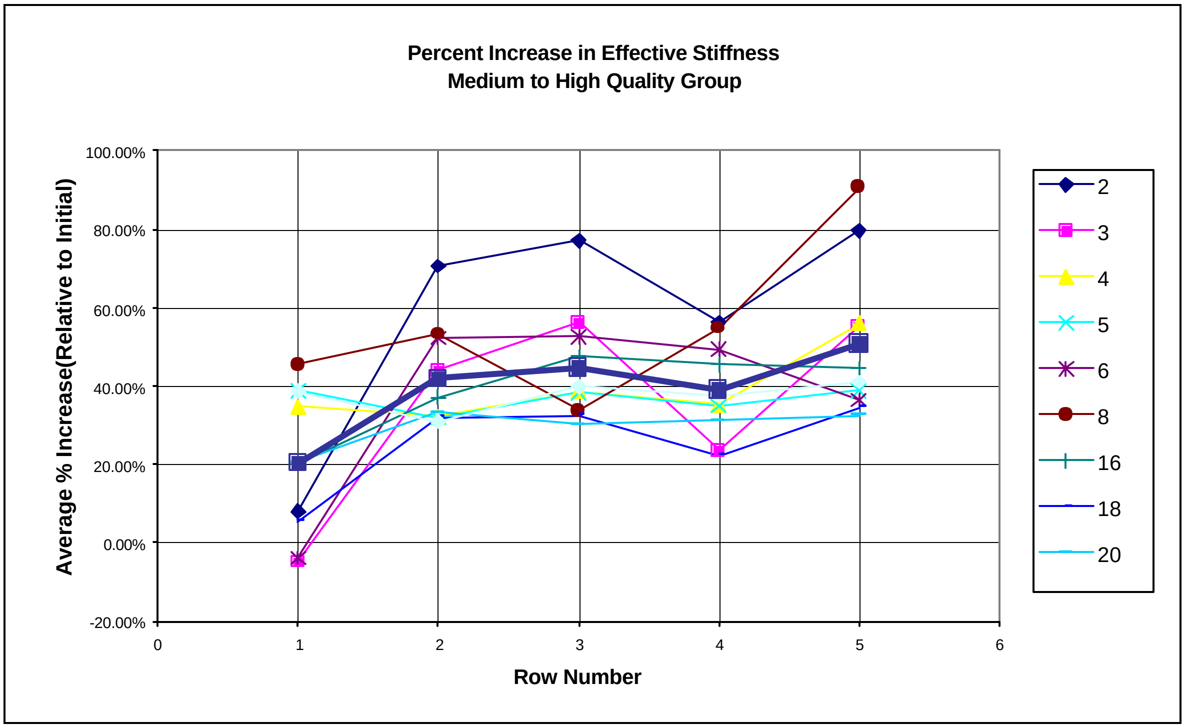

Figure 8. Average percent increase in effective stiffness for medium- to high-quality group

Figure 8 illustrates how the effective stiffness of each medium- to high-quality crosstie specimen increased (or decreased) as each row of shear spikes was inserted. In the plot the average value of effective stiffness increase is denoted by a bold line. It is evident that a wide variation in the effective stiffness gains occurred with an increasing trend for the first two shear spike rows and a plateau state for the remaining. However, some discrepancies were observed. As evident in Figure 8, the data set for eight of the 10 specimens showed a decrease in effective stiffness when the fourth row of shear spikes was installed. Perhaps the wood material removed to install the shear spike was sound material. Consequently, installing the shear spike where it was not necessary left a decayed void without a repair. By leaving the decayed void without a repair the shear spike was not used for its purpose. This drop in effective stiffness could also be due to an error in the epoxy resin mixture. If too much or too little hardener is added to the epoxy resin the cure time can vary widely resulting in the epoxy not reaching the desired strength in the two-day cure time allotted. This is believed to be the most likely cause of this drop because eight of the 10 specimens exhibited similar patterns. It is highly unlikely that sound material was removed from each of eighteen holes drilled for the nine specimens. It was also visibly observed that some epoxy resin was forced out of the hole when the shear spikes were installed. When the fifth row of shear spikes was inserted, six of those eight that showed a prior decrease exhibited an increase in their effective stiffness. Further graphical results are shown in Appendix III.

The effect of shear spikes in increasing the effective stiffness when installed beyond the clear span region was investigated. The first row of shear spikes inserted into the crossties was outside this region. In Figure 8, it is evident there is a wide range in resulting stiffness changes or this set of shear spikes, –5 percent to 45.5 percent. Two of the 10 crosstie specimens showed a decrease in effective stiffness while the other eight showed an increase. The reason for this wide range is unknown. However, the general trend shows an increase in effective stiffness can be achieved by installing shear spikes beyond the bounds of the clear span region. This phenomenon was previously observed in smaller specimens studied by Radford et al.[7]

3.3 Lower-Quality Group

The second set of crossties to be subjected to shear spike reinforcement and load testing was the lower-quality group. The results obtained from these load tests exhibited similar trends as the medium- to high-quality group on the effect the shear spikes had in increasing the crosstie effective stiffness. Table 8 lists the results obtained from the load tests conducted. The data presented has a wide range in effective stiffness gains. As is evident, the installation of one row of shear spikes increased the average effective stiffness to 1030 kN-m^2 (2500 k-ft^2). This is a 50 percent (standard deviation of 12.1 percent) increase from the initial average effective stiffness of 692 kN-m^2 (1680 k-ft^2). Once all five rows of shear spikes were present, the average effective stiffness was 1150 kN-m^2 (2780 k-ft^2), i.e. a 66 percent (relative to initial) increase with a standard deviation of 16.7 percent.

The graphical plot in Figure 9 shows how the effective stiffness of each lower-quality crosstie specimen increased as the shear spike rows were inserted. The average value of effective stiffness increase is denoted by the bold line. It is evident that there was a wide variation in the effective stiffness gains, but with a general increasing trend of increasing magnitude as spikes were inserted. The severity of decay present in this sample set was extreme. Thus, it is difficult to determine why some of the crossties had very significant effective stiffness increases, greater than 70 percent, and others had moderate effective stiffness increases comparable to the medium- to high-quality group. However, the average effective stiffness increase for this sample set shows a much higher value through all five rows of shear spikes than the medium- to high-quality group and an increase for each row of shear spikes inserted.

Table 8. Effective stiffness increase for reinforced lower-quality specimens.

Specimen	Quality	Initial EI (kN-m^2)	Row 1 EI (kN-m^2)	Row 1 % Change from Initial	Row 2 EI (kN-m^2)	Row 2 % Change from Initial	Row 3 EI (kN-m^2)	Row 3 % Change from Initial
7	L	714	1008	41.2%	1035	45.1%	1065	49.2%
9	L	694	1003	44.6%	1110	59.9%	1079	55.5%
13	ML	879	1340	52.4%	1283	46.0%	1336	52.0%
15	ML	598	854	42.9%	882	47.6%	933	56.1%
17	ML	561	965	71.9%	1016	81.0%	996	77.4%
19	ML	741	1138	53.6%	1395	88.3%	1352	82.5%
23	ML	616	1018	65.2%	1076	74.5%	995	61.4%
32	L	615	818	33.0%	806	31.1%	900	46.3%
34	L	750	1037	38.2%	1076	43.4%	1471	96.1%
35	ML	753	1142	51.7%	1148	52.5%	1137	51.0%
	Average	692	1032	49.5%	1083	56.9%	1126	62.7%
	Standard Dev.	96	150	0.121	172	0.185	195	0.167

Specimen	Quality	Row 4 EI (kN-m^2)	Row 4 % Change from Initial	Row 5 EI (kN-m^2)	Row 5 % Change from Initial
7	L	1051	47.4%	1052	47.5%
9	L	1067	53.7%	1115	60.7%
13	ML	1362	55.0%	1382	57.2%
15	ML	932	55.9%	994	66.3%
17	ML	1085	93.3%	1061	89.0%
19	ML	1413	90.7%	1471	98.6%
23	ML	1074	74.3%	1004	62.9%
32	L	799	30.0%	799	30.0%
34	L	1481	97.4%	1468	95.6%
35	ML	1136	50.8%	1134	50.6%
	Average	1140	64.8%	1148	65.8%
	Standard Dev.	216	0.227	222	0.223

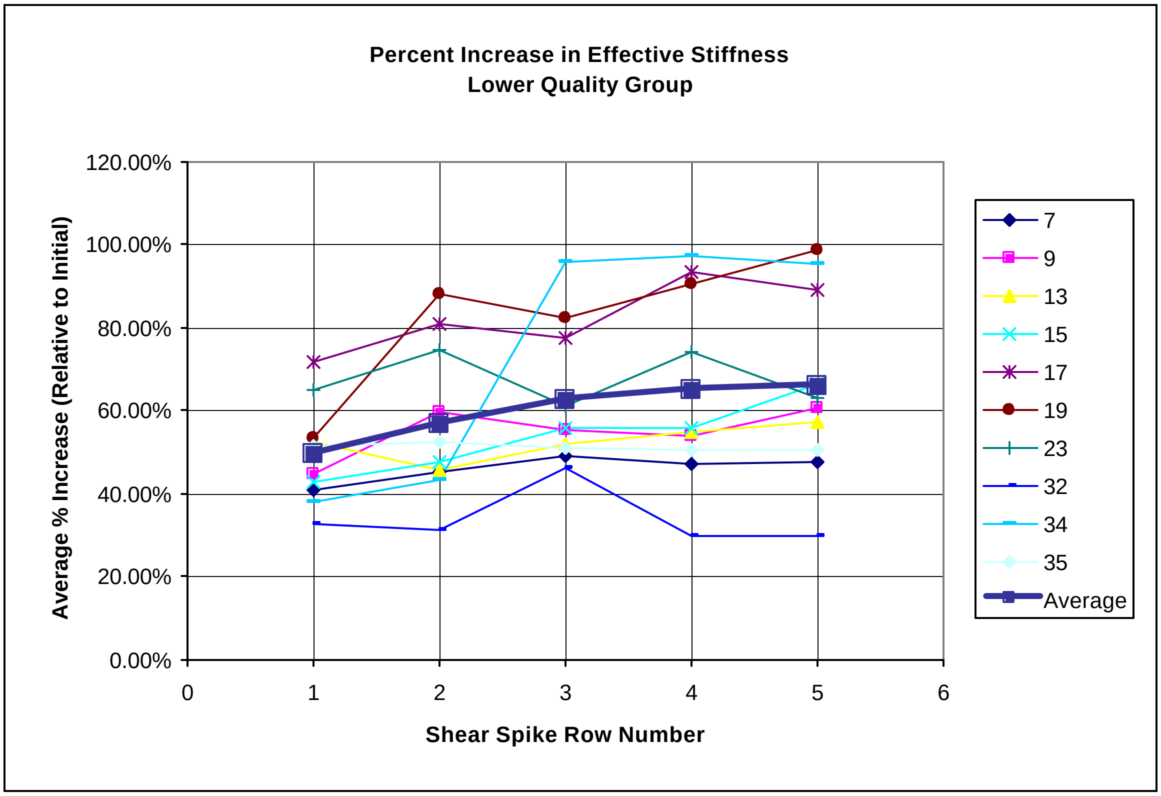

Figure 9. Average percent increase in effective stiffness for the lower-quality group.

In Figure 9, the average values of percent increase in effective stiffness shows a definite trend toward a plateau. This plateau is reached further along in the shear spike installation process, indicating the shear spikes have a greater effect on very-poor-quality specimens as compared to the medium- to high-quality group. This is most evident in specimen 34. As the shear spikes were installed the effective stiffness increased 38 percent with one row and up to 95 percent when all five rows were present. Further results are presented in Appendix III.

The effect of shear spikes in increasing the effective stiffness when installed beyond the clear center-span region was again investigated. The first row of shear spikes was inserted 64 mm (2.5 in) outside of the supports at each end of the crossties. Figure 9 shows this increase in effective stiffness ranges from 33 percent to 72 percent.

3.4 Repair Procedure Cost

Table 9 gives a price listing for each material required for the repair procedure, and the labor time associated. The total cost (prep time, materials, and installation of the shear spikes) was calculated to be $67.49/crosstie.

Table 9. Repair cost per crosstie

	Material Cost		
	Length per crosstie [ft]	Cost per foot	Cost
FRP (shear spike)	14	$0.96	$13.44
	Cost per quantity	Crossties per quantity	Cost
Epoxy-Resin	$70.00	10	$7.00
Hardener	$27.00	10	$2.70
Refillable Tubes	$6.00	10	$0.60
		Total Cost	$23.74

	Labor Cost			
	Hourly Wage	Time Required per hole [min]	Number of holes	Cost
Drill Holes	$15.00	5	20	$25.00
Measure and Mix epoxy-resin (5min)	$15.00			$1.25
Inject epoxy-resin	$15.00	0.5	20	$2.50
Cut Shear Spikes	$15.00	2	20	$10.00
Install Shear Spikes	$15.00	1	20	$5.00
			Total Cost	$43.75

Total Material Cost	$23.74
Total Labor Cost	$43.75
Total Cost	$67.49

All prices are per crosstie unless otherwise stated

The material cost for this study to be $23.74 per crosstie; which is approximately half the labor cost and is relatively close to the cost of a new, replacement crosstie. However, the time and labor associated with the replacement of a crosstie is much greater as it would require the railway to be shut down for the removal of the steel rails and the deteriorated crosstie. Despite this favorable economic comparison, the intent of this study is not only to repair deteriorated crossties but to use this testing as a preliminary step toward the repair of timber bridge structural members. In the case of repairing a full-scale structural member of a bridge, such as a three-span stringer, the cost of replacement would include approximately two days of labor for both removal and installation. This labor cost, for a five-person crew, is estimated as approximately $2,400/stringer. When compared to the cost of shear spike repair, estimated as approximately $135/ stringer in materials and $252/stringer in labor, the total cost is significantly reduced.

4. SHEAR STRENGTH OF EPOXY RESIN

An experimental parametric study was performed on the shear strength of the epoxy resin itself. Load tests were performed to apply a compressive axial load directly to a shear spike of 12.7 mm (0.5 in.) in diameter, which had been inserted into a crosstie specimen. The loading rate was 0.0127 mm/sec (0.0005 in/sec). A shear spike was inserted into a crosstie specimen to various depths with 57 mm (2.25 in.) of the shear spike remaining exposed. This portion was used as the point of loading. Axial load was applied using a 38.1 mm (1.5 in.) thick aluminum plate with a 12.7mm (0.5 in.) diameter hole drilled through its thickness. The aluminum plate was then bolted to the hydraulic actuator, see Figures 10 and 11. The aluminum plate confined the exposed end of the shear spike to insure the load applied would be vertical and applied only to the shear spike.

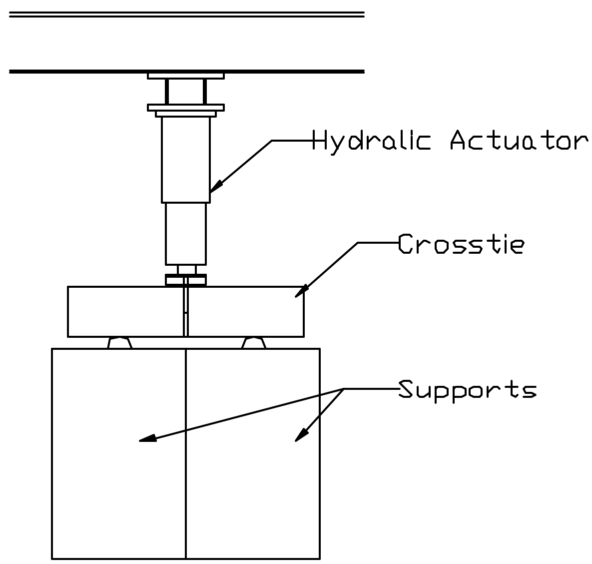

Figure 10. Epoxy-resin shear strength load test setup

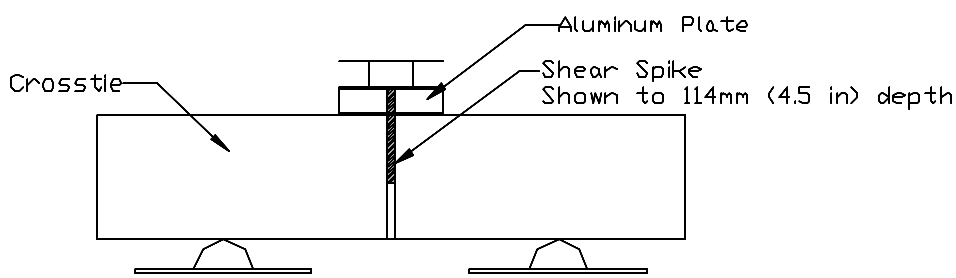

Figure 11. Detailed view of epoxy-resin shear strength load test setup

Shear spike installation was done in the same manner as described for the effective stiffness rejuvenation load testing. Shear spikes were installed in pairs into an untreated Douglas fir crosstie specimen to a specified penetration depth. Depths studied were 64 mm (2.5 in.), 114 mm (4.5 in.), and 165 mm (6.5 in.). For each load test conducted. The failure load was recorded for each specimen. Since the FRP rods did not completely pass through the depth of the crosstie it was not easy to attach instrumentation to record displacement, so it was omitted. An average ultimate load was determined (for each pair of spikes) and then used to calculate average ultimate shear strength. Table 10 lists the depths used for each pair of shear spikes and the results from their corresponding load tests.

Table 10. Shear strength of epoxy-resin and related values.

Test Number	Rod Insertion Depth		Epoxy Surface Area		Failure Load		Epoxy Bond Strength	
	[in]	[cm]	[in^2]	[cm^2]	[kip]	[kN]	[ksi]	[MPa]
1	2.5	6.35	3.93	25.34	6.16	27.39	1.57	10.81
2	2.5	6.35	3.93	25.34	7.27	32.32	1.85	12.76
3	4.5	11.43	7.07	45.60	11.09	49.31	1.57	10.81
4	4.5	11.43	7.07	45.60	8.06	35.87	1.14	7.87
5	6.5	16.51	10.21	65.87	7.47	33.22	0.73	5.04
6	6.5	16.51	10.21	65.87	6.90	30.69	0.68	4.66

Average Ultimate Load [kN]	34.80
Average Bond Strength [MPa]	8.66
Standard Deviation [MPa]	3.34
Coefficient of Variance	0.38

From the material properties presented earlier and in Appendix I, the average compressive strength of the shear spike rod is 276 MPa (40 ksi). For the 12.7 mm (0.5 in.) diameter shear spike, this converts to an ultimate compressive load of 35 kN (7.85 kips).[6] The average ultimate load for the epoxy-resin load tests was 34.8 MPa (7.82 kips). Thus the shear spike rod fails in compression before the epoxy-resin bond is fractured. If the shear spike was not loaded in a completely concentric manner, the load required for failure would be reduced due to the flexural effects associated with eccentric loading. Therefore the pure axial compression failure loads may be higher as evident from load test 3, where the failure load reached 49.31 kN (11.09 kips).

Epoxy-resin shear strength data was desired to know how well the shear spikes bonded to the wood fibers of the crossties. The epoxy resin is the primary link between the shear forces developed in the sound wood fibers and the shear resisting ability of the shear spikes. Thus ability of the epoxy-resin to transfer load is critical in improving the effective stiffness of the railroad crossties. These load tests also provide an insight into the strength gained from the epoxy resin when used as decay void filler. As exemplified in Figure 12, large decay voids can be present in the crosstie specimen near the spikes. By filling these voids with the epoxy-resin there is a high likelihood of strengthening the crosstie by providing an increase in shear strength to the now-composite crosstie. By knowing the shear strength of the epoxy resin, and its ability to bond to the wood fibers, a better rejuvenation technique may be developed and implemented in future research.

Figure 12. Large decay voids reinforced with shear spikes

5. CONCLUSION

The results of the test described indicate that the shear spike repair system is an effective (although imperfect) and economical method to rejuvenate the flexural stiffness of deteriorated railroad crossties. A significant increase in effective flexural stiffness can be attained through the use of FRP shear spikes, when vertically installed perpendicular to the primary bending axis. Specific findings and recommendations are:

- The shear spikes provided interlayer shear resistance by reconnecting the sound wood fibers of the upper and lower extremities of the crosstie specimens thus allowing for shear transfer through the deteriorated regions. The shear spikes spacing was far enough apart for them to be considered discrete connectors rather than a continuous repair. Further load testing could be performed with a much closer spacing to investigate the effects on the flexural stiffness that an approximate continuum would produce. It may also be advantageous to increase the spacing to investigate the possible savings of material and labor cost versus reduced effectiveness.

- Typically, the crossties had a dramatic increase in flexural stiffness and a corresponding significant decrease in deflection when all spikes had been installed. As the number of rows installed increased, the effective flexural stiffness increased as well, over a wide range (e.g. 32 percent to 98 percent at full reinforcement). A general trend toward a plateau state as more shear spikes were inserted was evident.

- A greater increase in effective flexural stiffness was produced in those crosstie specimens sorted into lower quality than those sorted into medium- to high-quality. From these results, it is concluded that specimens with a greater degree of deterioration show a greater potential to rejuvenate interlayer shear resistance and flexural stiffness.

- A greater increase in effective flexural stiffness by the lower quality compared to the medium- to high-quality sample set was most apparent with the installation of the first row of shear spikes. By having larger and more frequent voids, a lower-quality crosstie had a greater chance of having deteriorated wood near its ends. It may be useful to continue this study by either increasing shear spike density in that region or moving the single row of spikes closer to the end of the specimen.

- Compressive load tests showed the bond strength to be greater than the ultimate compressive strength of the FRP rods for the depth of penetrations examined in this study. It is deduced that the epoxy-resin shear strength is large enough that it does not fail under the loading conditions applied by the crosstie flexural stiffness load tests. It is hypothesized that the epoxy-resin would increase the flexural stiffness of the crossties when used as decay void filler. A further study should be conducted to investigate the effect of filling the decayed voids in conjunction with the shear spiking process. The filling process could be done by pressure-injecting the epoxy-resin into the shear spike holes prior to insertion to fill internal voids. Voids on the surface of the specimen could be hand filled. The effect mix ratio has on the epoxy-resin bond strength and full cure time should be further studied in controlled tests. It is noted from the flexural load test results that skewed mix ratios may inhibit the epoxy-resin from reaching its full cure state in the allotted time, resulting in less than full potential gain in effective stiffness.

- A study of the effect increased moisture content (humidity) has on the bonding capability of the epoxy-resin and the flexural effective stiffness is warranted for exposed wood members. It is recommended that specimens be conditioned to various moisture contents and moisture content histories prior to and after shear spike insertion to test the epoxy-resin bond strength to simulate the field shear spike insertion process and in situ flexural stiffness.

6. REFERENCES

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Appendix 1: Material Properties

Crosstie Dimensions

Specimen	Base (cm)	Height (cm)	Length (cm)
1	16.5	21.3	259.4
2	16.8	22.3	254.5
3	16.8	19.2	256.3
4	16.2	20.7	256.3
5	16.8	22.9	258.8
6	16.5	22.9	260.9
7	16.8	20.7	255.1
8	16.8	24.4	256.0
9	16.2	21.0	260.6
10	16.5	18.9	256.6
11	16.5	19.5	260.9
12	16.8	21.3	263.0
13	17.1	21.6	252.7
14	16.8	21.9	256.0
15	16.8	20.1	259.4
16	16.8	23.5	250.9
17	16.2	23.2	252.4
18	16.5	21.3	261.8
19	15.5	21.6	259.4

Specimen	Base (cm)	Height (cm)	Length (cm)
20	16.8	22.9	256.0
21	16.5	18.9	257.3
22	16.8	21.3	262.1
23	16.5	21.3	258.5
24	16.8	22.6	259.4
25	16.5	23.2	254.5
26	16.5	21.6	256.3
27	16.5	21.6	256.3
28	17.1	19.8	258.8
29	16.2	20.7	260.9
30	16.2	19.5	255.1
31	16.5	19.2	256.0
32	15.8	18.3	260.6
33	16.5	21.3	256.6
34	16.8	21.0	260.9
35	16.2	21.9	263.0

Liberty Pultrusions

Mechanical				
	Test Method	**Condition**	**Units**	**Value**
Ultimate Tensile Strength	ASTM D-638	RT	psi	70,000
Flexural Strength	ASTM D-790	RT	psi	70,000
		100^{o}C	psi	25,000
		150^{o}C	psi	15,000
Flexural Modulus	ASTM D-790	RT	psi	3.0E+06
		100^{o}C	psi	2.0E+06
		150^{o}C	psi	1.5E+06
Impact Strength	ASTM D-256	RT	FT-lb/in notch	30
Compressive Strength	ASTM D-695			
Flat wise		RT	psi	20,000
Lengthwise		RT	psi	40,000

Other				
Thermal Coefficient of Expansion	ASTM D-696		in/in/^{o}f	3.0E+06
Thermal Conductivity			BTU/hr/sq ft/in/^{o}f	4
Specific Gravity	ASTM D-792			1.95
Water Absorption	ASTM D-349	24 hrs.	%	0.3

Crosstie Initial Average Moisture Content

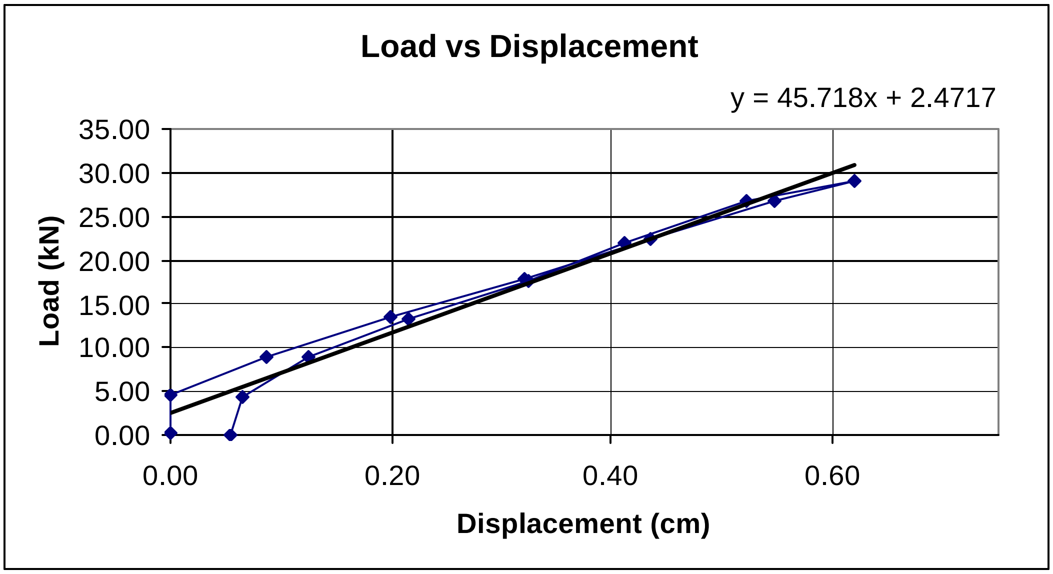
Specimen	Average M.C. %
1	9
2	9
3	8
4	8
5	8
6	8
7	9
8	9
9	9
10	9
11	9
12	9
13	8
14	9
15	9
16	10
17	10
18	9
19	11

Specimen	Average M.C. %
20	9
21	9
22	9
23	12
24	10
25	8
26	11
27	8
28	9
29	12
30	10
31	10
32	8
33	7
34	8
35	9
Total Avg.	9

Appendix 2: Initial Effective Stiffness Results

Specimen #	1		
Pot Number	F790	Max. Load (kN)	29.04
Constant [cm/V]	1.826	Span (cm)	208.28

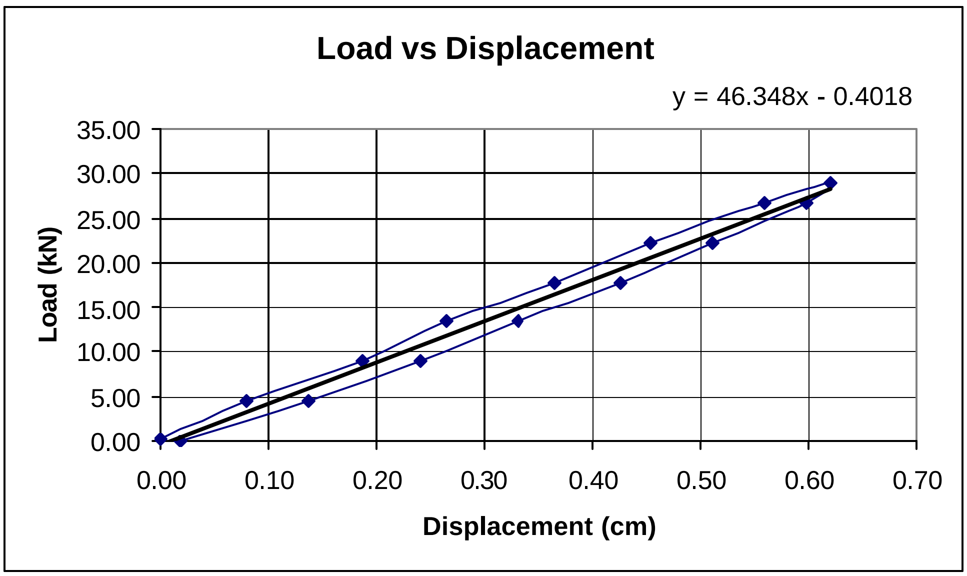
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	5.4161	0.0000	0.26
1	5.4153	0.0007	4.53
2	5.3301	0.0859	8.96
3	5.2172	0.1989	13.43
4	5.0960	0.3201	17.92
5	4.9812	0.4349	22.51
6	4.8685	0.5475	26.80
Peak Reading	4.7953	0.6207	29.04
6	4.8935	0.5226	26.73
5	5.0041	0.4120	22.00
4	5.0934	0.3227	17.64
3	5.2014	0.2147	13.28
2	5.2919	0.1242	8.84
1	5.3517	0.0644	4.41
Final Reading	5.3613	0.0547	0.11



Specimen # 2

Pot Number	F790	Max. Load (kN)	29.03
Constant [cm/V]	1.826	Span (cm)	208.28

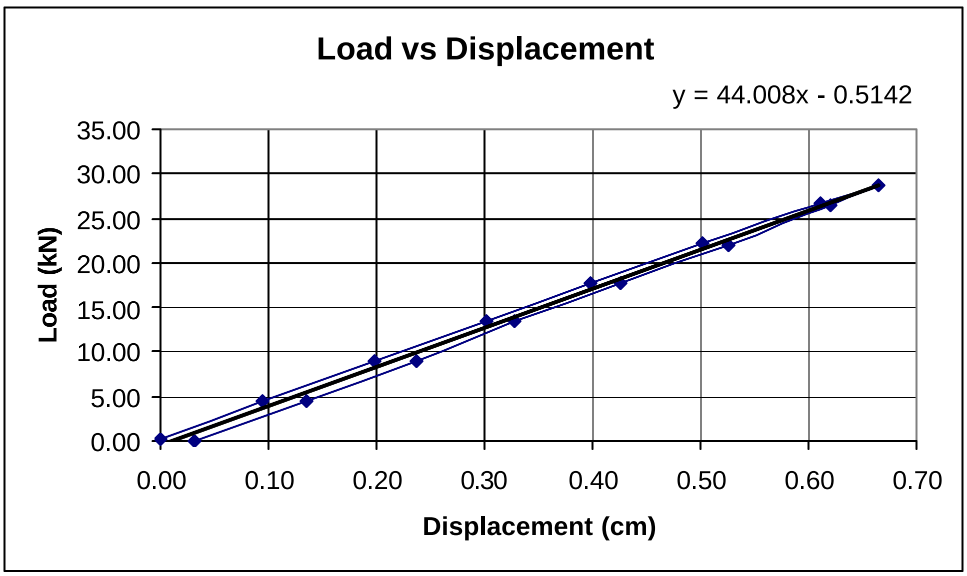
	Reading	d (cm)	Load (kN)
Initial Reading	5.9577	0.0000	0.25
1	5.8778	0.0799	4.49
2	5.7710	0.1867	8.94
3	5.6931	0.2646	13.33
4	5.5926	0.3652	17.77
5	5.5027	0.4551	22.23
6	5.3978	0.5599	26.66
Peak Reading	5.3374	0.6203	29.03
6	5.3597	0.5981	26.68
5	5.4459	0.5119	22.18
4	5.5313	0.4265	17.78
3	5.6266	0.3311	13.31
2	5.7182	0.2395	8.90
1	5.8216	0.1362	4.47
Final Reading	5.9396	0.0181	0.09



Specimen # 3

Pot Number	F790	Max. Load (kN)	28.87
Constant [cm/V]	1.826	Span (cm)	208.28

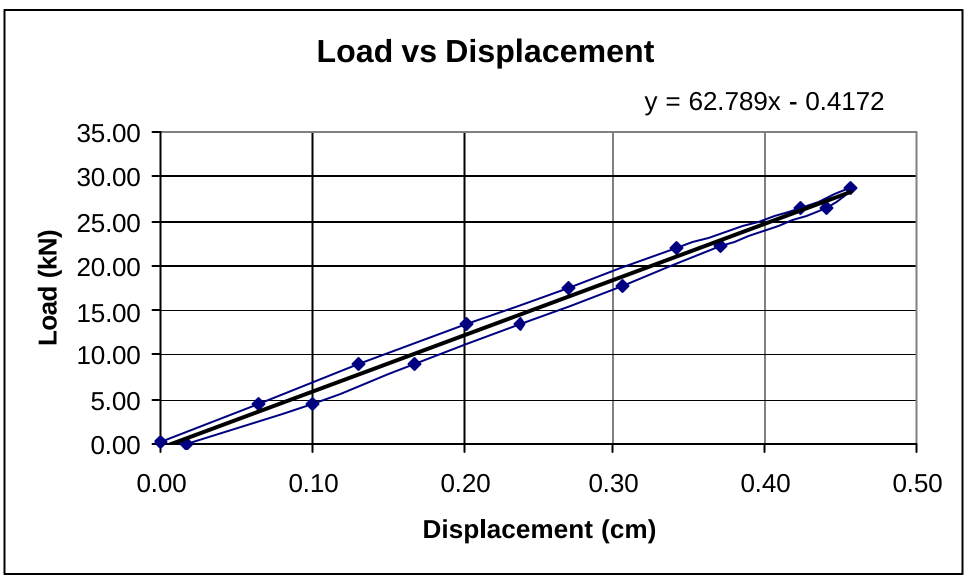
	Reading	d (cm)	Load (kN)
Initial Reading	6.6138	0.0000	0.28
1	6.5189	0.0950	4.49
2	6.4157	0.1982	8.93
3	6.3131	0.3007	13.30
4	6.2142	0.3996	17.79
5	6.1114	0.5024	22.23
6	6.0021	0.6117	26.69
Peak Reading	5.9493	0.6646	28.87
6	5.9925	0.6213	26.53
5	6.0877	0.5261	22.11
4	6.1879	0.4259	17.75
3	6.2861	0.3278	13.30
2	6.3778	0.2361	8.87
1	6.4790	0.1348	4.43
Final Reading	6.5825	0.0314	0.08



Specimen # 4

Pot Number	F790	Max. Load (kN)	28.85
Constant [cm/V]	1.826	Span (cm)	208.28

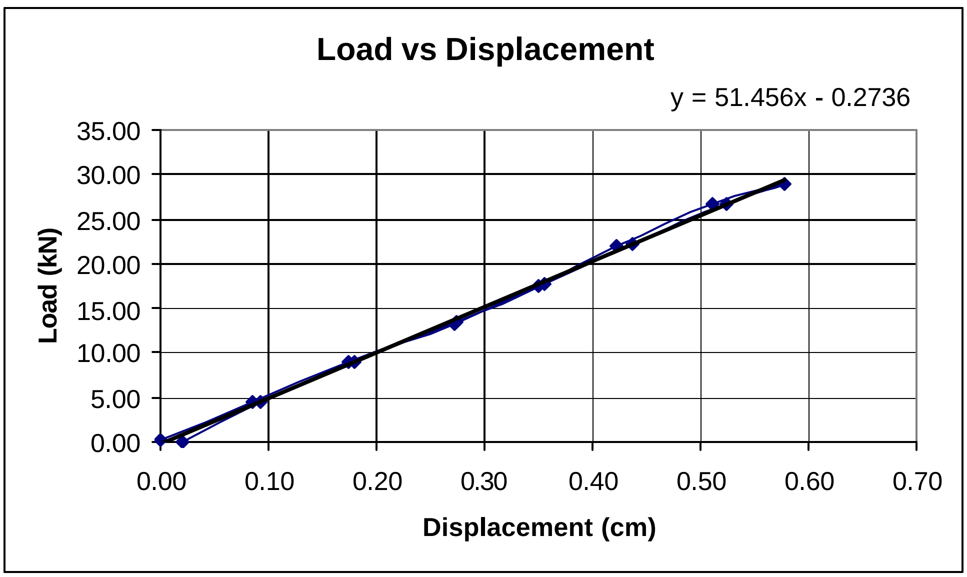
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	6.1926	0.0000	0.24
1	6.1280	0.0646	4.47
2	6.0621	0.1305	8.84
3	5.9905	0.2020	13.27
4	5.9227	0.2699	17.67
5	5.8513	0.3412	22.14
6	5.7697	0.4229	26.61
Peak Reading	5.7355	0.4571	28.85
6	5.7517	0.4409	26.48
5	5.8222	0.3704	22.19
4	5.8870	0.3056	17.74
3	5.9552	0.2374	13.30
2	6.0244	0.1682	8.88
1	6.0927	0.0999	4.48
Final Reading	6.1760	0.0166	0.07



Specimen # 5

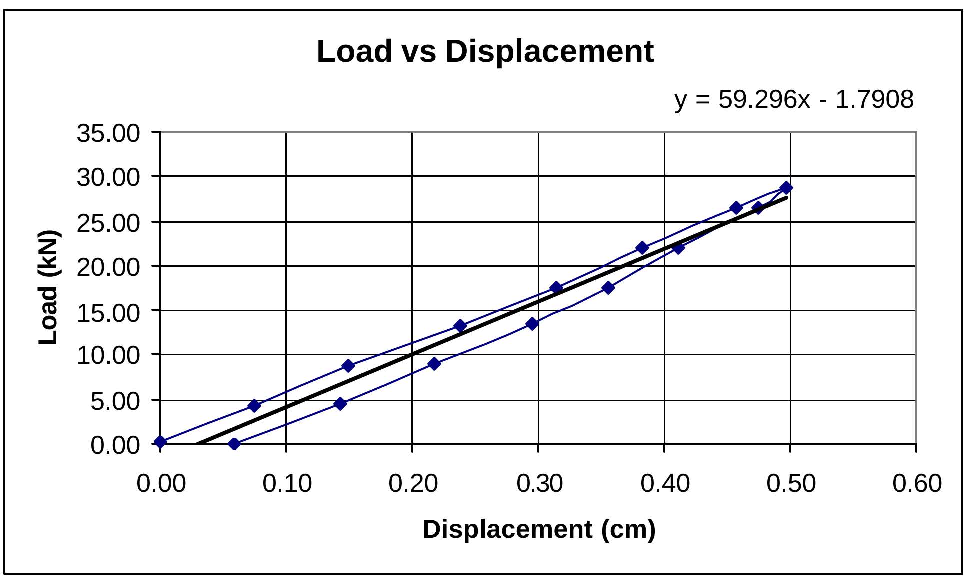
Pot Number	F790	Max. Load (kN)	28.98
Constant [cm/V]	1.826	Span (cm)	208.28

	Reading	d **(cm)**	**Load (kN)**
Initial Reading	7.0791	0.0000	0.27
1	6.9945	0.0846	4.56
2	6.9049	0.1743	8.92
3	6.8062	0.2729	13.45
4	6.7231	0.3560	17.81
5	6.6417	0.4374	22.29
6	6.5544	0.5247	26.69
Peak Reading	6.5013	0.5779	28.98
6	6.5667	0.5124	26.66
5	6.6565	0.4226	22.13
4	6.7291	0.3500	17.66
3	6.8077	0.2714	13.16
2	6.9001	0.1790	8.86
1	6.9859	0.0932	4.42
Final Reading	7.0592	0.0200	0.08



Specimen #	6		
Pot Number	F790	Max. Load (kN)	28.76
Constant [cm/V]	1.826	Span (cm)	208.28

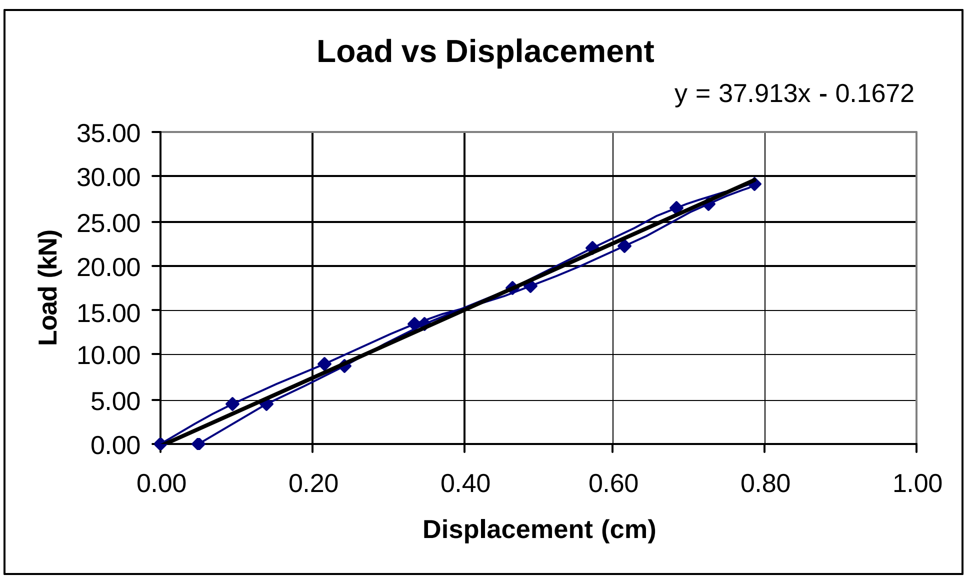
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	7.4496	0.0000	0.21
1	7.3751	0.0744	4.34
2	7.3015	0.1481	8.75
3	7.2127	0.2369	13.23
4	7.1351	0.3145	17.63
5	7.0671	0.3825	22.03
6	6.9915	0.4581	26.47
Peak Reading	6.9526	0.4970	28.76
6	6.9751	0.4745	26.49
5	7.0377	0.4119	22.16
4	7.0938	0.3558	17.70
3	7.1534	0.2962	13.30
2	7.2321	0.2175	8.84
1	7.3068	0.1428	4.44
Final Reading	7.3905	0.0591	0.07



Specimen # 7

Pot Number	F790	Max. Load (kN)	29.31
Constant [cm/V]	1.826	Span (cm)	208.28

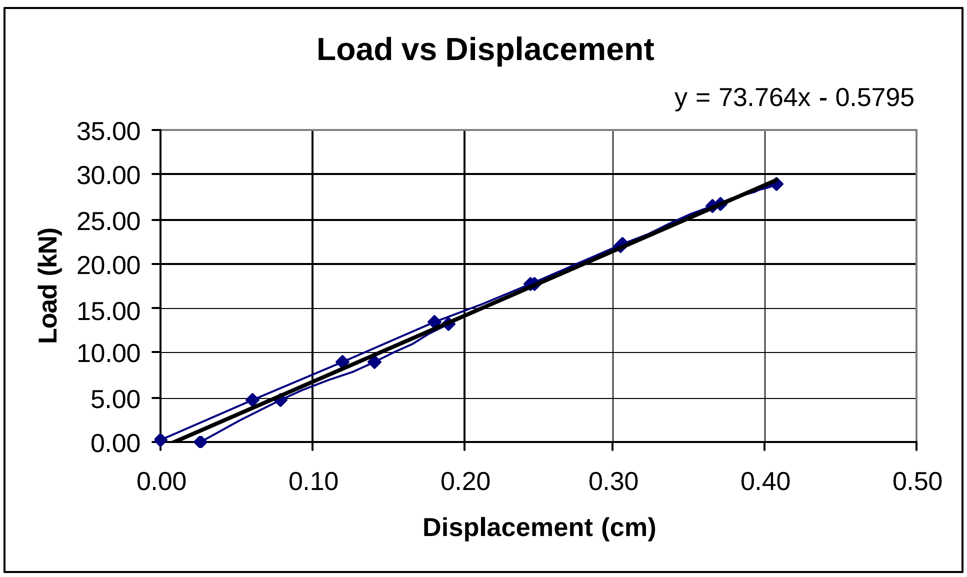
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	7.6768	0.0000	0.08
1	7.5812	0.0956	4.48
2	7.4595	0.2173	8.93
3	7.3418	0.3350	13.34
4	7.1874	0.4895	17.84
5	7.0625	0.6143	22.38
6	6.9515	0.7254	26.88
Peak Reading	6.8899	0.7869	29.31
6	6.9931	0.6838	26.50
5	7.1050	0.5718	22.07
4	7.2134	0.4634	17.65
3	7.3288	0.3481	13.31
2	7.4344	0.2424	8.77
1	7.5381	0.1387	4.38
Final Reading	7.6263	0.0505	0.09



Specimen # 8

Pot Number	F790	Max. Load (kN)	29.01
Constant [cm/V]	1.826	Span (cm)	208.28

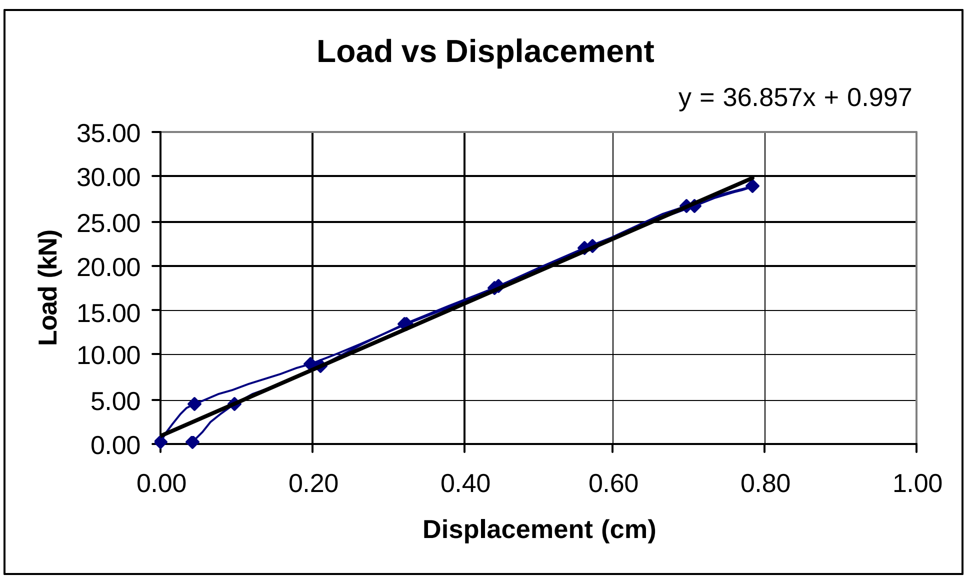
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	7.8502	0.0000	0.25
1	7.7894	0.0608	4.59
2	7.7297	0.1205	8.91
3	7.6691	0.1810	13.40
4	7.6045	0.2456	17.79
5	7.5442	0.3059	22.24
6	7.4797	0.3704	26.66
Peak Reading	7.4426	0.4076	29.01
6	7.4843	0.3659	26.56
5	7.5448	0.3054	22.10
4	7.6019	0.2483	17.73
3	7.6608	0.1893	13.19
2	7.7086	0.1415	9.01
1	7.7710	0.0791	4.63
Final Reading	7.8237	0.0265	0.06



Specimen # 9

Pot Number	F790	Max. Load (kN)	28.98
Constant [cm/V]	1.826	Span (cm)	208.28

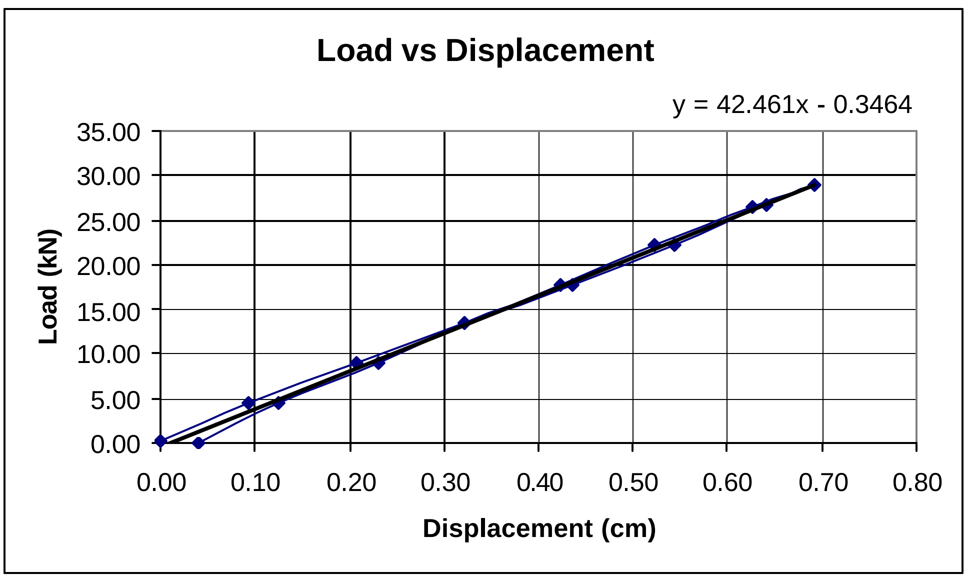
	Reading	**d (cm)**	**Load (kN)**
Initial Reading	5.2603	0.0000	0.22
1	5.2150	0.0453	4.50
2	5.0622	0.1981	8.99
3	4.9361	0.3242	13.45
4	4.8147	0.4457	17.91
5	4.6880	0.5724	22.22
6	4.5521	0.7082	26.68
Peak Reading	4.4756	0.7847	28.98
6	4.5632	0.6971	26.65
5	4.6978	0.5625	22.10
4	4.8189	0.4414	17.70
3	4.9388	0.3215	13.28
2	5.0480	0.2123	8.70
1	5.1626	0.0978	4.39
Final Reading	5.2169	0.0434	0.23



Specimen # 10

Pot Number	F790	Max. Load (kN)	28.98
Constant [cm/V]	1.826	Span (cm)	208.28

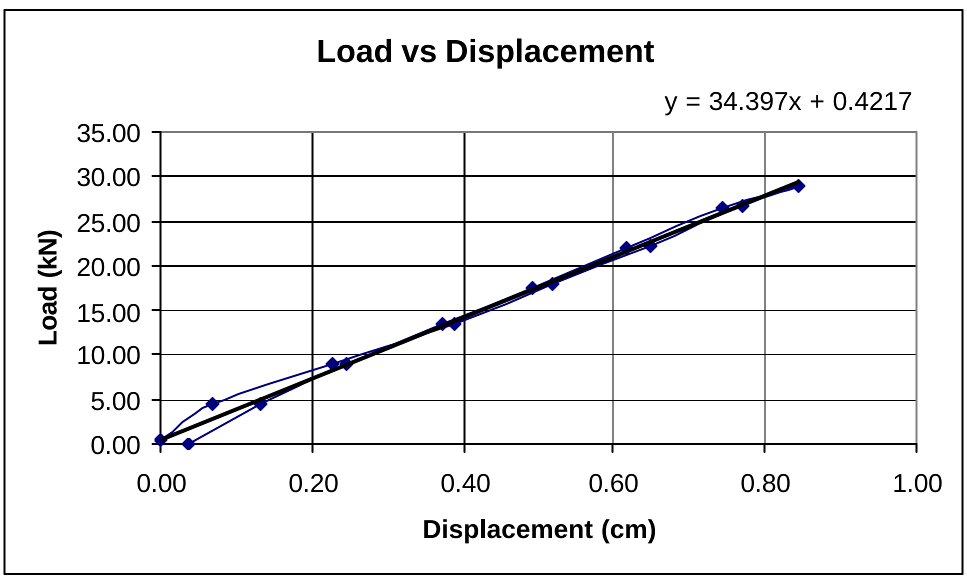
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	5.0407	0.0000	0.27
1	4.9479	0.0927	4.48
2	4.8337	0.2070	8.98
3	4.7203	0.3204	13.42
4	4.6039	0.4367	17.88
5	4.4968	0.5439	22.36
6	4.3996	0.6411	26.70
Peak Reading	4.3485	0.6922	28.98
6	4.4147	0.6260	26.64
5	4.5170	0.5236	22.18
4	4.6174	0.4233	17.73
3	4.7194	0.3213	13.30
2	4.8109	0.2298	9.00
1	4.9167	0.1240	4.49
Final Reading	5.0013	0.0394	0.09



Specimen # 11

Pot Number	F790	Max. Load (kN)	29.05
Constant [cm/V]	1.826	Span (cm)	208.28

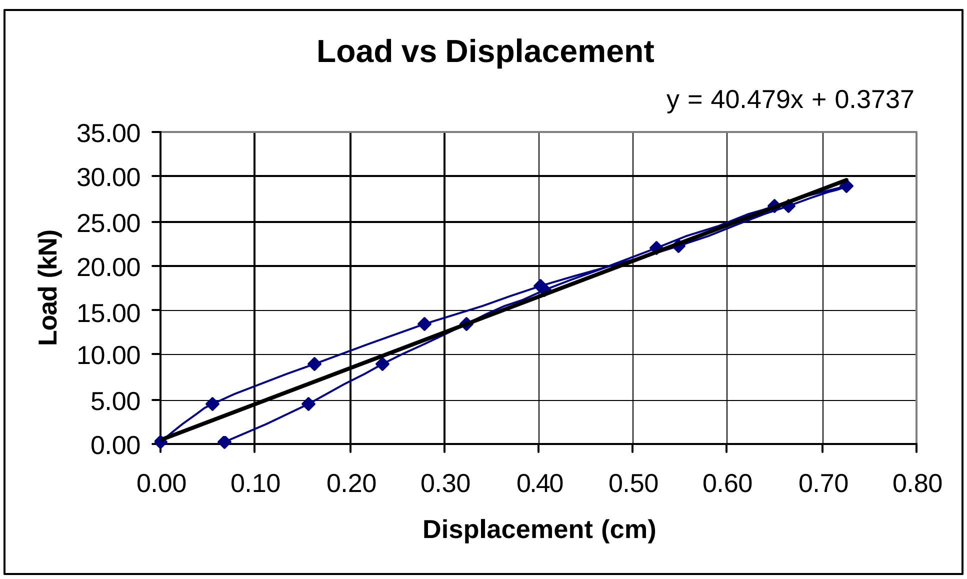
	Reading	d (cm)	Load (kN)
Initial Reading	5.0120	0.0000	0.35
1	4.9426	0.0695	4.48
2	4.7844	0.2276	8.95
3	4.6238	0.3882	13.43
4	4.4911	0.5210	17.96
5	4.3635	0.6485	22.36
6	4.2404	0.7716	26.73
Peak Reading	4.1689	0.8431	29.05
6	4.2683	0.7437	26.62
5	4.3937	0.6183	22.15
4	4.5174	0.4946	17.62
3	4.6400	0.3720	13.35
2	4.7672	0.2448	8.94
1	4.8811	0.1309	4.46
Final Reading	4.9746	0.0374	0.08



Specimen # 12

Pot Number	F790	Max. Load (kN)	28.97
Constant [cm/V]	1.826	Span (cm)	208.28

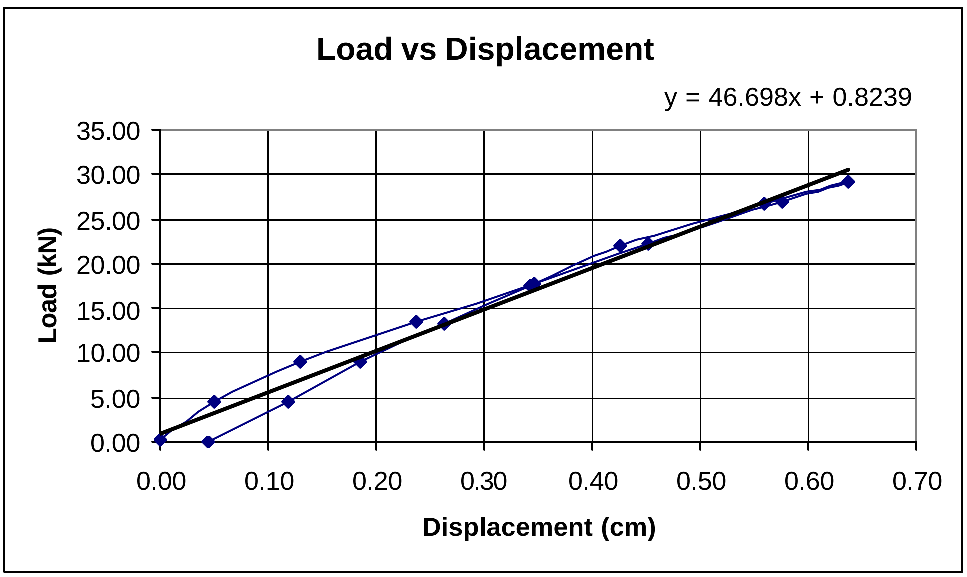
	Reading	**d (cm)**	**Load (kN)**
Initial Reading	5.5644	0.0000	0.26
1	5.5097	0.0547	4.54
2	5.4027	0.1617	8.99
3	5.2859	0.2786	13.42
4	5.1609	0.4035	17.88
5	5.0165	0.5480	22.29
6	4.8990	0.6655	26.79
Peak Reading	4.8393	0.7252	28.97
6	4.9149	0.6496	26.68
5	5.0384	0.5260	22.09
4	5.1563	0.4082	17.40
3	5.2425	0.3219	13.33
2	5.3301	0.2344	8.88
1	5.4089	0.1555	4.53
Final Reading	5.4959	0.0685	0.12



Specimen # 13

Pot Number	F790	Max. Load (kN)	29.11
Constant [cm/V]	1.826	Span (cm)	208.28

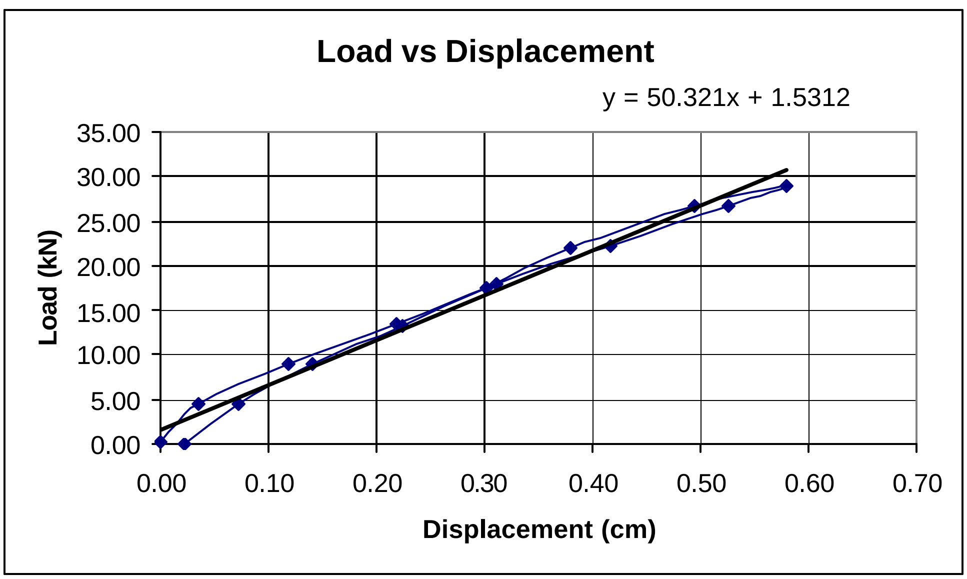
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	5.6295	0.0000	0.22
1	5.5797	0.0498	4.53
2	5.5000	0.1294	8.98
3	5.3927	0.2368	13.47
4	5.2831	0.3464	17.87
5	5.1761	0.4534	22.39
6	5.0539	0.5756	26.88
Peak Reading	4.9917	0.6378	29.11
6	5.0698	0.5597	26.64
5	5.2032	0.4262	22.06
4	5.2862	0.3433	17.62
3	5.3675	0.2620	13.22
2	5.4440	0.1854	8.86
1	5.5122	0.1173	4.37
Final Reading	5.5849	0.0446	0.09



Specimen # 14

Pot Number	F790	Max. Load (kN)	29.07
Constant [cm/V]	1.826	Span (cm)	208.28

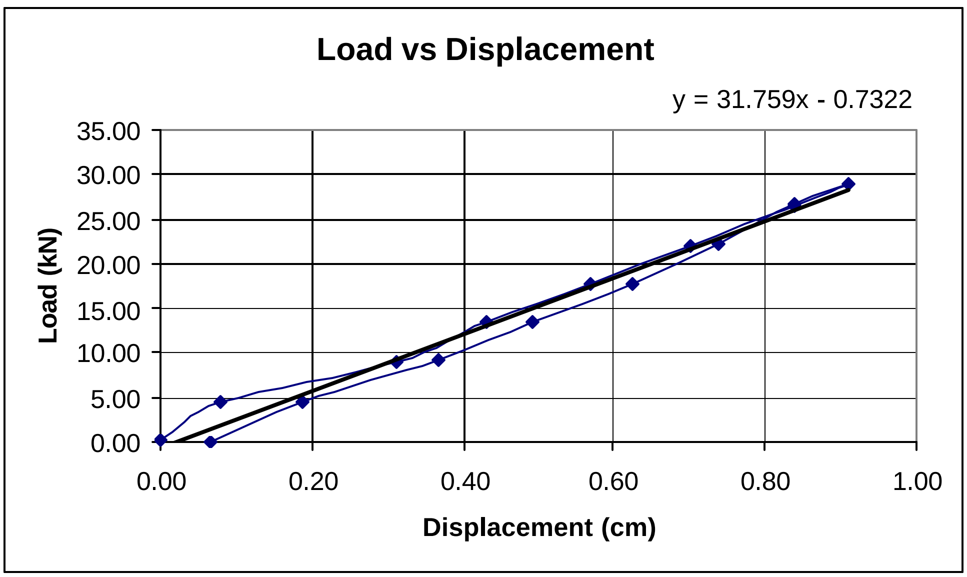
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	5.2783	0.0000	0.24
1	5.2427	0.0355	4.44
2	5.1597	0.1186	8.96
3	5.0597	0.2185	13.46
4	4.9676	0.3107	17.95
5	4.8605	0.4177	22.40
6	4.7523	0.5260	26.84
Peak Reading	4.6992	0.5791	29.07
6	4.7839	0.4944	26.66
5	4.8981	0.3802	22.00
4	4.9769	0.3014	17.65
3	5.0545	0.2237	13.24
2	5.1374	0.1409	8.81
1	5.2063	0.0719	4.41
Final Reading	5.2562	0.0221	0.10



Specimen # 15

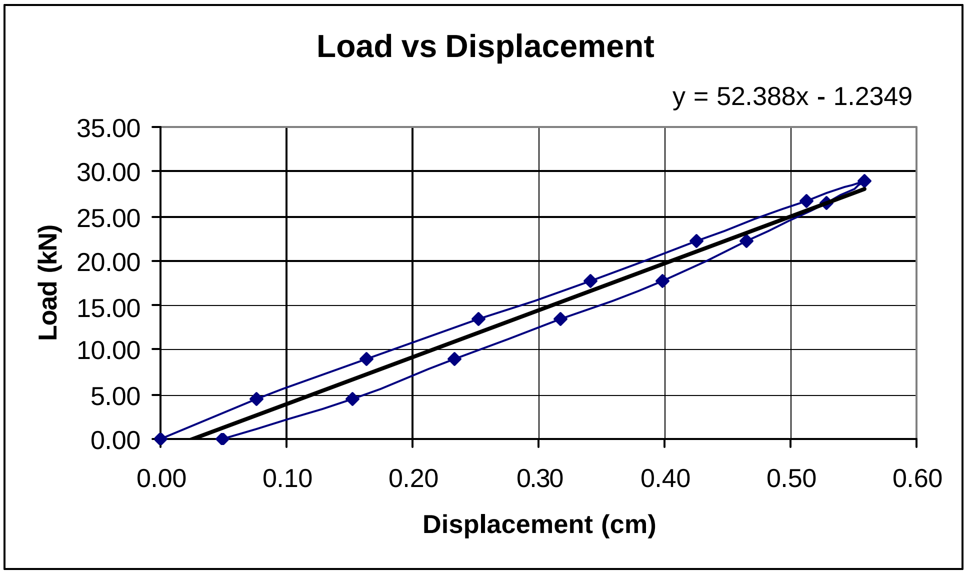
Pot Number	F790	Max. Load (kN)	28.88
Constant [cm/V]	1.826	Span (cm)	208.28

	Reading	d (cm)	Load (kN)
Initial Reading	5.2103	0.0000	0.31
1	5.1309	0.0794	4.50
2	4.8982	0.3121	9.00
3	4.7790	0.4313	13.36
4	4.6405	0.5698	17.74
5	4.5072	0.7031	22.16
6	4.3713	0.8390	26.59
Peak Reading	4.2987	0.9116	28.88
6	4.3700	0.8403	26.71
5	4.4708	0.7395	22.28
4	4.5840	0.6263	17.94
3	4.7164	0.4939	13.45
2	4.8433	0.3670	9.08
1	5.0231	0.1872	4.55
Final Reading	5.1437	0.0666	0.09



Specimen #	16		
Pot Number	F790	Max. Load (kN)	28.95
Constant [cm/V]	1.826	Span (cm)	208.28

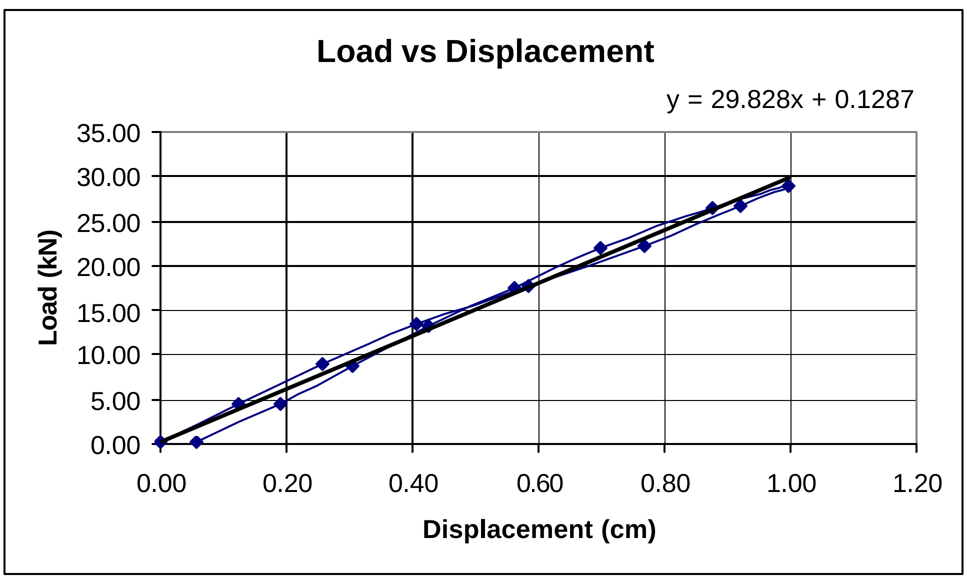
	Reading	d (cm)	Load (kN)
Initial Reading	8.5277	0.0000	0.07
1	8.4523	0.0755	4.50
2	8.3645	0.1632	8.91
3	8.2764	0.2514	13.39
4	8.1852	0.3425	17.84
5	8.1013	0.4264	22.27
6	8.0152	0.5126	26.66
Peak Reading	7.9687	0.5590	28.95
6	7.9982	0.5295	26.54
5	8.0621	0.4657	22.19
4	8.1291	0.3986	17.90
3	8.2099	0.3178	13.33
2	8.2946	0.2331	8.95
1	8.3754	0.1523	4.48
Final Reading	8.4784	0.0493	0.07



Specimen # 17

Pot Number	F790	Max. Load (kN)	29.09
Constant [cm/V]	1.826	Span (cm)	208.28

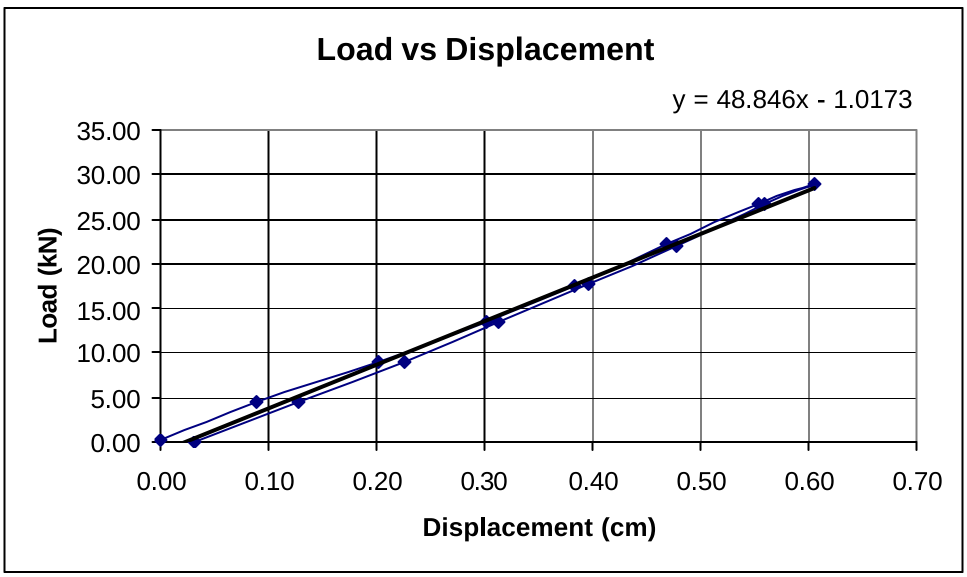
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	4.7315	0.0000	0.26
1	4.6076	0.1239	4.51
2	4.4739	0.2576	8.98
3	4.3254	0.4061	13.40
4	4.1447	0.5868	17.85
5	3.9611	0.7704	22.28
6	3.8090	0.9225	26.79
Peak Reading	3.7352	0.9963	29.09
6	3.8554	0.8760	26.63
5	4.0309	0.7006	22.09
4	4.1719	0.5595	17.60
3	4.3087	0.4228	13.18
2	4.4267	0.3048	8.79
1	4.5414	0.1901	4.40
Final Reading	4.6730	0.0585	0.12



Specimen # 18

Pot Number	F790	Max. Load (kN)	28.90
Constant [cm/V]	1.826	Span (cm)	208.28

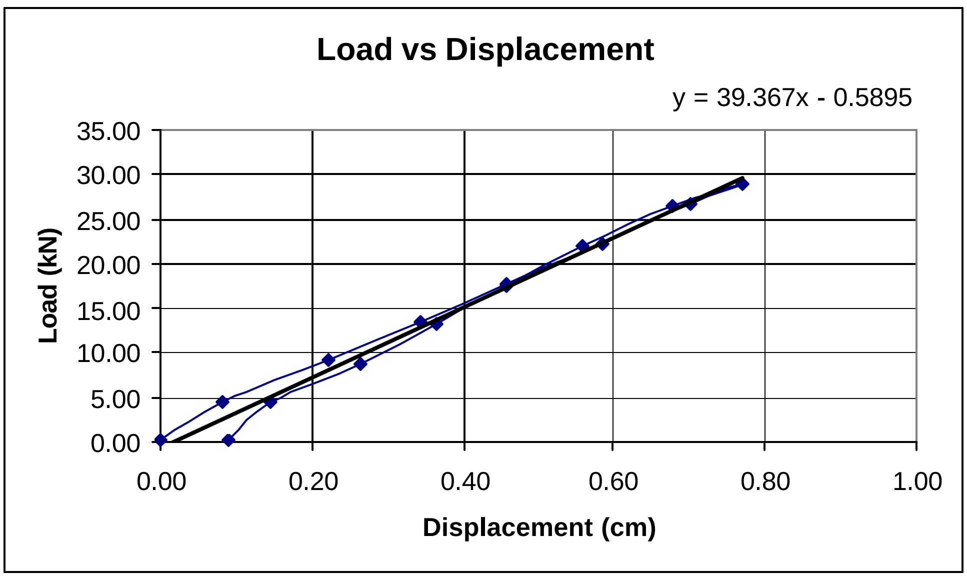
	Reading	d (cm)	Load (kN)
Initial Reading	7.8140	0.0000	0.22
1	7.7261	0.0879	4.49
2	7.6121	0.2020	8.93
3	7.5135	0.3005	13.42
4	7.4295	0.3845	17.72
5	7.3448	0.4692	22.26
6	7.2592	0.5549	26.67
Peak Reading	7.2089	0.6051	28.90
6	7.2548	0.5592	26.65
5	7.3361	0.4780	22.18
4	7.4171	0.3969	17.80
3	7.5013	0.3127	13.35
2	7.5883	0.2257	8.89
1	7.6868	0.1273	4.47
Final Reading	7.7835	0.0306	0.05



Specimen # 19

Pot Number	F790	Max. Load (kN)	29.04
Constant [cm/V]	1.826	Span (cm)	208.28

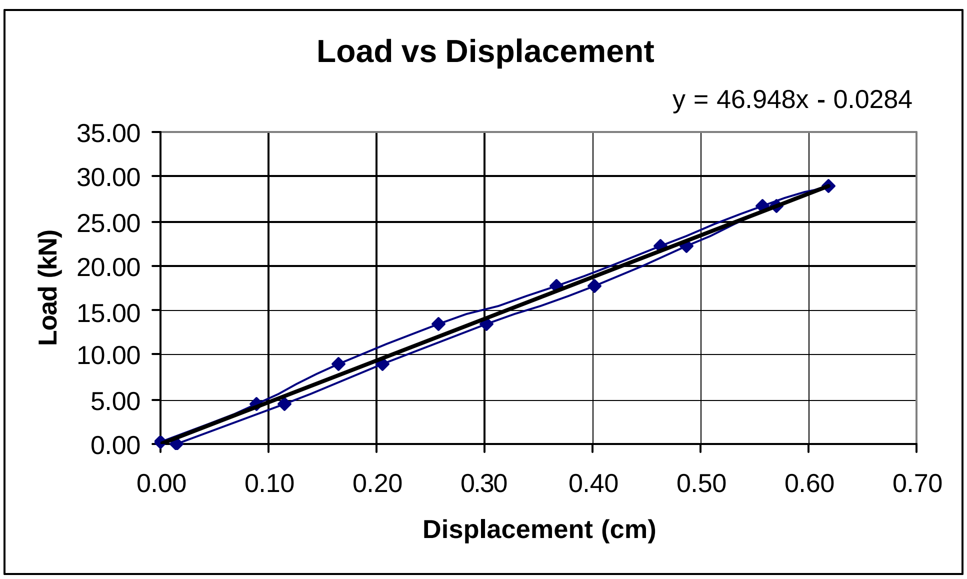
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	5.6664	0.0000	0.26
1	5.5844	0.0820	4.56
2	5.4449	0.2215	9.03
3	5.3229	0.3435	13.46
4	5.2103	0.4561	17.90
5	5.0813	0.5851	22.33
6	4.9655	0.7009	26.77
Peak Reading	4.8957	0.7707	29.04
6	4.9884	0.6780	26.63
5	5.1075	0.5590	22.03
4	5.2109	0.4555	17.61
3	5.3024	0.3640	13.17
2	5.4017	0.2647	8.80
1	5.5206	0.1458	4.41
Final Reading	5.5771	0.0893	0.18



Specimen # 20

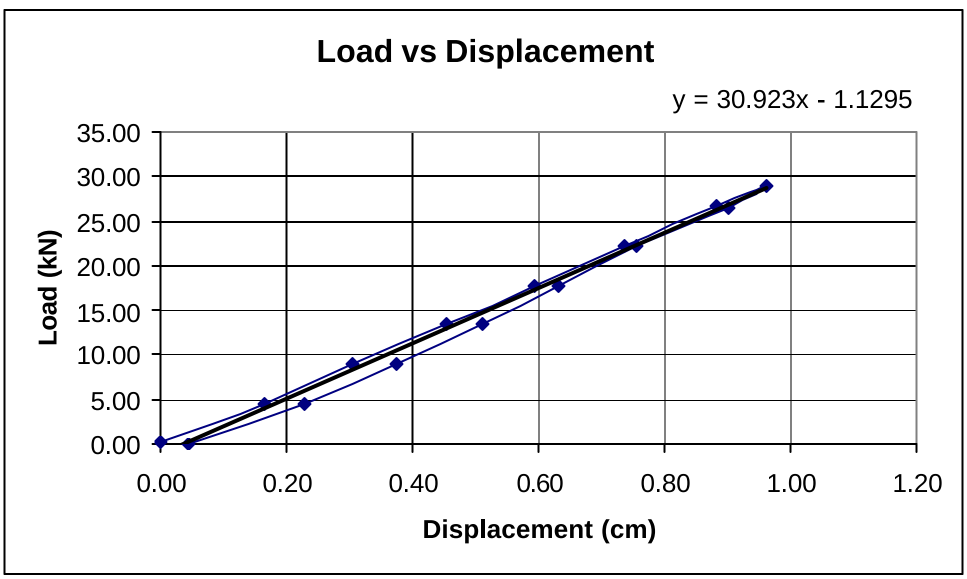
Pot Number	F790	Max. Load (kN)	28.97
Constant [cm/V]	1.826	Span (cm)	208.28

	Reading	d (cm)	Load (kN)
Initial Reading	7.1935	0.0000	0.29
1	7.1054	0.0881	4.47
2	7.0286	0.1649	8.92
3	6.9362	0.2574	13.36
4	6.8255	0.3680	17.76
5	6.7303	0.4632	22.19
6	6.6350	0.5585	26.69
Peak Reading	6.5756	0.6179	28.97
6	6.6237	0.5699	26.66
5	6.7054	0.4881	22.26
4	6.7903	0.4032	17.78
3	6.8919	0.3017	13.46
2	6.9889	0.2047	8.91
1	7.0798	0.1137	4.39
Final Reading	7.1789	0.0146	0.06



Specimen #	21		
Pot Number	F790	Max. Load (kN)	28.97
Constant [cm/V]	1.826	Span (cm)	208.28

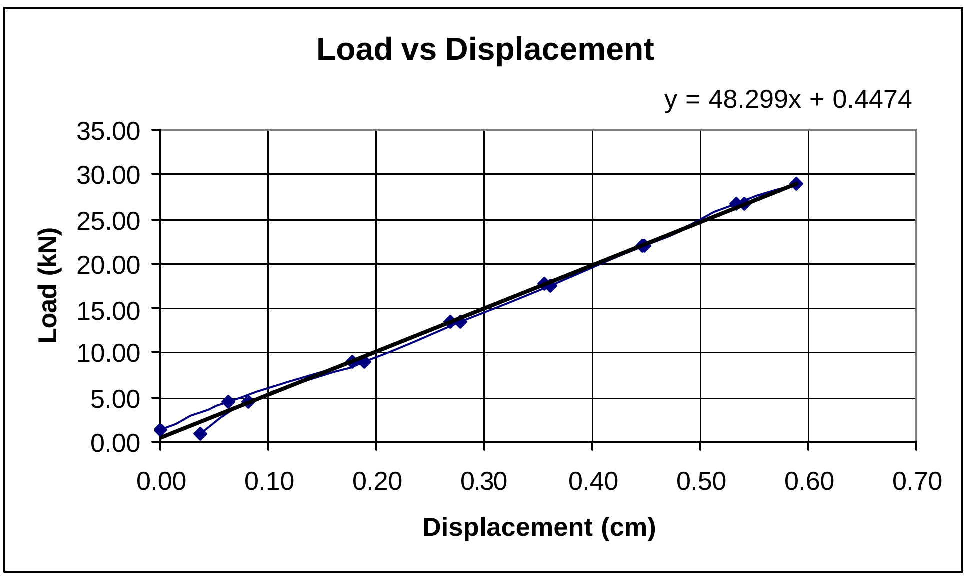
	Reading	d (cm)	Load (kN)
Initial Reading	6.9453	0.0000	0.25
1	6.7810	0.1644	4.47
2	6.6414	0.3039	8.92
3	6.4923	0.4530	13.42
4	6.3502	0.5951	17.82
5	6.2088	0.7366	22.26
6	6.0614	0.8839	26.73
Peak Reading	5.9823	0.9630	28.97
6	6.0444	0.9009	26.61
5	6.1880	0.7573	22.26
4	6.3113	0.6340	17.77
3	6.4368	0.5086	13.35
2	6.5723	0.3730	8.96
1	6.7172	0.2282	4.51
Final Reading	6.9024	0.0429	0.07



Specimen #	22

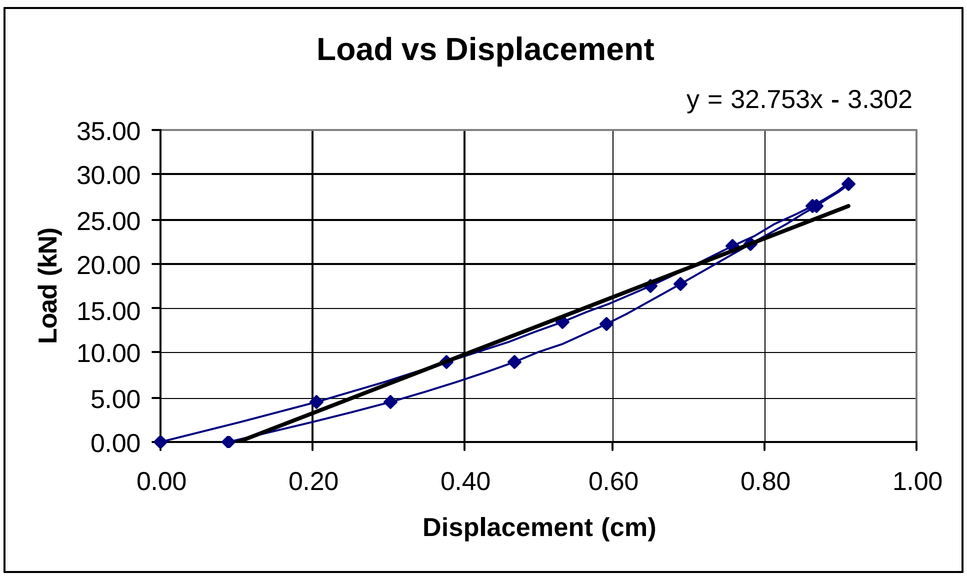
Pot Number	F790	Max. Load (kN)	28.88
Constant [cm/V]	1.826	Span (cm)	208.28

	Reading	d (cm)	Load (kN)
Initial Reading	5.0442	0.0000	1.44
1	4.9816	0.0626	4.49
2	4.8674	0.1769	9.00
3	4.7758	0.2684	13.44
4	4.6870	0.3572	17.76
5	4.5946	0.4496	22.17
6	4.5025	0.5418	26.65
Peak Reading	4.4556	0.5887	28.88
6	4.5105	0.5338	26.69
5	4.5964	0.4479	22.13
4	4.6825	0.3618	17.71
3	4.7665	0.2777	13.29
2	4.8566	0.1876	8.94
1	4.9625	0.0818	4.46
Final Reading	5.0066	0.0377	0.88



Specimen #	23		
Pot Number	F790	Max. Load (kN)	28.90
Constant [cm/V]	1.826	Span (cm)	208.28

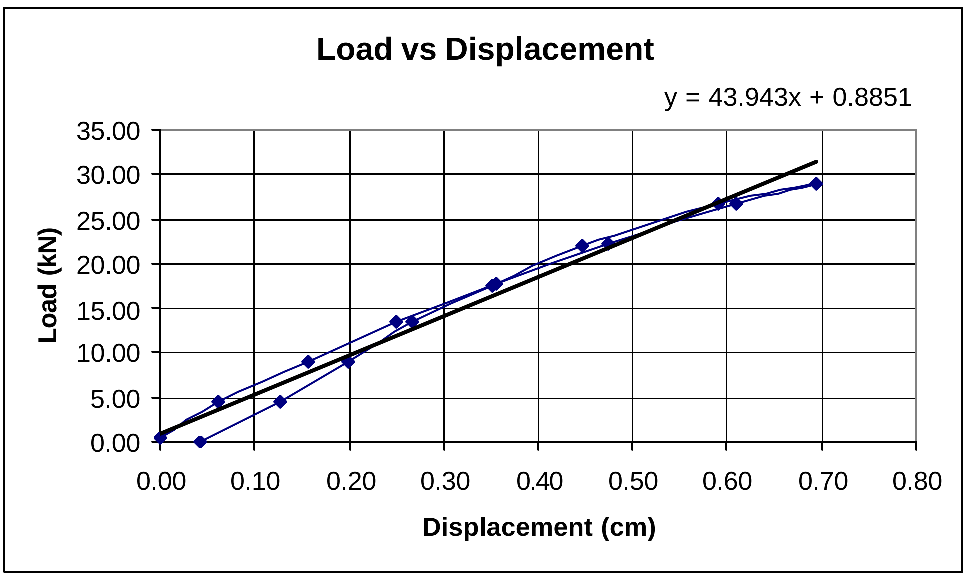
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	5.2564	0.0000	0.11
1	5.0512	0.2052	4.44
2	4.8781	0.3782	8.90
3	4.7236	0.5328	13.32
4	4.6080	0.6483	17.70
5	4.4995	0.7568	22.16
6	4.3945	0.8619	26.48
Peak Reading	4.3455	0.9109	28.90
6	4.3880	0.8684	26.53
5	4.4763	0.7801	22.23
4	4.5687	0.6877	17.73
3	4.6650	0.5914	13.26
2	4.7897	0.4667	8.87
1	4.9527	0.3037	4.55
Final Reading	5.1663	0.0901	0.01



Specimen # 24

Pot Number	F790	Max. Load (kN)	29.06
Constant [cm/V]	1.826	Span (cm)	208.28

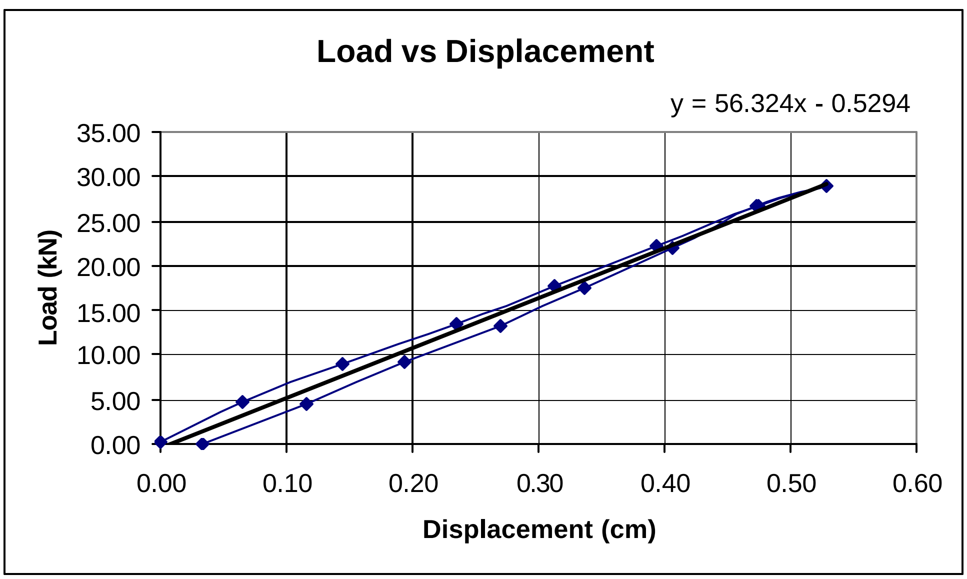
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	5.2256	0.0000	0.35
1	5.1651	0.0605	4.53
2	5.0690	0.1566	8.86
3	4.9770	0.2485	13.37
4	4.8702	0.3554	17.88
5	4.7499	0.4757	22.30
6	4.6147	0.6108	26.80
Peak Reading	4.5319	0.6937	29.06
6	4.6355	0.5901	26.71
5	4.7786	0.4470	22.10
4	4.8762	0.3494	17.66
3	4.9595	0.2661	13.30
2	5.0270	0.1986	8.84
1	5.0982	0.1274	4.56
Final Reading	5.1832	0.0424	0.07



Specimen # 25

Pot Number	F790	Max. Load (kN)	29.00
Constant [cm/V]	1.826	Span (cm)	208.28

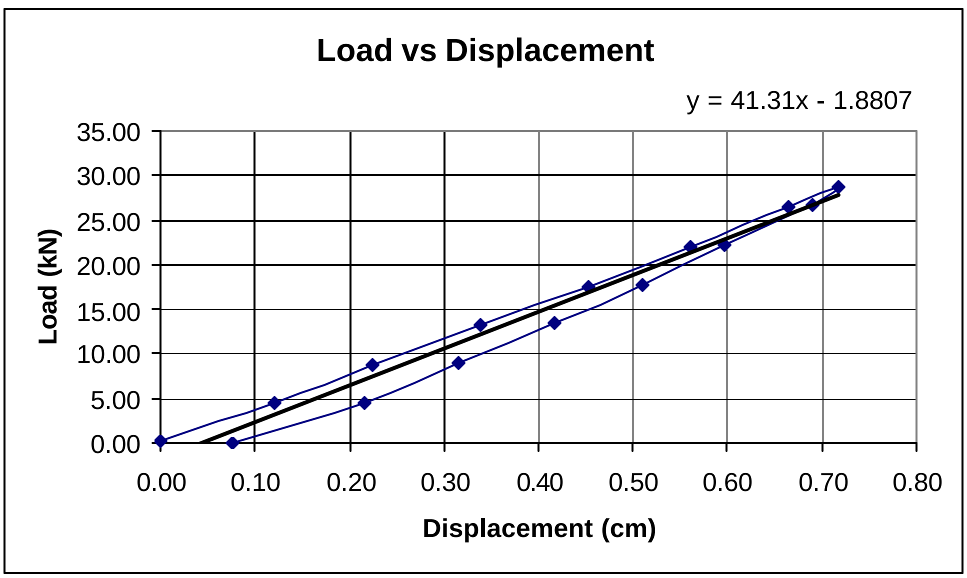
	Reading	d (cm)	Load (kN)
Initial Reading	5.6462	0.0000	0.32
1	5.5813	0.0649	4.79
2	5.5020	0.1442	8.93
3	5.4122	0.2340	13.48
4	5.3328	0.3134	17.73
5	5.2523	0.3938	22.22
6	5.1713	0.4749	26.77
Peak Reading	5.1177	0.5285	29.00
6	5.1726	0.4736	26.67
5	5.2386	0.4076	22.12
4	5.3098	0.3364	17.52
3	5.3763	0.2699	13.17
2	5.4523	0.1939	9.09
1	5.5312	0.1149	4.50
Final Reading	5.6133	0.0328	0.08



Specimen # 26

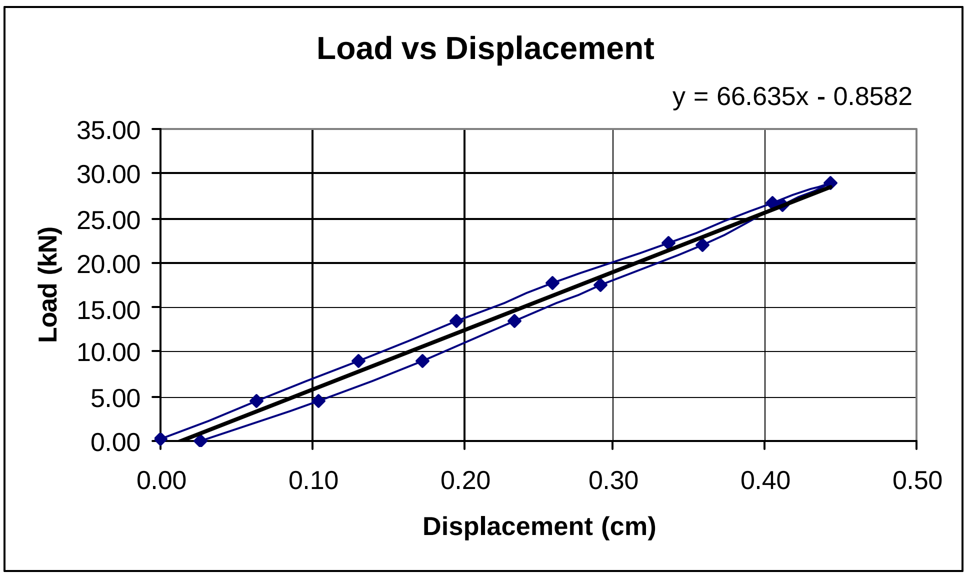
Pot Number	F790	Max. Load (kN)	28.86
Constant [cm/V]	1.826	Span (cm)	208.28

	Reading	d **(cm)**	**Load (kN)**
Initial Reading	5.0488	0.0000	0.24
1	4.9286	0.1202	4.43
2	4.8246	0.2242	8.77
3	4.7112	0.3375	13.22
4	4.5946	0.4542	17.69
5	4.4872	0.5616	22.15
6	4.3841	0.6647	26.59
Peak Reading	4.3313	0.7175	28.86
6	4.3577	0.6911	26.69
5	4.4517	0.5971	22.25
4	4.5374	0.5114	17.79
3	4.6307	0.4180	13.48
2	4.7342	0.3145	8.98
1	4.8324	0.2164	4.51
Final Reading	4.9722	0.0766	0.07



Specimen #	27		
Pot Number	F790	Max. Load (kN)	28.98
Constant [cm/V]	1.826	Span (cm)	208.28

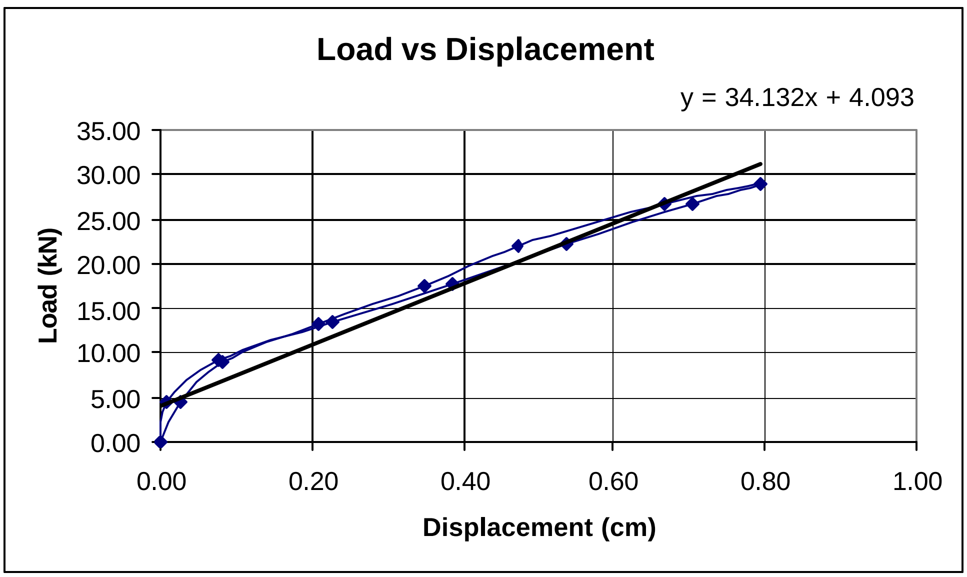
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	4.5457	0.0000	0.24
1	4.4828	0.0629	4.50
2	4.4145	0.1312	8.90
3	4.3505	0.1952	13.35
4	4.2854	0.2603	17.80
5	4.2090	0.3366	22.25
6	4.1401	0.4055	26.78
Peak Reading	4.1030	0.4427	28.98
6	4.1338	0.4119	26.56
5	4.1872	0.3585	22.11
4	4.2539	0.2918	17.69
3	4.3127	0.2330	13.34
2	4.3732	0.1725	8.90
1	4.4415	0.1042	4.40
Final Reading	4.5192	0.0265	0.08



Specimen # 28

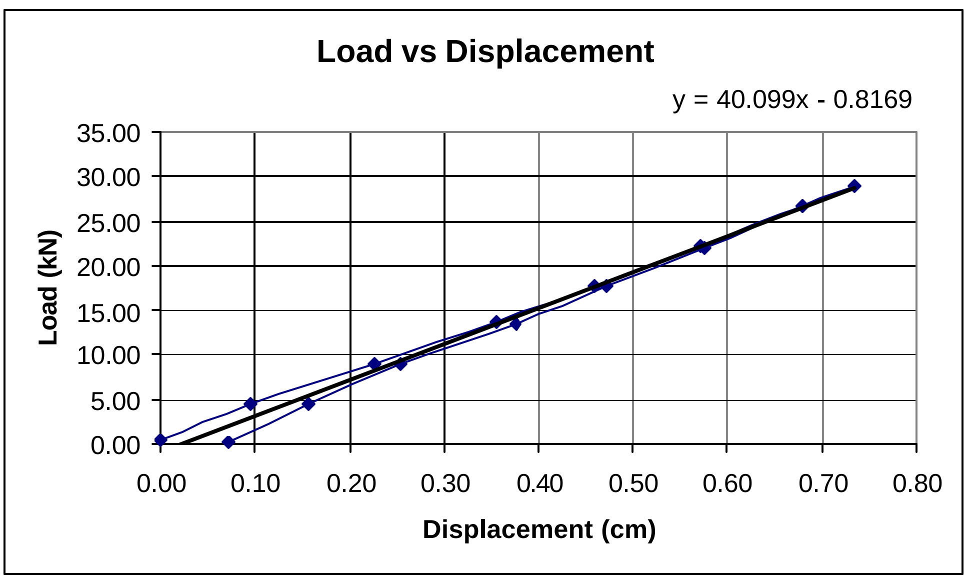
Pot Number	F790	Max. Load (kN)	29.03
Constant [cm/V]	1.826	Span (cm)	208.28

	Reading	d **(cm)**	**Load (kN)**
Initial Reading	4.3655	0.0000	0.11
1	4.3582	0.0073	4.55
2	4.2889	0.0767	9.06
3	4.1380	0.2276	13.48
4	3.9816	0.3840	17.93
5	3.8266	0.5389	22.38
6	3.6602	0.7053	26.81
Peak Reading	3.5707	0.7949	29.03
6	3.6987	0.6668	26.69
5	3.8920	0.4735	22.11
4	4.0166	0.3490	17.72
3	4.1582	0.2073	13.20
2	4.2849	0.0806	8.82
1	4.3379	0.0277	4.39
Final Reading	4.3668	0.0012	0.09



Specimen #	29		
Pot Number	F790	Max. Load (kN)	28.92
Constant [cm/V]	1.826	Span (cm)	208.28

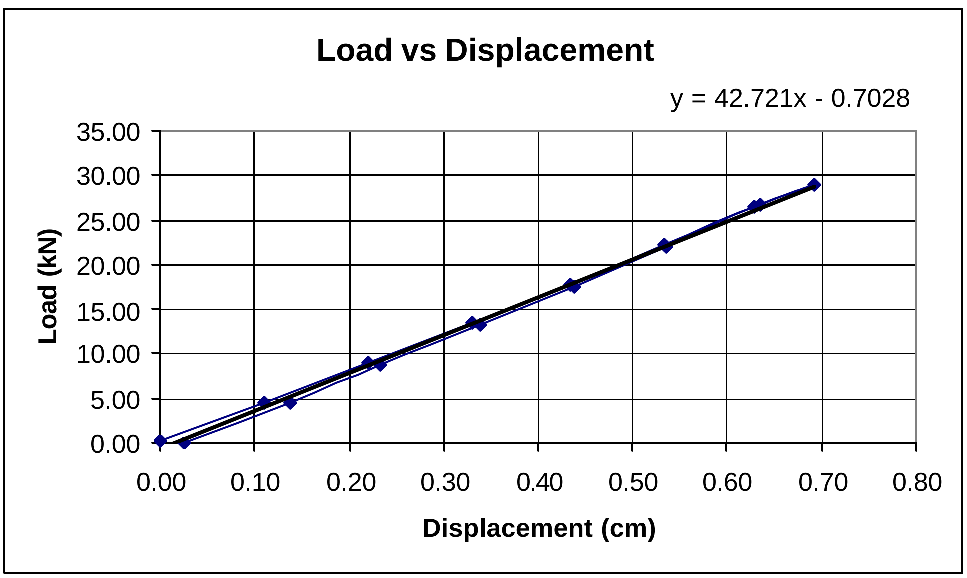
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	5.4344	0.0000	0.38
1	5.3399	0.0945	4.51
2	5.2090	0.2254	8.97
3	5.0806	0.3537	13.49
4	4.9733	0.4611	17.81
5	4.8628	0.5716	22.26
6	4.7536	0.6807	26.68
Peak Reading	4.6989	0.7355	28.92
6	4.7542	0.6802	26.69
5	4.8574	0.5769	22.15
4	4.9618	0.4726	17.76
3	5.0589	0.3755	13.36
2	5.1809	0.2535	8.89
1	5.2791	0.1553	4.46
Final Reading	5.3635	0.0709	0.25



Specimen # 30

Pot Number	F790	Max. Load (kN)	28.97
Constant [cm/V]	1.826	Span (cm)	208.28

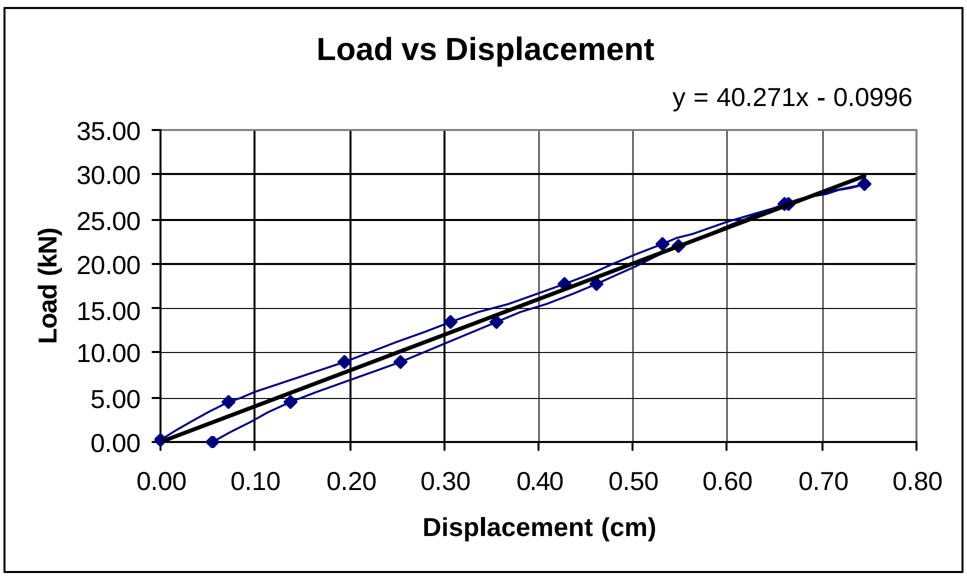
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	4.9350	0.0000	0.15
1	4.8246	0.1104	4.44
2	4.7157	0.2193	8.92
3	4.6065	0.3285	13.31
4	4.4999	0.4351	17.89
5	4.4006	0.5344	22.20
6	4.3001	0.6349	26.74
Peak Reading	4.2433	0.6917	28.97
6	4.3064	0.6286	26.45
5	4.3986	0.5364	22.02
4	4.4966	0.4383	17.64
3	4.5983	0.3367	13.18
2	4.7037	0.2313	8.80
1	4.7979	0.1371	4.55
Final Reading	4.9103	0.0247	0.08



Specimen # 31

Pot Number	F790	Max. Load (kN)	29.04
Constant [cm/V]	1.826	Span (cm)	208.28

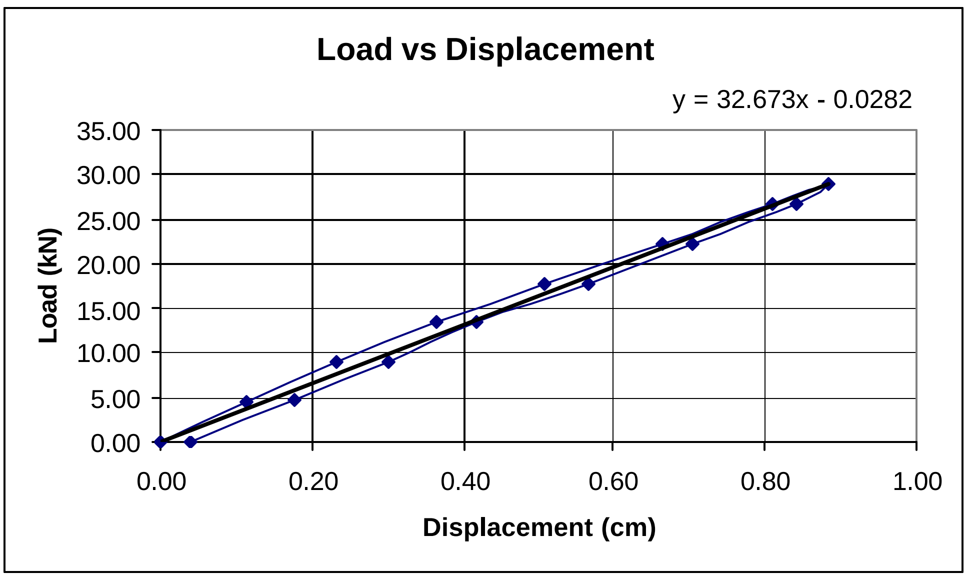
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	6.2170	0.0000	0.28
1	6.1443	0.0727	4.53
2	6.0223	0.1948	8.95
3	5.9099	0.3071	13.33
4	5.7876	0.4294	17.93
5	5.6859	0.5312	22.30
6	5.5524	0.6647	26.80
Peak Reading	5.4727	0.7444	29.04
6	5.5557	0.6613	26.77
5	5.6677	0.5493	22.04
4	5.7537	0.4633	17.76
3	5.8628	0.3542	13.32
2	5.9634	0.2536	9.02
1	6.0801	0.1370	4.55
Final Reading	6.1626	0.0544	0.02



Specimen # 32

Pot Number	F790	Max. Load (kN)	28.87
Constant [cm/V]	1.826	Span (cm)	208.28

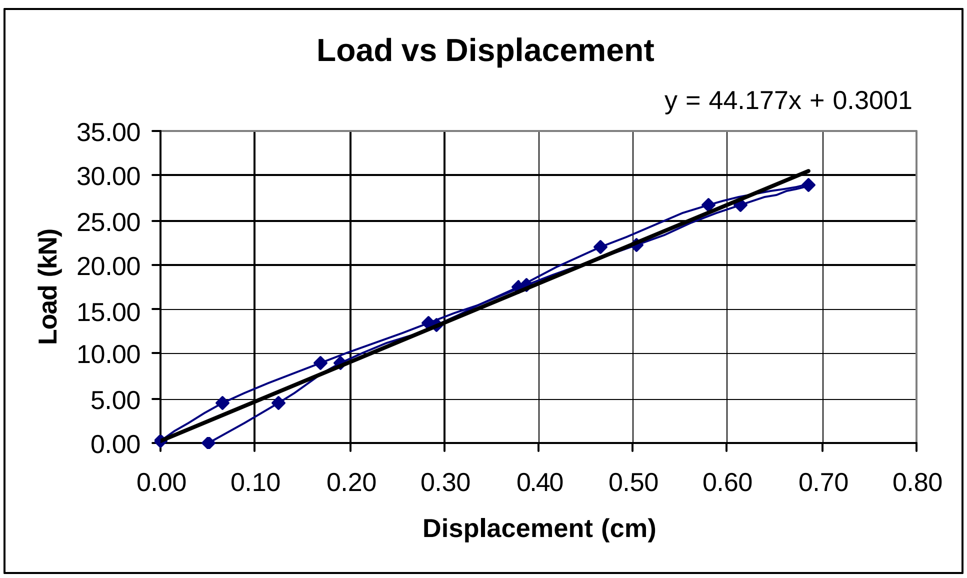
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	6.3279	0.0000	0.04
1	6.2145	0.1134	4.45
2	6.0949	0.2330	8.82
3	5.9629	0.3650	13.33
4	5.8177	0.5102	17.79
5	5.6620	0.6659	22.30
6	5.5171	0.8108	26.70
Peak Reading	5.4431	0.8848	28.87
6	5.4862	0.8417	26.68
5	5.6246	0.7032	22.29
4	5.7617	0.5661	17.92
3	5.9110	0.4169	13.36
2	6.0267	0.3012	8.98
1	6.1513	0.1765	4.57
Final Reading	6.2883	0.0396	0.05



Specimen # 33

Pot Number	F790	Max. Load (kN)	29.06
Constant [cm/V]	1.826	Span (cm)	208.28

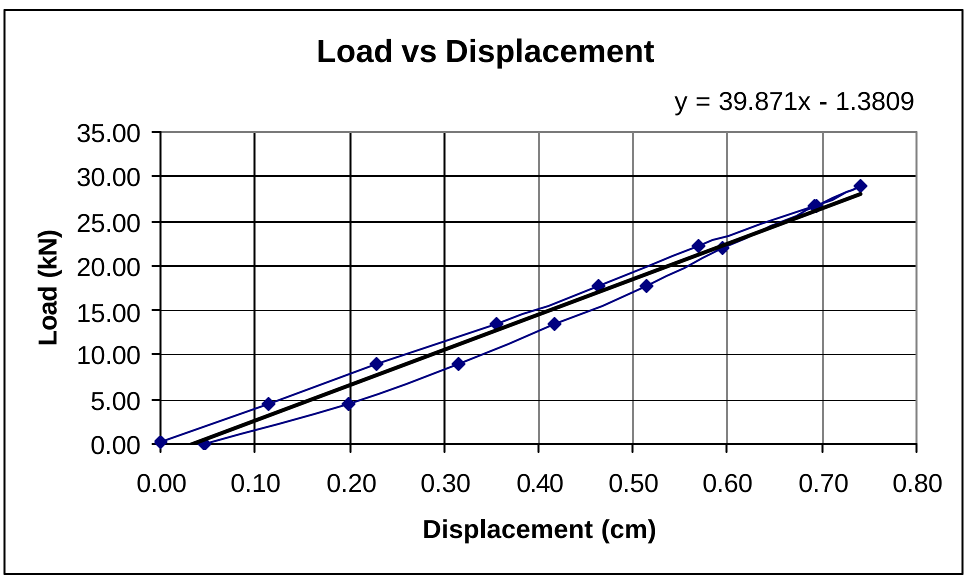
	Reading	d **(cm)**	**Load (kN)**
Initial Reading	4.6901	0.0000	0.12
1	4.6250	0.0651	4.47
2	4.5219	0.1682	9.02
3	4.4083	0.2818	13.43
4	4.3008	0.3893	17.89
5	4.1862	0.5039	22.27
6	4.0751	0.6150	26.73
Peak Reading	4.0033	0.6868	29.06
6	4.1103	0.5798	26.75
5	4.2234	0.4667	22.10
4	4.3119	0.3783	17.61
3	4.3992	0.2909	13.23
2	4.5009	0.1892	8.85
1	4.5659	0.1243	4.49
Final Reading	4.6393	0.0508	0.07



Specimen # 34

Pot Number	F790	Max. Load (kN)	28.98
Constant [cm/V]	1.826	Span (cm)	208.28

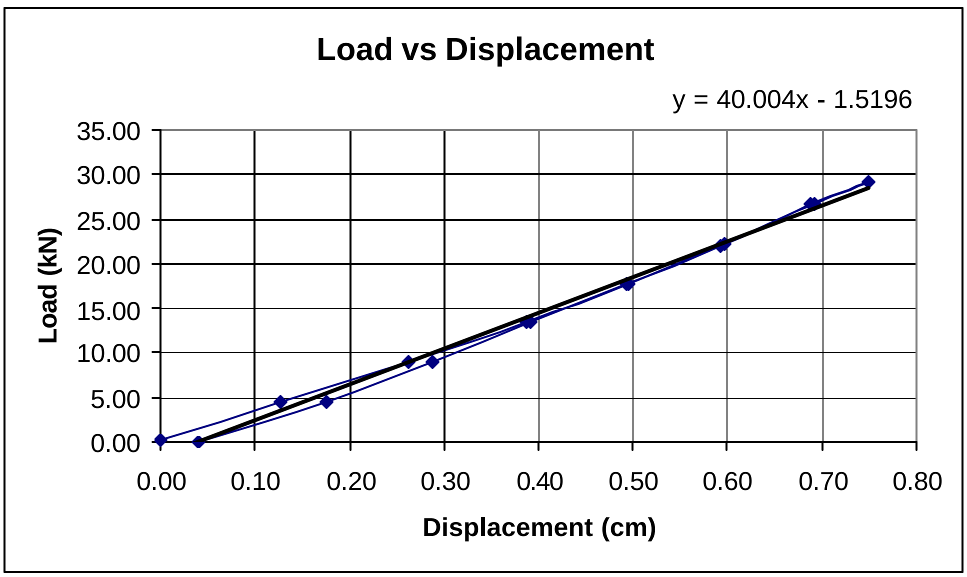
	Reading	d (cm)	Load (kN)
Initial Reading	5.7403	0.0000	0.23
1	5.6272	0.1131	4.51
2	5.5121	0.2282	8.87
3	5.3853	0.3550	13.36
4	5.2758	0.4645	17.80
5	5.1695	0.5708	22.23
6	5.0474	0.6929	26.73
Peak Reading	4.9994	0.7409	28.98
6	5.0467	0.6936	26.68
5	5.1458	0.5945	22.16
4	5.2254	0.5149	17.87
3	5.3230	0.4173	13.35
2	5.4265	0.3138	9.00
1	5.5416	0.1987	4.49
Final Reading	5.6948	0.0455	0.01



Specimen # 35

Pot Number	F790	Max. Load (kN)	29.12
Constant [cm/V]	1.826	Span (cm)	208.28

	Reading	**d (cm)**	**Load (kN)**
Initial Reading	4.9802	0.0000	0.11
1	4.8542	0.1260	4.46
2	4.7182	0.2621	9.02
3	4.5928	0.3874	13.43
4	4.4845	0.4957	17.89
5	4.3818	0.5984	22.30
6	4.2875	0.6928	26.83
Peak Reading	4.2317	0.7485	29.12
6	4.2923	0.6879	26.74
5	4.3874	0.5928	22.15
4	4.4861	0.4941	17.74
3	4.5883	0.3919	13.31
2	4.6923	0.2879	8.90
1	4.8041	0.1761	4.53
Final Reading	4.9393	0.0410	0.01



Appendix 3: Shear Spike Repair Results – Tables

Medium to High Quality

Specimen # 2

	1 Row		2 Rows		3 Rows	
	d **(cm)**	**Load (kN)**	d **(cm)**	**Load (kN)**	d **(cm)**	**Load (kN)**
Initial Reading	0.00	0.01	0.00	0.12	0.00	0.25
1	0.11	4.43	0.02	4.32	0.02	4.42
2	0.21	8.80	0.07	8.98	0.07	8.90
3	0.31	13.30	0.13	13.42	0.13	13.36
4	0.40	17.72	0.20	17.85	0.19	17.90
5	0.48	22.24	0.26	22.26	0.26	22.52
6	0.57	26.68	0.34	26.64	0.32	26.96
Peak Reading	0.61	28.80	0.37	28.89	0.36	29.10
6	0.58	26.61	0.32	26.77	0.30	26.85
5	0.52	22.28	0.25	21.99	0.25	22.31
4	0.47	17.92	0.20	17.82	0.20	17.88
3	0.41	13.43	0.15	13.35	0.14	13.24
2	0.35	8.92	0.11	8.85	0.10	8.83
1	0.27	4.43	0.07	4.44	0.06	4.24
Final Reading	0.17	0.94	0.03	1.07	0.03	1.03

	4 Rows		5 Rows	
	d **(cm)**	**Load (kN)**	d **(cm)**	**Load (kN)**
Initial Reading	0.00	0.00	0.00	0.14
1	0.07	4.54	0.02	4.45
2	0.13	9.02	0.08	9.05
3	0.19	13.46	0.13	13.46
4	0.25	17.94	0.19	17.91
5	0.32	22.41	0.25	22.39
6	0.38	26.78	0.33	26.88
Peak Reading	0.42	29.24	0.35	29.13
6	0.38	26.51	0.31	26.74
5	0.32	22.08	0.24	22.11
4	0.26	17.75	0.19	17.61
3	0.21	13.36	0.15	13.29
2	0.16	8.92	0.10	8.80
1	0.10	4.79	0.07	4.33
Final Reading	0.04	0.91	0.02	0.92

Specimen # 3

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.02	0.00	0.02	0.00	0.08
1	0.04	4.49	0.06	4.42	0.06	4.54
2	0.20	8.96	0.13	8.81	0.13	9.10
3	0.31	13.38	0.20	13.35	0.19	13.48
4	0.44	17.96	0.28	17.76	0.26	17.96
5	0.56	22.41	0.36	22.39	0.33	22.82
6	0.67	26.93	0.44	26.76	0.40	27.03
Peak Reading	0.72	29.35	0.47	28.95	0.44	29.02
6	0.64	26.71	0.42	26.80	0.38	26.65
5	0.54	22.05	0.34	22.10	0.31	22.23
4	0.48	17.73	0.27	17.68	0.24	17.54
3	0.43	12.81	0.22	13.24	0.19	13.07
2	0.38	8.81	0.16	8.94	0.13	8.76
1	0.32	4.33	0.11	4.44	0.08	4.04
Final Reading	0.25	0.96	0.03	1.06	0.01	0.93

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.05	0.00	0.04
1	0.06	4.48	0.07	4.48
2	0.16	8.98	0.13	8.89
3	0.26	13.43	0.20	13.43
4	0.36	17.85	0.27	17.93
5	0.44	22.36	0.34	22.36
6	0.51	26.61	0.40	26.74
Peak Reading	0.55	29.07	0.44	29.12
6	0.52	26.56	0.38	26.67
5	0.45	22.09	0.31	21.99
4	0.39	17.68	0.25	17.61
3	0.32	13.24	0.20	13.22
2	0.26	8.90	0.15	8.67
1	0.19	4.66	0.09	4.35
Final Reading	0.14	0.87	0.00	0.93

Specimen # 4

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.02	0.00	0.02	0.00	0.80
1	0.06	4.43	0.06	4.38	0.04	4.32
2	0.11	8.87	0.11	8.94	0.09	8.83
3	0.16	13.36	0.17	13.43	0.14	13.17
4	0.22	17.90	0.23	17.99	0.20	17.73
5	0.28	22.29	0.29	22.47	0.26	22.21
6	0.34	26.79	0.35	26.87	0.31	26.75
Peak Reading	0.38	29.21	0.38	29.09	0.35	29.06
6	0.32	26.63	0.32	26.72	0.30	26.82
5	0.25	21.76	0.25	21.79	0.23	22.10
4	0.21	17.31	0.21	17.46	0.18	17.45
3	0.18	13.32	0.18	13.30	0.15	13.36
2	0.14	8.72	0.14	8.86	0.11	8.85
1	0.11	4.57	0.11	4.36	0.08	4.41
Final Reading	0.05	0.96	0.05	1.08	0.03	0.98

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.03	0.00	0.07
1	0.04	4.44	0.01	4.37
2	0.09	8.83	0.04	8.89
3	0.15	13.36	0.09	13.34
4	0.21	17.79	0.14	17.84
5	0.27	22.15	0.20	22.18
6	0.33	26.55	0.26	26.66
Peak Reading	0.36	29.03	0.31	29.31
6	0.32	26.67	0.26	26.78
5	0.27	21.99	0.19	21.90
4	0.22	17.68	0.14	17.62
3	0.18	13.33	0.11	13.20
2	0.14	8.76	0.07	8.68
1	0.10	4.42	0.05	4.39
Final Reading	0.06	0.93	0.04	0.96

Specimen # 5

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.05	0.00	0.10	0.00	0.13
1	0.06	4.83	0.04	4.31	0.06	4.55
2	0.11	9.41	0.10	8.86	0.12	9.01
3	0.17	13.89	0.18	13.29	0.17	13.30
4	0.24	18.46	0.25	17.90	0.25	17.96
5	0.33	23.42	0.32	22.30	0.32	22.31
6	0.38	27.03	0.39	26.57	0.38	26.67
Peak Reading	0.41	29.23	0.43	28.96	0.42	29.17
6	0.35	26.81	0.37	26.95	0.36	26.73
5	0.25	22.02	0.30	22.26	0.28	22.10
4	0.20	17.59	0.23	17.96	0.24	17.84
3	0.15	13.37	0.18	13.51	0.19	13.15
2	0.09	9.08	0.12	9.01	0.12	9.04
1	0.06	4.56	0.07	4.70	0.08	4.46
Final Reading	0.00	0.77	0.01	1.09	0.02	0.94

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.06	0.00	0.12
1	0.06	4.32	0.06	4.49
2	0.12	8.93	0.11	9.00
3	0.18	13.39	0.17	13.46
4	0.25	17.87	0.24	17.97
5	0.33	22.37	0.32	22.81
6	0.40	26.79	0.38	26.90
Peak Reading	0.42	28.92	0.41	29.10
6	0.37	26.64	0.34	26.68
5	0.30	22.31	0.27	22.28
4	0.24	17.83	0.21	17.74
3	0.18	13.46	0.16	13.21
2	0.12	8.86	0.11	9.11
1	0.07	4.53	0.07	4.61
Final Reading	0.01	0.94	0.00	0.92

Specimen # 6

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.01	0.00	0.08	0.00	0.13
1	0.08	4.22	0.05	4.28	0.06	4.39
2	0.17	8.84	0.10	8.50	0.12	8.67
3	0.25	13.19	0.16	13.14	0.17	13.15
4	0.33	17.69	0.22	17.79	0.22	17.69
5	0.40	22.09	0.26	22.04	0.27	22.16
6	0.48	26.59	0.31	26.46	0.32	26.43
Peak Reading	0.52	28.66	0.33	28.72	0.34	28.76
6	0.50	26.78	0.31	26.66	0.31	26.69
5	0.45	22.25	0.27	22.32	0.26	22.17
4	0.40	17.92	0.24	17.98	0.23	17.84
3	0.35	13.24	0.20	13.48	0.19	13.32
2	0.31	9.06	0.14	8.96	0.15	8.80
1	0.25	4.72	0.09	3.94	0.09	3.73
Final Reading	0.15	0.99	0.05	1.07	0.04	0.98

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.10	0.00	0.12
1	0.06	4.46	0.07	4.37
2	0.10	8.81	0.13	8.73
3	0.16	13.33	0.18	13.24
4	0.21	17.69	0.24	17.68
5	0.27	22.12	0.30	22.09
6	0.32	26.59	0.35	26.71
Peak Reading	0.35	28.95	0.38	28.93
6	0.31	26.66	0.35	26.44
5	0.26	22.13	0.31	22.04
4	0.22	17.60	0.26	17.29
3	0.18	13.24	0.23	13.29
2	0.14	8.84	0.19	8.89
1	0.10	4.73	0.13	4.38
Final Reading	0.04	0.94	0.06	0.87

Specimen # 8

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.05	0.00	0.03	0.00	0.01
1	0.04	4.42	0.04	4.48	0.02	4.27
2	0.07	8.85	0.08	8.89	0.06	8.89
3	0.12	13.32	0.12	13.41	0.10	13.30
4	0.16	17.78	0.16	17.89	0.15	17.93
5	0.21	22.21	0.21	22.29	0.21	22.29
6	0.26	26.82	0.25	26.70	0.27	26.88
Peak Reading	0.29	28.90	0.28	28.98	0.31	29.01
6	0.25	26.70	0.24	26.76	0.26	26.87
5	0.20	22.26	0.19	22.11	0.19	22.00
4	0.15	17.79	0.16	17.65	0.15	17.64
3	0.12	13.26	0.13	13.43	0.12	13.29
2	0.09	8.95	0.09	8.93	0.09	8.82
1	0.05	4.51	0.07	4.52	0.06	4.36
Final Reading	0.04	0.98	0.04	1.09	0.04	0.89

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.00	0.00	0.05
1	0.05	4.48	0.03	4.35
2	0.09	8.91	0.05	8.96
3	0.12	13.38	0.08	13.43
4	0.17	17.87	0.11	17.84
5	0.21	22.29	0.15	22.38
6	0.25	26.77	0.19	26.95
Peak Reading	0.28	29.25	0.22	29.14
6	0.23	26.78	0.17	26.69
5	0.19	22.09	0.13	22.03
4	0.16	17.68	0.10	17.59
3	0.12	13.33	0.08	13.29
2	0.09	8.83	0.05	8.87
1	0.06	4.52	0.03	4.36
Final Reading	0.03	0.93	0.01	0.32

Specimen # 16

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.01	0.00	0.00	0.00	0.05
1	0.06	4.40	0.05	4.35	0.06	4.24
2	0.14	8.87	0.12	8.80	0.12	8.85
3	0.22	13.39	0.19	13.32	0.19	13.27
4	0.30	17.88	0.27	18.15	0.24	17.91
5	0.37	22.13	0.34	22.47	0.31	22.51
6	0.45	26.49	0.40	26.95	0.36	26.71
Peak Reading	0.48	28.87	0.42	29.29	0.38	29.22
6	0.45	26.86	0.38	26.58	0.35	26.27
5	0.37	22.18	0.34	22.17	0.28	21.97
4	0.33	17.92	0.26	17.74	0.23	17.40
3	0.27	13.33	0.22	13.42	0.19	13.21
2	0.22	9.11	0.18	8.97	0.13	8.91
1	0.16	4.46	0.13	4.26	0.09	4.57
Final Reading	0.08	0.97	0.07	1.04	0.02	1.00

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.11	0.00	0.12
1	0.05	4.37	0.06	4.41
2	0.12	9.11	0.13	8.96
3	0.18	13.47	0.19	13.56
4	0.25	18.04	0.25	18.04
5	0.31	22.40	0.32	22.34
6	0.37	27.13	0.37	26.92
Peak Reading	0.39	29.18	0.40	29.16
6	0.35	26.49	0.35	26.38
5	0.29	22.01	0.30	22.02
4	0.24	17.39	0.25	17.76
3	0.19	13.27	0.20	13.29
2	0.14	8.80	0.15	9.01
1	0.09	4.41	0.10	4.45
Final Reading	0.03	0.94	0.03	0.94

Specimen # 18

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.06	0.00	0.05	0.00	0.01
1	0.10	4.40	0.07	4.14	0.09	4.70
2	0.20	8.90	0.15	8.77	0.17	9.02
3	0.28	13.27	0.23	13.34	0.24	13.34
4	0.37	17.62	0.30	17.65	0.31	17.84
5	0.46	22.22	0.36	22.21	0.38	22.59
6	0.54	26.62	0.42	26.60	0.43	26.88
Peak Reading	0.58	29.07	0.45	28.79	0.46	28.93
6	0.54	26.75	0.43	26.76	0.43	27.06
5	0.48	22.22	0.37	22.32	0.38	22.25
4	0.42	17.88	0.32	17.88	0.33	18.27
3	0.35	13.65	0.26	13.48	0.26	13.47
2	0.26	9.04	0.19	8.95	0.19	8.71
1	0.17	4.57	0.14	5.29	0.12	4.32
Final Reading	0.07	0.89	0.02	1.08	0.03	1.02

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.01	0.00	0.17
1	0.11	4.35	0.10	6.03
2	0.19	8.75	0.15	8.76
3	0.26	13.19	0.22	13.27
4	0.33	17.67	0.28	17.73
5	0.41	22.04	0.35	22.17
6	0.48	26.59	0.41	26.53
Peak Reading	0.52	28.80	0.45	28.81
6	0.48	26.52	0.43	26.69
5	0.43	22.34	0.37	22.29
4	0.36	17.85	0.31	17.88
3	0.30	13.34	0.26	13.38
2	0.24	9.01	0.19	8.89
1	0.16	4.59	0.14	5.42
Final Reading	0.07	0.89	0.03	0.96

Specimen # 20

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.01	0.00	0.06	0.00	0.00
1	0.08	4.56	0.09	4.67	0.08	4.73
2	0.18	8.90	0.15	9.17	0.17	9.87
3	0.24	13.24	0.21	13.31	0.24	13.45
4	0.33	17.74	0.29	18.07	0.32	18.06
5	0.41	22.24	0.37	22.16	0.38	22.32
6	0.49	26.71	0.45	26.97	0.46	26.93
Peak Reading	0.53	28.90	0.49	29.06	0.50	29.00
6	0.49	26.84	0.43	26.95	0.44	26.58
5	0.41	22.16	0.35	22.14	0.37	21.75
4	0.34	17.76	0.28	17.51	0.31	17.51
3	0.27	13.37	0.21	12.89	0.27	12.91
2	0.21	9.03	0.17	9.41	0.18	8.77
1	0.14	4.56	0.10	4.98	0.11	4.61
Final Reading	0.05	0.99	0.03	0.75	0.06	0.71

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.07	0.00	0.08
1	0.03	4.49	0.09	4.60
2	0.11	8.98	0.16	9.12
3	0.20	13.52	0.24	13.67
4	0.28	17.91	0.30	17.79
5	0.37	22.64	0.38	22.25
6	0.44	26.93	0.46	27.02
Peak Reading	0.47	29.01	0.49	29.05
6	0.40	26.61	0.43	26.72
5	0.32	22.35	0.35	21.98
4	0.26	17.75	0.28	17.21
3	0.19	13.20	0.22	13.03
2	0.13	8.90	0.16	9.13
1	0.08	4.46	0.09	4.43
Final Reading	0.03	0.89	0.04	0.17

Specimen # 21

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.04	0.00	0.01	0.00	0.02
1	0.13	4.52	0.11	4.35	0.09	4.48
2	0.24	8.95	0.23	8.88	0.21	9.40
3	0.34	13.44	0.34	13.28	0.31	13.65
4	0.42	17.87	0.45	17.76	0.42	18.32
5	0.53	22.33	0.56	22.20	0.53	22.73
6	0.63	26.84	0.67	26.73	0.63	27.09
Peak Reading	0.70	29.16	0.72	28.81	0.67	29.02
6	0.65	26.43	0.68	26.80	0.61	26.23
5	0.54	22.29	0.58	22.31	0.52	21.78
4	0.46	17.74	0.49	17.95	0.44	17.53
3	0.37	13.28	0.39	13.52	0.34	13.21
2	0.27	8.70	0.29	8.86	0.24	8.65
1	0.17	4.42	0.19	4.60	0.14	4.57
Final Reading	0.01	0.81	0.04	1.11	0.02	1.00

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.01	0.00	0.32
1	0.11	4.32	0.12	4.49
2	0.22	8.69	0.23	9.11
3	0.32	13.10	0.33	13.79
4	0.43	17.80	0.44	18.17
5	0.53	22.09	0.53	22.79
6	0.63	26.65	0.63	27.38
Peak Reading	0.68	29.00	0.67	29.50
6	0.65	26.77	0.63	26.70
5	0.56	22.34	0.53	22.06
4	0.46	17.80	0.44	17.56
3	0.37	13.40	0.34	13.35
2	0.27	8.95	0.24	8.65
1	0.17	4.62	0.15	4.62
Final Reading	0.01	1.00	0.01	0.87

Lower Quality

Specimen # 7

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.13	0.00	0.05	0.00	0.10
1	0.08	4.44	0.09	4.62	0.07	4.55
2	0.16	8.93	0.17	8.86	0.16	9.03
3	0.25	13.37	0.26	13.46	0.23	13.55
4	0.34	17.77	0.34	18.04	0.32	18.07
5	0.44	22.31	0.42	22.36	0.41	22.55
6	0.52	26.92	0.50	26.63	0.48	26.94
Peak Reading	0.56	29.27	0.54	29.04	0.52	29.32
6	0.50	26.58	0.49	26.69	0.45	26.60
5	0.41	22.11	0.40	22.17	0.37	21.99
4	0.34	17.67	0.32	17.72	0.29	17.53
3	0.27	13.20	0.25	13.23	0.22	13.16
2	0.20	8.87	0.18	8.79	0.16	8.67
1	0.13	4.38	0.11	4.41	0.08	4.48
Final Reading	0.04	0.84	0.02	0.89	0.00	0.80

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.07	0.00	0.70
1	0.08	4.53	0.10	4.58
2	0.17	8.90	0.19	9.00
3	0.25	13.46	0.27	13.57
4	0.34	17.99	0.35	18.22
5	0.42	22.55	0.42	22.37
6	0.49	26.73	0.50	26.87
Peak Reading	0.53	29.34	0.54	29.34
6	0.47	26.65	0.48	26.69
5	0.39	22.12	0.39	22.03
4	0.31	17.67	0.31	17.59
3	0.24	13.19	0.24	13.21
2	0.17	8.86	0.17	8.78
1	0.09	4.43	0.10	4.28
Final Reading	0.02	0.83	0.03	0.78

Specimen # 9

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.02	0.00	0.01	0.00	0.00
1	0.10	4.51	0.08	4.57	0.08	4.58
2	0.20	8.96	0.16	9.02	0.18	9.22
3	0.29	13.43	0.23	13.41	0.26	13.50
4	0.37	17.93	0.31	17.78	0.33	17.92
5	0.45	22.36	0.38	22.22	0.41	22.38
6	0.53	26.75	0.46	26.73	0.49	26.84
Peak Reading	0.58	29.29	0.50	29.04	0.53	29.18
6	0.51	26.52	0.45	26.61	0.48	26.62
5	0.45	22.28	0.38	22.10	0.41	22.19
4	0.38	17.77	0.32	17.86	0.35	17.70
3	0.31	13.10	0.25	13.40	0.27	13.08
2	0.23	8.82	0.18	8.96	0.20	8.78
1	0.14	4.26	0.11	4.44	0.13	4.41
Final Reading	0.05	0.81	0.01	0.89	0.05	0.83

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.04	0.00	0.11
1	0.09	4.46	0.09	4.54
2	0.18	9.04	0.17	9.02
3	0.25	13.40	0.25	13.58
4	0.33	17.87	0.32	18.08
5	0.40	22.21	0.40	22.47
6	0.48	26.74	0.48	26.84
Peak Reading	0.53	29.11	0.52	29.30
6	0.48	26.62	0.46	26.63
5	0.40	21.91	0.38	22.09
4	0.34	17.63	0.31	17.72
3	0.26	13.18	0.25	13.32
2	0.19	8.84	0.18	8.87
1	0.11	4.57	0.11	4.50
Final Reading	0.02	0.87	0.04	0.86

Specimen # 13

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.05	0.00	0.16	0.00	0.60
1	0.03	4.47	0.07	4.45	0.03	4.51
2	0.11	8.77	0.16	8.84	0.09	8.93
3	0.17	13.38	0.23	13.38	0.16	13.37
4	0.24	17.82	0.29	17.81	0.23	17.88
5	0.30	22.27	0.36	22.39	0.30	22.33
6	0.37	26.80	0.42	26.81	0.37	26.77
Peak Reading	0.42	29.03	0.46	29.14	0.41	29.09
6	0.36	26.63	0.41	26.61	0.35	26.69
5	0.29	22.08	0.34	22.06	0.28	22.13
4	0.23	17.70	0.29	17.65	0.22	17.73
3	0.18	13.16	0.23	13.21	0.16	13.23
2	0.12	8.74	0.18	8.80	0.11	8.82
1	0.07	4.33	0.13	4.34	0.06	4.51
Final Reading	0.01	0.92	0.07	0.85	0.02	0.89

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.04	0.00	0.03
1	0.06	4.54	0.05	4.48
2	0.12	9.02	0.11	8.96
3	0.18	13.46	0.17	13.57
4	0.25	17.97	0.24	18.02
5	0.31	22.34	0.31	22.43
6	0.38	26.89	0.37	26.84
Peak Reading	0.41	29.16	0.40	29.30
6	0.36	26.54	0.35	26.58
5	0.29	21.98	0.28	22.04
4	0.23	17.59	0.22	17.67
3	0.17	13.12	0.16	13.33
2	0.12	8.88	0.11	8.74
1	0.08	4.46	0.07	4.44
Final Reading	0.02	0.75	0.01	0.83

Specimen # 15

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.14	0.00	0.06	0.00	0.14
1	0.11	4.36	0.11	4.48	0.09	4.46
2	0.22	8.86	0.21	8.88	0.18	8.92
3	0.31	13.28	0.30	13.32	0.27	13.35
4	0.40	17.71	0.38	17.34	0.36	17.84
5	0.50	22.19	0.49	22.26	0.45	22.17
6	0.60	26.65	0.58	26.63	0.54	26.67
Peak Reading	0.65	29.07	0.64	29.00	0.59	29.04
6	0.60	26.69	0.59	26.75	0.54	26.73
5	0.52	22.28	0.48	22.15	0.45	22.33
4	0.44	17.75	0.40	17.84	0.37	18.02
3	0.35	13.36	0.32	13.54	0.29	13.43
2	0.27	9.04	0.24	8.95	0.21	9.07
1	0.18	4.48	0.16	4.58	0.12	4.65
Final Reading	0.02	0.92	0.02	0.88	0.01	0.88

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.11	0.00	0.14
1	0.09	4.41	0.08	4.45
2	0.19	8.86	0.17	8.92
3	0.28	13.38	0.26	13.42
4	0.36	17.54	0.34	17.92
5	0.45	22.27	0.42	22.40
6	0.55	26.74	0.51	26.84
Peak Reading	0.60	28.95	0.56	29.24
6	0.55	26.69	0.50	26.59
5	0.45	22.24	0.42	22.16
4	0.37	17.78	0.34	17.80
3	0.30	13.47	0.27	13.45
2	0.22	8.99	0.19	8.91
1	0.13	4.57	0.12	4.57
Final Reading	0.01	0.82	0.00	0.84

Specimen # 17

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.09	0.00	0.06	0.00	0.01
1	0.06	4.34	0.07	4.47	0.07	4.46
2	0.14	8.92	0.15	8.96	0.13	8.96
3	0.22	13.32	0.23	13.46	0.21	13.35
4	0.31	17.90	0.32	17.97	0.31	17.94
5	0.42	22.32	0.41	22.43	0.41	22.26
6	0.53	26.78	0.52	26.79	0.51	26.80
Peak Reading	0.58	29.05	0.57	29.10	0.56	29.24
6	0.49	26.72	0.48	26.68	0.47	26.70
5	0.38	22.10	0.38	22.00	0.37	22.11
4	0.30	17.61	0.31	17.54	0.29	17.74
3	0.23	13.25	0.25	13.19	0.22	13.29
2	0.16	8.88	0.18	8.80	0.14	8.87
1	0.09	4.45	0.12	4.32	0.08	4.55
Final Reading	0.02	0.94	0.04	0.85	0.01	0.90

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.04	0.00	0.02
1	0.07	4.60	0.06	4.27
2	0.15	9.07	0.15	9.00
3	0.23	13.54	0.23	13.43
4	0.30	18.00	0.32	17.76
5	0.39	22.49	0.41	22.42
6	0.48	26.93	0.49	26.94
Peak Reading	0.51	29.05	0.53	29.33
6	0.43	26.81	0.44	26.43
5	0.34	22.18	0.36	22.33
4	0.27	17.52	0.29	17.76
3	0.20	13.24	0.23	13.35
2	0.14	8.83	0.16	8.98
1	0.07	4.38	0.09	4.42
Final Reading	0.01	0.63	0.02	0.83

Specimen # 19

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.11	0.00	0.02	0.00	0.07
1	0.10	4.36	0.07	4.44	0.08	4.64
2	0.17	8.85	0.14	8.81	0.15	9.00
3	0.25	13.32	0.19	13.31	0.20	13.31
4	0.33	17.74	0.25	17.59	0.26	17.67
5	0.41	22.22	0.31	22.22	0.32	21.53
6	0.47	26.64	0.38	26.56	0.39	26.70
Peak Reading	0.50	29.07	0.41	29.01	0.42	29.13
6	0.46	26.62	0.38	26.69	0.39	26.75
5	0.41	22.40	0.32	22.24	0.33	22.15
4	0.34	17.76	0.27	17.87	0.28	17.92
3	0.28	13.33	0.22	13.41	0.23	13.40
2	0.20	8.22	0.17	8.83	0.17	9.07
1	0.15	4.70	0.12	4.63	0.11	4.52
Final Reading	0.06	0.89	0.03	0.89	0.03	0.86

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.04	0.00	0.03
1	0.09	4.47	0.07	4.39
2	0.14	8.69	0.13	8.89
3	0.20	13.35	0.18	13.37
4	0.25	17.64	0.23	17.89
5	0.32	22.26	0.29	21.22
6	0.38	26.62	0.35	26.76
Peak Reading	0.41	29.17	0.39	29.18
6	0.38	26.70	0.36	26.80
5	0.32	22.30	0.30	22.28
4	0.27	17.80	0.25	17.66
3	0.23	13.45	0.21	13.35
2	0.17	8.83	0.16	8.75
1	0.12	4.65	0.10	4.37
Final Reading	0.03	0.82	0.02	0.82

Specimen # 23

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.04	0.00	0.02	0.00	0.03
1	0.12	4.51	0.12	4.39	0.11	4.54
2	0.24	10.16	0.21	8.89	0.20	9.07
3	0.29	13.31	0.27	13.44	0.28	13.30
4	0.36	17.73	0.34	17.70	0.35	17.87
5	0.43	22.02	0.42	22.23	0.44	22.30
6	0.52	26.67	0.49	26.60	0.52	26.78
Peak Reading	0.55	29.10	0.53	29.06	0.56	28.97
6	0.51	26.66	0.49	26.55	0.52	26.75
5	0.45	22.31	0.43	22.18	0.45	22.24
4	0.38	17.82	0.37	17.86	0.37	17.82
3	0.32	13.36	0.30	13.33	0.29	13.29
2	0.26	8.74	0.24	8.89	0.21	8.62
1	0.17	4.59	0.15	4.61	0.13	4.43
Final Reading	0.02	0.86	0.03	0.92	0.02	0.76

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.04	0.00	0.02
1	0.10	4.53	0.11	5.02
2	0.17	8.54	0.19	8.89
3	0.26	13.30	0.27	13.16
4	0.33	17.79	0.35	17.71
5	0.41	22.32	0.44	22.29
6	0.47	26.56	0.51	26.70
Peak Reading	0.51	28.90	0.55	29.25
6	0.47	26.51	0.51	26.65
5	0.42	22.38	0.45	22.26
4	0.36	18.01	0.38	17.93
3	0.28	13.34	0.31	13.61
2	0.20	8.60	0.22	9.00
1	0.12	4.47	0.12	3.84
Final Reading	0.01	0.80	0.02	0.87

Specimen # 32

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.02	0.00	0.03	0.00	0.03
1	0.13	4.47	0.13	4.55	0.09	4.53
2	0.24	8.94	0.24	8.95	0.20	9.10
3	0.35	13.34	0.35	13.36	0.29	13.39
4	0.46	17.82	0.45	17.85	0.38	17.89
5	0.57	22.31	0.56	22.24	0.48	22.31
6	0.67	26.79	0.66	26.79	0.58	26.78
Peak Reading	0.72	29.16	0.71	29.14	0.63	29.22
6	0.64	26.76	0.66	26.78	0.55	26.75
5	0.55	22.11	0.56	22.22	0.45	22.17
4	0.46	17.60	0.47	17.71	0.37	17.70
3	0.37	13.06	0.38	13.32	0.29	13.37
2	0.29	8.25	0.31	8.84	0.21	8.80
1	0.22	4.63	0.22	4.35	0.13	4.73
Final Reading	0.08	0.87	0.07	0.93	0.02	0.87

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.06	0.00	0.04
1	0.12	4.46	0.11	4.53
2	0.23	8.82	0.22	8.90
3	0.34	13.30	0.33	13.42
4	0.44	17.82	0.43	17.81
5	0.56	22.24	0.54	22.21
6	0.66	26.68	0.65	26.61
Peak Reading	0.71	29.00	0.70	29.16
6	0.66	26.61	0.65	26.64
5	0.57	22.11	0.55	22.22
4	0.47	17.87	0.45	17.83
3	0.37	13.21	0.36	13.31
2	0.29	8.72	0.27	8.96
1	0.19	4.43	0.17	4.46
Final Reading	0.08	0.93	0.04	0.88

Specimen # 34

	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.07	0.00	0.12	0.00	0.32
1	0.10	4.37	0.09	4.39	0.05	4.50
2	0.18	8.81	0.17	8.87	0.11	8.86
3	0.26	13.18	0.26	13.30	0.17	13.34
4	0.35	17.67	0.34	17.74	0.23	17.83
5	0.43	22.19	0.42	22.22	0.29	22.34
6	0.51	26.55	0.49	26.66	0.34	26.62
Peak Reading	0.55	28.88	0.53	29.00	0.37	29.05
6	0.52	26.67	0.50	26.68	0.34	26.69
5	0.46	22.46	0.43	22.19	0.29	22.16
4	0.40	18.00	0.37	17.86	0.24	17.81
3	0.33	13.52	0.31	13.44	0.19	13.38
2	0.26	9.10	0.25	9.07	0.14	8.98
1	0.19	4.74	0.18	4.56	0.09	4.52
Final Reading	0.08	0.90	0.07	0.94	0.00	0.88

	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.12	0.00	0.06
1	0.06	4.51	0.07	4.60
2	0.12	8.94	0.13	8.96
3	0.17	13.25	0.18	13.31
4	0.23	17.73	0.24	17.69
5	0.29	22.23	0.30	22.28
6	0.35	26.72	0.35	26.69
Peak Reading	0.38	29.15	0.38	29.05
6	0.35	26.75	0.35	26.56
5	0.29	22.13	0.30	22.12
4	0.24	17.86	0.24	17.76
3	0.19	13.40	0.19	13.36
2	0.15	8.96	0.14	8.94
1	0.10	4.49	0.10	4.53
Final Reading	0.01	0.95	0.01	0.88

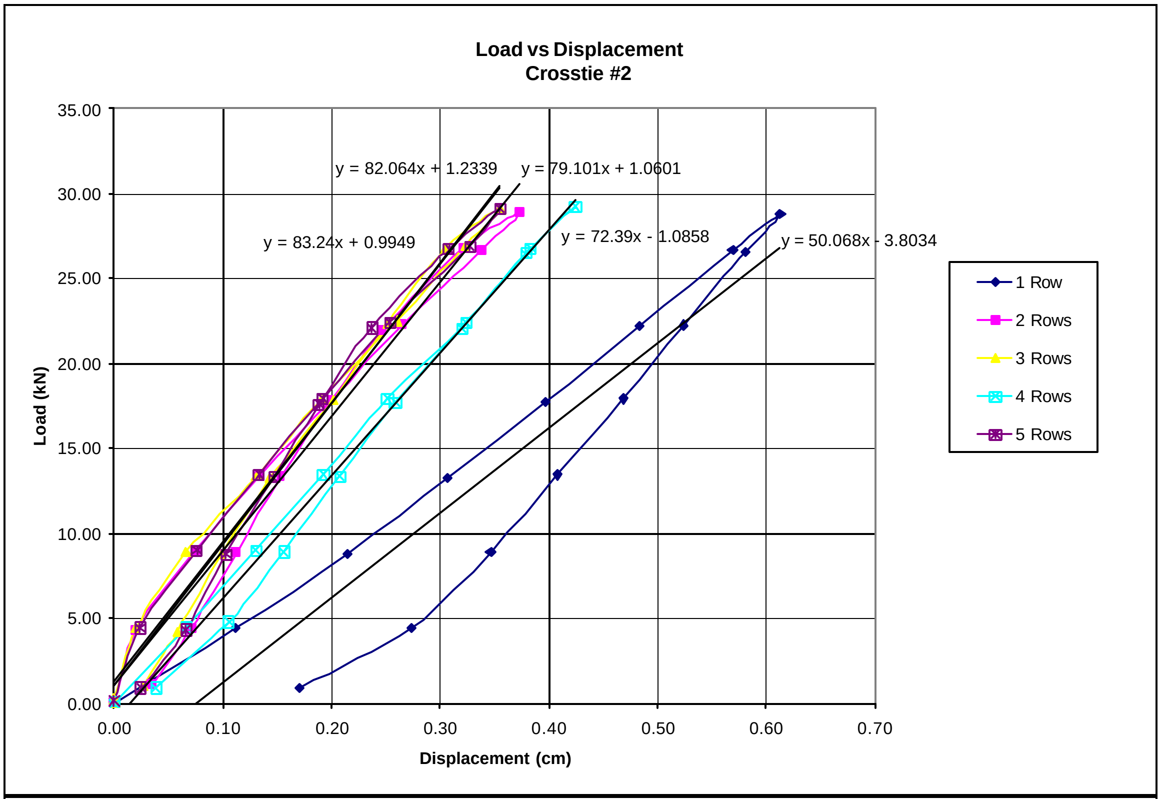
Specimen # 35

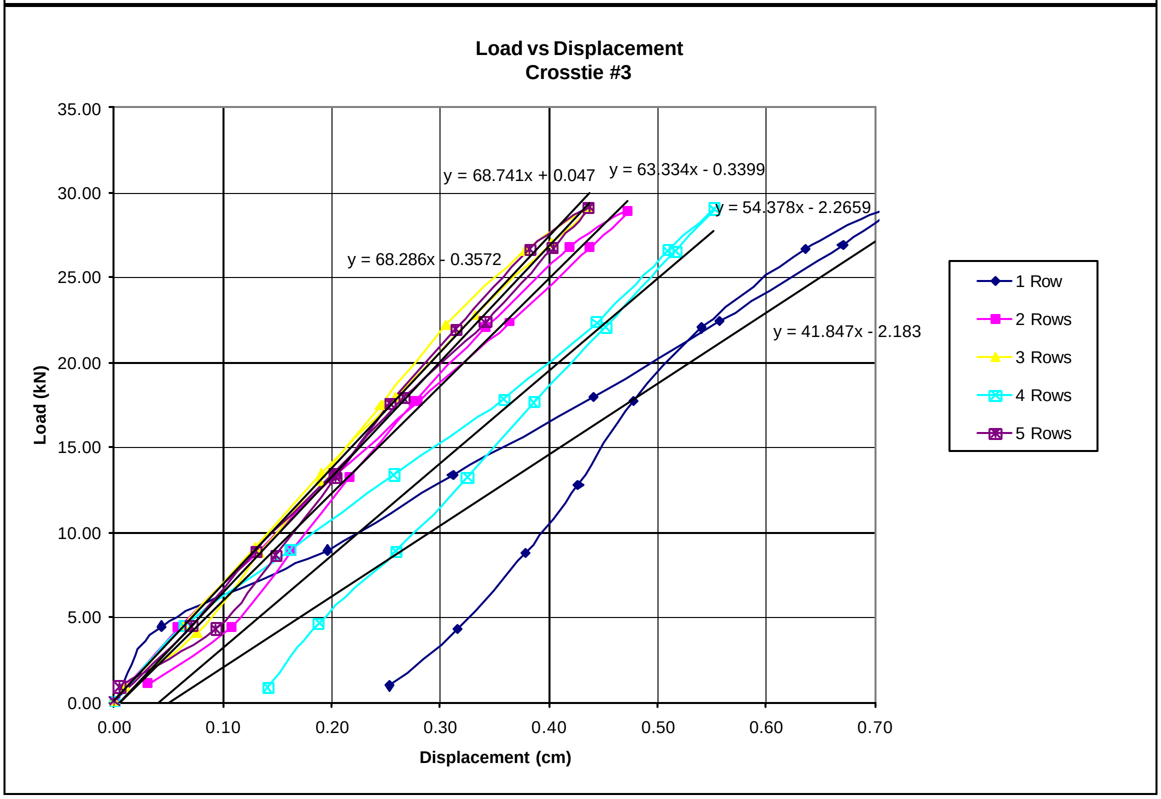
	1 Row		2 Rows		3 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.04	0.00	0.03	0.00	0.04
1	0.09	4.43	0.09	4.51	0.08	4.55
2	0.16	8.86	0.16	9.01	0.17	8.99
3	0.24	13.31	0.23	13.34	0.24	13.41
4	0.31	17.79	0.30	17.88	0.31	17.90
5	0.38	22.21	0.37	22.25	0.39	22.32
6	0.45	26.52	0.45	26.62	0.46	26.69
Peak Reading	0.49	28.82	0.49	29.04	0.49	29.08
6	0.46	26.71	0.45	26.66	0.45	26.65
5	0.40	22.30	0.39	22.33	0.38	22.22
4	0.34	17.85	0.32	17.84	0.31	17.72
3	0.27	13.38	0.25	13.35	0.25	13.31
2	0.20	8.89	0.19	8.84	0.19	9.03
1	0.13	4.53	0.13	4.48	0.11	4.63
Final Reading	0.03	0.89	0.02	0.94	0.02	0.87

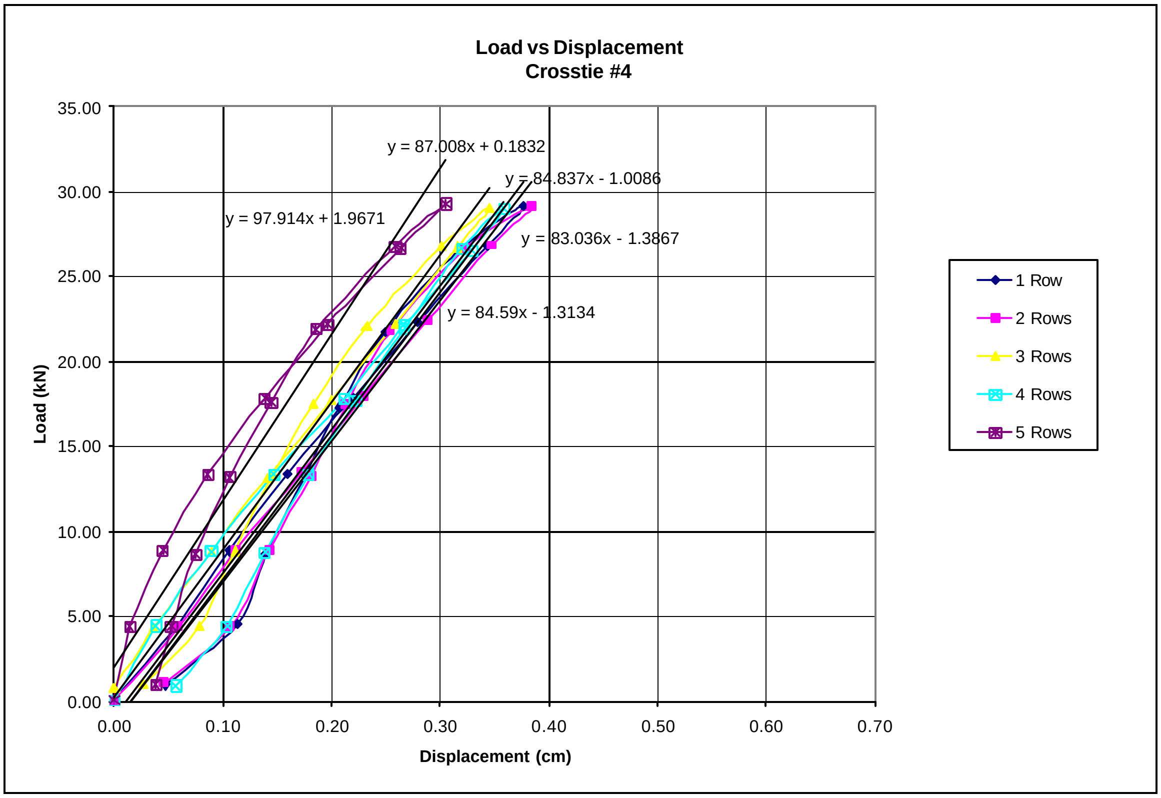
	4 Rows		5 Rows	
	d (cm)	Load (kN)	d (cm)	Load (kN)
Initial Reading	0.00	0.01	0.00	0.05
1	0.10	4.67	0.08	4.52
2	0.17	8.93	0.16	8.99
3	0.24	13.34	0.23	13.40
4	0.30	17.80	0.30	17.87
5	0.38	22.14	0.37	22.28
6	0.46	26.56	0.45	26.74
Peak Reading	0.49	28.88	0.48	29.03
6	0.46	26.59	0.45	26.75
5	0.39	22.22	0.38	22.28
4	0.33	17.82	0.31	17.80
3	0.26	13.28	0.24	13.32
2	0.19	8.86	0.18	8.93
1	0.10	3.25	0.12	4.87
Final Reading	0.02	0.93	0.02	0.88

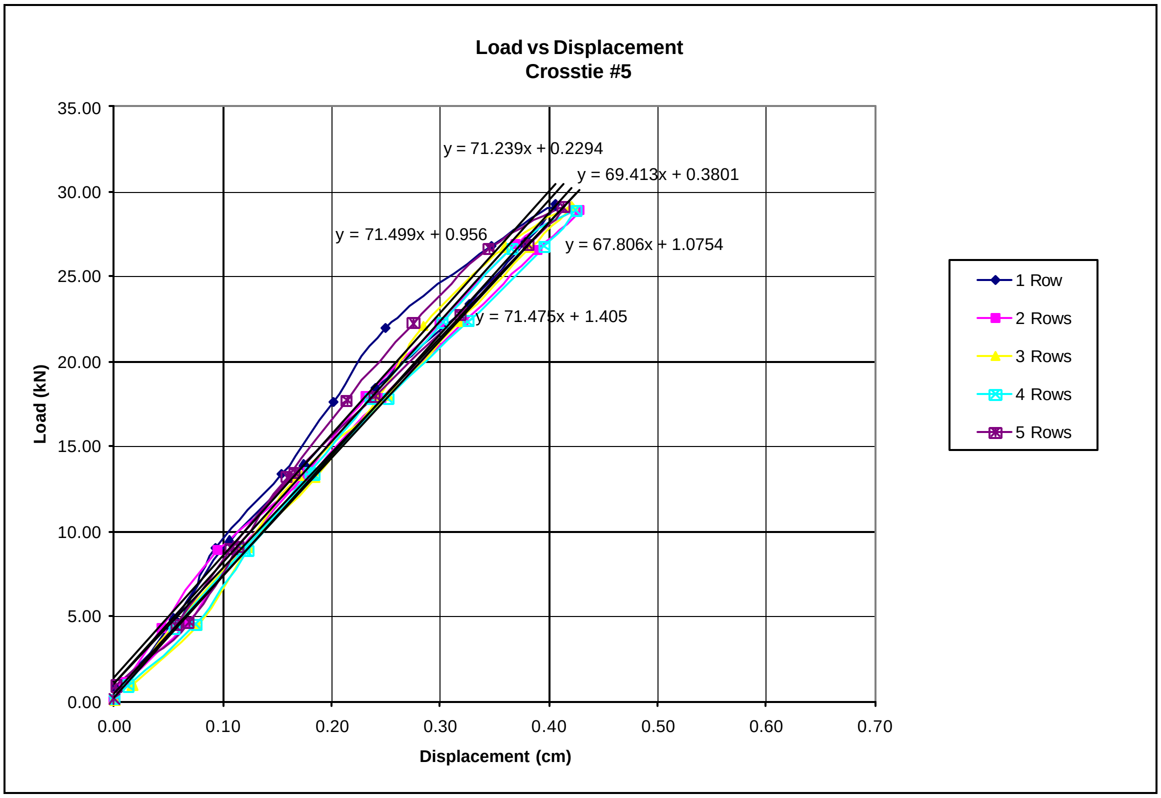
Shear Spike Repair Results – Charts

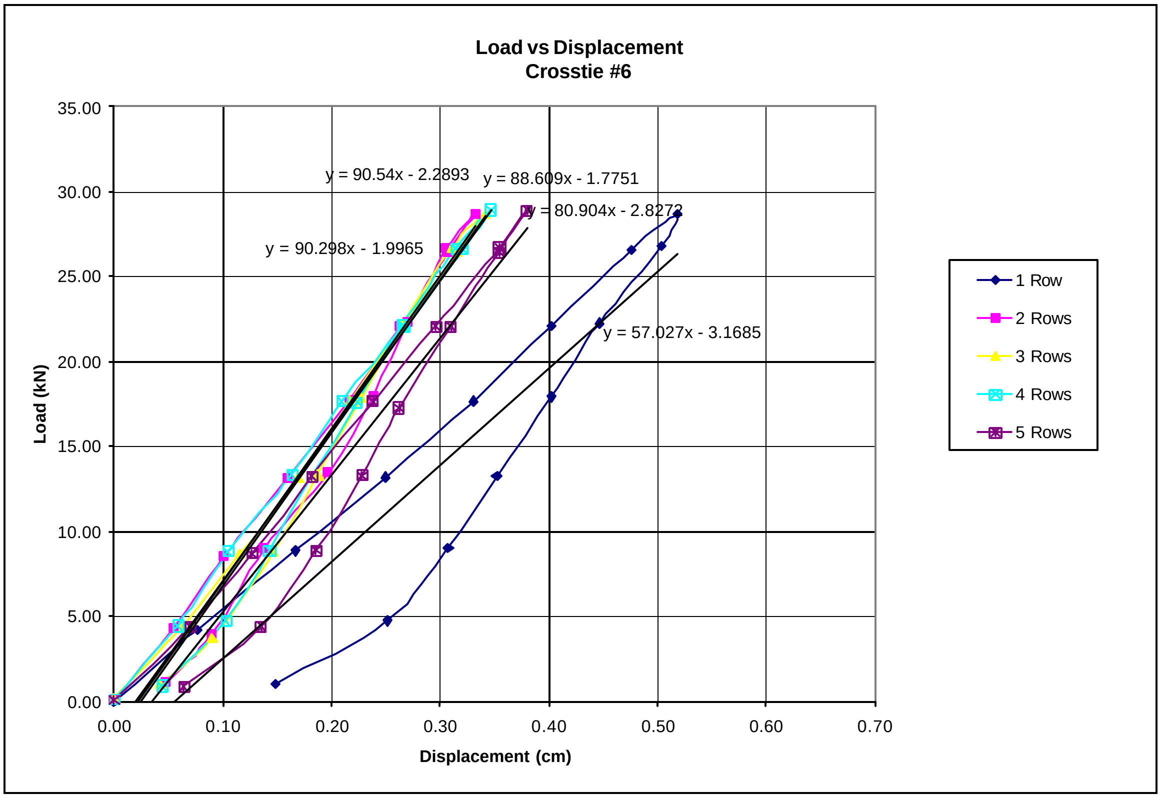
Medium to High Quality

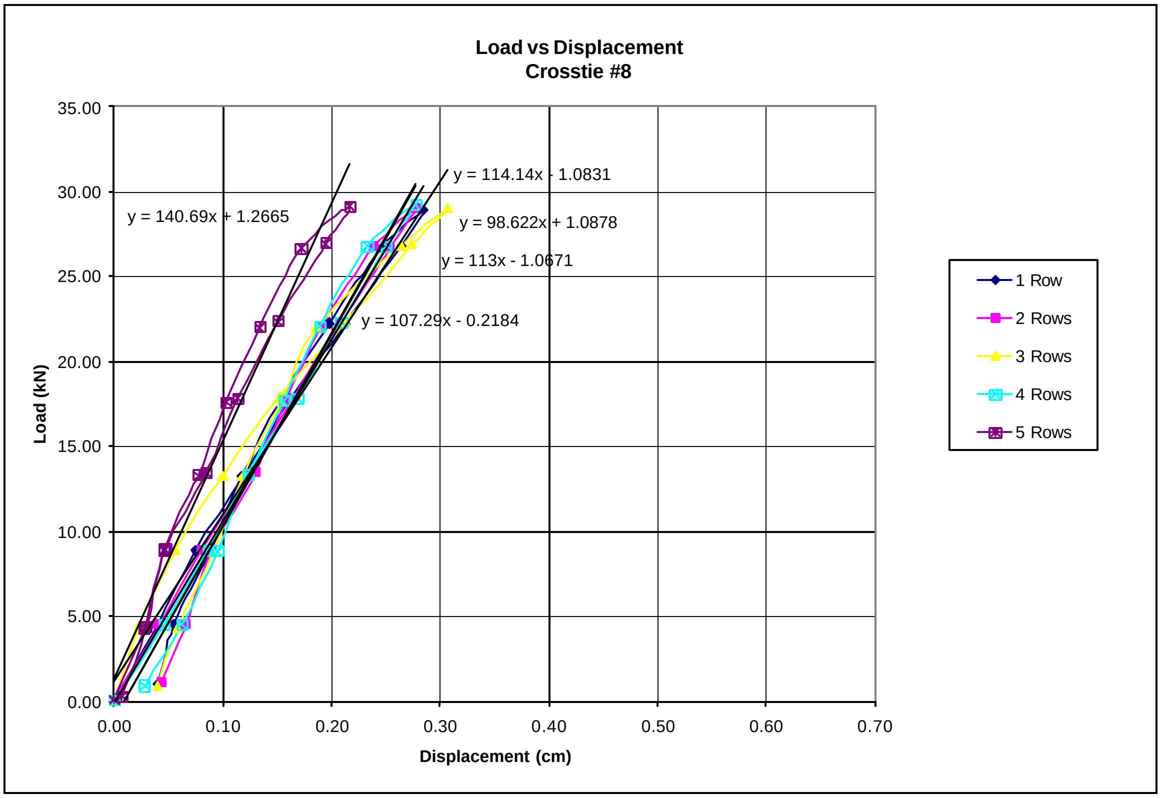


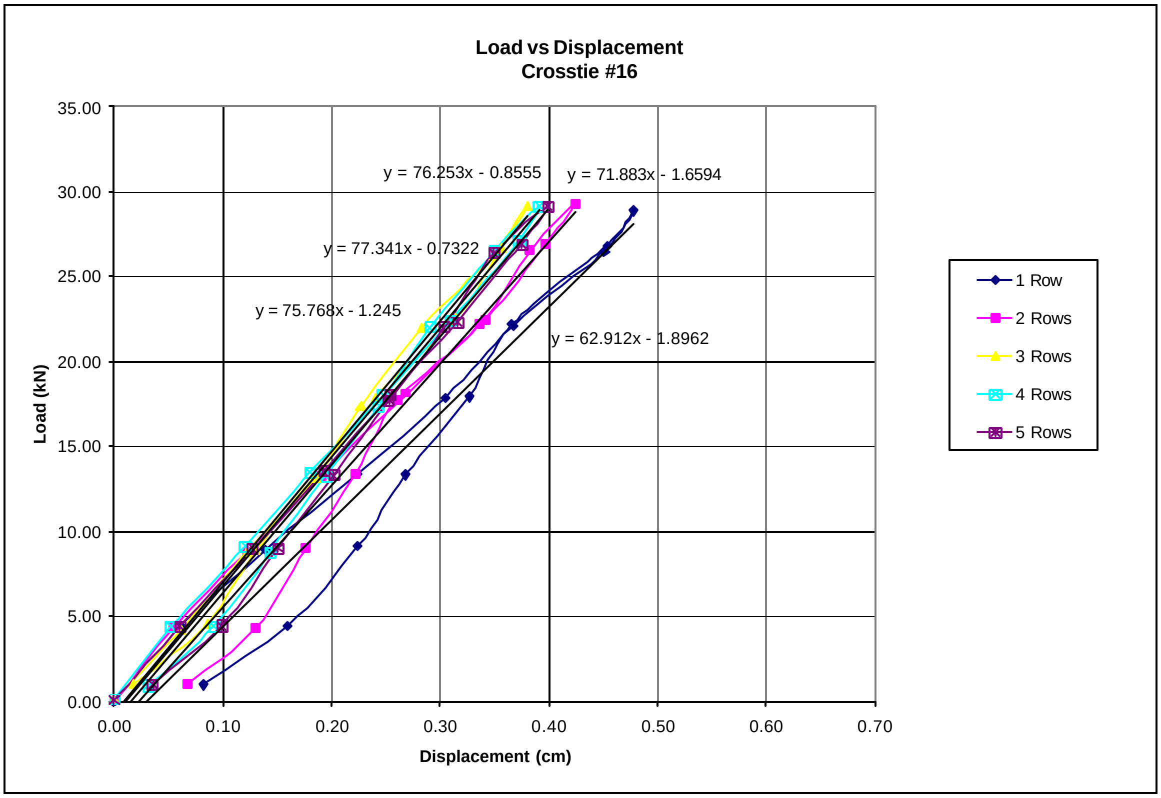



Load vs Displacement
Crosstie #4
y = 87.008x + 0.1832
y = 84.837x - 1.0086
y = 97.914x + 1.9671
y = 83.036x - 1.3867
y = 84.59x - 1.3134
Load (kN)
Displacement (cm)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
1 Row
2 Rows
3 Rows
4 Rows
5 Rows

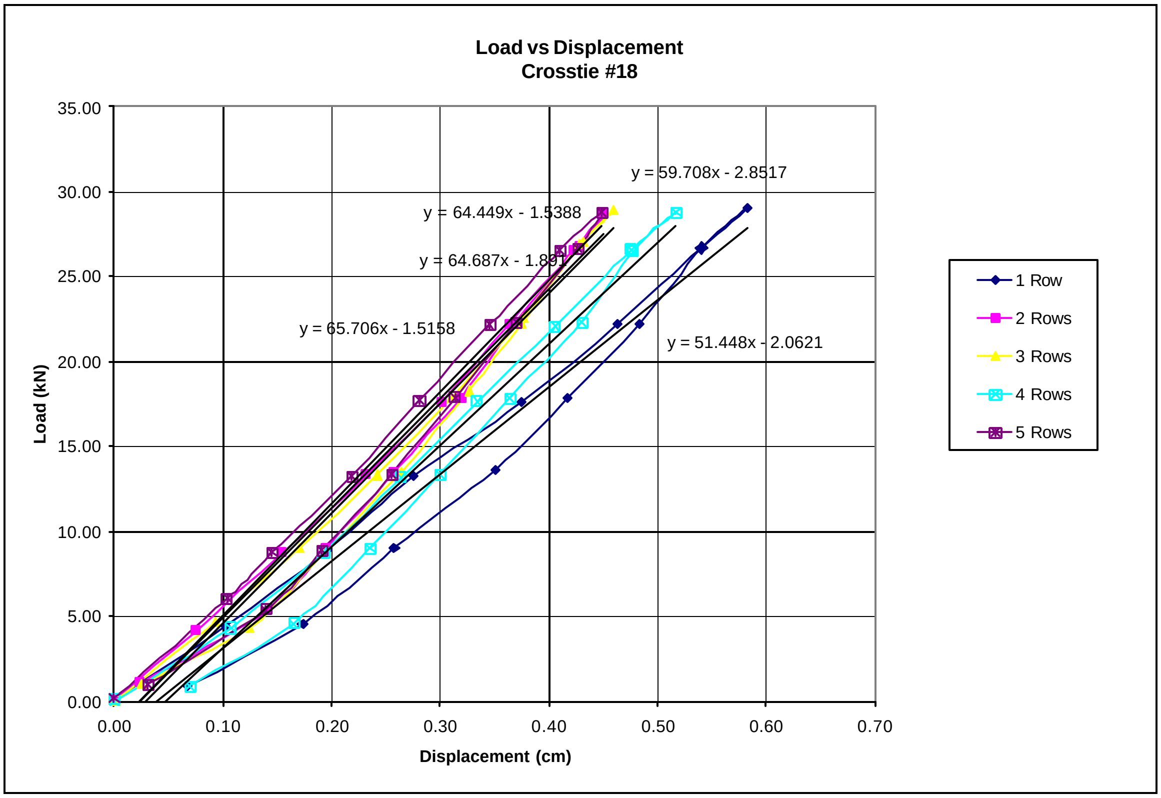

Load vs Displacement
Crosstie #5
y = 71.239x + 0.2294
y = 69.413x + 0.3801
y = 71.499x + 0.956
y = 67.806x + 1.0754
y = 71.475x + 1.405
Load (kN)
Displacement (cm)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
1 Row
2 Rows
3 Rows
4 Rows
5 Rows


Load vs Displacement
Crosstie #6
y = 90.54x - 2.2893
y = 88.609x - 1.7751
y = 80.904x - 2.8272
y = 90.298x - 1.9965
y = 57.027x - 3.1685
Load (kN)
Displacement (cm)
1 Row
2 Rows
3 Rows
4 Rows
5 Rows

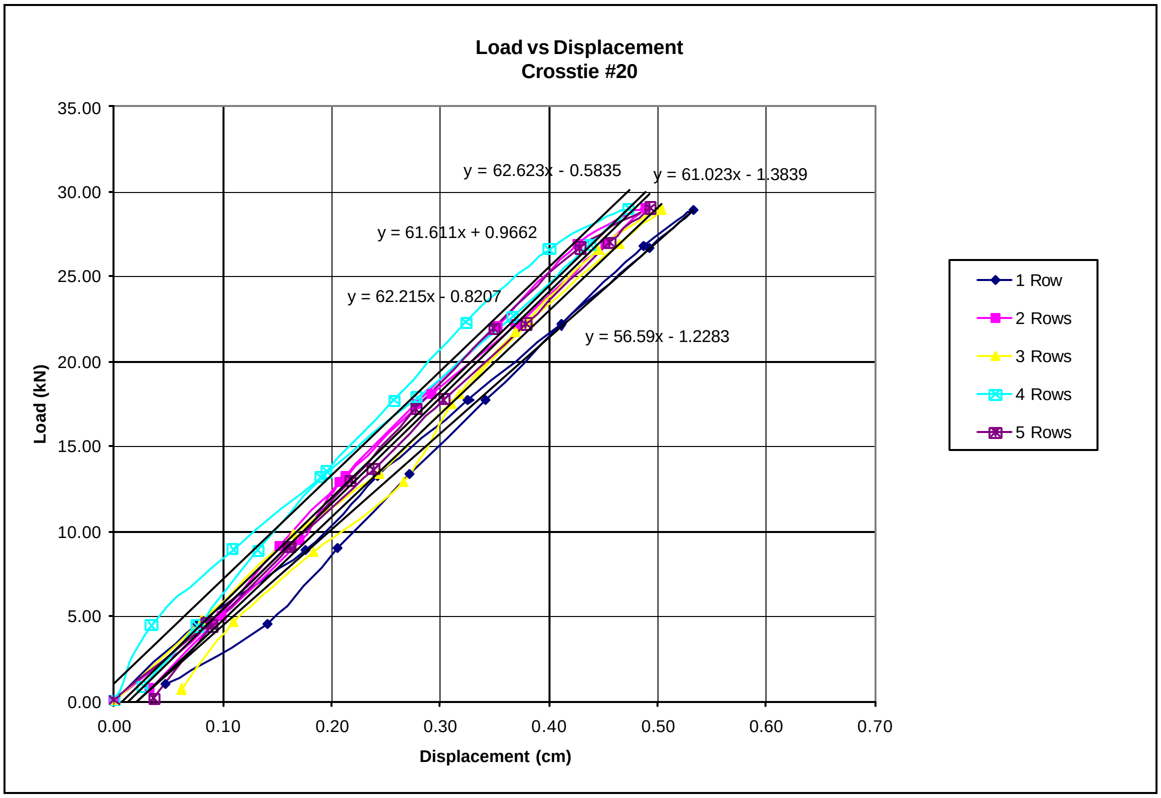

Load vs Displacement
Crosstie #8
y = 114.14x - 1.0831
y = 140.69x + 1.2665
y = 98.622x + 1.0878
y = 113x - 1.0671
y = 107.29x - 0.2184
Load (kN)
Displacement (cm)
1 Row
2 Rows
3 Rows
4 Rows
5 Rows

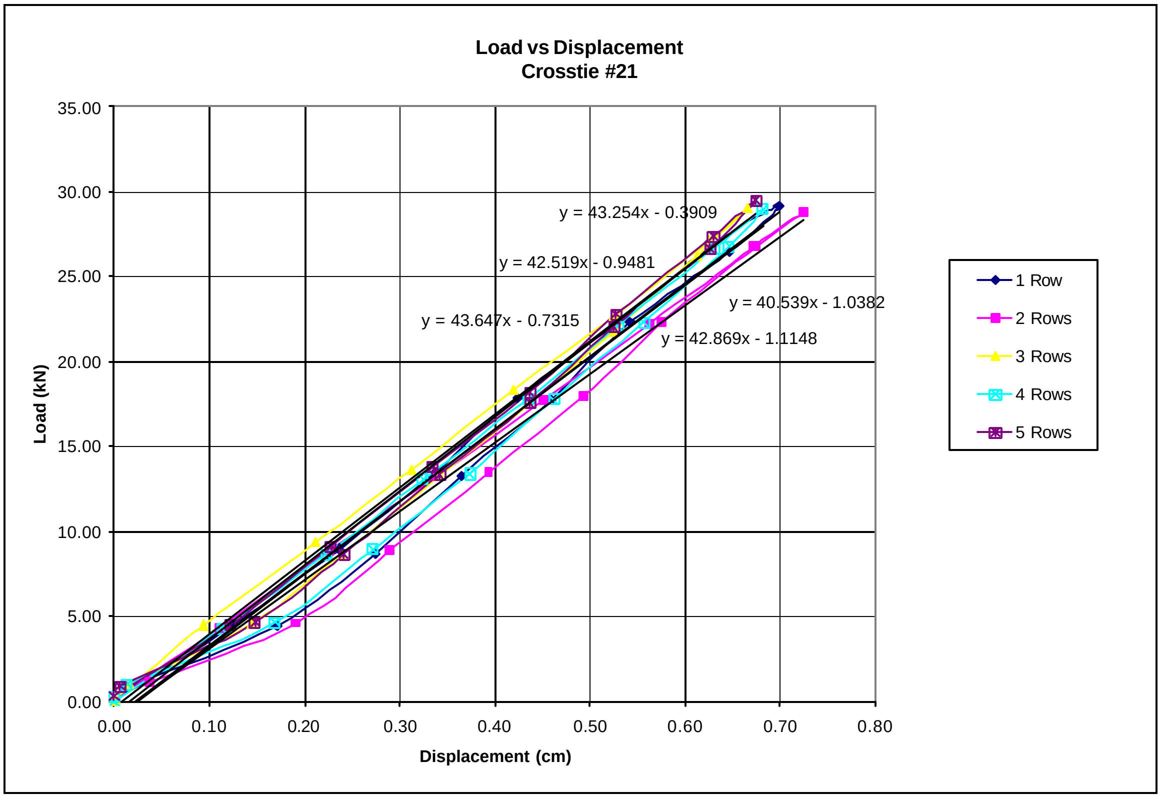


Load vs Displacement
Crosstie #16
y = 76.253x - 0.8555
y = 71.883x - 1.6594
y = 77.341x - 0.7322
y = 75.768x - 1.245
y = 62.912x - 1.8962
Load (kN)
Displacement (cm)
1 Row
2 Rows
3 Rows
4 Rows
5 Rows

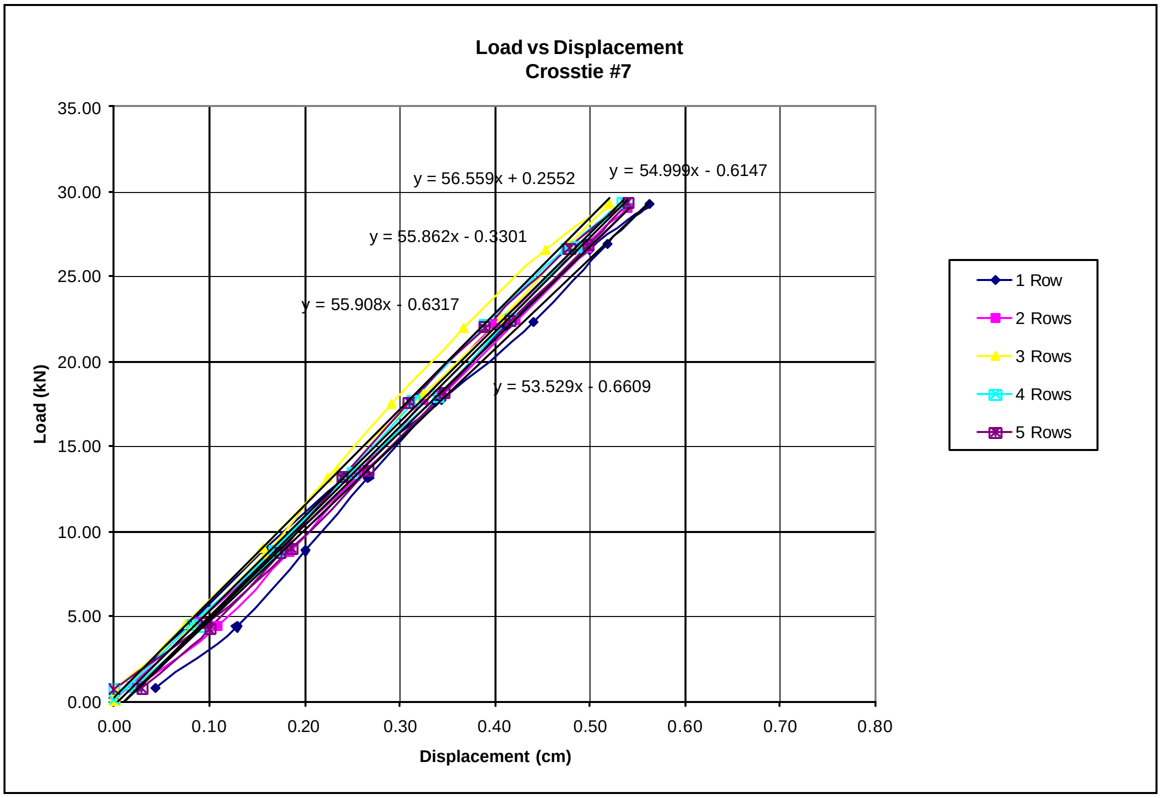


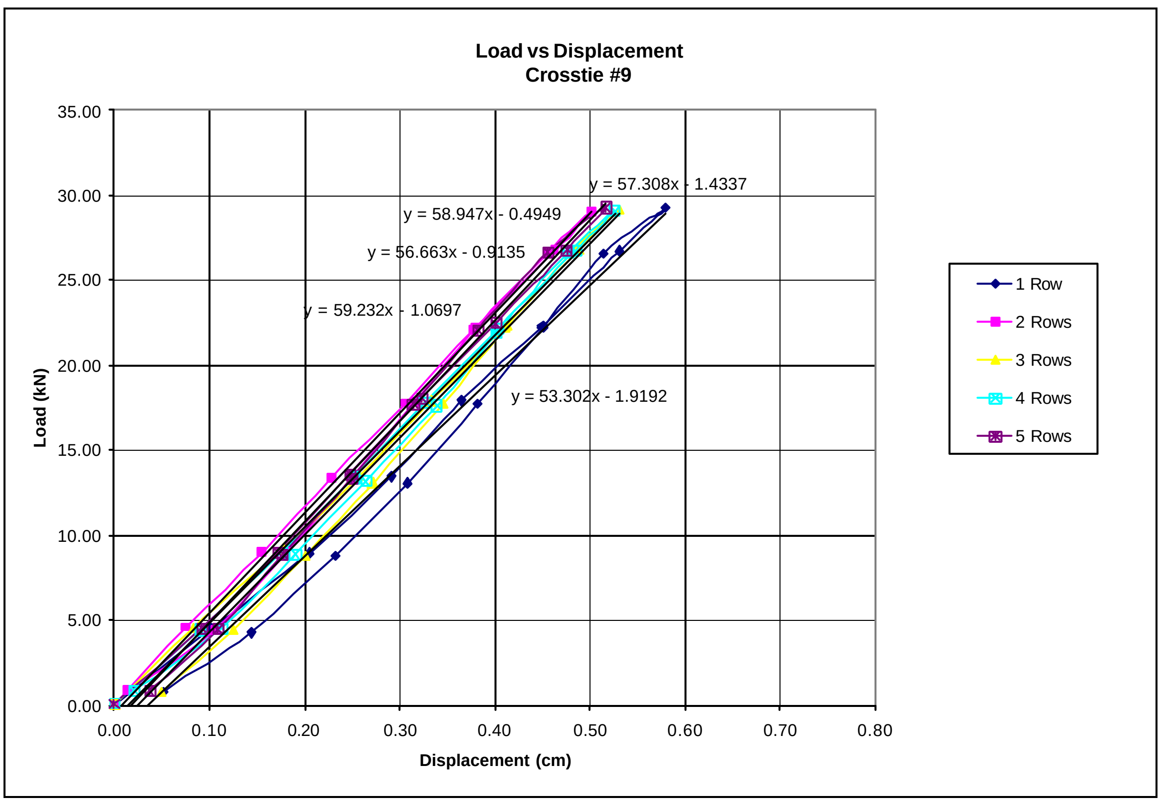
Load vs Displacement
Crosstie #18
y = 59.708x - 2.8517
y = 64.449x - 1.5388
y = 64.687x - 1.891
y = 65.706x - 1.5158
y = 51.448x - 2.0621
Load (kN)
Displacement (cm)
1 Row
2 Rows
3 Rows
4 Rows
5 Rows

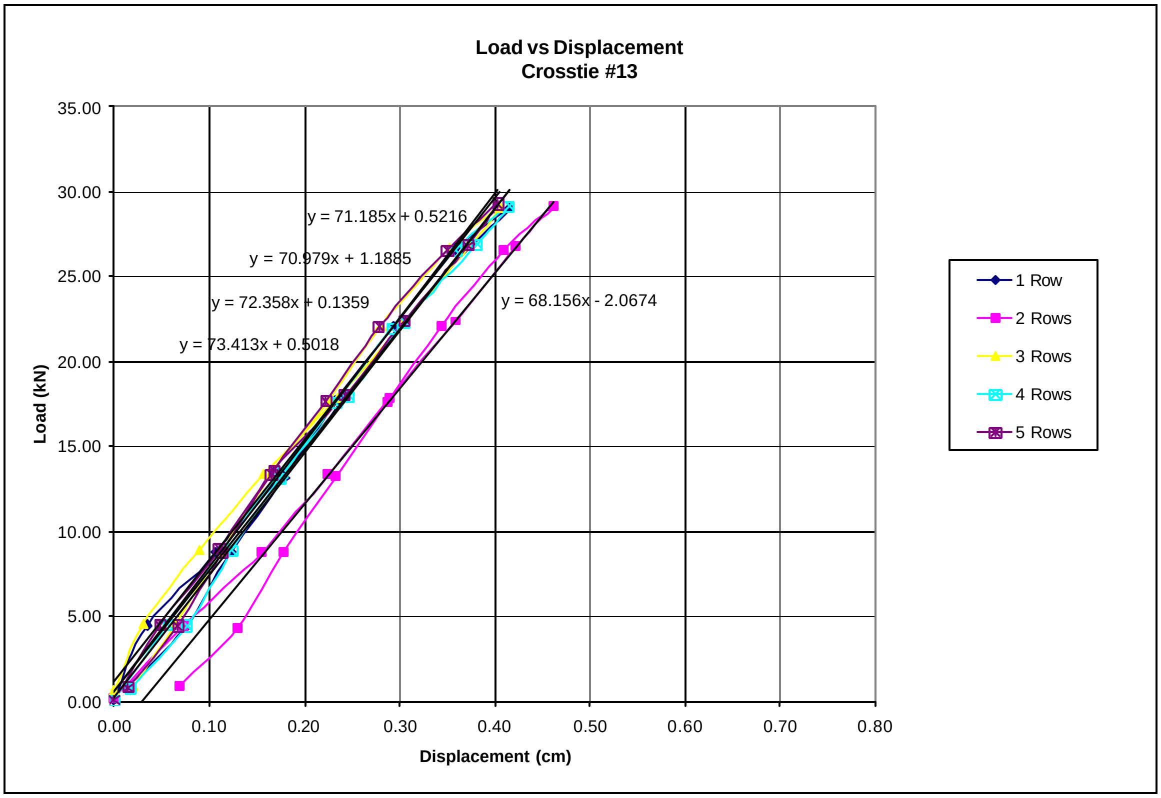

Load vs Displacement
Crosstie #20
y = 62.623x - 0.5835
y = 61.023x - 1.3839
y = 61.611x + 0.9662
y = 62.215x - 0.8207
y = 56.59x - 1.2283
Load (kN)
Displacement (cm)
1 Row
2 Rows
3 Rows
4 Rows
5 Rows

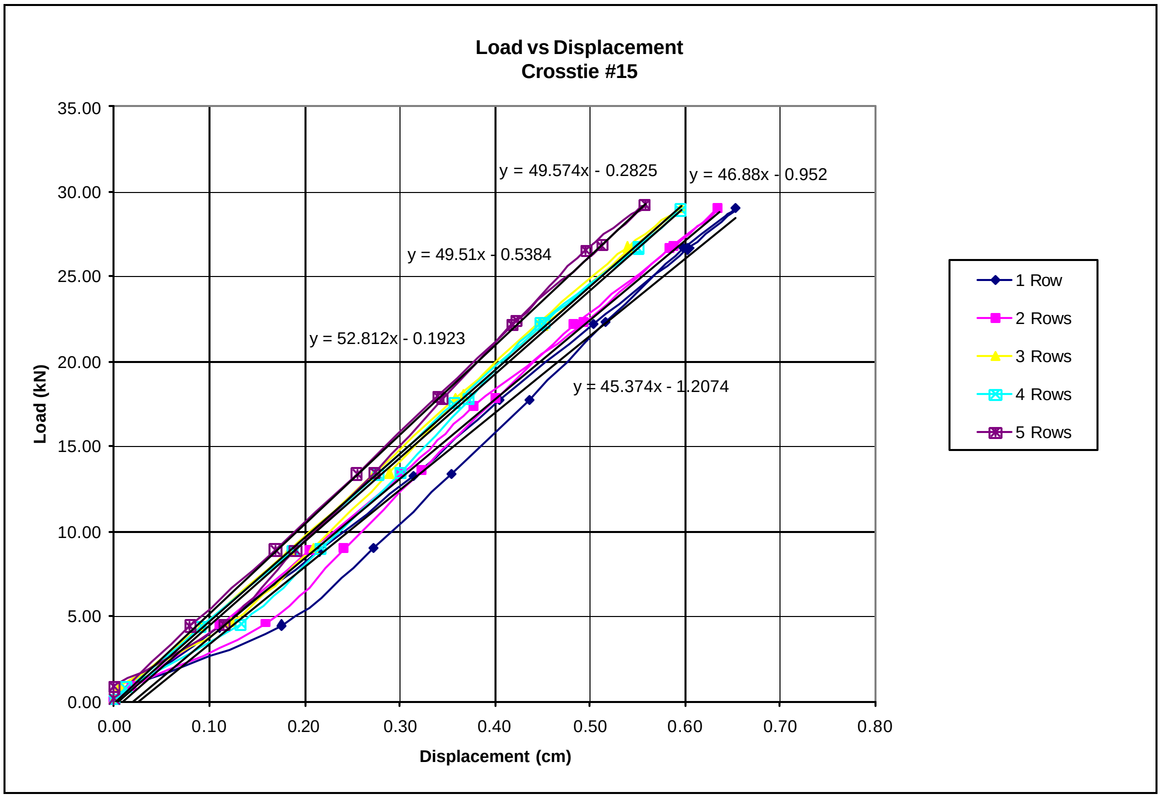

Load vs Displacement
Crosstie #21
y = 43.254x - 0.3909
y = 42.519x - 0.9481
y = 40.539x - 1.0382
y = 43.647x - 0.7315
y = 42.869x - 1.1148
Load (kN)
Displacement (cm)
1 Row
2 Rows
3 Rows
4 Rows
5 Rows

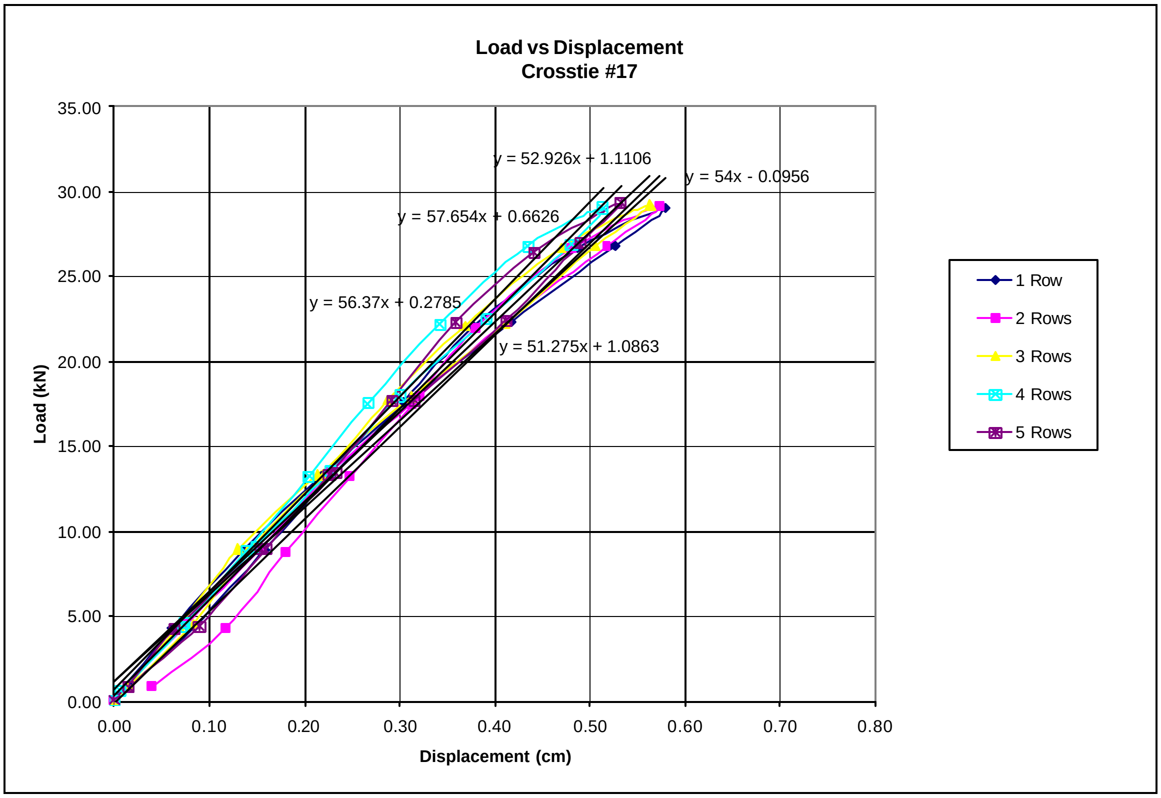
Lower Quality

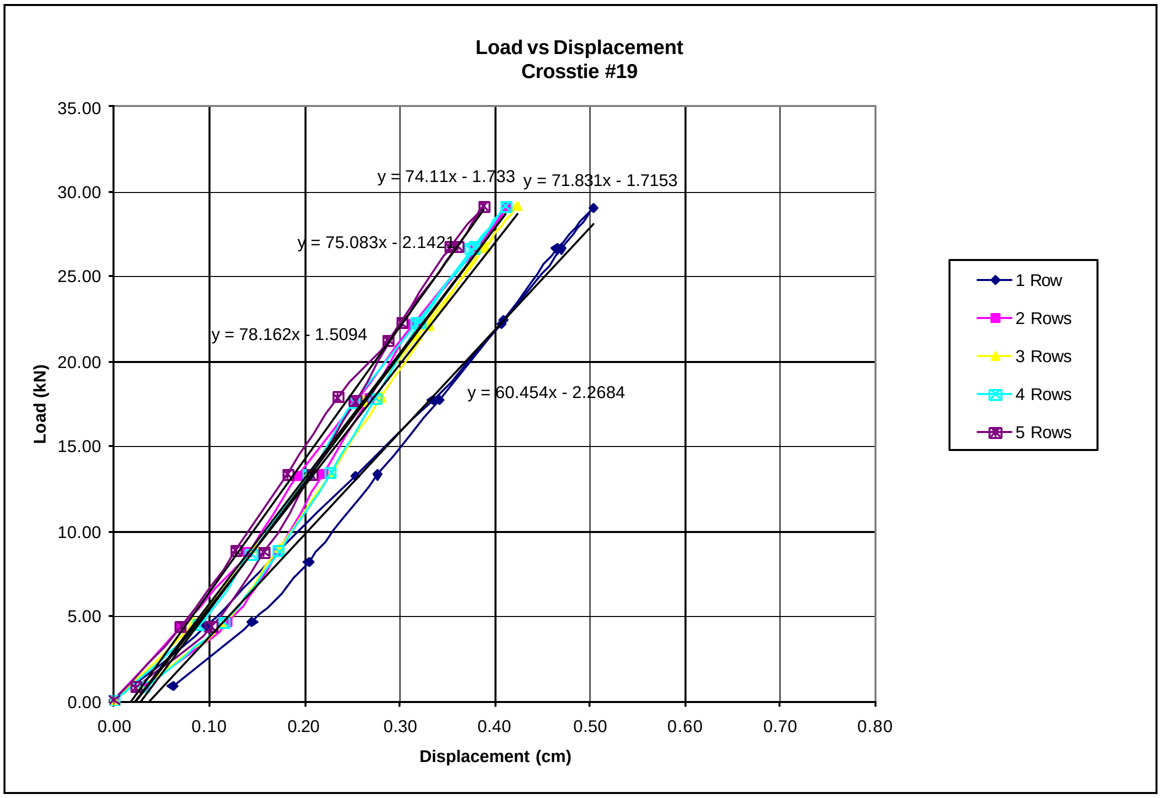


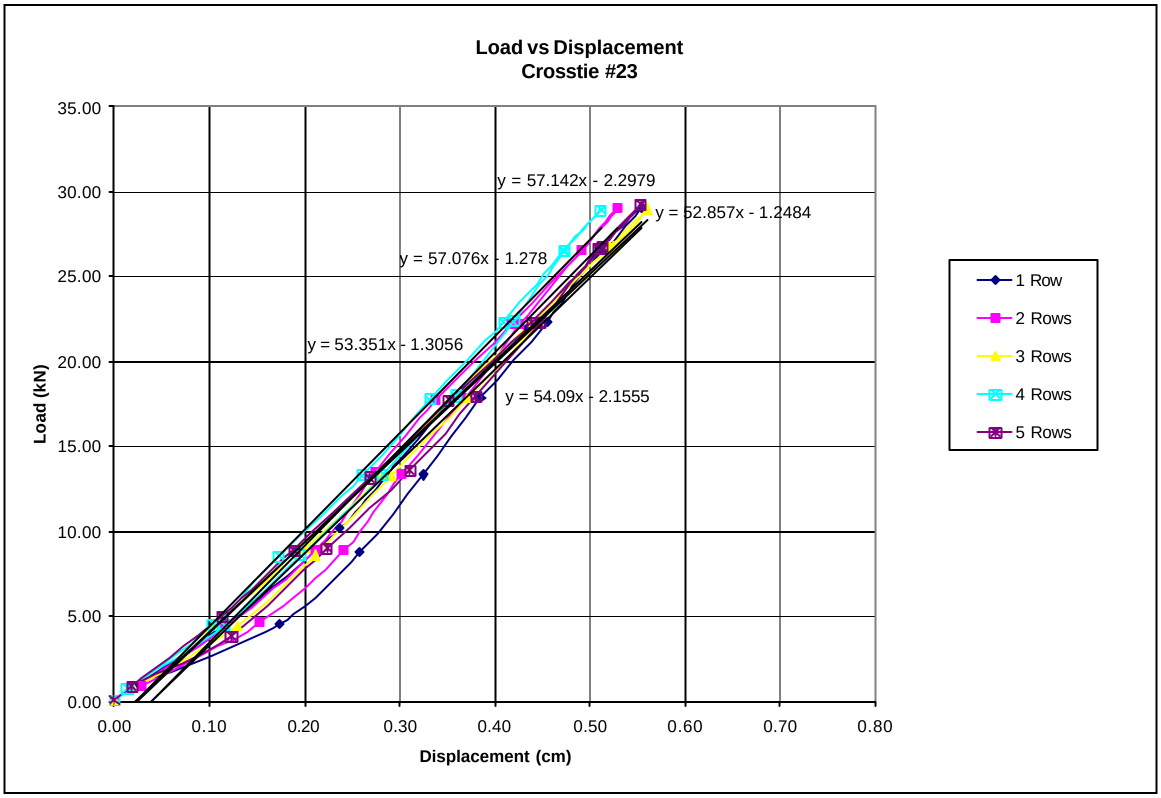


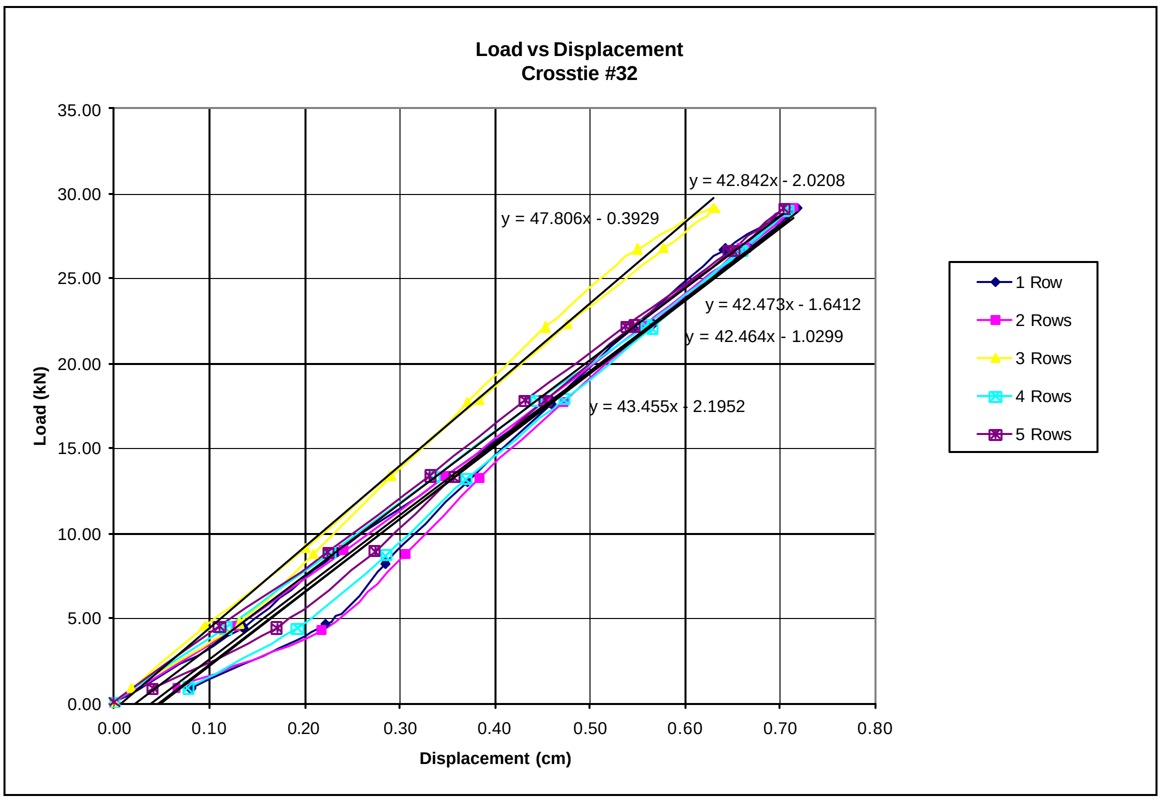

Load vs Displacement
Crosstie #13
Load (kN)
Displacement (cm)
y = 71.185x + 0.5216
y = 70.979x + 1.1885
y = 72.358x + 0.1359
y = 73.413x + 0.5018
y = 68.156x - 2.0674
1 Row
2 Rows
3 Rows
4 Rows
5 Rows

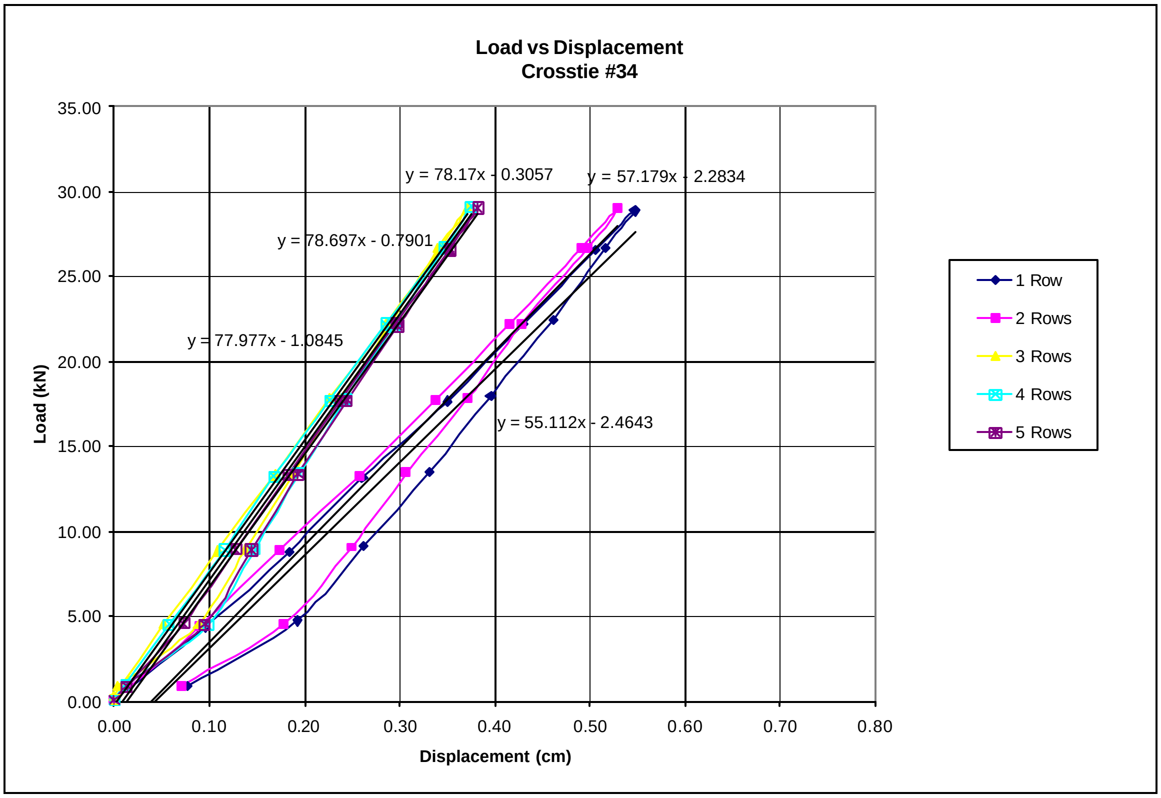

Load vs Displacement
Crosstie #15
Load (kN)
Displacement (cm)
y = 49.574x - 0.2825
y = 46.88x - 0.952
y = 49.51x - 0.5384
y = 52.812x - 0.1923
y = 45.374x - 1.2074
1 Row
2 Rows
3 Rows
4 Rows
5 Rows


Load vs Displacement
Crosstie #17
y = 52.926x + 1.1106
y = 54x - 0.0956
y = 57.654x + 0.6626
y = 56.37x + 0.2785
y = 51.275x + 1.0863
Load (kN)
Displacement (cm)
1 Row
2 Rows
3 Rows
4 Rows
5 Rows

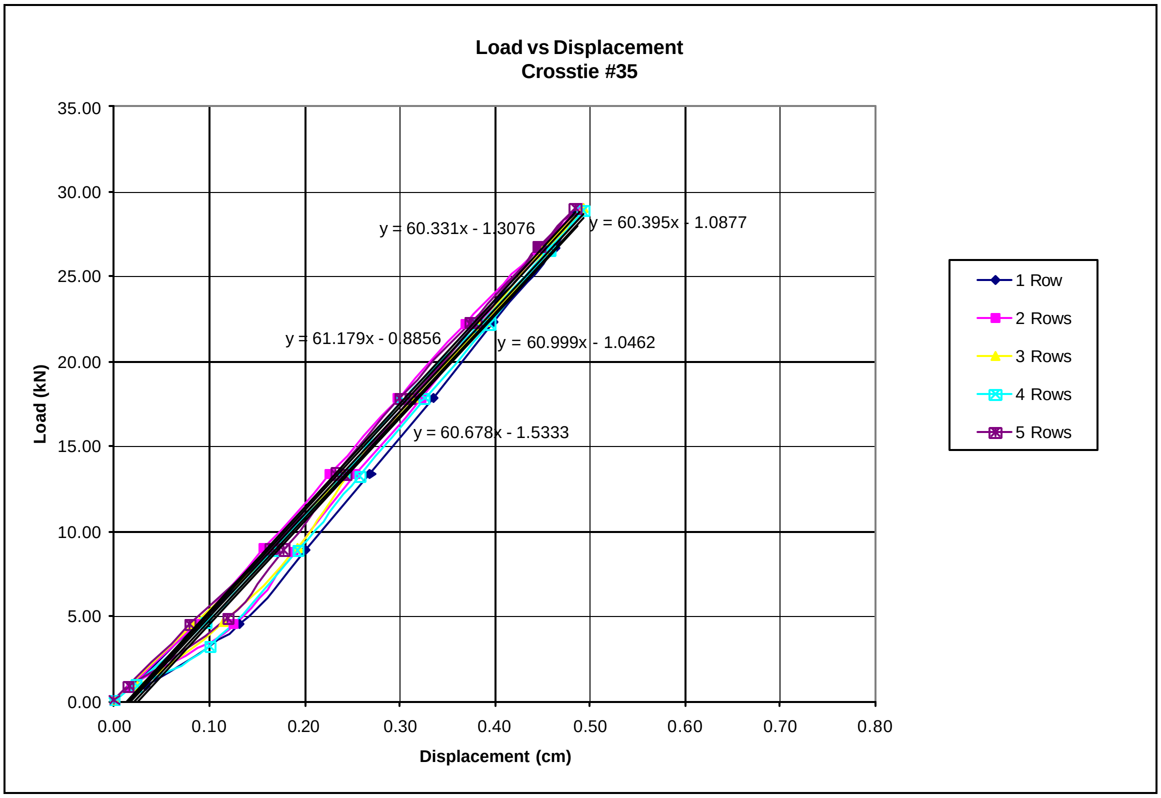

Load vs Displacement
Crosstie #19
y = 74.11x - 1.733
y = 71.831x - 1.7153
y = 75.083x - 2.1421
y = 78.162x - 1.5094
y = 60.454x - 2.2684
Load (kN)
Displacement (cm)
1 Row
2 Rows
3 Rows
4 Rows
5 Rows


Load vs Displacement
Crosstie #23
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Load (kN)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Displacement (cm)
y = 57.142x - 2.2979
y = 52.857x - 1.2484
y = 57.076x - 1.278
y = 53.351x - 1.3056
y = 54.09x - 2.1555
1 Row
2 Rows
3 Rows
4 Rows
5 Rows

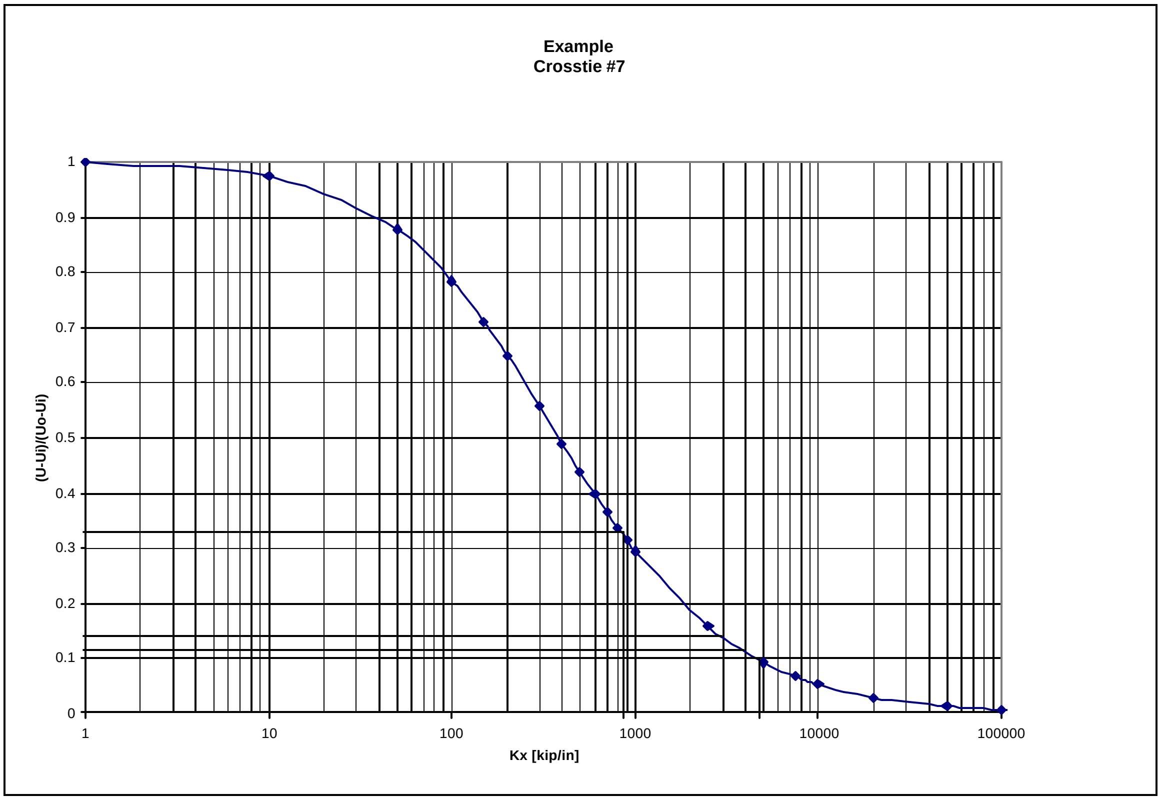

Load vs Displacement
Crosstie #32
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Load (kN)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Displacement (cm)
y = 42.842x - 2.0208
y = 47.806x - 0.3929
y = 42.473x - 1.6412
y = 42.464x - 1.0299
y = 43.455x - 2.1952
1 Row
2 Rows
3 Rows
4 Rows
5 Rows

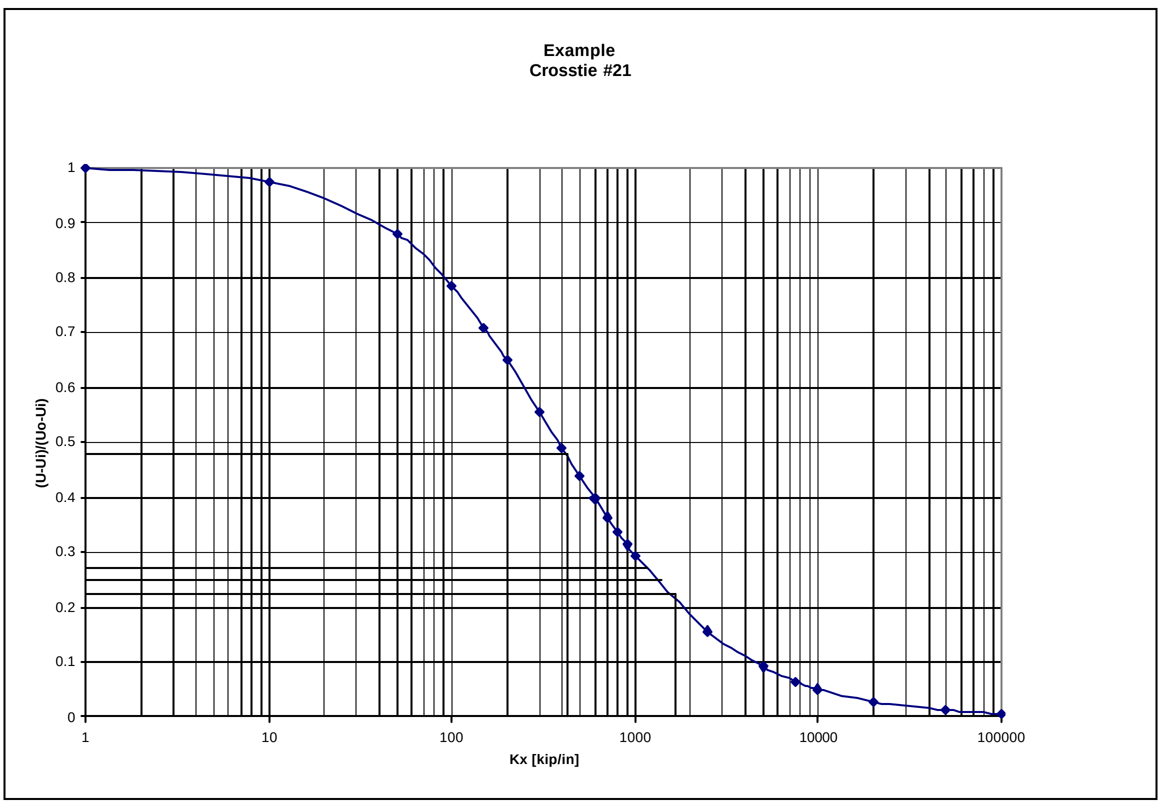


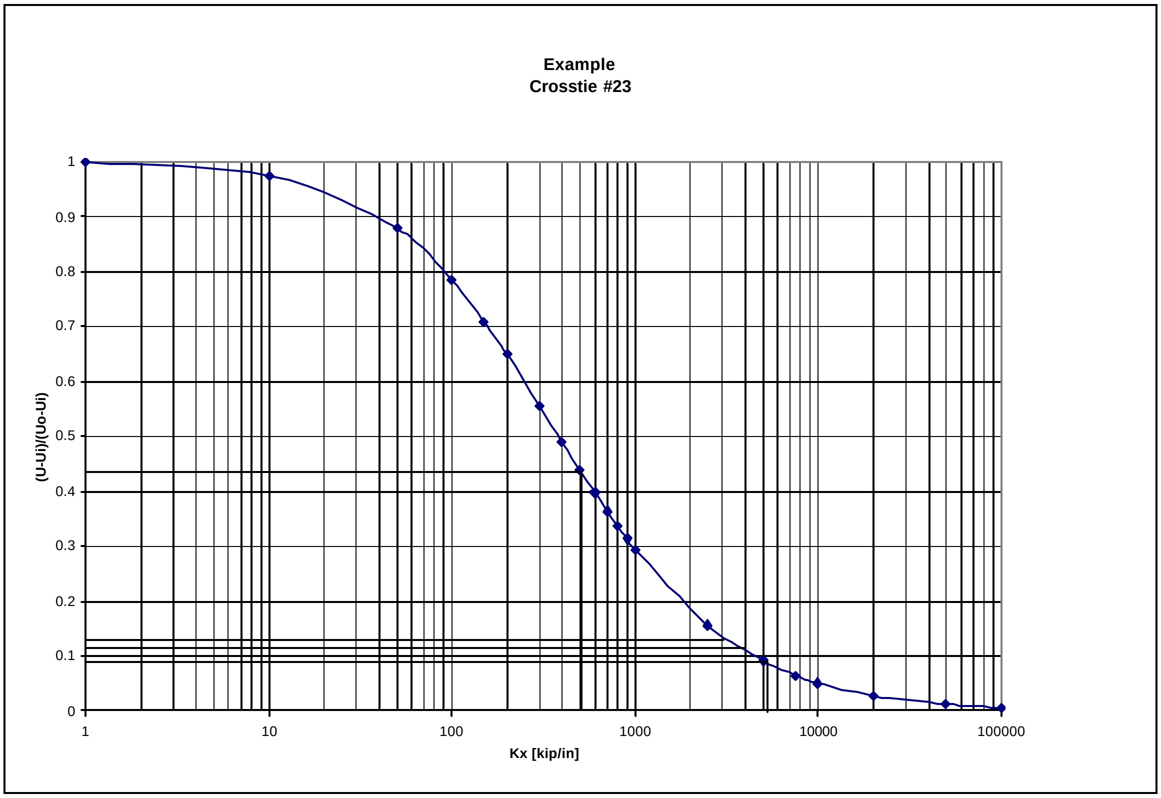
Load vs Displacement
Crosstie #34
Load (kN)
Displacement (cm)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
y = 78.17x - 0.3057
y = 57.179x - 2.2834
y = 78.697x - 0.7901
y = 77.977x - 1.0845
y = 55.112x - 2.4643
1 Row
2 Rows
3 Rows
4 Rows
5 Rows

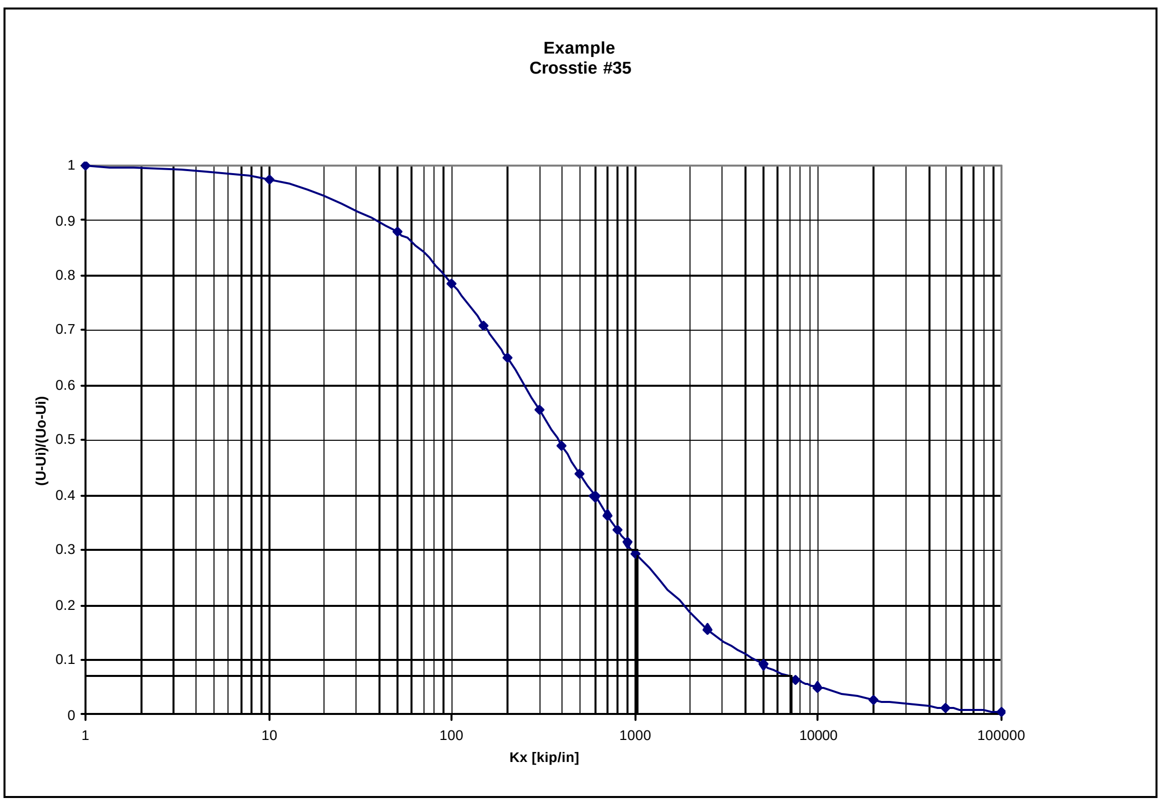

Load vs Displacement
Crosstie #35
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Load (kN)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Displacement (cm)
y = 60.331x - 1.3076
y = 60.395x - 1.0877
y = 61.179x - 0.8856
y = 60.999x - 1.0462
y = 60.678x - 1.5333
1 Row
2 Rows
3 Rows
4 Rows
5 Rows

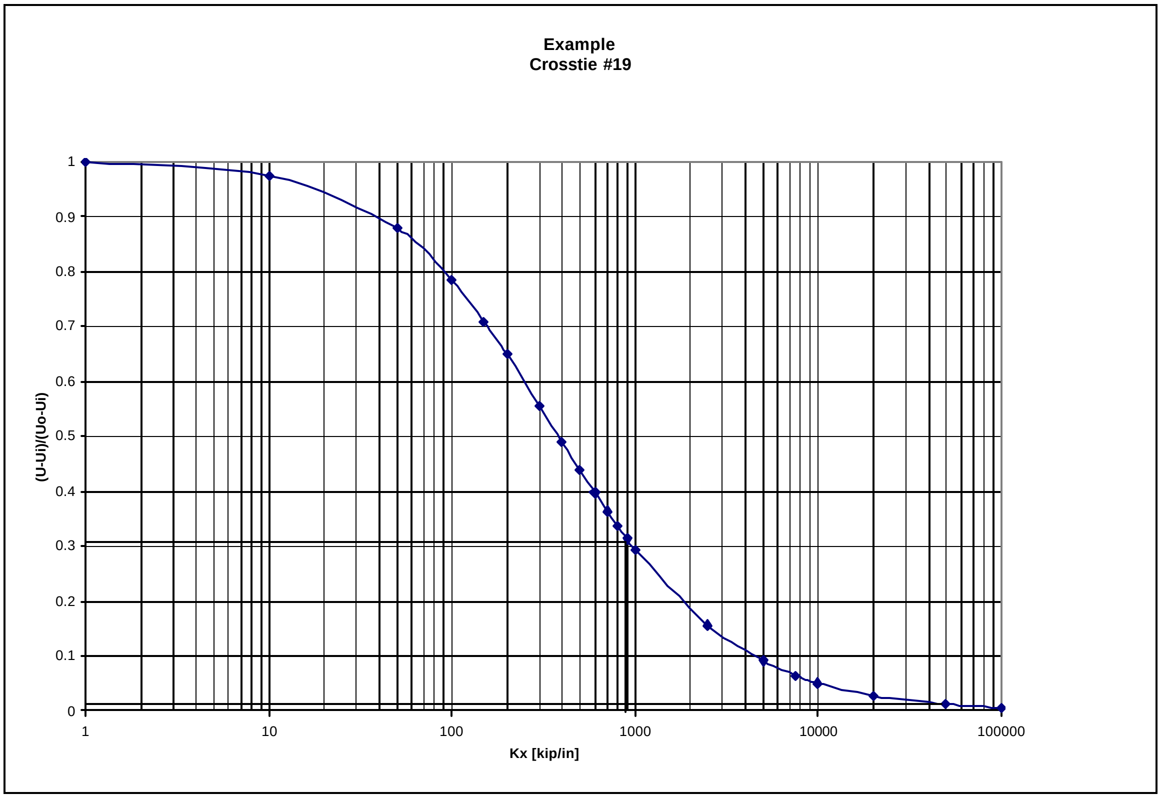
Appendix 4.

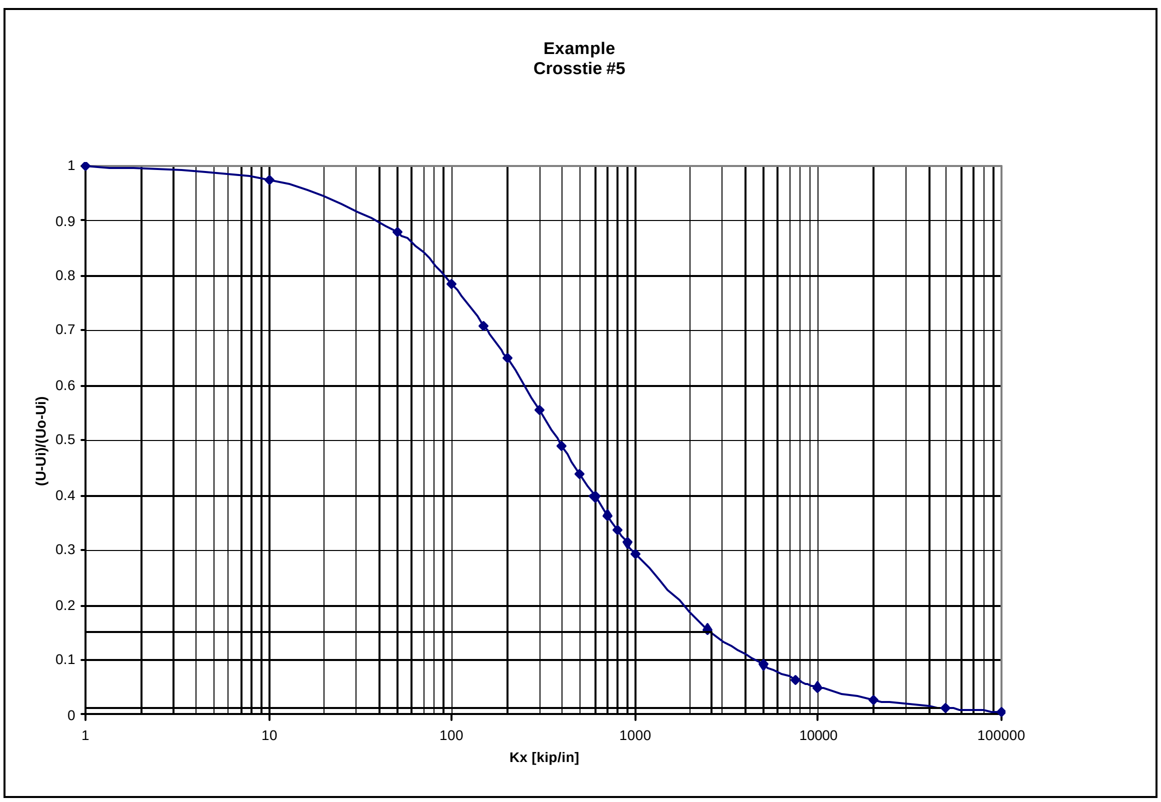

Example
Crosstie #7
(U-Ui)/(Uo-Ui)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
10000
100000
Kx [kip/in]

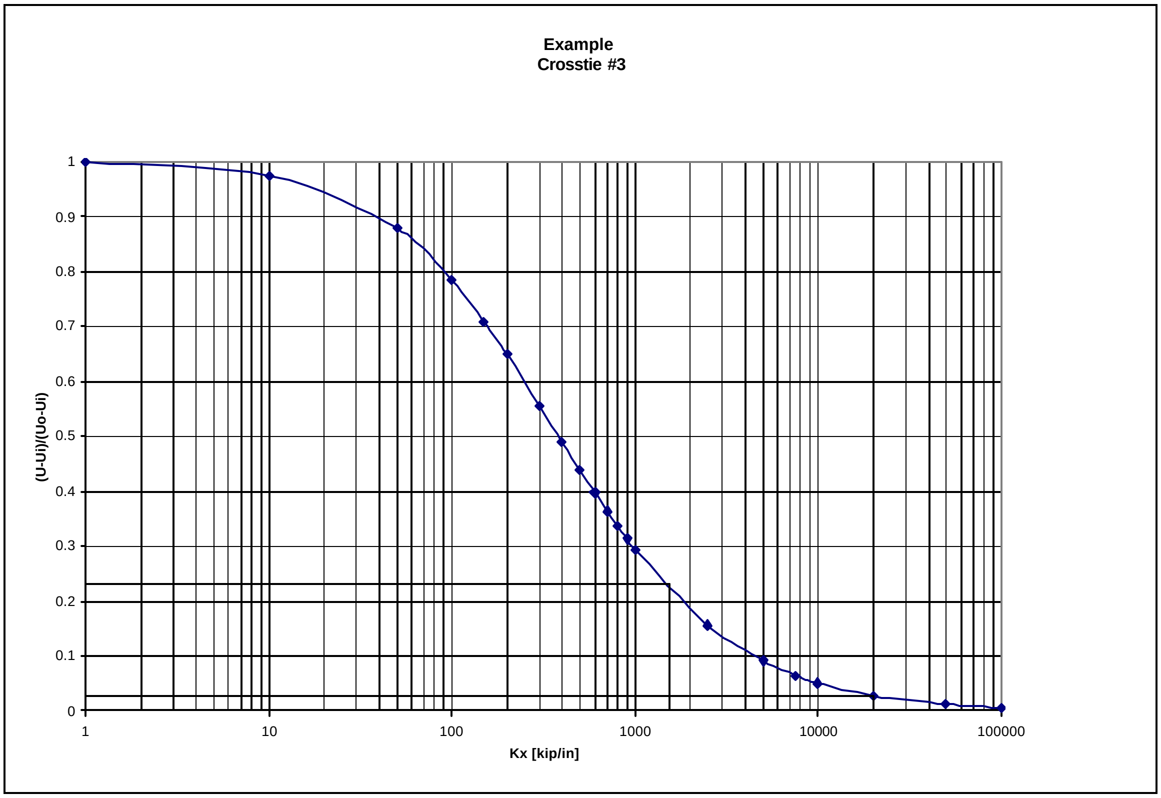

Example
Crosstie #21
(U-Ui)/(Uo-Ui)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
10000
100000
Kx [kip/in]


Example
Crosstie #23
(U-Ui)/(Uo-Ui)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
10000
100000
Kx [kip/in]


Example
Crosstie #35
(U-Ui)/(Uo-Ui)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
10000
100000
Kx [kip/in]


Example
Crosstie #19
(U-Ui)/(Uo-Ui)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
10000
100000
Kx [kip/in]


Example
Crosstie #5
(U-Ui)/(Uo-Ui)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
10000
100000
Kx [kip/in]


Example
Crosstie #3
(U-Ui)/(Uo-Ui)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
10
100
1000
10000
100000
Kx [kip/in]