Final Report

Design of Durable Concrete Railroad Crossings

FHWA/IN/JTRP-2002/28

by

Anthony J. Lamanna*
Civil & Environmental Engineering Department
Tulane University

** formerly School of Civil Engineering graduate research assistant*

and

Charles F. Scholer
Professor

School of Civil Engineering
Purdue University

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16. Abstract

Existing precast concrete railroad crossings in the state of Indiana are experiencing too short a life expectancy. This study proposes methods that can be used to produce durable concrete railroad crossings with satisfactory rideability, durability, and longevity.

Thirty-two precast concrete railroad crossings were visited in central and northern Indiana. Failures were determined to belong to three major categories: structural capacity causes, environmental causes, and material property causes.

A concrete mix was evaluated at three different polyolefin fiber contents and without fibers. Beams were tested in flexure, and modulus of rupture and first crack deflection were recorded for each beam. Cylinders were cast for compressive testing and splitting tensile testing.

Modulus of rupture was increased by the addition of fibers. The spread in data was observed to increase with an increase in fiber content. Compressive strength and splitting tensile strength were increased slightly by the addition of fibers. Panels are currently being produced that utilize post tensioning. These panels are less likely to crack under extreme loading conditions. If a crack forms, it closes upon removal of the load.

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Design of Durable Concrete Railroad Crossings

Introduction

A grade railroad crossing is the physical crossing of two different modes of transportation. The crossing creates a discontinuity in both the highway and the railroad line at the point of intersection, and in many cases the approaches must be altered. The crossing must transmit the highway traffic wheel loads and the rail loads through the crossing to the foundation structure. Rideability and durability are two concerns associated with a concrete railroad crossing. Conventional timber or rubber crossings deteriorate and become rough and even dangerous. Concrete surfaces can provide excellent long term performance, however many have failed. The goal of this project was to optimize the performance and life span of concrete crossings.

Findings

Modulus of rupture was significantly increased with the addition of polyolefin fibers. An increase in midpoint deflection accompanied this increased strength. The addition of polyolefin fibers to a precast concrete railroad crossing will impart increased flexibility and strength to the panel. The fibers will also serve to keep cracks from propagating and opening further in the case a crack does form. The addition of fibers, however, does not improve the properties of concrete enough to design a lay-in type panel of limited height using ordinary reinforced concrete. Post-tensioning used in conjunction with polyolefin fibers would allow a limited height panel to be designed adequately for both the strength and durability required.

Implementation

It is necessary that the ties supporting lay-in precast concrete panels be properly aligned so that the panel lies on all of the ties beneath it. If a tie is too low, it does not provide support, and if it is too high it may place undue stresses on fasteners.

When fasteners loosen, the panels are subjected to a rocking motion which causes further wear on the ties beneath it. The rocking motion continues to grow worse and can cause panels to crack.

For these reasons it is important to make sure the ties are aligned properly prior to installation. Lag screws should not be fastened to damaged ties, or ties that have been used to fasten previous panels.

Contacts

For more information:

Tommy Nantung
Indiana Department of Transportation
Research Division
1205 Montgomery Road
P.O.Box 2279
West Lafayette, IN 47906
Phone: (765) 463-1521
Fax: (765) 497-1665

Indiana Department of Transportation
Division of Research
1205 Montgomery Street
P.O. Box 2279
West Lafayette, IN 47906
Phone: (765) 463-1521
Fax: (765) 497-1665

Purdue University
Joint Transportation Research Program
School of Civil Engineering
West Lafayette, IN 47907-1284
Phone: (765) 494-9310
Fax: (765) 496-1105

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INTRODUCTION

A grade railroad crossing is the physical crossing of two different modes of transportation. The crossing creates a discontinuity in both the highway and the railroad line at the point of intersection, and in many cases the approaches must be altered. The crossing must transmit the highway traffic wheel loads and the rail loads through the crossing to the foundation structure. Rideability and durability are two concerns associated with a concrete railroad crossing. Conventional timber or rubber crossings deteriorate and become rough and even dangerous. Concrete surfaces can provide excellent long term performance, however many have failed. The goal of this project was to optimize the performance and life span of concrete crossings.

Site Visits

A list of all precast concrete crossings in Indiana was provided by INDOT. Starting in the Fall of 1997, visits were made to 37 of the crossings on the list. Most of the sites were in central and northern Indiana. A complete listing of the crossings is located in table A-1 in Appendix A. Sites that were visited and inspected are clearly marked. Sites were checked for cracks perpendicular to the long side of the panels. Surface scaling, movement of panels under traffic load, and bolts with the head sheared off were also found at some crossings. Five of the sites visited had been replaced with rubber crossings.

Of the 32 concrete crossings visited, 6 had panels which exhibited significant amounts of vertical movement while subject to vehicular traffic loads. During certain site visits there was no vehicular traffic, so there may be more crossings containing panels that move. It is also important to note that all the panels which moved significantly contained cracks perpendicular to the long edge.

19 of the sites contained one or more panels which exhibited cracks perpendicular to the long edge. These cracks spanned the entire width of the panel. 15 crossings contained one or more panels which showed severe surface scaling. In some cases the surface scaling was so severe that up to 50 mm (2 inches) of the surface concrete was spalled off. Four of the crossings contained bolts with heads sheared off.

From studying many crossings in Indiana, potential causes leading to the observed problems vary, but can be placed into three groups: structural capacity related causes, performance related causes, and material property causes.

Structural Capacity Causes

Concrete slabs at a railroad crossing are normally under a complicated loading scheme. Vehicle wheel loads produce a combined action of bending and shear, and the passing of a train induces a wave motion in the tracks. Non-uniform support beneath the slab also adds difficulties in design. The panel may not rest on all ties that it spans, and is attached to some ties with lag screws. This results in an unknown loading condition for each panel.

The slab thickness is limited by the height of the railroad tracks, which is usually 6 to 8 inches. This small slab thickness cannot provide enough carrying capacity to resist the action of the wheel loads and poses problems to the design of reinforcement. For example, if the standard 38 mm (1 1/2 inches) cover is used, the reinforcing steel is placed extremely close to the neutral axis, where it contributes very little to the strength of the member.

Environmental Causes

Rideability principally depends on roughness as perceived by the highway users. Roughness arises from cracked slabs and failure due to the different stiffnesses required by the two modes of transportation. The railroad is designed to flex under the weight of the heavy trains, whereas the highway is designed to be rigid under the loading of highway vehicles. A highway surface is impermeable and constructed with a crown so that rainfall runs off to the edges and does not saturate the base. A railway is flat over short distances and is designed so that rainfall filters down through the coarse ballast.

Material Property Causes

Durability in freezing and thawing conditions is based on the properties of the concrete used in the crossing. Poor properties result in scaling, spalling, and cracking. As a result of these, poor rideablilty and poor durability are sometimes experienced at concrete railroad crossings. When cracking occurs, water and dissolved de-icing salts reach the reinforcing steel and speed up the corrosion process. The expansive corrosion products further increase cracking of the concrete crossing. Railroad companies are very aware of the risk of a severely cracked concrete section popping up and derailing a train.

Concrete has a low tensile strength and a low strain at failure. The tensile strength is low because concrete contains many microcracks. These microcracks propogate swiftly under applied stresses, not allowing large deformations before failure. These intrinsic properties of concrete can be altered by adding fibers.

Current Technology

There are several types of precast concrete railroad crossings available in the market. They fall into two catagories: “platform” and “lay-in.” Platform type crossings consist of one large cross section that spans beneath the rails and eliminates the need for ties underneath the crossing. This type is more expensive to install, and it increases the stiffness of the railroad more than the other type. The lay-in type consists of concrete panels that are set on top of the ties and are attached using lag screws. The lay-in crossings are cheaper to install and do not significantly reduce the track flexibility, but the height limitation creates design problems. Lay-in type crossings also reduce the amount of traffic control needed during installation.

Lay-in type crossings are preferred by railroad companies because they do not significantly reduce the flexibility of the track at the grade intersection. The major problem with these precast members is their tendancy to crack. Further deterioration is accelerated once a crack is opened as water and foreign elements can enter through the crack.

Fiber Reinforced Concrete

Durable concrete should ideally be resistant to crack formation and propagation. Realistically, concrete's low tensile strength and brittle nature make it a material which is prone to cracking. The addition of fibers provides an energy absorbing capacity that can hold the concrete together during fracture. Since the 1960s, fiber reinforced concrete (FRC) has been used to increase the durability of transportation structures (Ozyildirim 1997).

Cracks allow water and solutions to penetrate the concrete, which leads to further deterioration of the concrete. Alkali-aggregate reactions, corrosion of reinforcement, freezing-thawing, and sulfate attack may be magnified with this increased permeability in the concrete matrix. These problems produce expansive materials within the concrete and result in further cracking and deterioration of the concrete.

Fibers stop crack propogation, which results in smaller cracks. Smaller cracks create a lower permeablility and an increased ultimate cracking strain (Ramakrishnan 1995). Steel fibers have typically been used to improve the properties of hardened concrete. Fibers have been used in beams subjected to impact loading in instrumented drop-weight and Charpy type systems. It was reported that the total energy absorbed by fiber concretes can be as much as 40-100 times more than that for unreinforced beams (Ramakrishnan 1997).

Synthetic fibers are typically used to reduce plastic shrinkage cracking in fresh concrete. While synthetic fibers do not corrode, conduct, or create harmful protrusions, they cannot be used at high volume contents because they cause the fresh concrete to ball up in the mixer. This prevents the concrete from mixing properly. Polyolefin fibers are much larger than typical synthetic fibers and can be used in higher volume percentages than previously used synthetic fibers without balling.

Prestressing

Prestressing concrete involves applying loads, prior to applying the service loads, in order to eliminate or reduce the tensile loads that would occur. By improving this service load behavior and utilizing high strength materials, smaller and lighter members may be used.

Prestressed concrete members are either pretensioned or post-tensioned. Pretensioned concrete members are made by stretching the tendons before the concrete is placed. The concrete is allowed to harden, and when it reaches the required strength, the stretching force is released and the force is transfered from the steel to the concrete through the bond. Post-tensioning of members is accomplished by jacking the unbonded tendons against the ends of the member after the concrete is hardened.

Lay-in precast concrete railroad crossing panels are too short for pretensioning. There is not enough length to develop the bond between the steel prestressing tendon and the concrete. Post-tensioning the panel would allow the entire length between the end anchorage plates to benefit from the prestressing force. If the panels were longer, heavier equipment would be needed to install them.

If a large enough load occurs on a prestressed member, a crack occurs. When the load is removed, the compressive force in the prestressing tendon forces the crack together. This prevents intrusion of harmful elements, which cause further deterioration of the concrete around the crack.

The inherent qualities of precast and prestressed concrete make it ideal for lay-in railroad crossings. The increased corrosion resistance, fire resistance, durability, and fast installation have even been used as a good alternative to timber railroad ties (PCA 1992).

Site Selection

Of several sites that were inspected, the crossings on US 41 in Boswell and US 421 in Reynolds were potential sites for a test of full scale panels. The Reynolds crossing has one lane of traffic in each direction, and is a relativly low traffic road. The Boswell crossing has two lanes of traffic in each direction. Lay-in precast concrete panels used in the past at the Boswell crossing have failed in a short amount of time.

The southbound lanes are of particular importance as they carry a high volume of truck traffic at high speeds. The presence of a quarry to the north of the crossing means heavier wheel loads created by the loaded trucks heading south than the unloaded trucks traveling north. The average speed of truck traffic passing the crossing is about 115 km/h (72 mph), according to INDOT officials.

The high speed of the traffic creates a severe loading on the panels and the rails themselves. Over time, the rails become lose as the spikes pull out from the timber ties. These rails then “flap” up and down when a highway vehicle crosses them. The rails were refastened to the ties in mid August, but by the September 18th meeting at the site, the rails were loose again.

Minutes of important meetings are included in Appendix B. Photographs of the US 41 site in Boswell are in Appendix C.

TESTING PROGRAM

Materials

Type I Lonestar Portland Cement from Greencastle, Indiana was used in making all test specimens. It was stored in the original 42.63 kg (94 lb) cement sacks in a dry room. The concrete mixtures were designed to produce compressive strengths of 41.37 Mpa (6000 psi) at 28 days. A workability as shown by a 76.2 mm (3 inch) slump in the non fiber reinforced concrete mix was chosen. The addition of fibers eliminated the slump. The cement used was ground very finely so that the strengths of the 152.4 mm (6 inch) cylinders reached strengths upwards of 55.16 Mpa (8000 psi) at 14 days. Results are reported for each specimen.

The fibers were type 50/63 polyolefin fibers manufactured by 3M. The fibers were 50.0 mm (2 inches) long and 0.63 mm (0.025 inches) in diameter. Individual fibers were wrapped together in approximately 50 mm (2 inch) diameter bundles and packaged in boxes of 11.3 kg (25 lbs.). The physical properties are listed in Table 1.

Table 1 : Mechanical Properties of 3M Polyolefin Type 50/63 Fibers

Specific Gravity	0.91
Tensile Strength	275 MPa (40,000 psi)
Modulus of Elasticity	2647 MPa (384,000 psi)
Elongation at Break	15 - 17 %
Ignition Point	596°C (1100°F)
Melt Point	160°C(320°F)

Details of Test Specimens

All test beams were 152.4 mm x 152.4 mm x 533.4 mm (6 inch x 6 inch x 21 inch) and cylinders 152.4 mm (6 inch) diameter and 304.8 mm (12 inch) height. All specimens were made in accordance with ASTM 192 M - 95. The specimens were labeled with three numbers separated by dashes. The first number indicates the volume percentage of fiber reinforcing. The second number indicates the batch number from which the specimen was cast. The last number indicates the specimen number of that particular batch. For example, beam 1.6 - 5 - 2 indicates that the specimen has a 1.66 volume percentage of fiber reinforcing, was cast from batch 5, and was the second beam cast. Three beams were cast from each batch in most cases.

Fabrication and Curing of Test Specimens

The concrete was mixed in a 1.5 cubic foot batch mixer. All materials were measured by weight. The coarse and fine aggregates were mixed with the cement for one minute before the addition of water. The concrete was allowed to mix two minutes before adding the fibers. The fibers were sprinkled into the mixer over approximately two more minutes, and the concrete was then mixed for an additional minute once all the fibers had been added.

Multiple use steel forms were used for making beams and plastic forms were used for making cylinders. The forms were oiled using form release oil prior to batching. Concrete was placed into the forms using a metal scoop and then vibrated using a 25mm (1 inch) diameter electric immersion vibrator. Additional concrete was added until flush with the top of the form. An oiled steel plate was used to cap the beam specimens.

Cylinders were cast in three equal lifts. Each lift was vibrated with a 25mm (1 inch) diameter electric immersion vibrator. The top surface of the cylinders was struck with a metal bar and any protruding fibers were removed. The first few attempts at striking off and smoothing exposed surfaces proved difficult, but after working with the fibers it became easier. The cylinders were then capped.

The concrete was allowed to cure for 24 hours. The forms were stripped 24 hours later and the specimens were labeled and placed into a moist room. The specimens were rinsed in tap water if there was an obvious excess of form oil present. The steel forms were then cleaned with a steel brush for the next batch of beams. After two weeks, the two weeks stock of beams was restacked so that the older beams were on the top for easy access prior to testing. Cylinders were placed on wooden shelves in the moist room for easy access.

Load-Deflection Testing

Beams, spanning 18 inches, were tested in flexure in sets of three at 28 days. During the flexure test, load on and deflection of the beam were recorded to establish a load-deflection history.

The linear voltage differential transducer (LVDT) was placed beneath the center of the bottom testing fixture to measure the deflection. The beam was then centered on the reaction frame. The top frame was placed so as to apply load at the third points on the top of the beam. The reaction frames do not allow translation at the supports, but do allow rotation. The SATEC testing machine was programmed to stop at 2224 N (500 lb) intervals for 30 seconds so that the LVDT reading could be recorded. The machine was programmed to stop at 20 set points. Fewer points were recorded below 13.34 kN (4000 lb) due to settlement in the supports. The loading was performed at a constant ram speedof 0.508 mm (0.02 inch) per minute.

Compressive Strength Testing

Cylinders were tested at 14 days of age to determine the compressive strength. After continuous curing in a moist room at a constant temperature, the cylinders were tested using end caps.

Splitting Tensile Strength

Cylinders were tested at 14 days of age to determine the tensile strength of the concrete. The cylinders were tested on their side at a loading rate of 66.72 kN (15,000 lb) per minute, as per ASTM standard C 496 - 96.

Problems

There were many problems encountered both while preparing to test and during the testing phase. Most of these problems were due to lack of equipment or improper functioning of equipment.

The first problem was lack of a proper testing machine and data acquisition computer. While planning testing in January 1998, the person working on the testing machine and data aqusition system said it would be ready in March. Samples were prepared to reach 28 day strength two weeks after the testing apparatus was scheduled to be completed. The testing machine was not ready when the samples reached 28 days. In April the system was finished, but it was extremely unreliable, only recording data occasionally.

The samples were tested without a computer data aqusition system. However, the testing machines had an internal safety device which ended a test when the computer sensed a release of load. Similar to the data aqusition system, this safety device was unreliable and allowed a small percentage of beams to be tested past first crack load.

The ends of the first set of beams were sawed into 152.4 mm (6 inch) cubes so that they could be tested in compression. However, these cubes could not be broken in the 1,112 kN (250 kip) hydraulic compression tester. The only available machine in the School of Civil Engineering that is capable of a load greater than 250 kips is located in the structures lab, and it frequently has a full scale beam loaded in it. These cubes could therefore not be tested.

The same type of problem was encountered when testing the 152.4 mm (6 inch) cylinders in compression. At 14 days, they cylinders came close to the maximum capacity of the machine, breaking at about 1,045 kN (235 kips). Due to lack of a testing machine capable of more than 1,112 kN (250 kips), the cylinders were not saved as planned to be tested at 28 days. 152.4 mm (6 inch) cylinders were used instead of smaller cylinders because of the 50.0 mm (2 inch) length of the polyolefin fibers.

RESULTS AND DISCUSSION

Test results are presented in Appendix D in tabular form for each volume percent of fiber content. Average and standard deviations are given for flexural tests, compression tests, and splitting tensile tests.

Load - Deflection Testing

When the load-deflection data was graphed, the slope varied until the load reached about 17.79 kN (4000 pounds). This was due to the supports in the testing it was apparent that there was a fair amount of settlement in the supports of the apparatus. At higher loads, the load deflection curve becomes linear. In order to correct for this, a linear regression was performed on the linear upper portion of the load-deflection graph, and the x intercept was calculated and taken to be the new origin, O'. Appendix E contains the load-deflection curves for all of the flexure specimens.

Many of the beams failed with a center crack straight across the base. A few failed with the crack slightly skewed, indicating a torsional loading. This torsion is most likely a result of a misaligned load frame. These added tosional loads have a minute effect on elements in the stress field and less effect on the deflection (Tatro 1985).

Visual inspection of the failure surfaces shows a high variability in the fiber distribution. The modulus of rupture was increased 5.6%, 9.2%, and 13.4% for the addition of fibers by 1.00%, 1.33%, and 1.66% by volume. Figure 1 shows the average modulus of rupture for each series of beam specimens. Higher fiber contents lead to more fibers in the tensile zone of the beam. The additional fibers in the tensile zone assist the concrete matrix in carrying a higher tensile load, increasing the modulus of rupture.

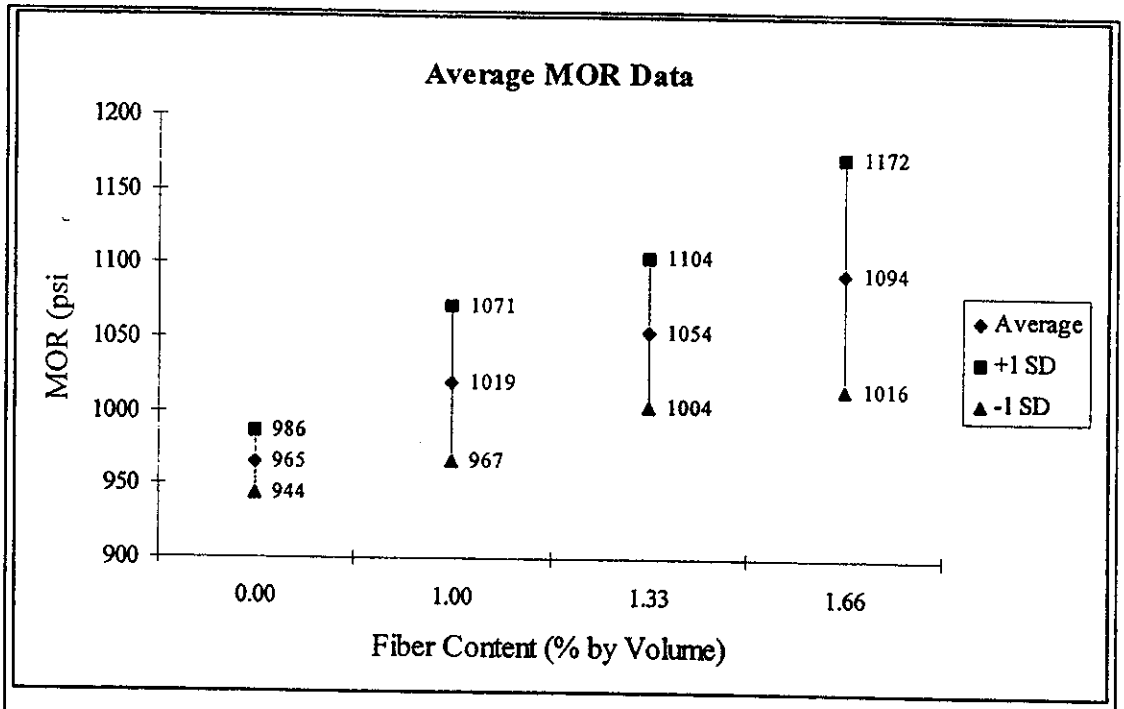

Figure 1: MOR data for flexural specimens.

Another trend observed in Figure 1 is the increase in the standard deviations. As the fiber contents increase, the standard deviations increase. Small changes in the concentration and alignment of fibers in the tensile zone can result in large variations in the load capacity. Low fiber concentrations and nonpreferential fiber alignment in the tensile zone can result in a low modulus of rupture.

The modulus of rupture is calculated assuming a linear stress distribution across the height of the beam. In reality the stress is not linear, and the actual ultimate strength is always lower than the modulus of rupture. The random distribution and alignment of the fibers further modifies the stress distribution, particularly in the tensile zone, which contributes to the increased deviation in the results.

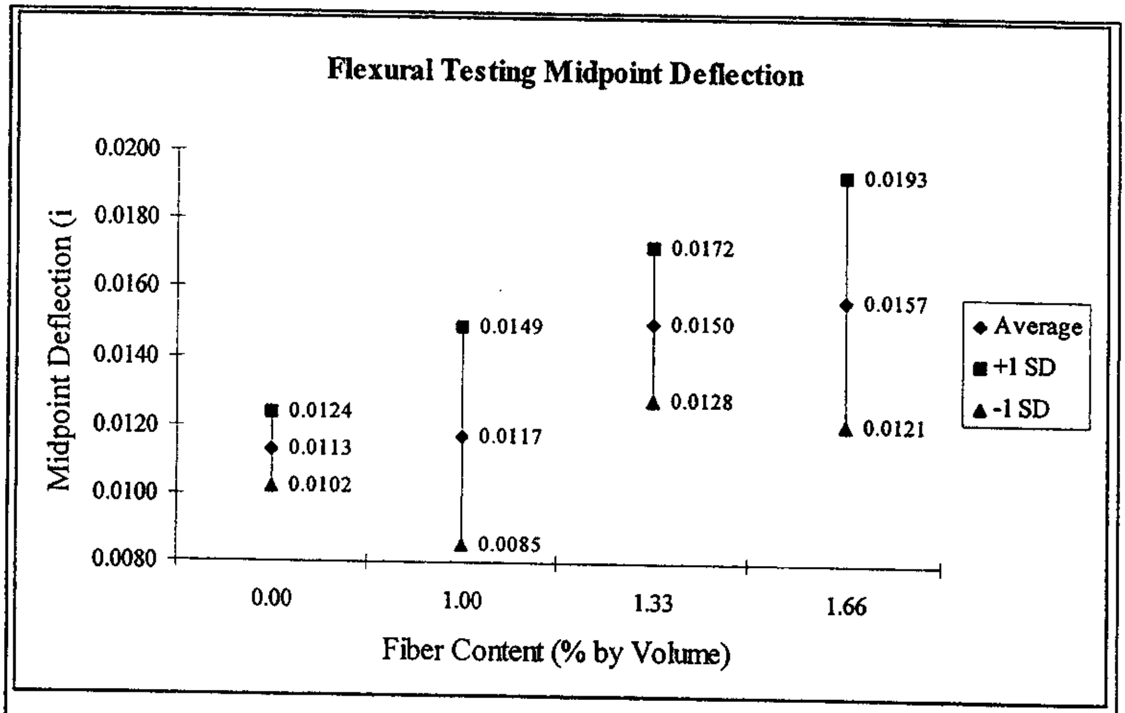

Figure 2: Flexural Testing Midpoint Deflection at Failure

Data indicates that the addition of fibers increases the ultimate midpoint deflection of the third point specimens. As expected the plain concrete specimens had a relatively small standard deviation, while the specimens containing fibers had significantly larger deviations. Since strains are related to the stresses within the material, it is not suprising that the deviations tend to be larger for the concrete containing fibers.

Compression Testing

The addition of polyolefin fibers to the concrete matix increased the compressive strength slightly. The addition 1.00%, 1.33% and 1.66% fibers by volume increased the compressive strength by 0.9%, 1.4%, and 3.5% respectively. While these increases are minimal, it is important to note that the stiffness of a concrete is generally related to its compressive strength. This generalization does not apply in this case as the deflection of the third point specimens increases with the increasing fiber content. The increasing modulus of rupture creates the potential to deflect through a higher load level, creating a higher deflection at failure.

Splitting Tensile Testing

The precise identification of the first crack is difficult to determine in a splitting tensile test "without strain gages or other sophisticated means of crack detection, such as acoustic emission or laser holography" (ACI Committee 544). The polyolefin fiber reinforced concrete samples failed with an audible cracking sound. When the load was removed, the cracks were not easily visible. Upon closer inspection, hairline cracks could be seen crossing the ends of the cylinder, dividing them almost exactly in half. After testing, specimens could not be pried apart along this failure crack.

The splitting tensile strength of the mixes was increased by 0.3%, 4.9%, and 7.2% with the addition of fibers by 1.00%, 1.33%, and 1.66%. While these increases are less than the increases in the modulus of rupture, they follow the same general trend.

Conclusions

Modulus of rupture was significantly increased with the addition of polyolefin fibers. An increase in midpoint deflection accompanied this increased strength. The addition of polyolefin fibers to a precast concrete railroad crossing will impart increased flexibility and strength to the panel. The fibers will also serve to keep cracks from propagating and opening further in the case a crack does form.

The addition of fibers, however, does not improve the properties of concrete enough to design a lay-in type panel of limited height using ordinary reinforced concrete. Post-tensioning used in conjunction with polyolefin fibers would allow a limited height panel to be designed adequately for both the strength and durability required.

Recommendations for Field Installation

It is necessary that the ties supporting lay-in precast concrete panels be properly aligned so that the panel lies on all of the ties beneath it. If a tie is too low, it does not provide support, and if it is too high it may place undue stresses on fasteners.

When fasteners loosen, the panels are subjected to a rocking motion which causes further wear on the ties beneath it. The rocking motion continues to grow worse and can cause panels to crack.

For these reasons it is important to make sure the ties are aligned properly prior to installation. Lag screws should not be fastened to damaged ties, or ties that have been used to fasten previous panels.

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LIST OF CONTACTS

LIST OF CONTACTS

Name	Affiliation	Phone
Hohl, Fred	INDOT Railroad Unit	(317)232-5301
Hull, Steve	INDOT	(317)232-5340
Nantung, Tommy	INDOT Research	(765)463-1521
Shaw, Larry	INDOT	(317)233-3701
Scholer, Charles	Purdue University	(765)494-5017
Baker, James	Star Track	(303)791-1120
Brookhart, Clint	Star Track	(303)791-1120
Burleson, Lon	Star Track	(708)839-2676
McDonald, Cliffton	3M	(651)736-7390

APPENDIX A - LIST OF PRECAST CONCRETE RAILROAD CROSSINGS

Table A1: Precast Concrete Railroad Crossings in the State of Indiana

Agency	Road Name	Surface $	Visited?	Movement	Cracks	Scaling	Broken Bolts	Replaced Panel	Comments
INDOT	SR109	235,100							
INDOT	SR 45	100,608							
INDOT	SR 64	96,715							
INDOT	SR 15	154,400	Y						Replaced with rubber
INDOT	SR 22	152,949	Y		X	X			
INDOT	US 31	180,390	Y						Replaced with rubber
INDOT	US 50	55,446							
INDOT	US 50	190,889							
INDOT	SR 55	49,499	Y		X				
INDOT	SR 218	65,176	Y						
INDOT	SR 9	97,768	Y	X	X	X			
INDOT	SR 3	72,200	Y		X	X			
INDOT	US 20	81,355	Y	X	X				Metal angle debonded
INDOT	SR 44	73,341	Y		X	X			
INDOT	SR 45	67,851							
INDOT	SR 101	50,196	Y		X	X			
INDOT	SR 135	49,929							
INDOT	SR 356	68,527							
INDOT	US 52	88,100	Y		X				
INDOT	SR 67	197,390							
INDOT	SR 427	120,947							
INDOT	SR 111	45,859							
INDOT	SR 252	210,026							
Evansville	FULTON AVE	65,290							
South Bend	KEMBLE AVE	50,800	Y	X	X				
INDOT	SR 5	99,042	Y		X				
INDOT	SR 26	99,815							
INDOT	SR 63	115,210							
INDOT	US 421	118,388	Y	X	X		X	X	
INDOT	US 41	106,000							
INDOT	US 41	114,904							

Table A1 Continued: Precast Concrete Railroad Crossings in the State of Indiana

Agency	Road Name	Surface $	Visited?	Movement	Cracks	Scaling	Broken Bolts	Replaced Panel	Comments
INDOT	US 50	426,454							
Anderson	NICHOL AVE	100,500	Y						Replaced with rubber
Evansville	MAIN ST	66,200							
Evansville	WASHINGTON	96,400							
Kokomo	PLATE ST	308,157	Y						Not Found
INDOT	SR 327	182,488							
INDOT	SR 5	64,037	Y						
INDOT	SR 827	154,632	Y		X	X	X		
INDOT	SR 9	39,473	Y		X	X			
INDOT	SR 135	45,160							
Bartholemew	CR 450S	62,883							
Tipton	DIVISION RD		Y						Not Found
Noblesville	8TH ST	1,366,859	Y			X			3 blocks long
Dekalb	CR 141(CR31)	59,651							
Kokomo	N MAIN ST	156,113	Y		X	X			Major surface scaling
St. Joseph	WALNUT RD	126,000	Y			X			
INDOT	SR 26	54,200							
INDOT	SR 111	158,561							
INDOT	US 41	116,352	Y	X		X		X	
INDOT	SR 62	45,100							
INDOT	SR 71	170,000							
INDOT	SR 1	118,070	Y				X		Bolt head sheared off
INDOT	SR 45	79,008							
INDOT	SR 526	98,380							
INDOT	US 12	81,437							
INDOT	US 12	71,745							
Gary	BUCHANAN ST	106,901							
Pike	ILLINOIS ST	114,763							
Lapel	MAIN ST	57,850	Y						Welded lay in panels
INDOT	SR 930	32,770	Y						Platform Type
Terre Haute	FRUITRIDGE	500,000							

Table A1 Continued: Precast Concrete Railroad Crossings in the State of Indiana

Agency	Road Name	Surface $	Visited?	Movement	Cracks	Scaling	Broken Bolts	Replaced Panel	Comments
Martinsville	MORGAN ST	72,847							
INDOT	SR 9	133,500	Y			X			
INDOT	SR 28	89,100	Y						Replaced with rubber
INDOT	SR 3	198,040							
Marion	WEST ST	148,000	Y		X	X			
East Chicago	MICHIGAN AVE	356,400							
East Chicago	MICHIGAN AVE	99,565							
East Chicago	KENNEDY AVE	90,127							
East Chicago	DICKEY RD	185,000							
Fishers	116TH ST	242,228	Y		X	X			
East Chicago	MICHIGAN AVE	99,500							
Evansville	OHIO ST	84,889							
Brownsburg	CR 600E	143,200	Y			X			
Pittsboro	MERIDIAN ST	61,900	Y	X	X		X		
Clinton	MAIN ST	62,763							
Whiting	129TH ST	49,900							
INDOT	US 30	104,000	Y		X				Platform type
INDOT	SR 206(CR 61)	68,593							
	GREENE RD	136,200	Y						Replaced with rubber
INDOT	SR 66	35,239	Y		X				
Jancock	CR 600W	146,150	Y						
Madison	CR 450S	134,400							

APPENDIX B - MINUTES OF MEETINGS

7-23-98 Meeting in Indianappolis, Governmental Center South

Clint Brookhart, from Oldcastle Plant in Littleton CO.

- Littleton is the newest plant
- Usually makes underground utility structures (for US West)
- Durability Issues:
  - Production Process:
    - panels finished upside down
    - 6,000 psi at 28 day strength
    - 0.44 water - cement ratio
    - plasticizers and 4 - 6% air entrainment
  - Loading Conditions:
    - indeterminant loading conditions
    - 60^k impact loading
    - section too thin to resist with reinforced concrete design
  - Design Summary:
    - flangeway = outer panel
    - gage = inner panel
    - wheel load per HS20 (AASHTO)
    - f'_{cr} from equation, not tests
    - each strand post tensioned to 33,000 lbs
    - first visible cracks at 779.9 psi
    - visble cracks at 1,223 psi
    - cracks close when load is removed
    - strand at center of gravity
    - hydrozo sealer on top of panel
    - bumps cast into riding surface - no finish work needed
- Possibilities of replacing crossings in Boswell or Reynolds discussed.
- The representatives at INDOT to start the procedures for purchasing a crossing.
- Star Track to be contacted by Purdue researchers with information about 3M fibers.

9/18/98 Meeting At Boswell Site

Representatives from INDOT / Purdue / KBS
Kevin Stroo, Trainmaster, Kankakee, Beaverville and Southern Railroad

Frank Litherland:

- 10" - 12" concrete bed with about 10" ballast on top:

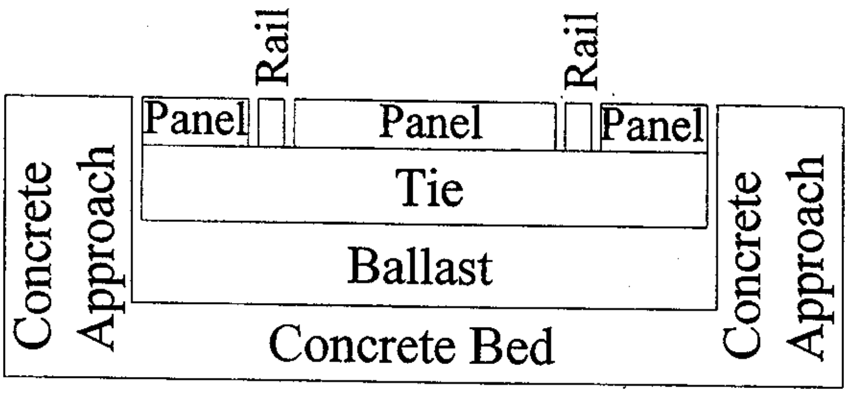

Figure B1: Proposed Site Cross Section

- concrete approaches
- construction can start after October 18 (end of covered bridge days)

APPENDIX C - BOSWELL SITE PHOTOGRAPHS

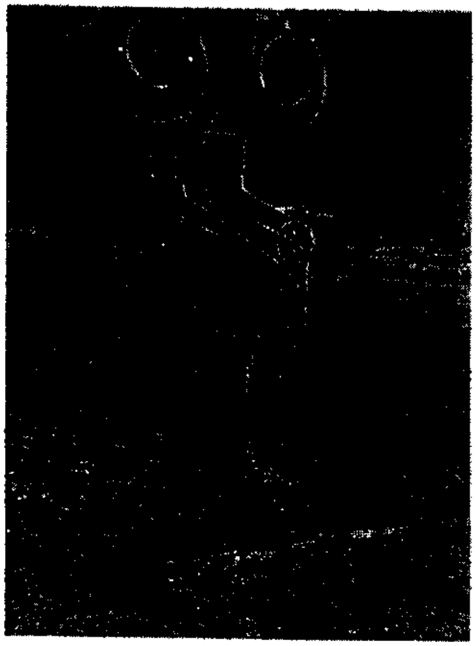

Figure C1: Southbound US 41 signaling gate. High speed truck traffic occasionally damages equipment if the stopping distance is too short.

Figure C2: Railroad spikes can be seen pulling out of the timber ties less than two months after tightening.

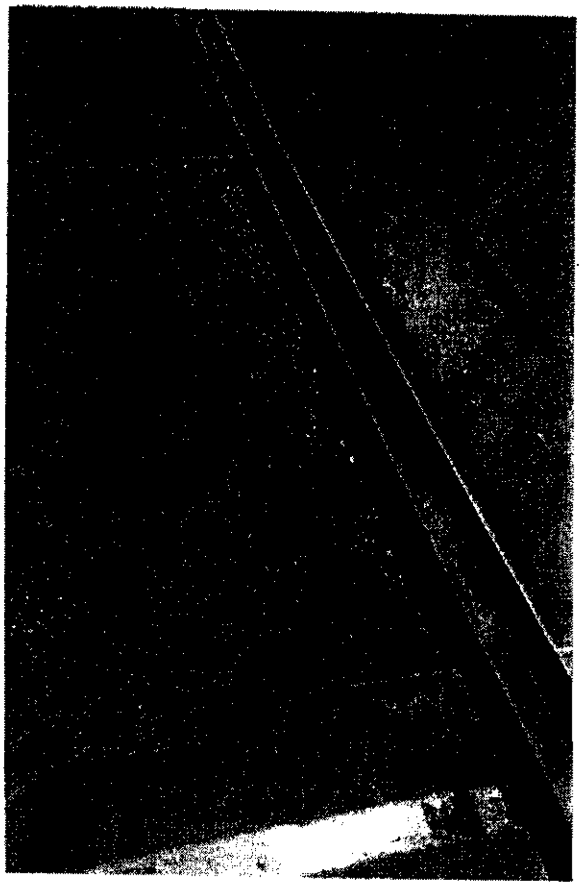

Figure C3: A panel cracked so much it had to be removed. Temporary asphalt fill was placed between the rails.

APPENDIX D - TEST RESULTS

Table D1: 0.00 % Fiber Content Test Results

0.00 % Fiber Content
Modulus of Rupture Data

Specimen	MOR (psi)	Deflection (in)
0 - 2 - 1	969	0.0122
0 - 2 - 2	964	0.0109
0 - 2 - 3	948	0.0099
0 - 3 - 1	957	0.0108
0 - 3 - 2	968	0.0105
0 - 3 - 3	989	0.0104
0 - 4 - 1	976	0.0116
0 - 4 - 2	960	0.0105
0 - 4 - 3	1,005	0.0106
0 - 5 - 1	990	0.0123
0 - 5 - 2	950	0.0118
0 - 5 - 3	969	0.0111
0 - 6 - 1	966	0.0136
0 - 6 - 2	943	0.0107
0 - 6 - 3	995	0.0123
0 - 7 - 1	938	0.0106
0 - 7 - 2	925	0.0135
0 - 7 - 3	962	0.0104
Average	965	0.0113
SD	21	0.0011

0.00 % Fiber Content
Compression Tests

Specimen	f'c (psi)
0 - 20 - 1	7958
0 - 20 - 2	8099
0 - 20 - 6	7922
0 - 20 - 7	8223
0 - 21 - 2	8117
0 - 21 - 6	7869
0 - 21 - 7	7728
0 - 22 - 1	8170
0 - 22 - 2	8188
0 - 22 - 6	8170
0 - 22 - 7	8188
Average	8057
SD	163

0.00 % Fiber Content
Tension Tests

Specimen	T (psi)
0 - 20 - 3	588
0 - 20 - 4	596
0 - 20 - 5	654
0 - 21 - 3	623
0 - 21 - 4	582
0 - 21 - 5	631
0 - 22 - 3	610
0 - 22 - 4	622
0 - 22 - 5	591
Average	611
SD	24

Table D2: 1.00 % Fiber Content Test Results

1.00 % Fiber Content
Modulus of Rupture Data

Specimen	MOR (psi)	Deflection (in)
1.0 - 3 - 1	1,150	0.0122
1.0 - 3 - 2	1,070	0.0103
1.0 - 3 - 3	1,110	0.0225
1.0 - 4 - 1	988	0.0114
1.0 - 4 - 2	995	0.0135
1.0 - 4 - 3	1,010	0.0116
1.0 - 5 - 1	980	0.0106
1.0 - 5 - 2	992	0.0088
1.0 - 5 - 3	984	0.0118
1.0 - 6 - 1	1,030	0.0102
1.0 - 6 - 2	1,020	0.0101
1.0 - 6 - 3	998	0.0107
1.0 - 7 - 1	970	0.0121
1.0 - 7 - 2	990	0.0091
1.0 - 7 - 3	992	0.0100
Average	1,019	0.0117
SD	52	0.0032

1.00 % Fiber Content
Compression Tests

Specimen	f'c (psi)
1.0 - 20 - 1	8329
1.0 - 20 - 2	8311
1.0 - 20 - 7	8170
1.0 - 21 - 1	7958
1.0 - 21 - 2	8117
1.0 - 21 - 6	8152
1.0 - 21 - 7	7852
Average	8127
SD	174

1.00 % Fiber Content
Tension Tests

Specimen	T (psi)
1.0 - 20 - 3	615
1.0 - 20 - 4	643
1.0 - 20 - 5	606
1.0 - 21 - 3	592
1.0 - 21 - 4	621
1.0 - 21 - 5	601
Average	613
SD	18

Table D3: 1.33 % Fiber Content Test Results

1.33 % Fiber Content
Modulus of Rupture Data

Specimen	MOR (psi)	Deflection (in)
1.3-3-2	1190	0.0142
1.3-3-3	1040	0.0180
1.3-4-1	1050	0.0127
1.3-4-2	1080	0.0129
1.3-4-3	988	0.0165
1.3-5-1	1060	0.0140
1.3-5-2	988	0.0203
1.3-6-1	1050	0.0126
1.3-6-2	1090	0.0150
1.3-6-3	1100	0.0132
1.3-7-1	1030	0.0148
1.3-7-2	1040	0.0145
1.3-7-3	995	0.0180
1.3-8-1	1070	0.0157
1.3-8-2	1030	0.0127
1.3-8-3	1110	0.0176
1.3-9-1	990	0.0137
1.3-9-2	1050	0.0147
1.3-9-3	1080	0.0130
Average	1054	0.0150
SD	50	0.0022

1.33 % Fiber Content
Compression Tests

Specimen	f'c (psi)
1.3 - 20 - 1	8205
1.3 - 20 - 2	8329
1.3 - 20 - 6	8294
1.3 - 20 - 7	8329
1.3 - 21 - 2	8011
1.3 - 21 - 6	8064
1.3 - 21 - 7	7958
Average	8170
SD	158

1.33 % Fiber Content
Tension Tests

Specimen	T (psi)
1.3 - 20 - 3	671
1.3 - 20 - 4	604
1.3 - 20 - 5	614
1.3 - 21 - 3	674
1.3 - 21 - 4	657
1.3 - 21 - 5	627
Average	641
SD	30

Table D4: 1.66 % Fiber Content Test Results

1.66 % Fiber Content
Modulus of Rupture Data

Specimen	MOR (psi)	Deflection (in)
1.6-1-2	978	0.0114
1.6-3-1	1180	0.0244
1.6-3-2	1170	0.0151
1.6-3-3	1050	0.0242
1.6-4-1	1130	0.0144
1.6-4-2	1110	0.0148
1.6-4-3	1140	0.0190
1.6-5-1	1070	0.0129
1.6-5-2	1040	0.0188
1.6-5-3	1080	0.0168
1.6-6-1	994	0.0162
1.6-6-2	975	0.0141
1.6-6-3	967	0.0116
1.6-7-1	1110	0.0144
1.6-7-2	1230	0.0142
1.6-7-3	1090	0.0140
1.6-8-1	1130	0.0136
1.6-8-2	1190	0.0143
1.6-8-3	1160	0.0139
Average	1094	0.0157
SD	78	0.0036

1.66 % Fiber Content
Compression Tests

Specimen	f'c (psi)
1.6 - 20 - 1	8311
1.6 - 20 - 2	8241
1.6 - 20 - 6	8594
1.6 - 20 - 7	8311
1.6 - 22 - 1	8364
1.6 - 22 - 2	8258
1.6 - 22 - 6	8258
1.6 - 22 - 7	8347
Average	8336
SD	113

1.66 % Fiber Content
Tension Tests

Specimen	T (psi)
1.6 - 20 - 3	676
1.6 - 20 - 4	671
1.6 - 20 - 5	671
1.6 - 22 - 3	657
1.6 - 22 - 4	630
1.6 - 22 - 5	622
Average	655
SD	23

APPENDIX E - MODULUS OF RUPTURE LOAD - DEFLECTION CURVES

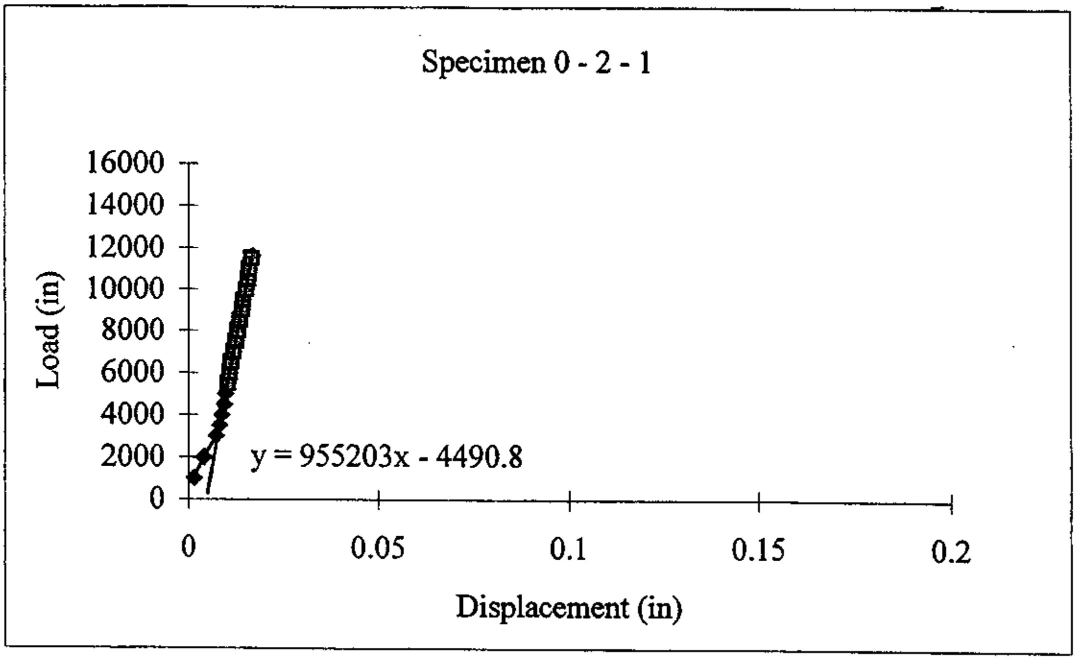

Figure E1: Load Deflection Curve for Specimen 0 - 2 - 1

Table E1: Load Deflection Data for Specimen 0 - 2 - 1

First Crack Load = 11,630 lbs
Midspan First Crack Deflection = 0.0122 in
Modulus of Rupture = 969 psi
First Crack Toughness = 70.94 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0047 in

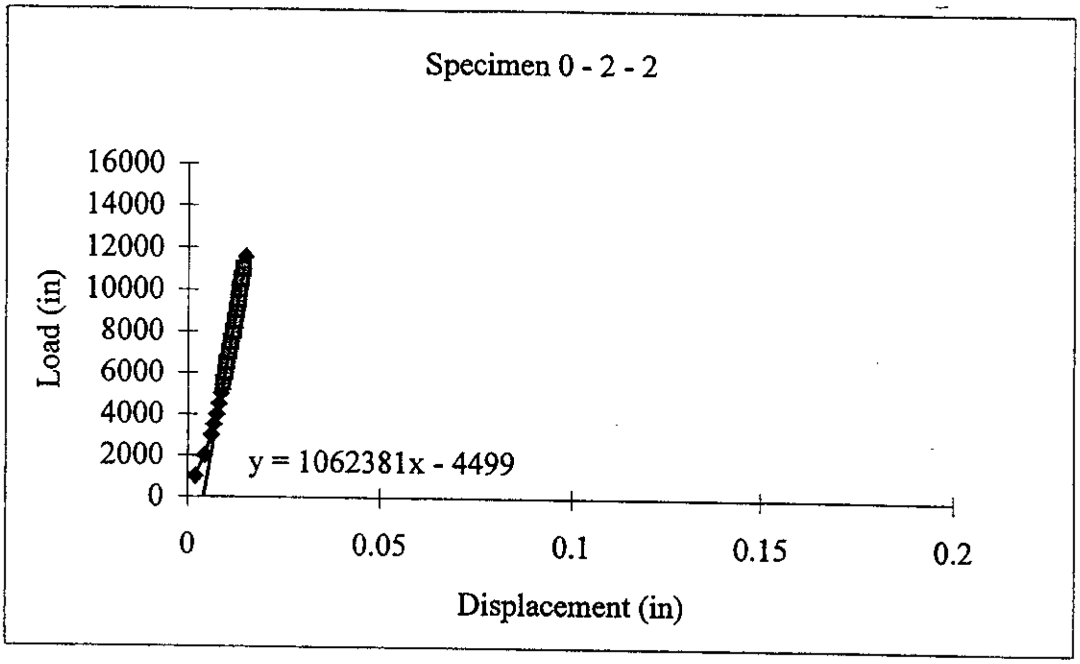

Figure E2: Load Deflection Curve for Specimen 0 - 2 - 2

Table E2: Load Deflection Data for Specimen 0 - 2 - 2

First Crack Load = 11,570 lbs
Midspan First Crack Deflection = 0.0109 in
Modulus of Rupture = 964 psi
First Crack Toughness = 63.06 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0042 in

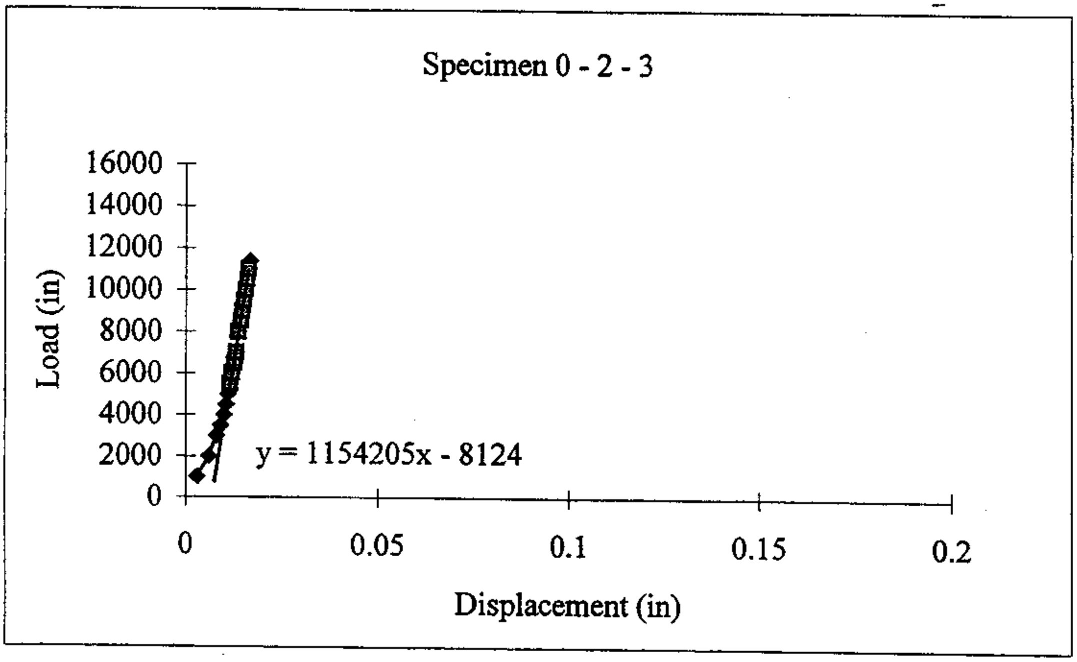

Figure E3: Load Deflection Curve for Specimen 0 - 2 - 3

Table E3: Load Deflection Data for Specimen 0 - 2 - 3

First Crack Load =	11,380	lbs
Midspan First Crack Deflection =	0.0099	in
Modulus of Rupture =	948	psi
First Crack Toughness =	56.33	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.007 in

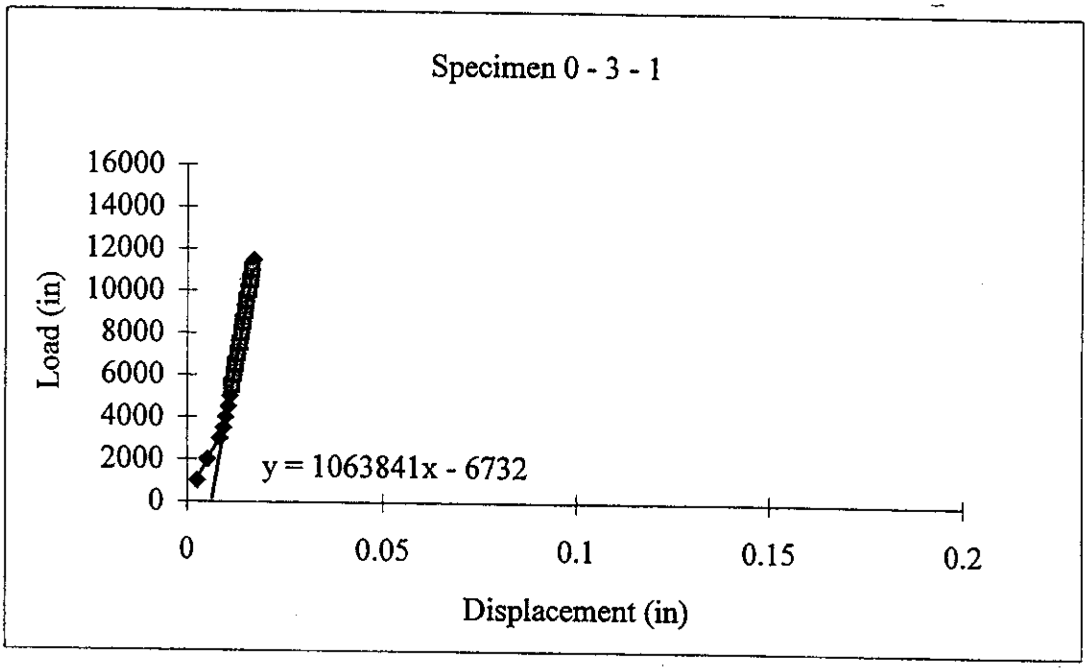

Figure E4: Load Deflection Curve for Specimen 0 - 3 - 1

Table E4: Load Deflection Data for Specimen 0 - 3 - 1

First Crack Load =	11,480	lbs
Midspan First Crack Deflection =	0.0108	in
Modulus of Rupture =	957	psi
First Crack Toughness =	61.99	lb-in

Specimen Type =	Molded	
Specimen Age =	28	days
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.0063	in

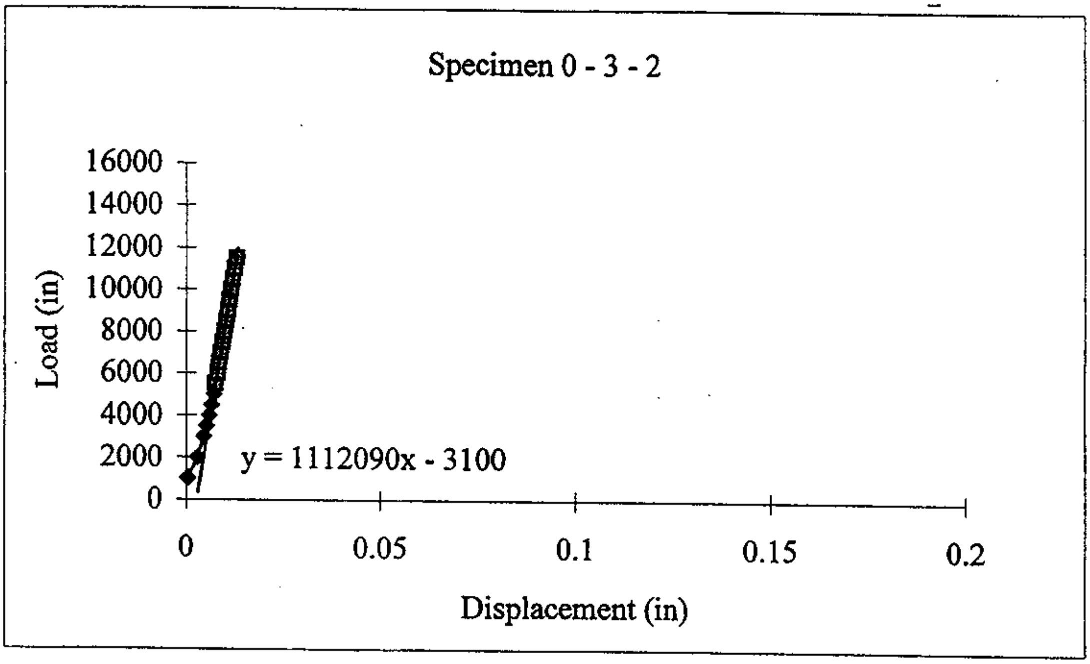

Figure E5: Load Deflection Curve for Specimen 0 - 3 - 2

Table E5: Load Deflection Data for Specimen 0 - 3 - 2

First Crack Load =	11,620	lbs
Midspan First Crack Deflection =	0.0105	in
Modulus of Rupture =	968	psi
First Crack Toughness =	61.01	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0028 in

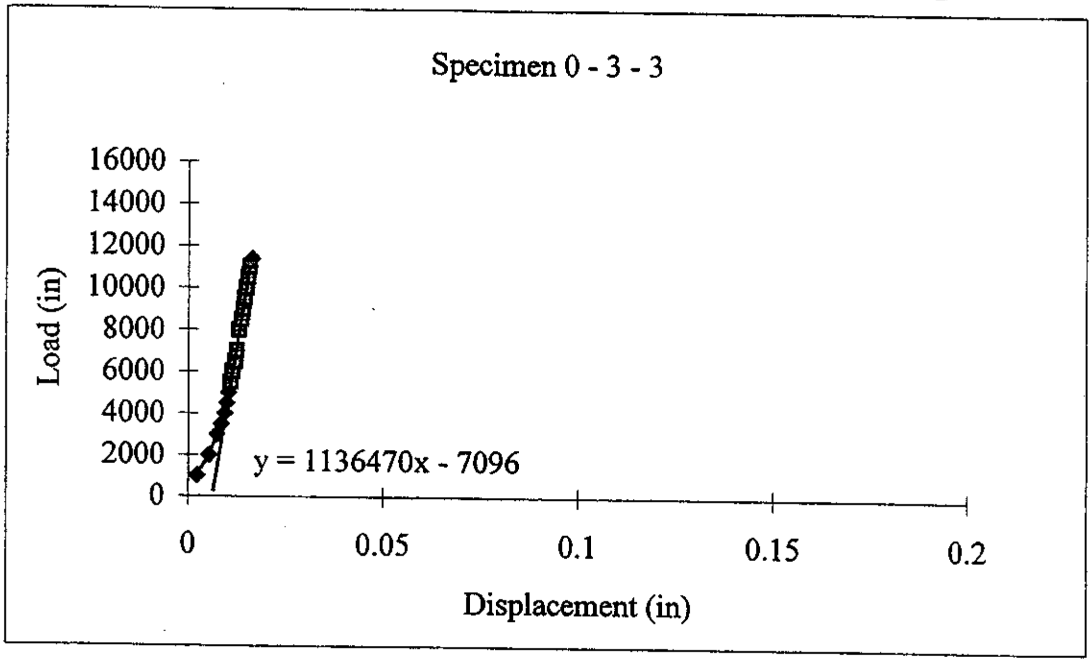

Figure E6: Load Deflection Curve for Specimen 0 - 3 - 3

Table E6: Load Deflection Data for Specimen 0 - 3 - 3

First Crack Load =	11,870	lbs
Midspan First Crack Deflection =	0.0104	in
Modulus of Rupture =	989	psi
First Crack Toughness =	61.72	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0062 in

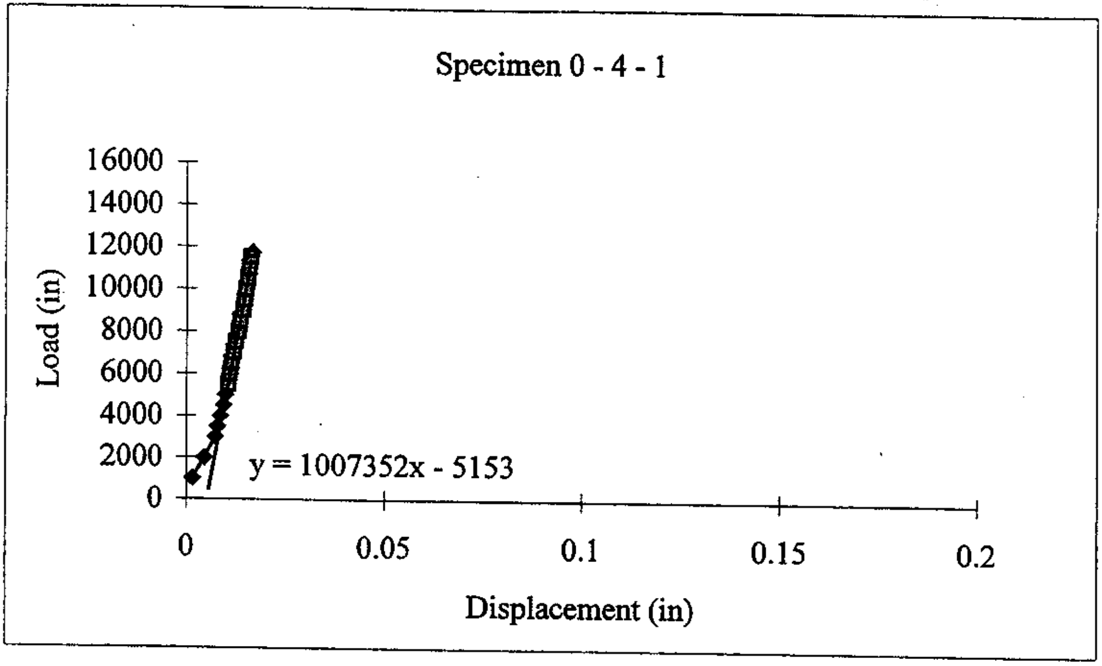

Figure E7: Load Deflection Curve for Specimen 0 - 4 - 1

Table E7: Load Deflection Data for Specimen 0 - 4 - 1

First Crack Load = 11,710 lbs
Midspan First Crack Deflection = 0.0116 in
Modulus of Rupture = 976 psi
First Crack Toughness = 67.92 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0051 in

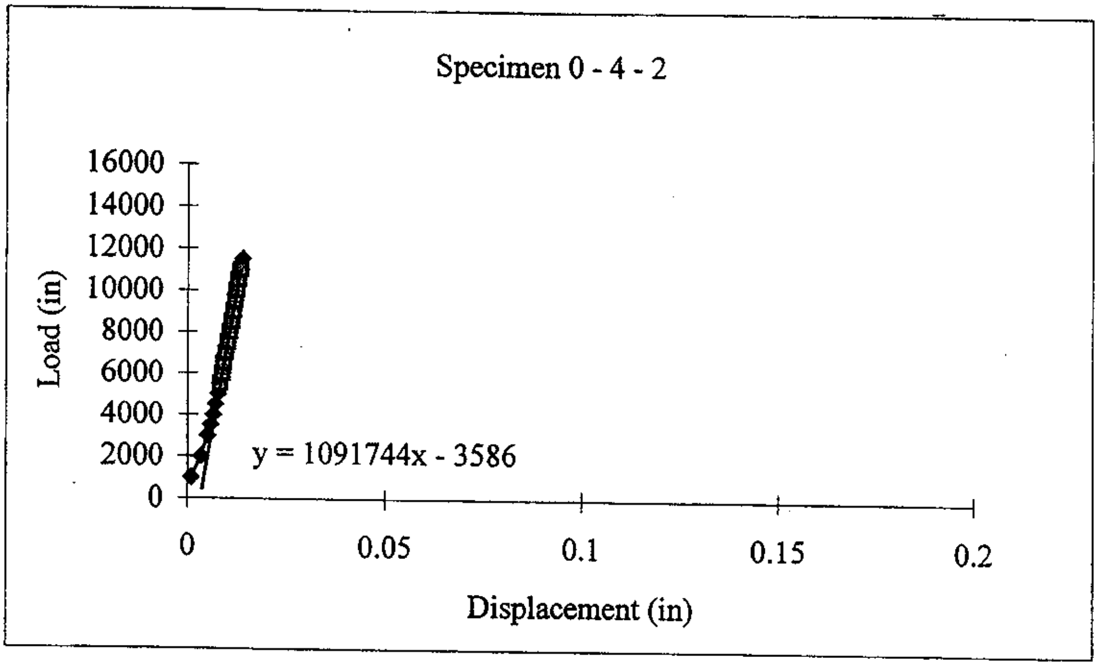

Figure E8: Load Deflection Curve for Specimen 0 - 4 - 2

Table E8: Load Deflection Data for Specimen 0 - 4 - 2

First Crack Load =	11,520	lbs
Midspan First Crack Deflection =	0.0105	in
Modulus of Rupture =	960	psi
First Crack Toughness =	60.48	lb-in

Specimen Type =	Molded	
Specimen Age =	28	days
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.0033	in

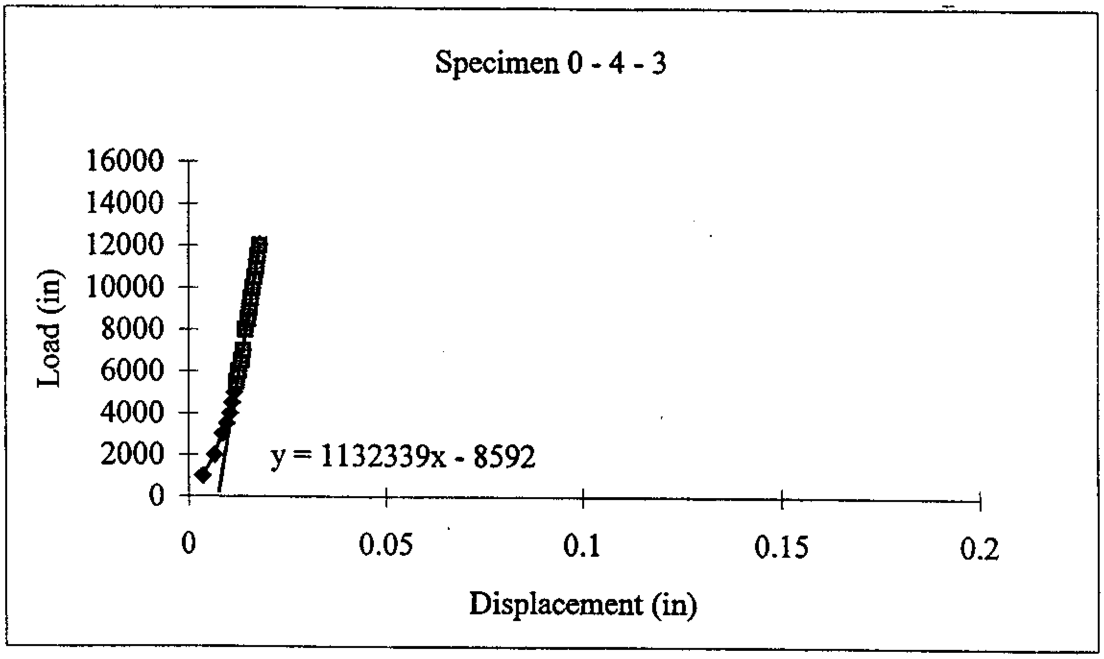

Figure E9: Load Deflection Curve for Specimen 0 - 4 - 3

Table E9: Load Deflection Data for Specimen 0 - 4 - 3

First Crack Load = 12,060 lbs
Midspan First Crack Deflection = 0.0106 in
Modulus of Rupture = 1005 psi
First Crack Toughness = 63.92 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0076 in

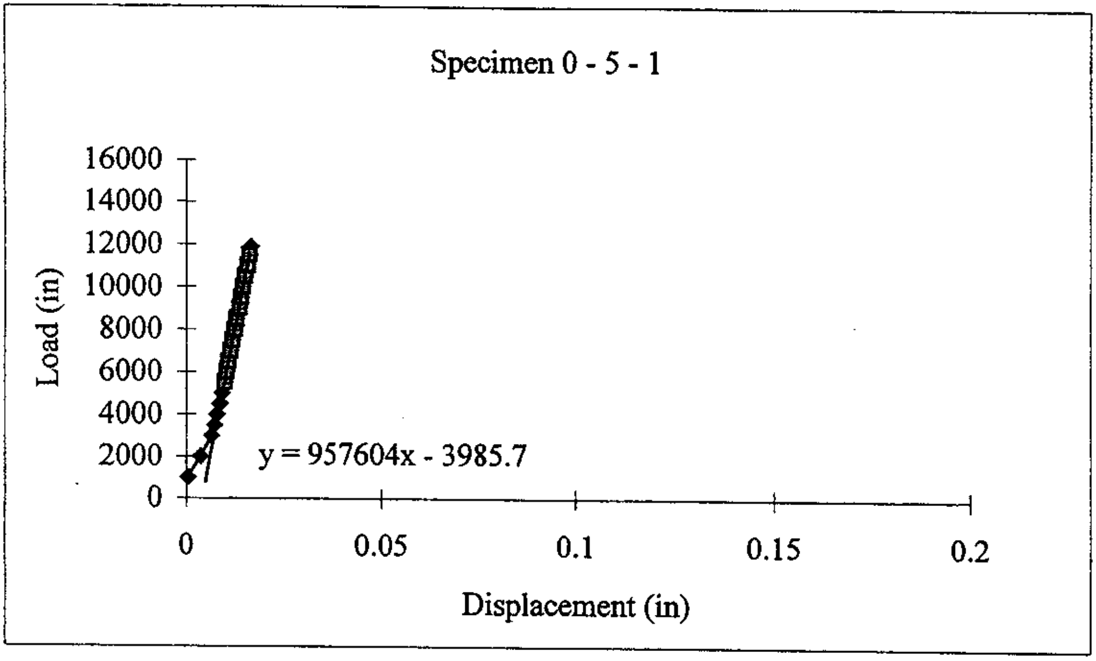

Figure E10: Load Deflection Curve for Specimen 0 - 5 - 1

Table E10: Load Deflection Data for Specimen 0 - 5 - 1

First Crack Load = 11,880 lbs
Midspan First Crack Deflection = 0.0123 in
Modulus of Rupture = 990 psi
First Crack Toughness = 73.06 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0042 in

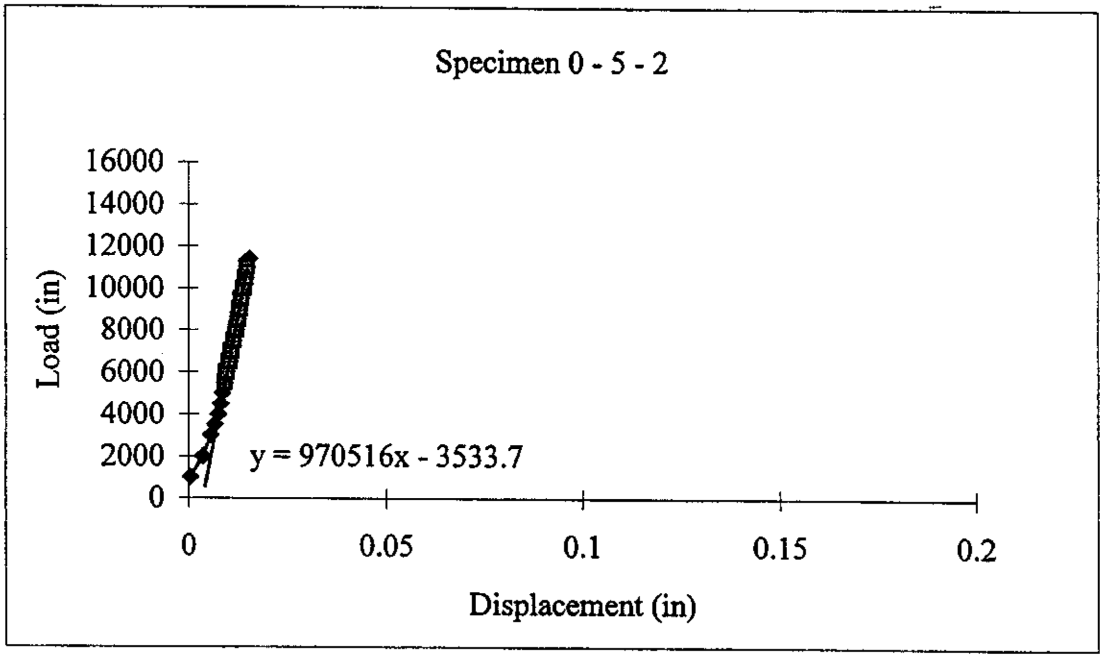

Figure E11: Load Deflection Curve for Specimen 0 - 5 - 2

Table E11: Load Deflection Data for Specimen 0 - 5 - 2

First Crack Load =	11,400	lbs
Midspan First Crack Deflection =	0.0118	in
Modulus of Rupture =	950	psi
First Crack Toughness =	67.26	lb-in

Specimen Type =	Molded	
Specimen Age =	28	days
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.0036	in

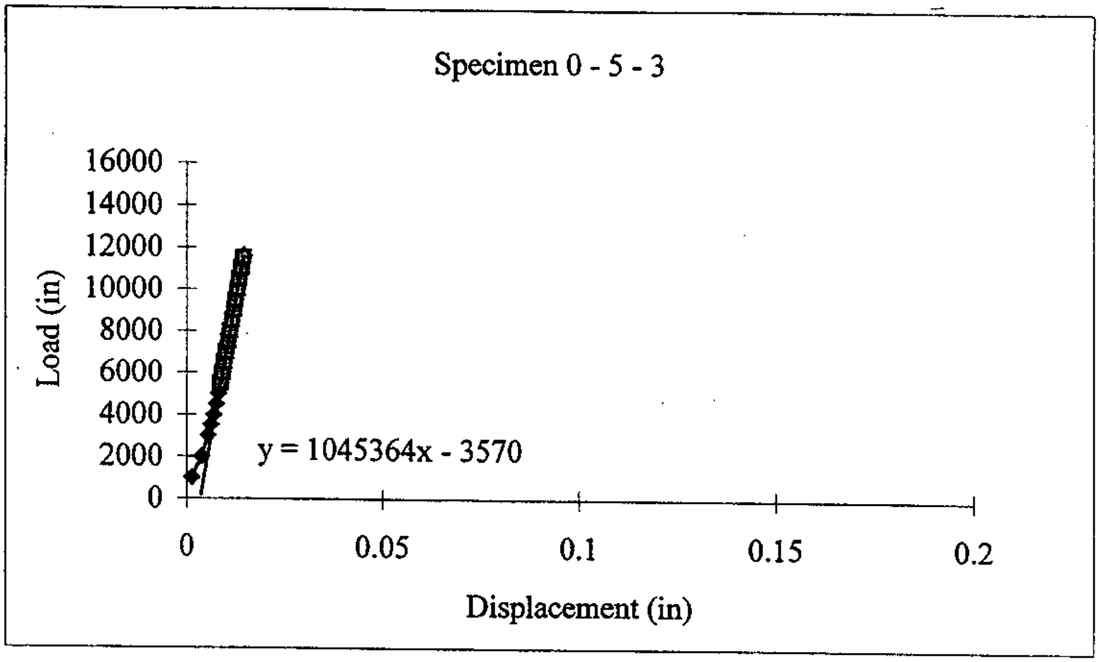

Figure E12: Load Deflection Curve for Specimen 0 - 5 - 3

Table E12: Load Deflection Data for Specimen 0 - 5 - 3

First Crack Load = 11,630 lbs
Midspan First Crack Deflection = 0.0111 in
Modulus of Rupture = 969 psi
First Crack Toughness = 64.55 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0034 in

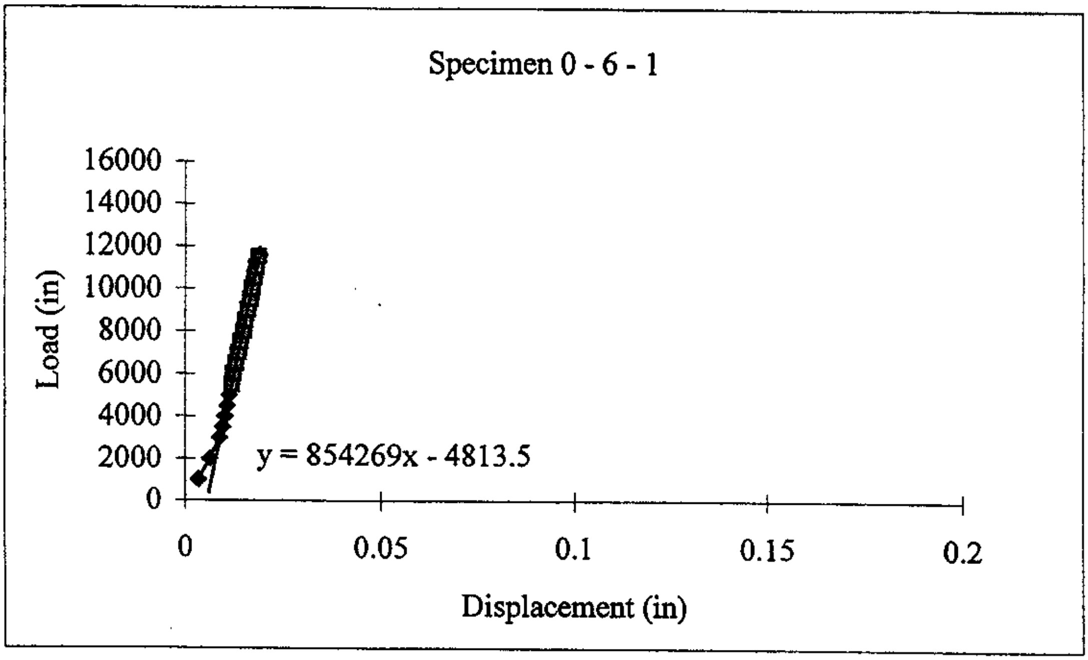

Figure E13: Load Deflection Curve for Specimen 0 - 6 - 1

Table E13: Load Deflection Data for Specimen 0 - 6 - 1

First Crack Load = 11,590 lbs
Midspan First Crack Deflection = 0.0136 in
Modulus of Rupture = 966 psi
First Crack Toughness = 78.81 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0056 in

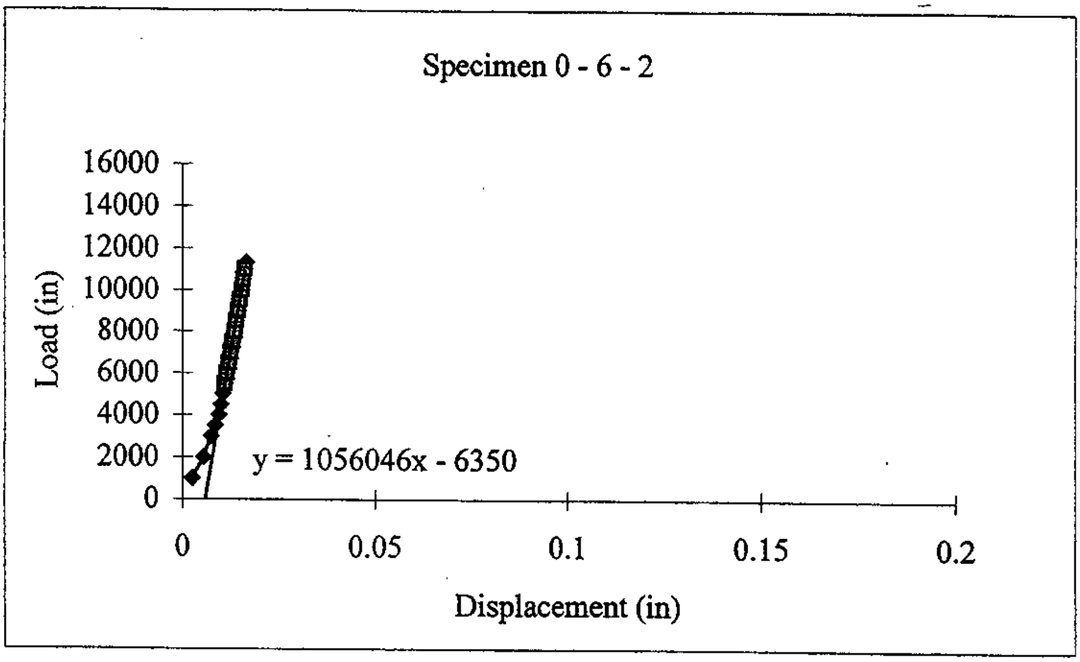

Figure E14: Load Deflection Curve for Specimen 0 - 6 - 2

Table E14: Load Deflection Data for Specimen 0 - 6 - 2

First Crack Load =	11,320	lbs
Midspan First Crack Deflection =	0.0107	in
Modulus of Rupture =	943	psi
First Crack Toughness =	60.56	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.006 in

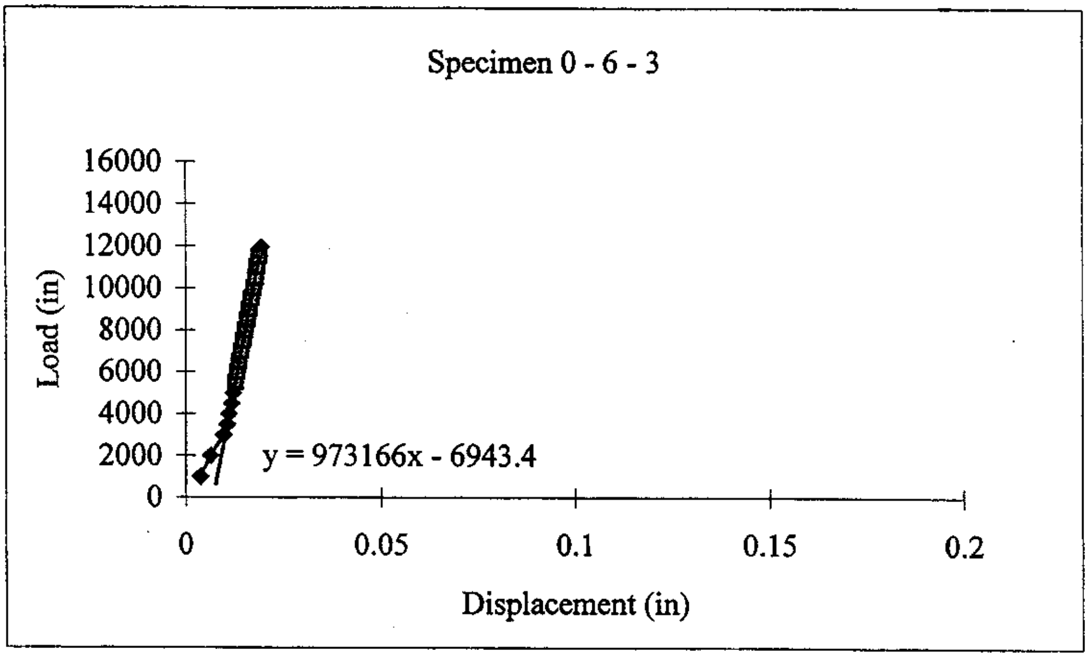

Figure E15: Load Deflection Curve for Specimen 0 - 6 - 3

Table E15: Load Deflection Data for Specimen 0 - 6 - 3

First Crack Load =	11,940	lbs
Midspan First Crack Deflection =	0.0123	in
Modulus of Rupture =	995	psi
First Crack Toughness =	73.43	lb-in

Specimen Type =	Molded	
Specimen Age =	28	days
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.0071	in

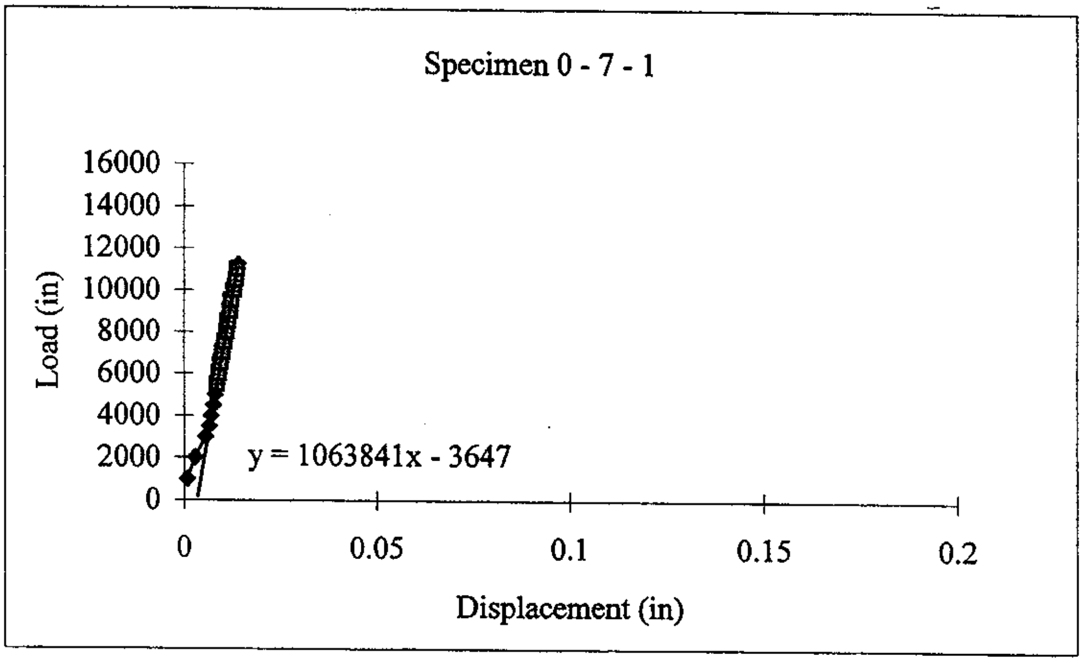

Figure E16: Load Deflection Curve for Specimen 0 - 7 - 1

Table E16: Load Deflection Data for Specimen 0 - 7 - 1

First Crack Load =	11,250	lbs
Midspan First Crack Deflection =	0.0106	in
Modulus of Rupture =	938	psi
First Crack Toughness =	59.63	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0034 in

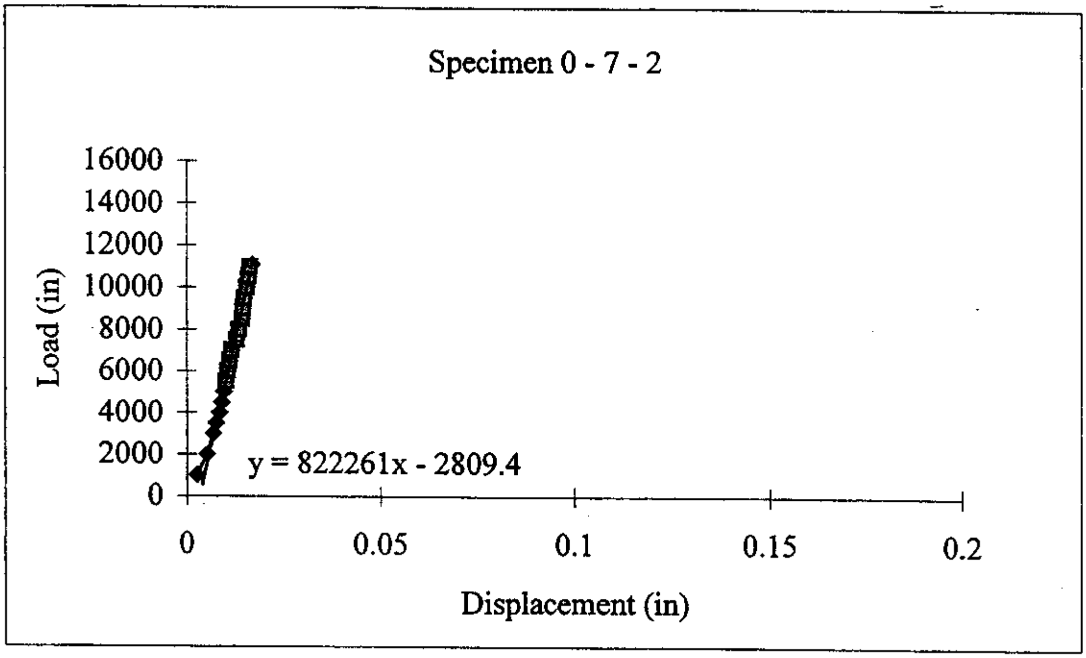

Figure E17: Load Deflection Curve for Specimen 0 - 7 - 2

Table E17: Load Deflection Data for Specimen 0 - 7 - 2

First Crack Load =	11,100	lbs
Midspan First Crack Deflection =	0.0135	in
Modulus of Rupture =	925	psi
First Crack Toughness =	74.93	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0034 in

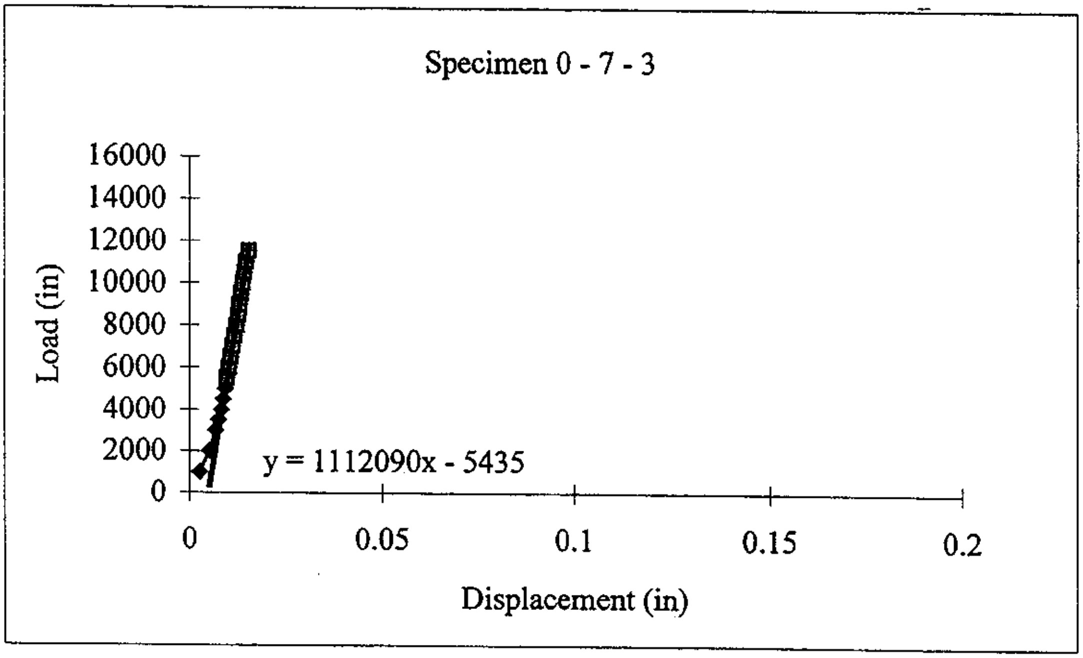

Figure E18: Load Deflection Curve for Specimen 0 - 7 - 3

Table E18: Load Deflection Data for Specimen 0 - 7 - 3

First Crack Load =	11,540	lbs
Midspan First Crack Deflection =	0.0104	in
Modulus of Rupture =	962	psi
First Crack Toughness =	60.01	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0049 in

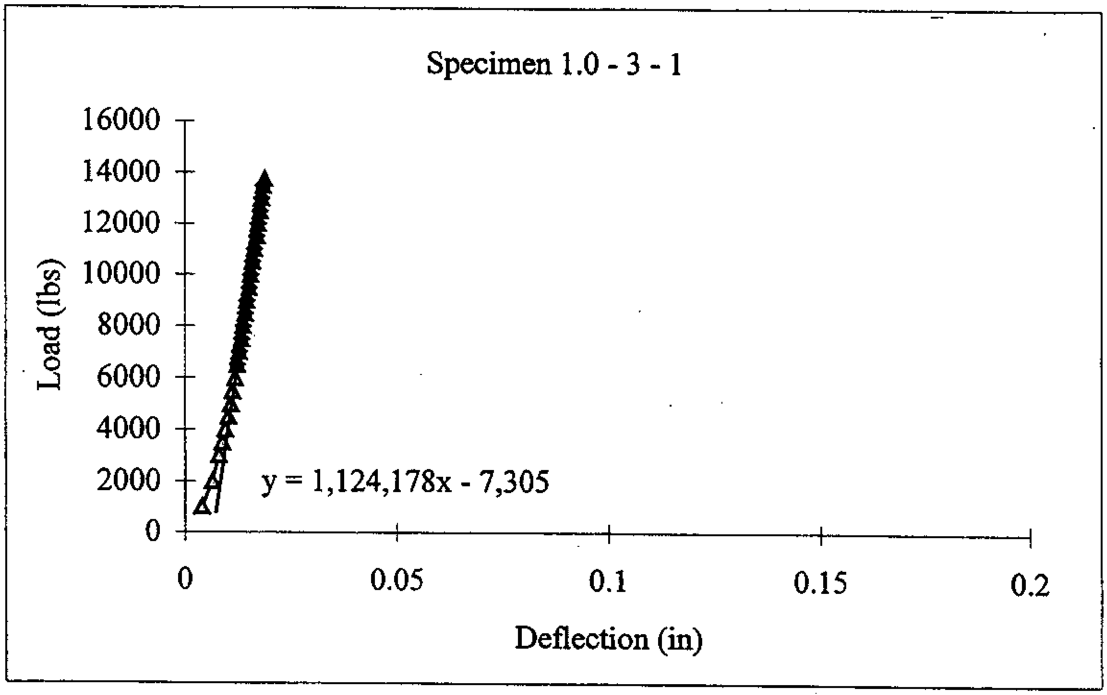

Figure E19: Load Deflection Curve for Specimen 1.0 - 3 - 1

Table E19: Load Deflection Data for Specimen 1.0 - 3 - 1

First Crack Load =	13,740	lbs
Midspan First Crack Deflection =	0.0122	in
Modulus of Rupture =	1145	psi
First Crack Toughness =	83.81	lb-in

Specimen Type =	Molded	
Specimen Age =	28	DAYS
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.0065	in

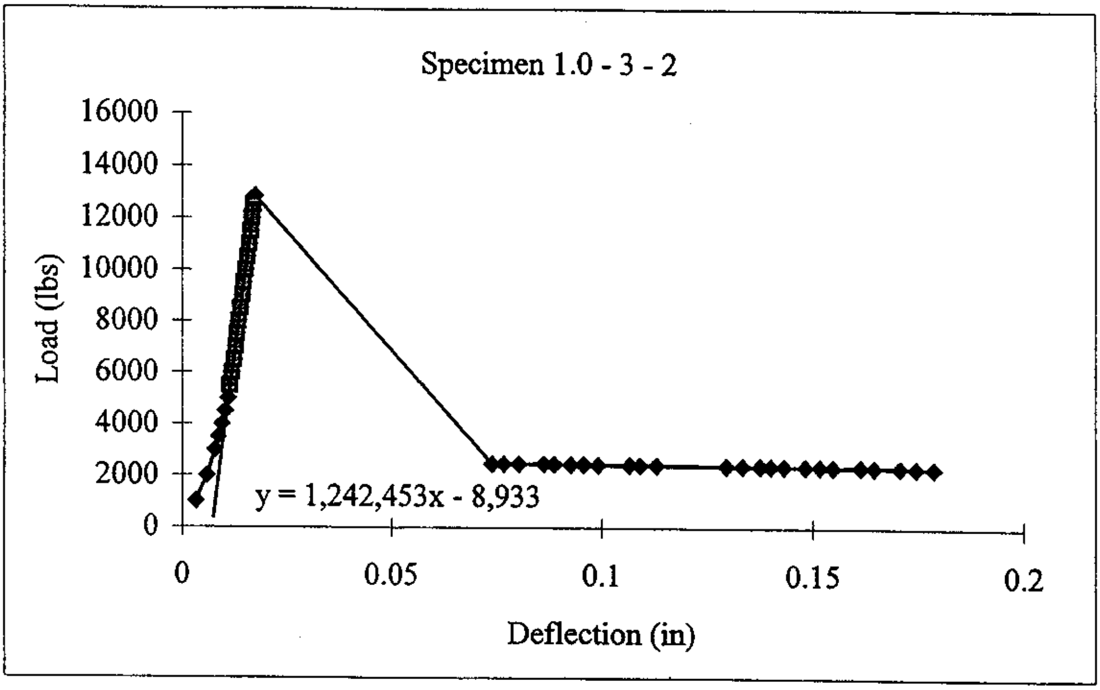

Figure E20: Load Deflection Curve for Specimen 1.0 - 3 - 2

Table E20: Load Deflection Data for Specimen 1.0 - 3 - 2

First Crack Load =	12,850	lbs
Midspan First Crack Deflection =	0.0103	in
Modulus of Rupture =	1070.8	psi
First Crack Toughness =	66.24	lb-in

Specimen Type = Molded
Specimen Age = 28 DAYS
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.00719 in

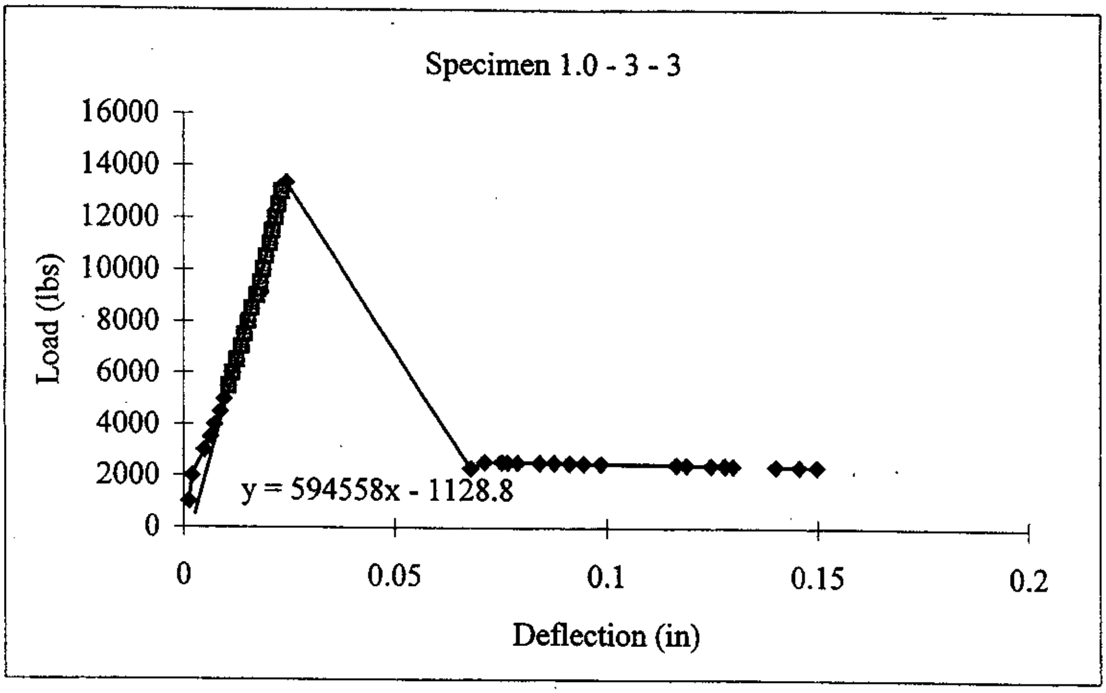

Figure E21: Load Deflection Curve for Specimen 1.0 - 3 - 3

Table E21: Load Deflection Data for Specimen 1.0 - 3 - 3

First Crack Load =	13,350	lbs
Midspan First Crack Deflection =	0.0225	in
Modulus of Rupture =	1112.5	psi
First Crack Toughness =	150.19	lb-in

Specimen Type = Molded
Specimen Age = 28 DAYS
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0019 in

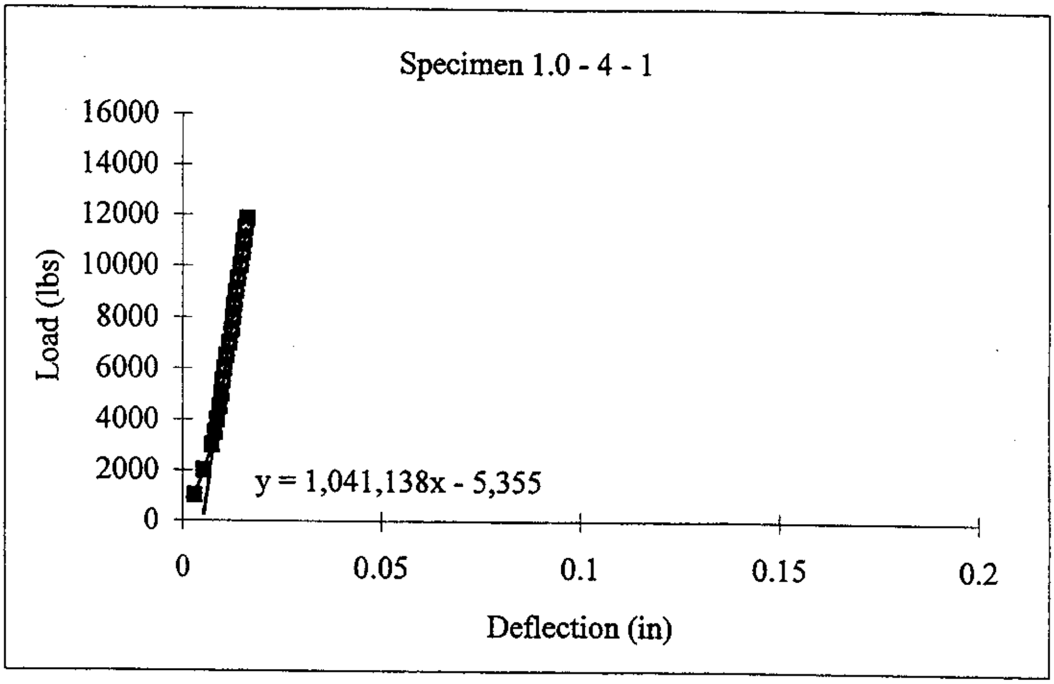

Figure E22: Load Deflection Curve for Specimen 1.0 - 4 - 1

Table E22: Load Deflection Data for Specimen 1.0 - 4 - 1

First Crack Load =	11,860	lbs
Midspan First Crack Deflection =	0.0114	in
Modulus of Rupture =	988	psi
First Crack Toughness =	67.60	lb-in

Specimen Type = Molded
Specimen Age = 28 DAYS
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0051 in

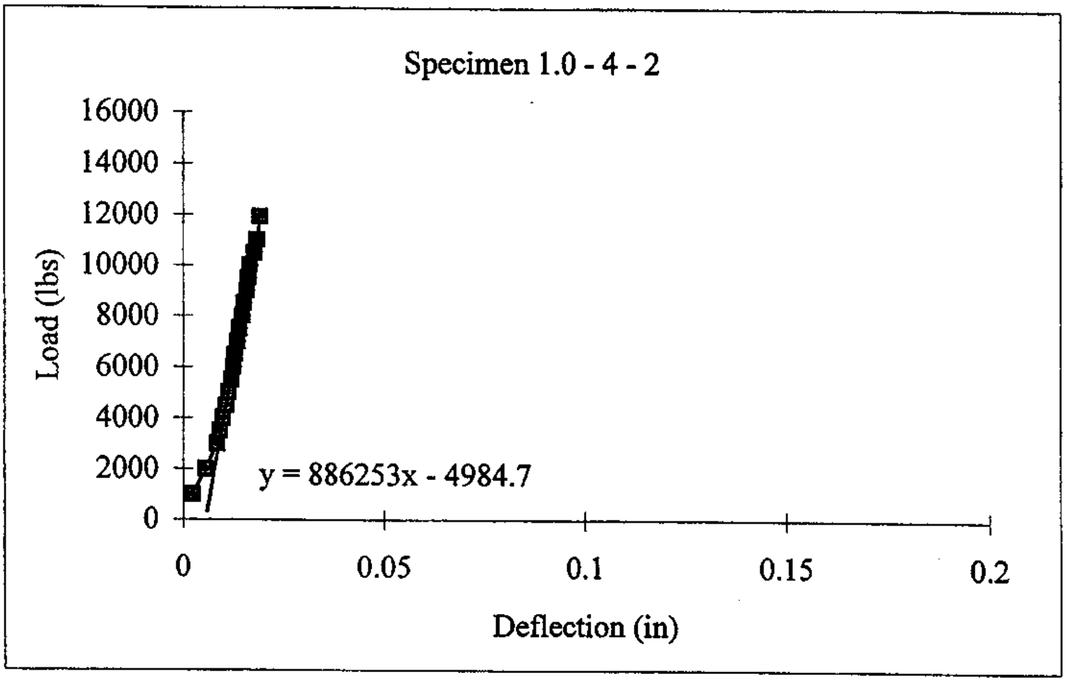

Figure E23: Load Deflection Curve for Specimen 1.0 - 4 - 2

Table E23: Load Deflection Data for Specimen 1.0 - 4 - 2

First Crack Load =	11,940	lbs
Midspan First Crack Deflection =	0.0116	in
Modulus of Rupture =	995	psi
First Crack Toughness =	69.25	lb-in

Specimen Type = Molded
Specimen Age = 28 DAYS
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0075 in

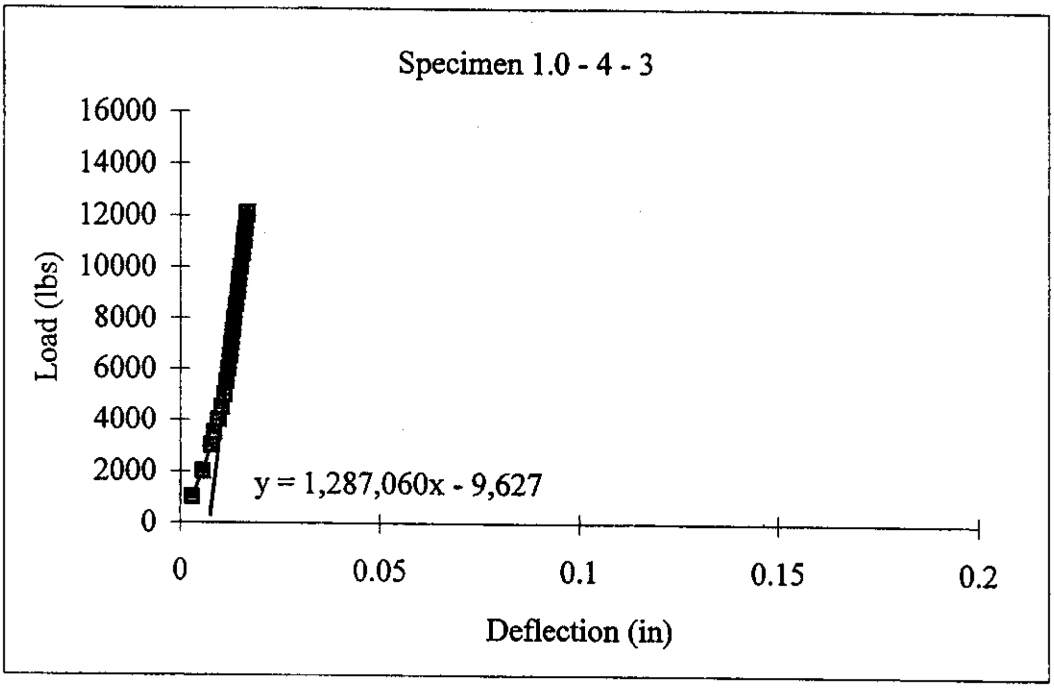

Figure E24: Load Deflection Curve for Specimen 1.0 - 4 - 3

Table E24: Load Deflection Data for Specimen 1.0 - 4 - 3

First Crack Load =	12,100	lbs
Midspan First Crack Deflection =	0.0073	in
Modulus of Rupture =	1008	psi
First Crack Toughness =	44.17	lb-in

Specimen Type = Molded
Specimen Age = 28 DAYS
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0096 in

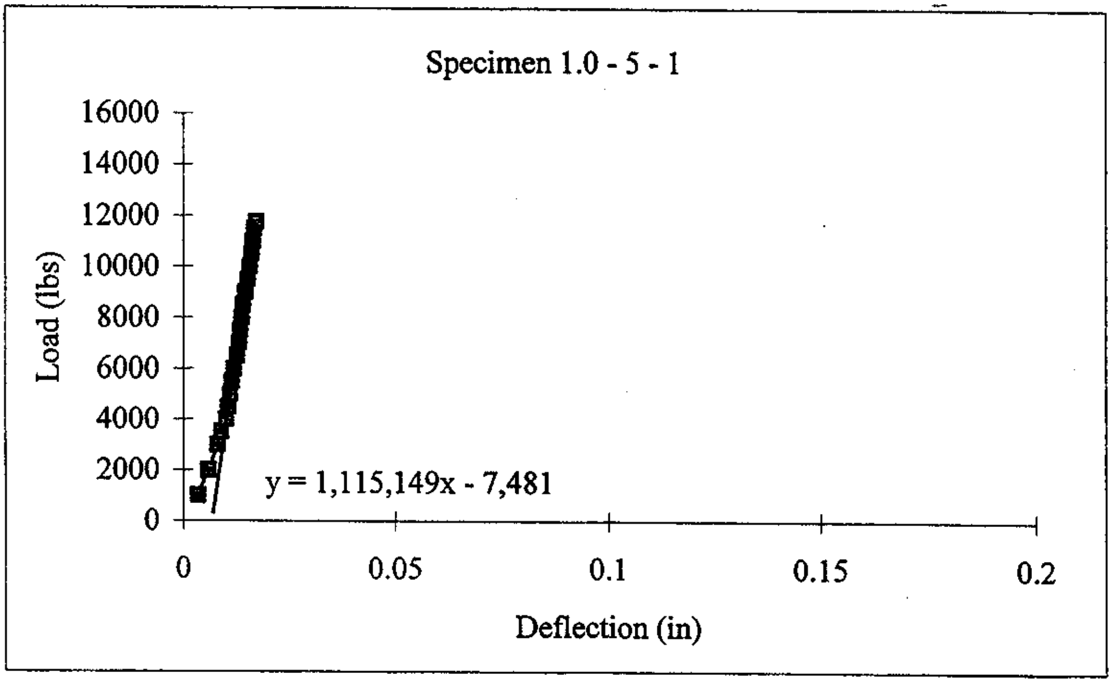

Figure E25: Load Deflection Curve for Specimen 1.0 - 5 - 1

Table E25: Load Deflection Data for Specimen 1.0 - 5 - 1

First Crack Load = 11,760 lbs
Midspan First Crack Deflection = 0.0106 in
Modulus of Rupture = 980 psi
First Crack Toughness = 62.33 lb-in

Specimen Type = Molded
Specimen Age = 28 DAYS
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0067 in

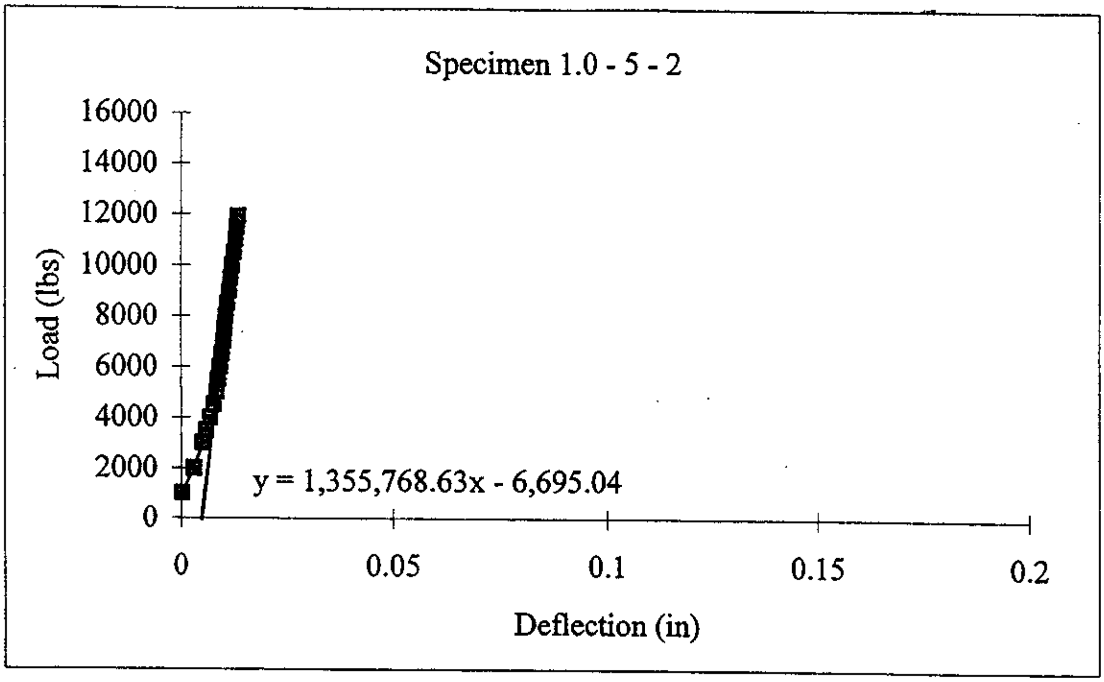

Figure E26: Load Deflection Curve for Specimen 1.0 - 5 - 2

Table E26: Load Deflection Data for Specimen 1.0 - 5 - 2

First Crack Load =	11,900	lbs
Midspan First Crack Deflection =	0.0088	in
Modulus of Rupture =	992	psi
First Crack Toughness =	52.36	lb-in

Specimen Type =	Molded	
Specimen Age =	28	DAYS
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.0049	in

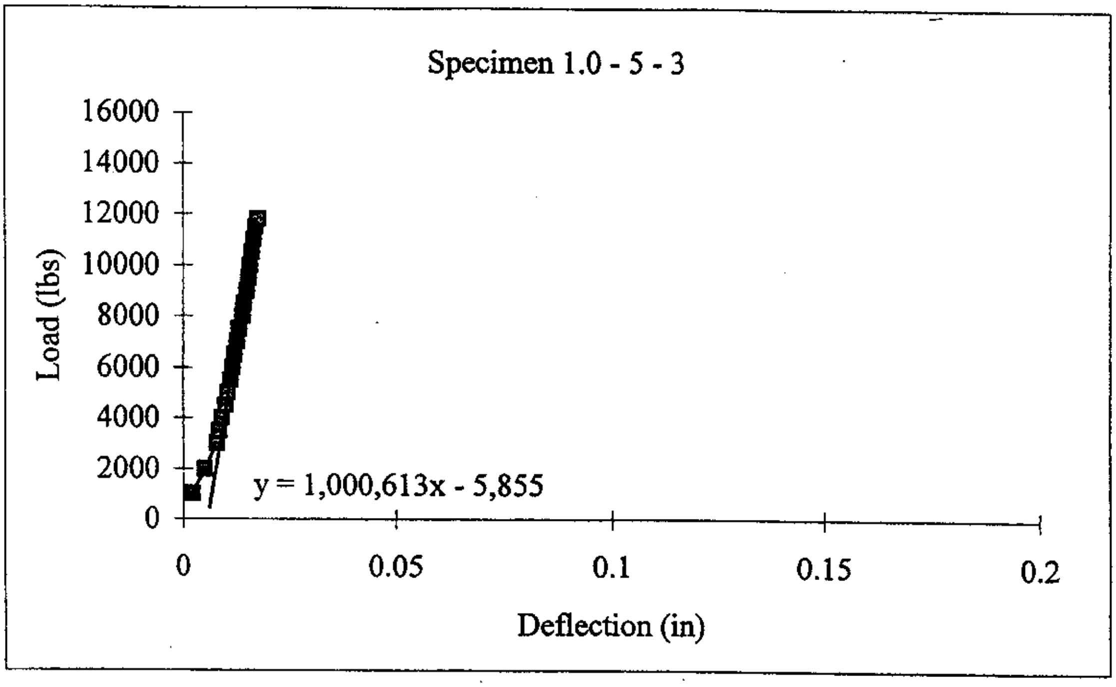

Figure E27: Load Deflection Curve for Specimen 1.0 - 5 - 3

Table E27: Load Deflection Data for Specimen 1.0 - 5 - 3

First Crack Load = 11,810 lbs
Midspan First Crack Deflection = 0.0118 in
Modulus of Rupture = 984 psi
First Crack Toughness = 69.68 lb-in

Specimen Type = Molded
Specimen Age = 28 DAYS
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0059 in

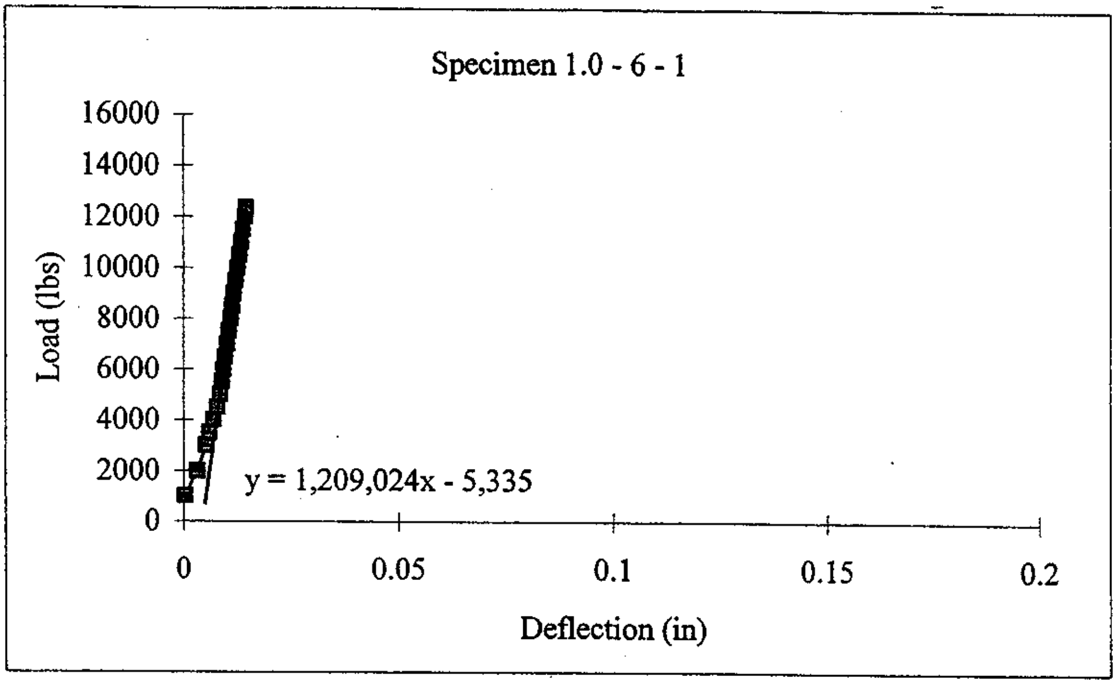

Figure E28: Load Deflection Curve for Specimen 1.0 - 6 - 1

Table E28: Load Deflection Data for Specimen 1.0 - 6 - 1

First Crack Load =	12,360	lbs
Midspan First Crack Deflection =	0.0102	in
Modulus of Rupture =	1030	psi
First Crack Toughness =	63.04	lb-in

Specimen Type = Molded
Specimen Age = 28 DAYS
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0044 in

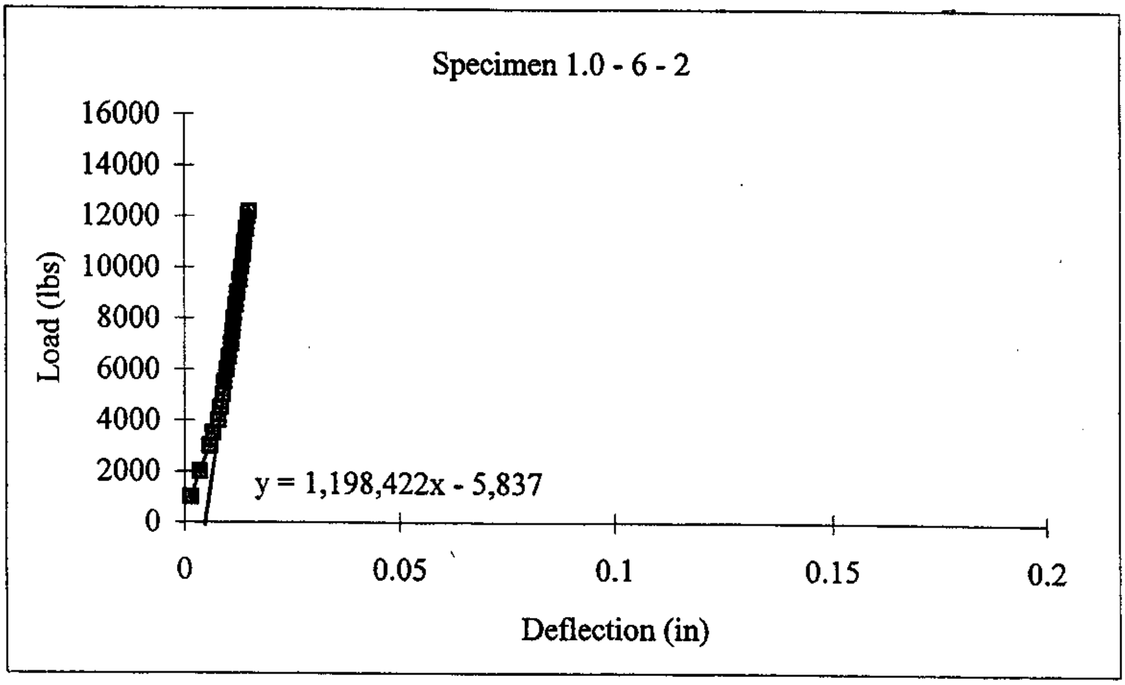

Figure E29: Load Deflection Curve for Specimen 1.0 - 6 - 2

Table E29: Load Deflection Data for Specimen 1.0 - 6 - 2

First Crack Load =	12,180	lbs
Midspan First Crack Deflection =	0.0101	in
Modulus of Rupture =	1015	psi
First Crack Toughness =	61.51	lb-in

Specimen Type = Molded
Specimen Age = 28 DAYS
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0049 in

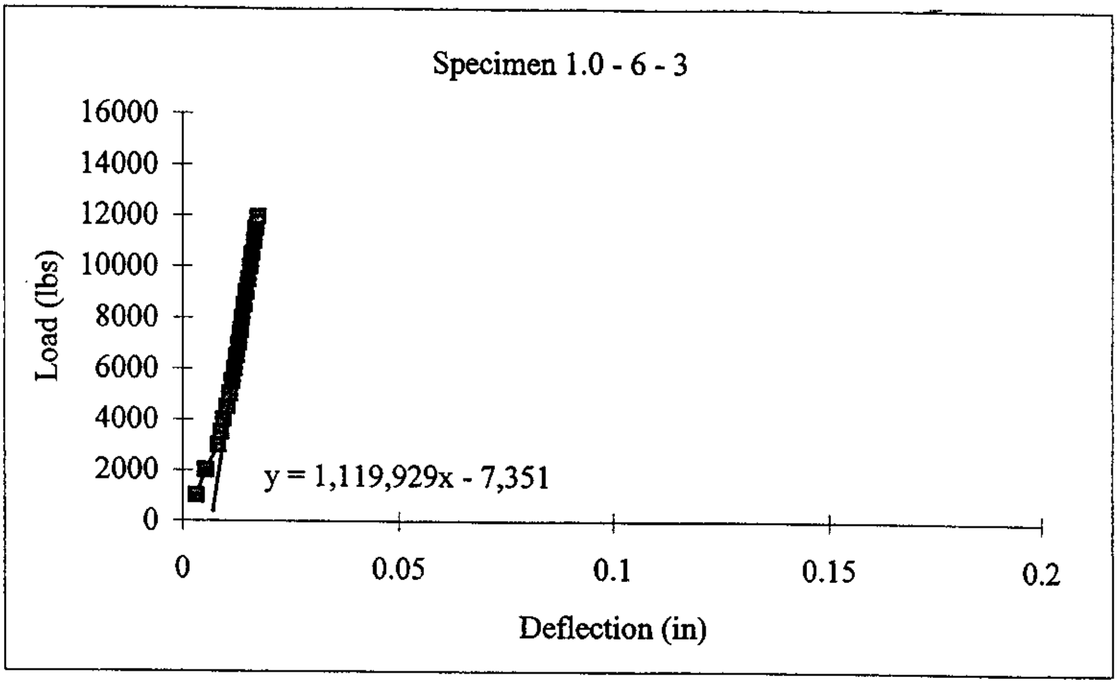

Figure E30: Load Deflection Curve for Specimen 1.0 - 6 - 3

Table E30: Load Deflection Data for Specimen 1.0 - 6 - 3

First Crack Load = 11,970 lbs
Midspan First Crack Deflection = 0.0107 in
Modulus of Rupture = 998 psi
First Crack Toughness = 64.04 lb-in

Specimen Type = Molded
Specimen Age = 28 DAYS
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0066 in

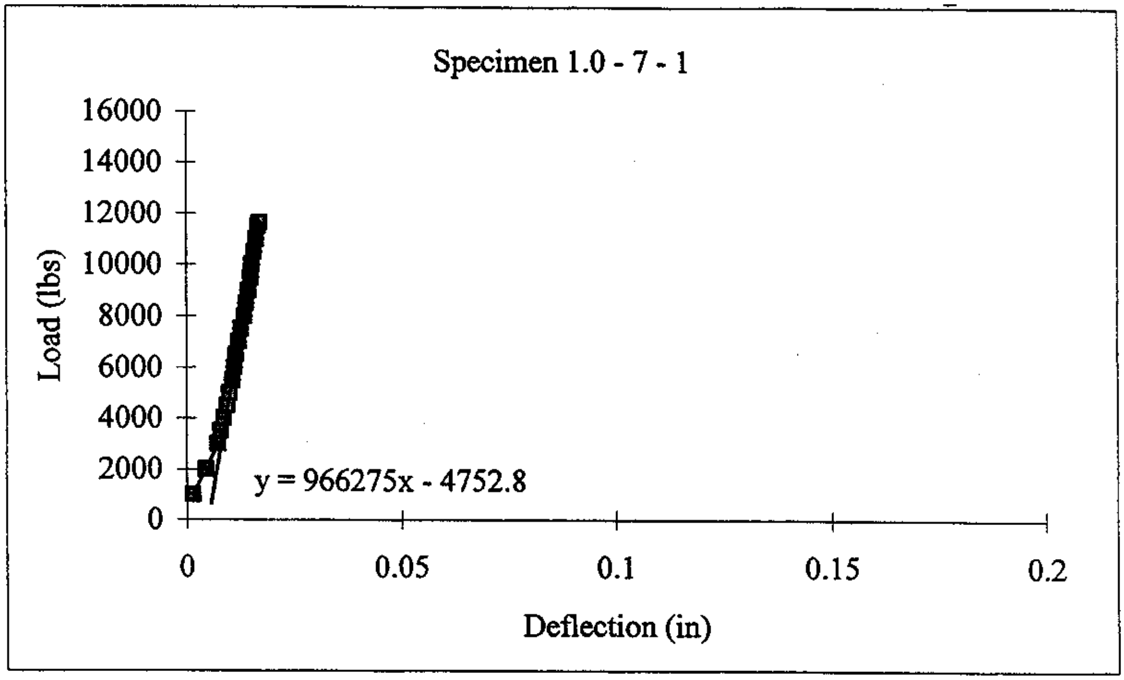

Figure E31: Load Deflection Curve for Specimen 1.0 - 7 - 1

Table E31: Load Deflection Data for Specimen 1.0 - 7 - 1

First Crack Load = 11,640 lbs
Midspan First Crack Deflection = 0.0121 in
Modulus of Rupture = 970 psi
First Crack Toughness = 70.42 lb-in

Specimen Type = Molded
Specimen Age = 28 DAYS
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0049 in

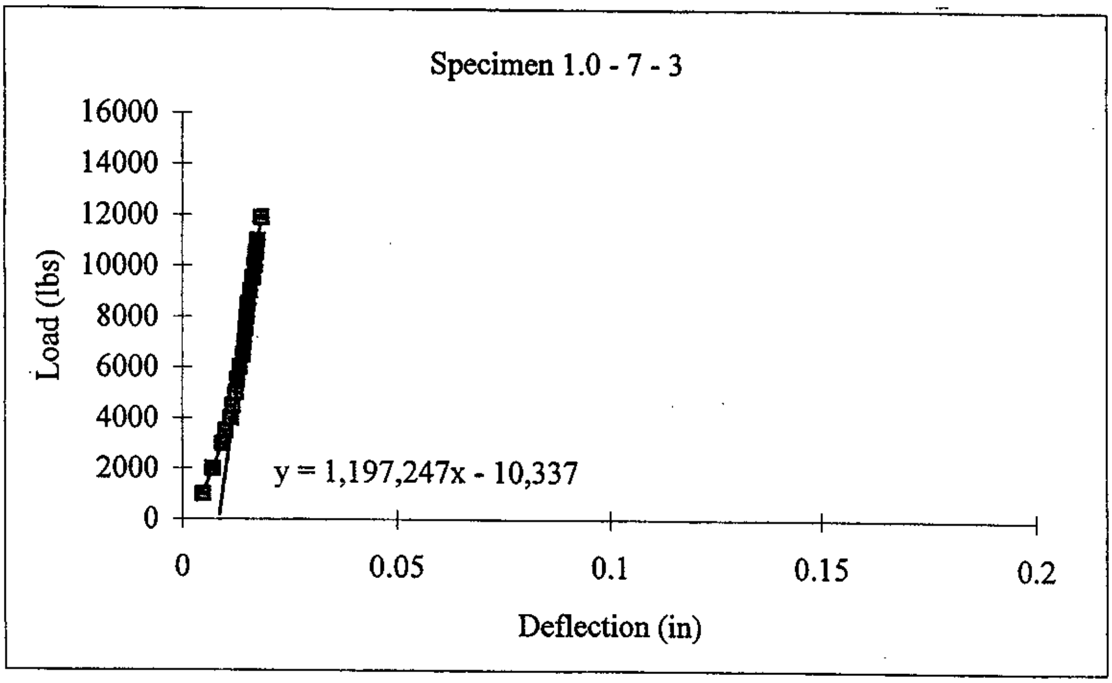

Figure E33: Load Deflection Curve for Specimen 1.0 - 7 - 3

Table E33: Load Deflection Data for Specimen 1.0 - 7 - 3

First Crack Load =	11,900	lbs
Midspan First Crack Deflection =	0.01	in
Modulus of Rupture =	992	psi
First Crack Toughness =	59.50	lb-in

Specimen Type = Molded
Specimen Age = 28 DAYS
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0086 in

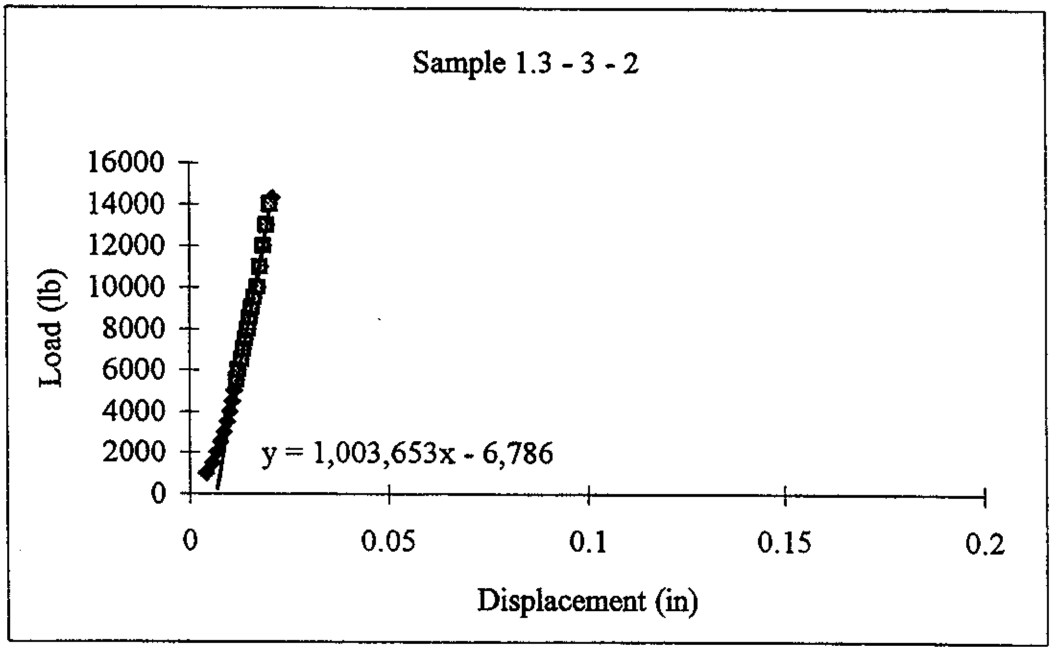

Figure E34: Load Deflection Curve for Specimen 1.3 - 3 - 2

Table E34: Load Deflection Data for Specimen 1.3 - 3 - 2

First Crack Load = 14,300 lbs
Midspan First Crack Deflection = 0.0142 in
Modulus of Rupture = 1191.67 psi
First Crack Toughness = 101.53 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0068 in

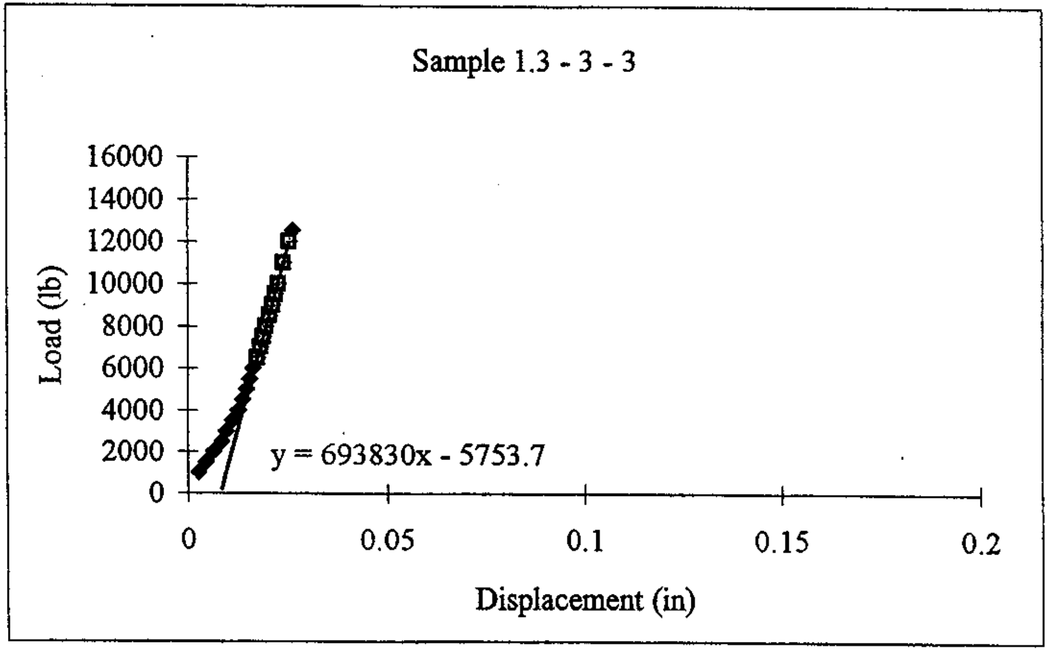

Figure E35: Load Deflection Curve for Specimen 1.3 - 3 - 3

Table E35: Load Deflection Data for Specimen 1.3 - 3 - 3

First Crack Load =	12,520	lbs
Midspan First Crack Deflection =	0.018	in
Modulus of Rupture =	1043.33	psi
First Crack Toughness =	112.68	lb-in

Specimen Type =	Molded	
Specimen Age =	28	days
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.0083	in

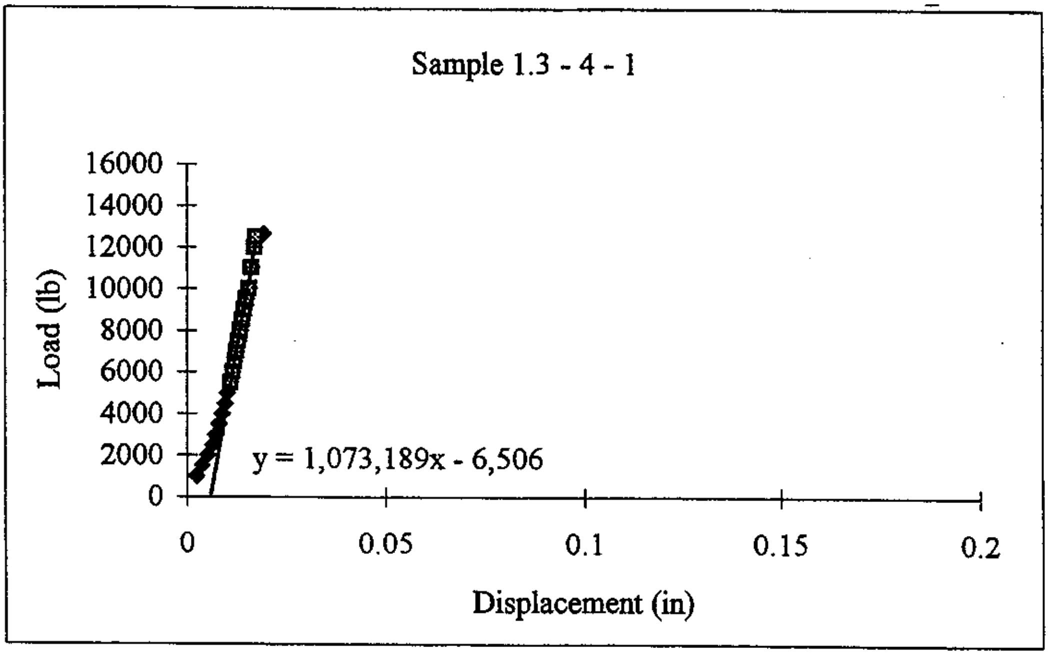

Figure E36: Load Deflection Curve for Specimen 1.3 - 4 - 1

Table E36: Load Deflection Data for Specimen 1.3 - 4 - 1

First Crack Load = 12,650 lbs
Midspan First Crack Deflection = 0.0127 in
Modulus of Rupture = 1054.17 psi
First Crack Toughness = 80.33 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0065 in

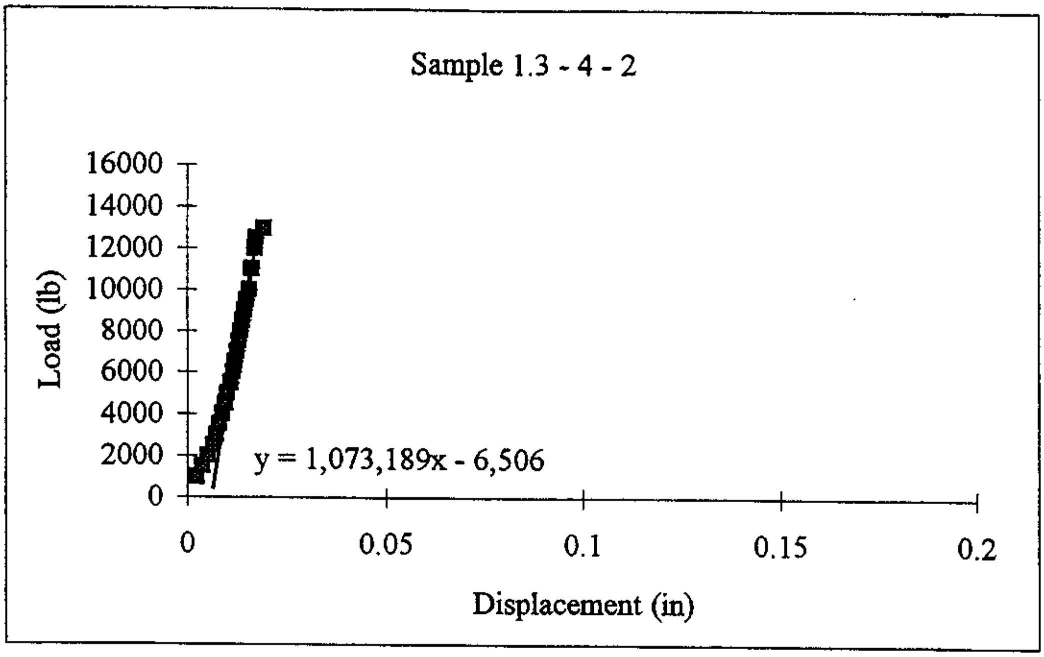

Figure E37: Load Deflection Curve for Specimen 1.3 - 4 - 2

Table E37: Load Deflection Data for Specimen 1.3 - 4 - 2

First Crack Load = 12,940 lbs
Midspan First Crack Deflection = 0.0129 in
Modulus of Rupture = 1078.33 psi
First Crack Toughness = 83.46 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0065 in

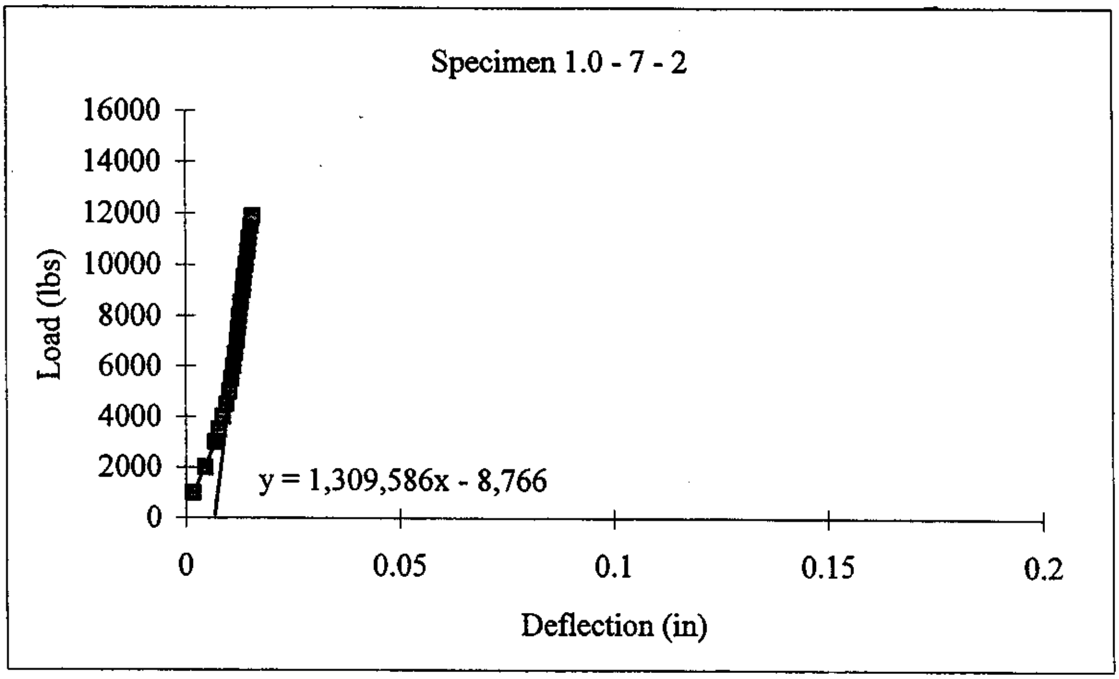

Figure E32: Load Deflection Curve for Specimen 1.0 - 7 - 2

Table E32: Load Deflection Data for Specimen 1.0 - 7 - 2

First Crack Load =	11,880	lbs
Midspan First Crack Deflection =	0.0091	in
Modulus of Rupture =	990	psi
First Crack Toughness =	54.05	lb-in

Specimen Type = Molded
Specimen Age = 28 DAYS
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0067 in

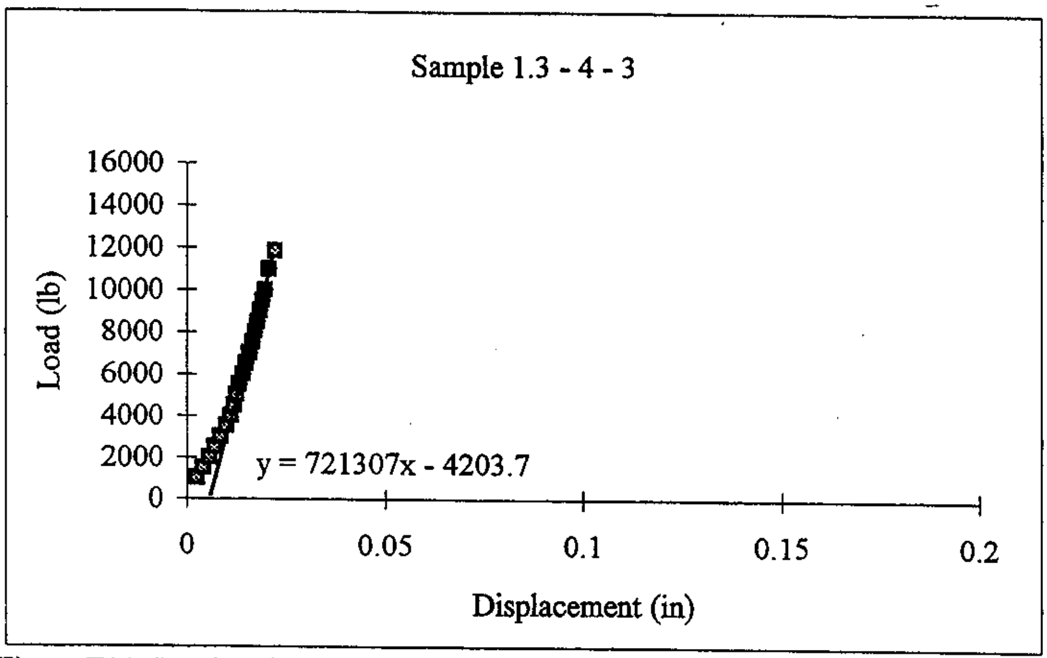

Figure E38: Load Deflection Curve for Specimen 1.3 - 4 - 3

Table E38: Load Deflection Data for Specimen 1.3 - 4 - 3

First Crack Load = 11,850 lbs
Midspan First Crack Deflection = 0.0165 in
Modulus of Rupture = 987.5 psi
First Crack Toughness = 97.76 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0058 in

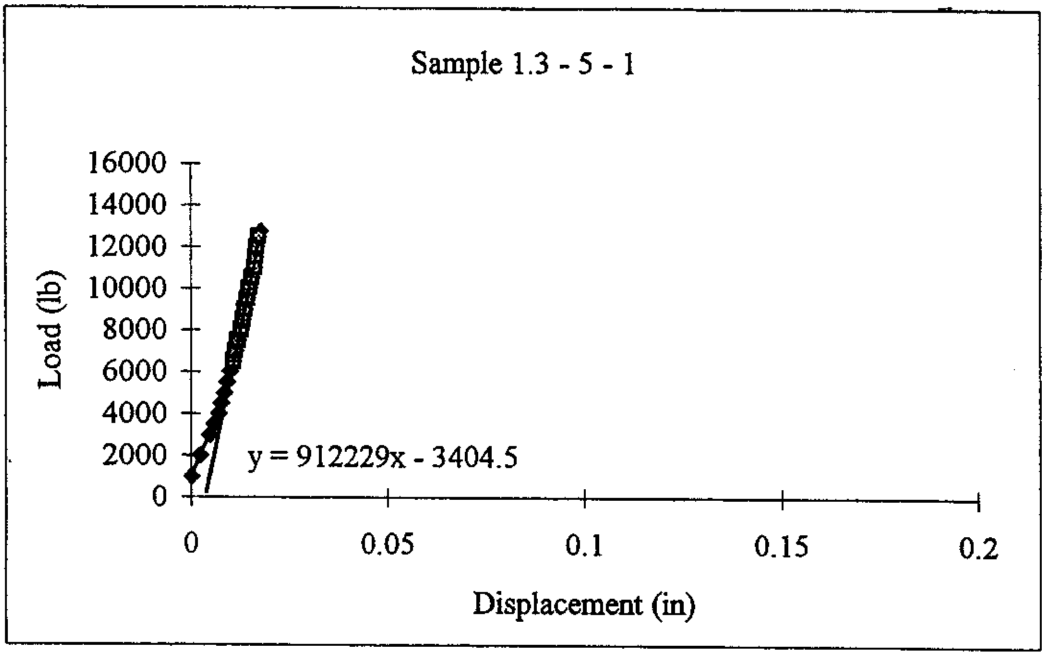

Figure E39: Load Deflection Curve for Specimen 1.3 - 5 - 1

Table E39: Load Deflection Data for Specimen 1.3 - 5 - 1

First Crack Load =	12,740	lbs
Midspan First Crack Deflection =	0.014	in
Modulus of Rupture =	1061.67	psi
First Crack Toughness =	89.18	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0037 in

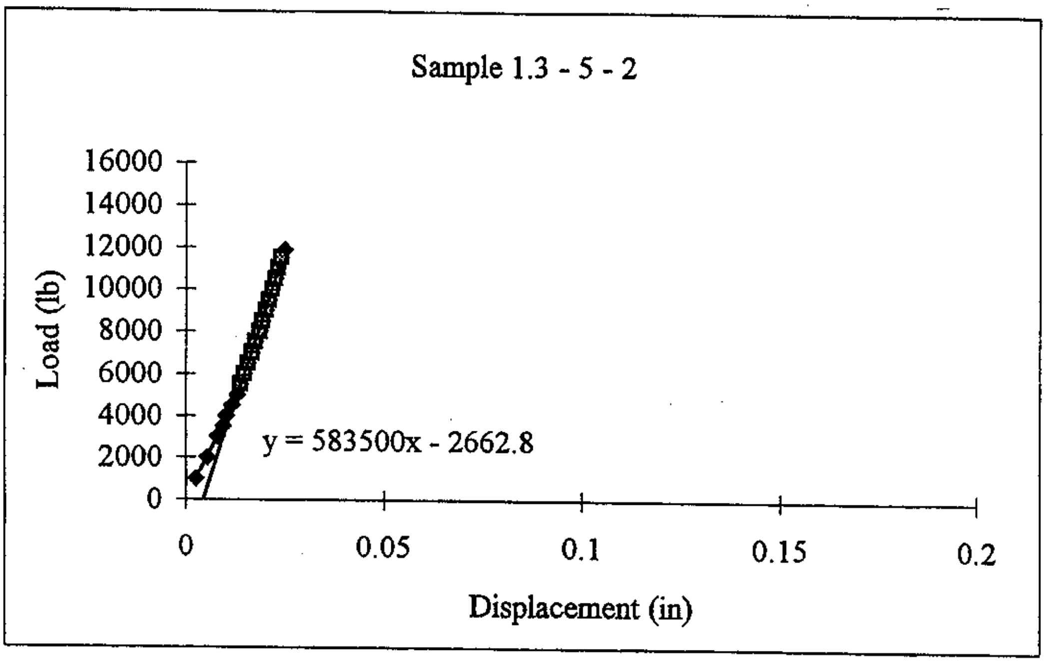

Figure E40: Load Deflection Curve for Specimen 1.3 - 5 - 2

Table E40: Load Deflection Data for Specimen 1.3 - 5 - 2

First Crack Load =	11,850	lbs
Midspan First Crack Deflection =	0.0203	in
Modulus of Rupture =	987.5	psi
First Crack Toughness =	120.28	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0046 in

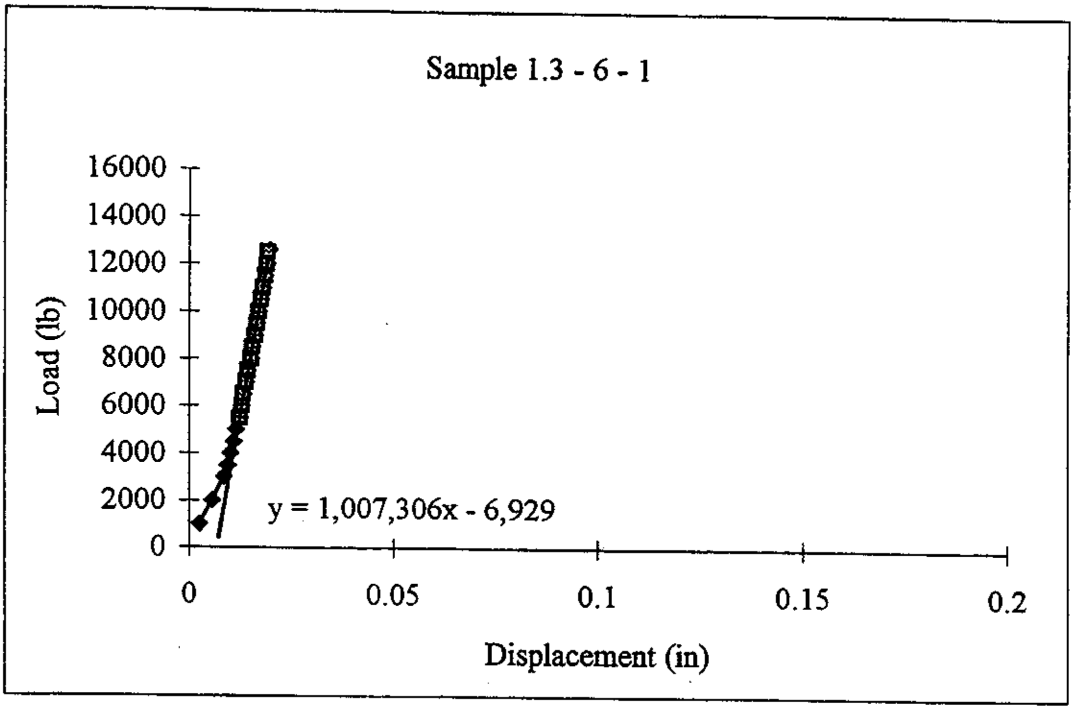

Figure E41: Load Deflection Curve for Specimen 1.3 - 6 - 1

Table E41: Load Deflection Data for Specimen 1.3 - 6 - 1

First Crack Load =	12,600	lbs
Midspan First Crack Deflection =	0.0126	in
Modulus of Rupture =	1050	psi
First Crack Toughness =	79.38	lb-in

Specimen Type =	Molded	
Specimen Age =	28	days
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.0069	in

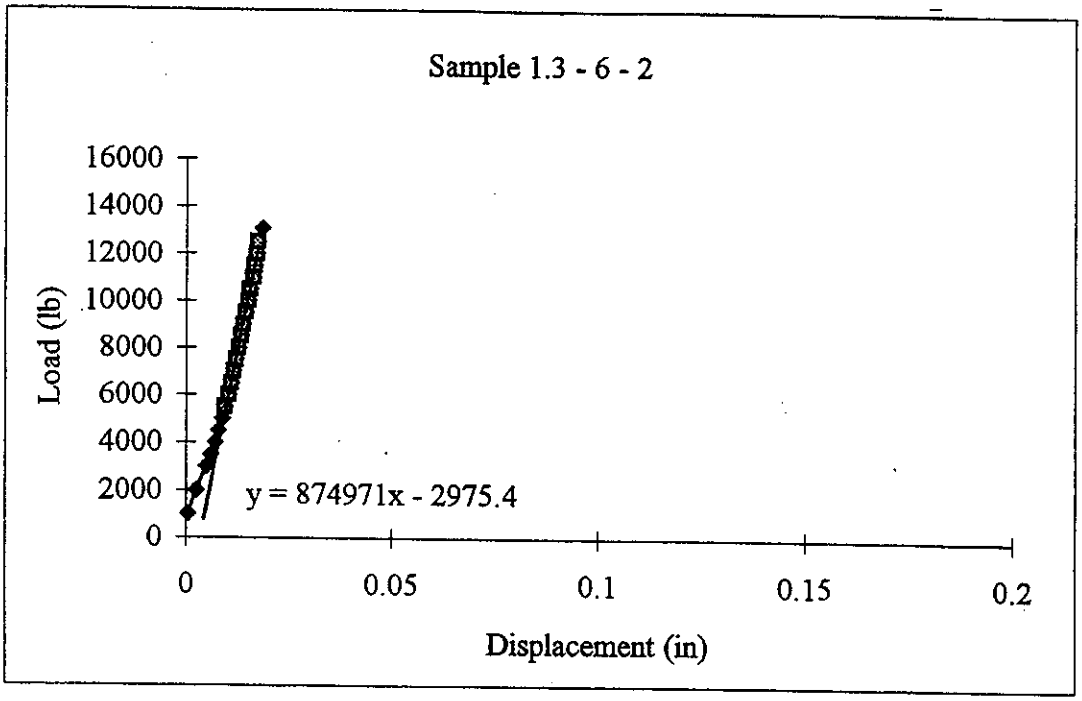

Figure E42: Load Deflection Curve for Specimen 1.3 - 6 - 2

Table E42: Load Deflection Data for Specimen 1.3 - 6 - 2

First Crack Load =	13,080	lbs
Midspan First Crack Deflection =	0.015	in
Modulus of Rupture =	1090	psi
First Crack Toughness =	98.10	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0034 in

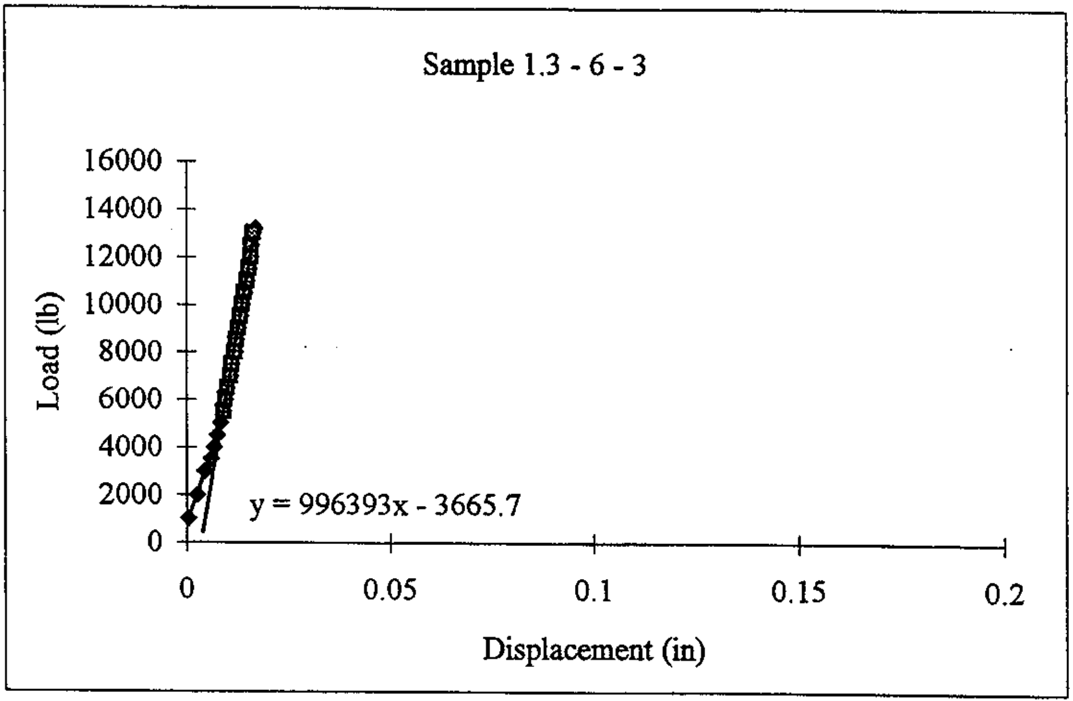

Figure E43: Load Deflection Curve for Specimen 1.3 - 6 - 3

Table E43: Load Deflection Data for Specimen 1.3 - 6 - 3

First Crack Load =	13,200	lbs
Midspan First Crack Deflection =	0.0132	in
Modulus of Rupture =	1100	psi
First Crack Toughness =	87.12	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0037 in

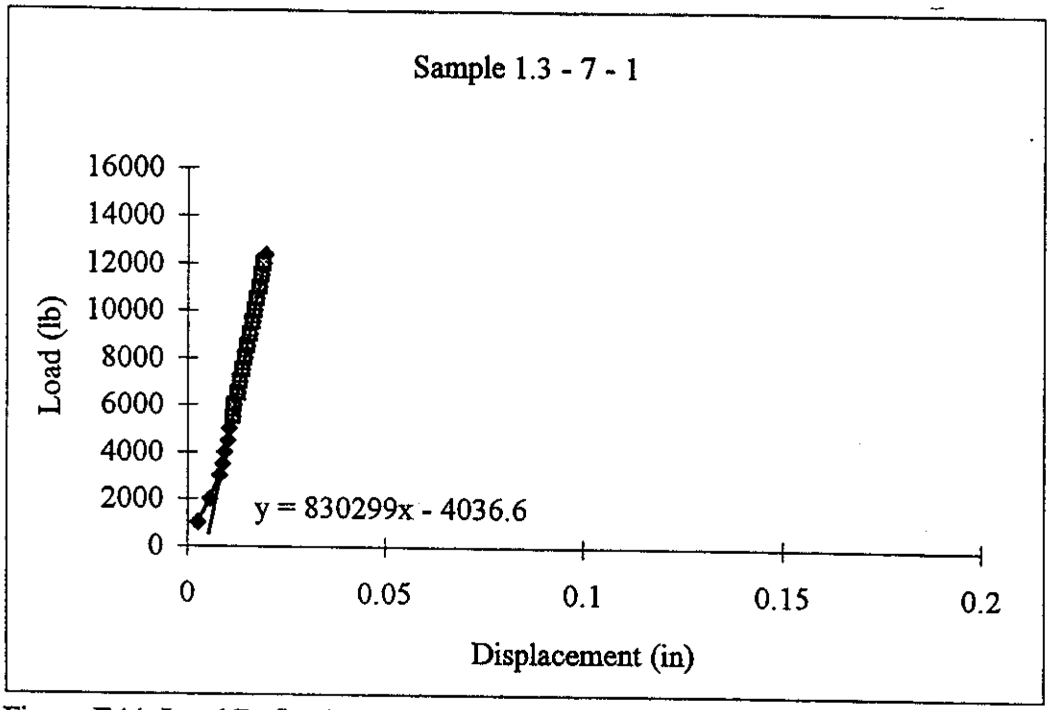

Figure E44: Load Deflection Curve for Specimen 1.3 - 7 - 1

Table E44: Load Deflection Data for Specimen 1.3 - 7 - 1

First Crack Load = 12,360 lbs
Midspan First Crack Deflection = 0.0148 in
Modulus of Rupture = 1030 psi
First Crack Toughness = 91.46 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0049 in

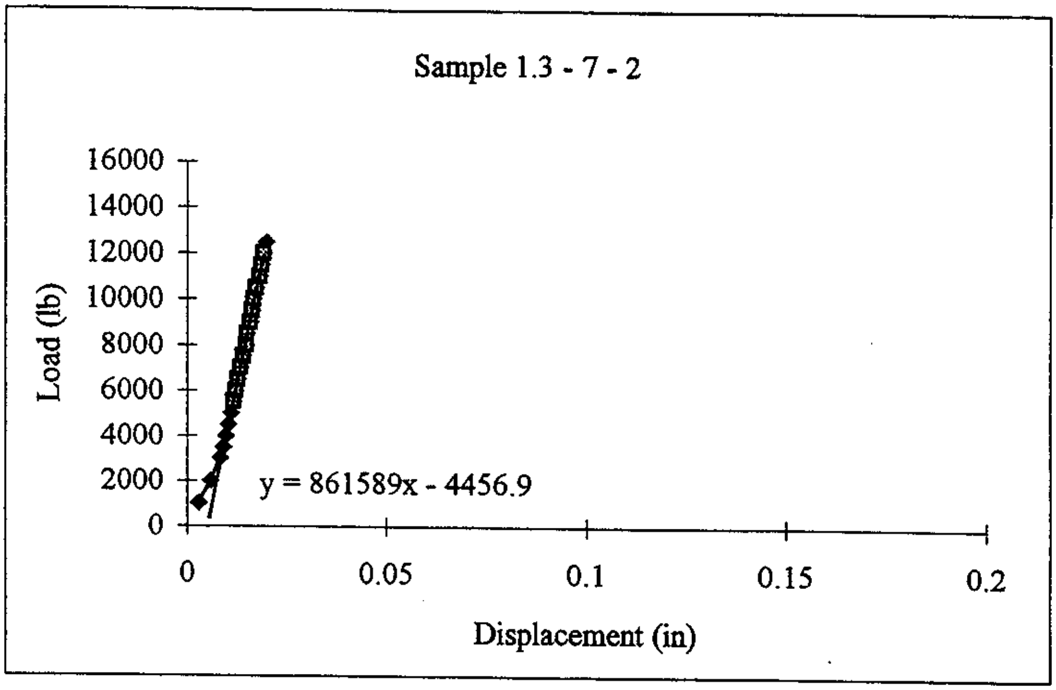

Figure E45: Load Deflection Curve for Specimen 1.3 - 7 - 2

Table E45: Load Deflection Data for Specimen 1.3 - 7 - 2

First Crack Load =	12,480	lbs
Midspan First Crack Deflection =	0.0145	in
Modulus of Rupture =	1040	psi
First Crack Toughness =	90.48	lb-in

Specimen Type =	Molded	
Specimen Age =	28	days
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.0052	in

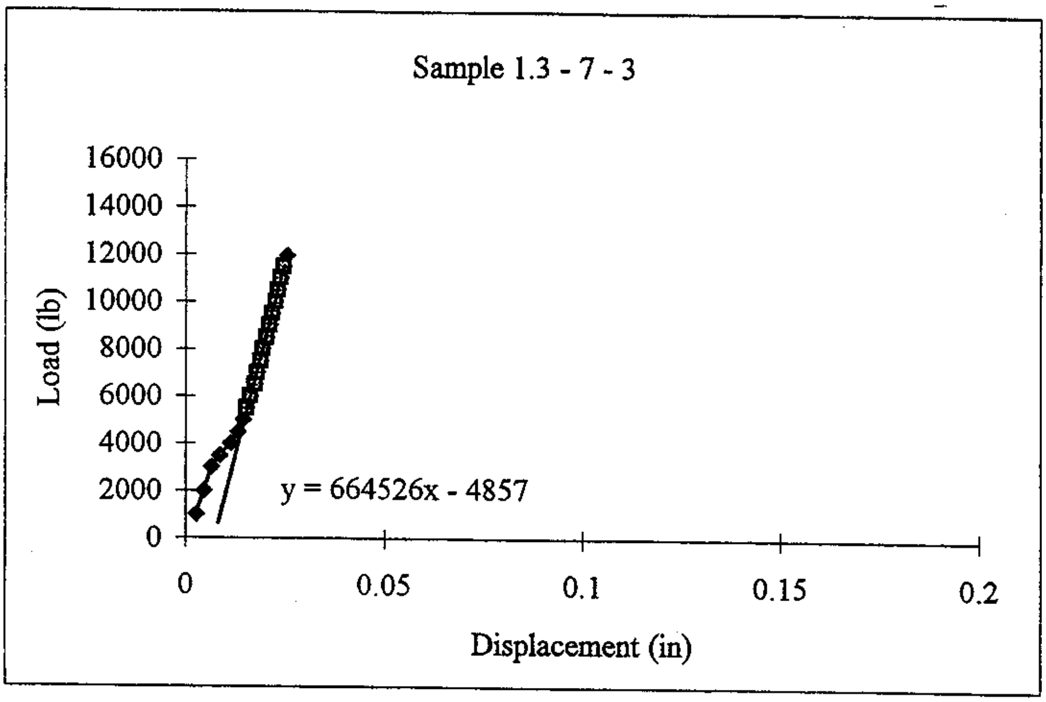

Figure E46: Load Deflection Curve for Specimen 1.3 - 7 - 3

Table E46: Load Deflection Data for Specimen 1.3 - 7 - 3

First Crack Load =	11,940	lbs
Midspan First Crack Deflection =	0.018	in
Modulus of Rupture =	995	psi
First Crack Toughness =	107.46	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0073 in

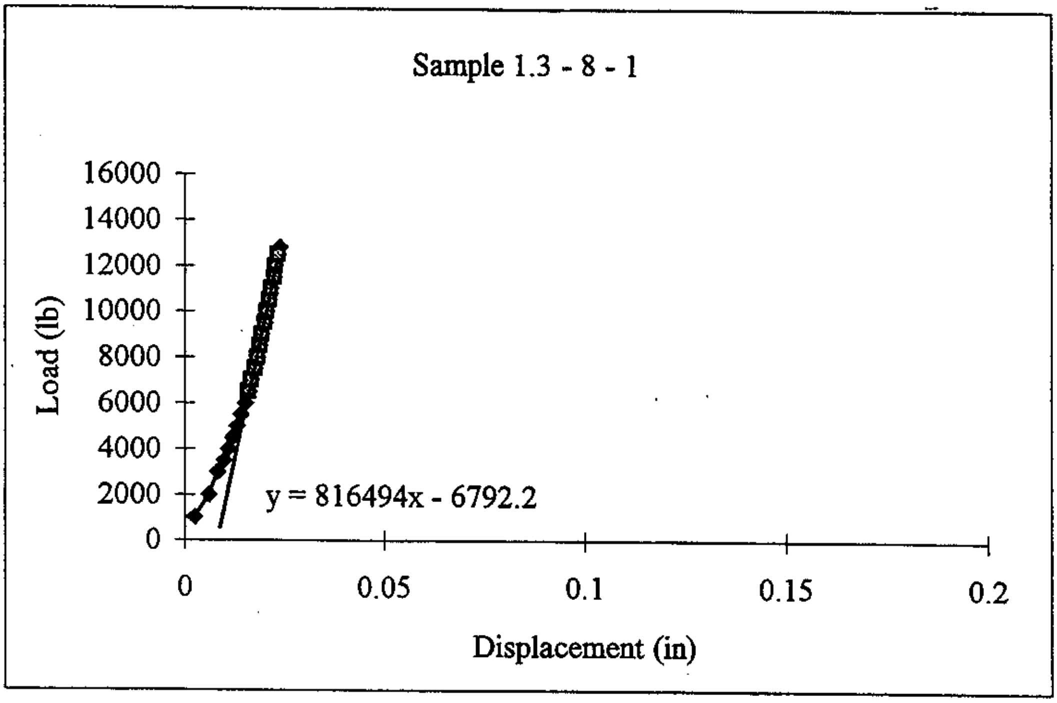

Figure E47: Load Deflection Curve for Specimen 1.3 - 8 - 1

Table E47: Load Deflection Data for Specimen 1.3 - 8 - 1

First Crack Load = 12,800 lbs
Midspan First Crack Deflection = 0.0157 in
Modulus of Rupture = 1067 psi
First Crack Toughness = 100.48 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0083 in

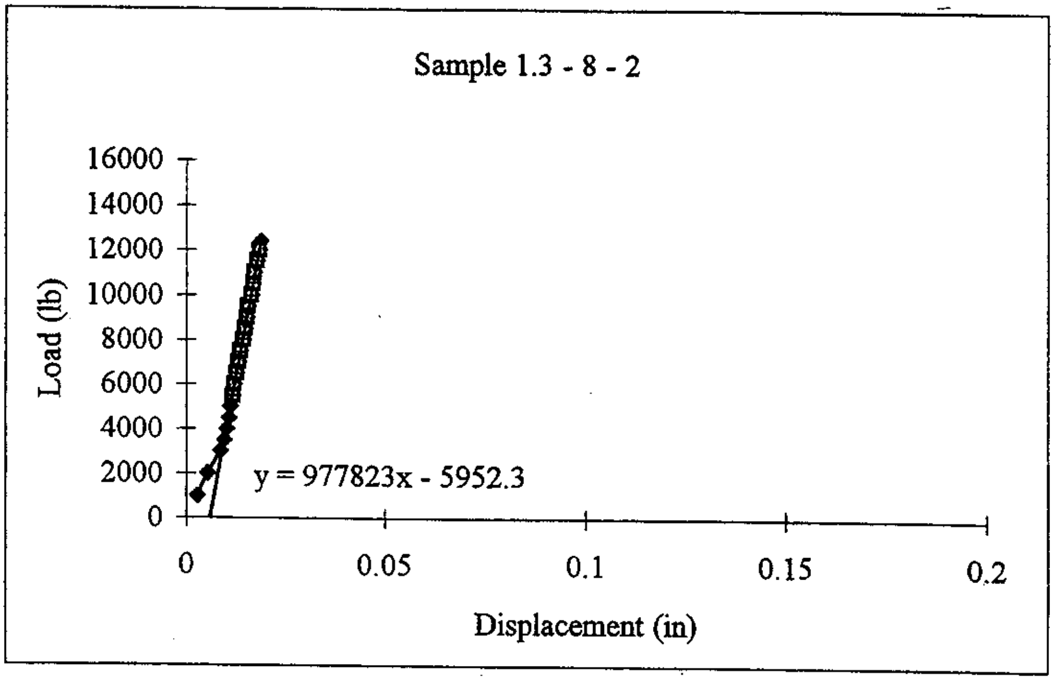

Figure E48: Load Deflection Curve for Specimen 1.3 - 8 - 2

Table E48: Load Deflection Data for Specimen 1.3 - 8 - 2

First Crack Load =	12,400	lbs
Midspan First Crack Deflection =	0.0127	in
Modulus of Rupture =	1033	psi
First Crack Toughness =	78.74	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0061 in

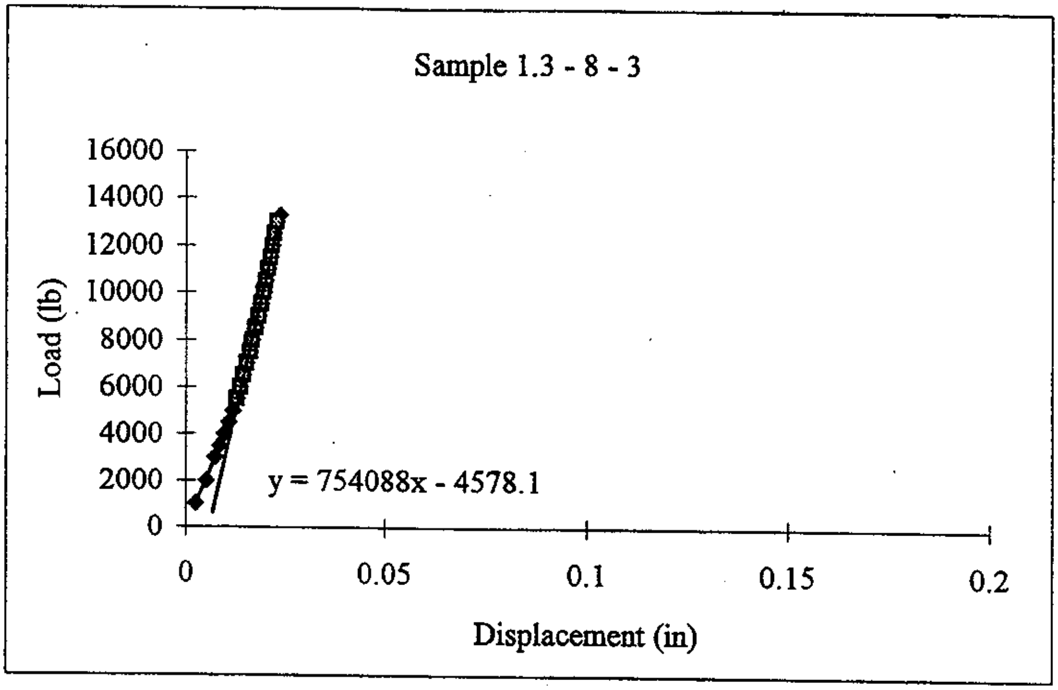

Figure E49: Load Deflection Curve for Specimen 1.3 - 8 - 3

Table E49: Load Deflection Data for Specimen 1.3 - 8 - 3

First Crack Load =	13,280	lbs
Midspan First Crack Deflection =	0.0176	in
Modulus of Rupture =	1107	psi
First Crack Toughness =	116.86	lb-in

Specimen Type =	Molded	
Specimen Age =	28	days
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.0061	in

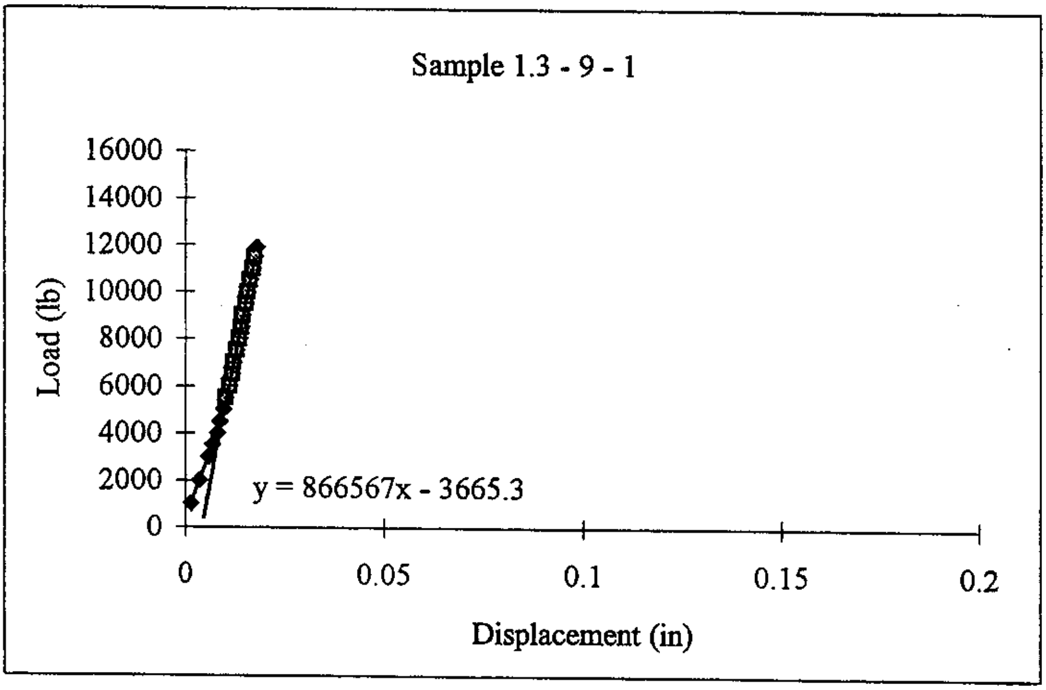

Figure E50: Load Deflection Curve for Specimen 1.3 - 9 - 1

Table E50: Load Deflection Data for Specimen 1.3 - 9 - 1

First Crack Load =	11,880	lbs
Midspan First Crack Deflection =	0.0137	in
Modulus of Rupture =	990	psi
First Crack Toughness =	81.38	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0042 in

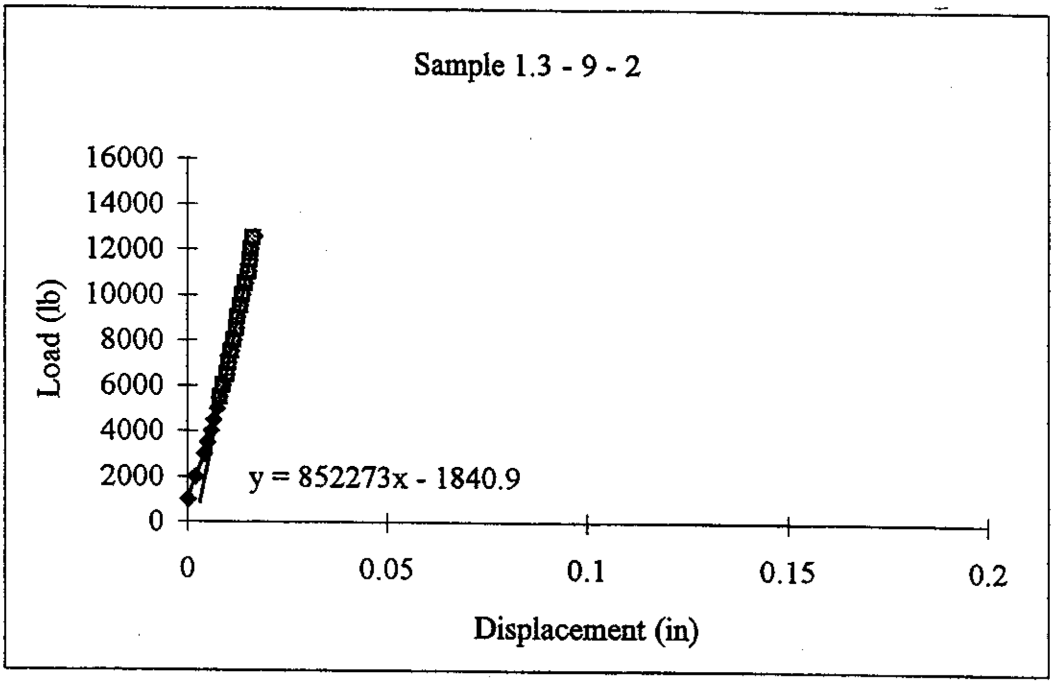

Figure E51: Load Deflection Curve for Specimen 1.3 - 9 - 2

Table E51: Load Deflection Data for Specimen 1.3 - 9 - 2

First Crack Load =	12,550	lbs
Midspan First Crack Deflection =	0.0147	in
Modulus of Rupture =	1046	psi
First Crack Toughness =	92.24	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0022 in

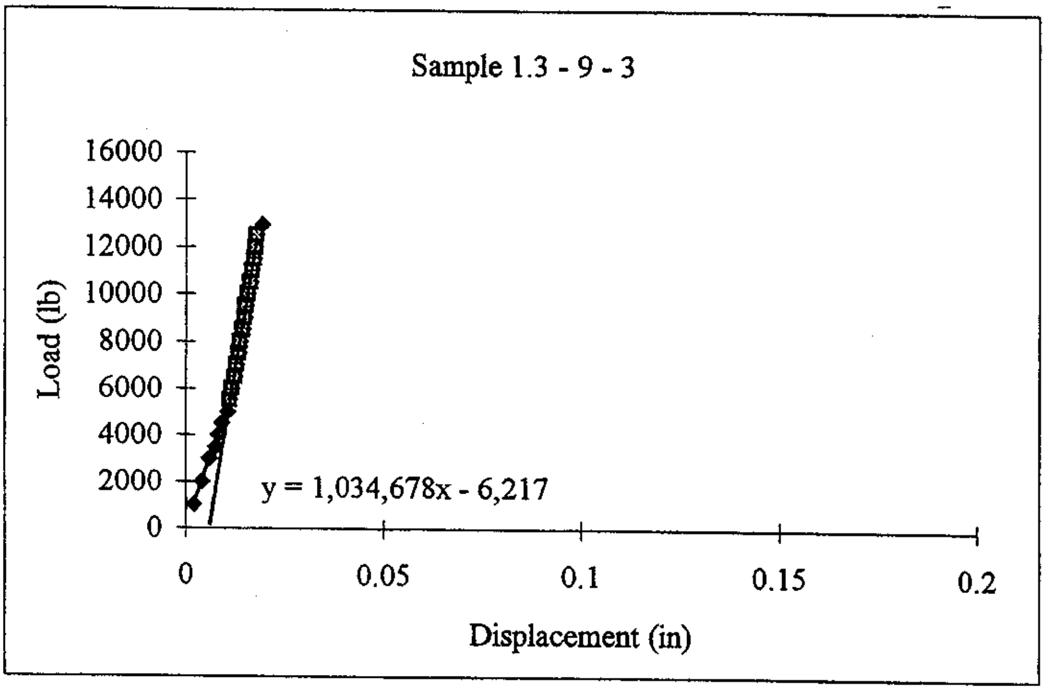

Figure E52: Load Deflection Curve for Specimen 1.3 - 9 - 3

Table E52: Load Deflection Data for Specimen 1.3 - 9 - 3

First Crack Load = 12,940 lbs
Midspan First Crack Deflection = 0.013 in
Modulus of Rupture = 1078 psi
First Crack Toughness = 84.11 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0062 in

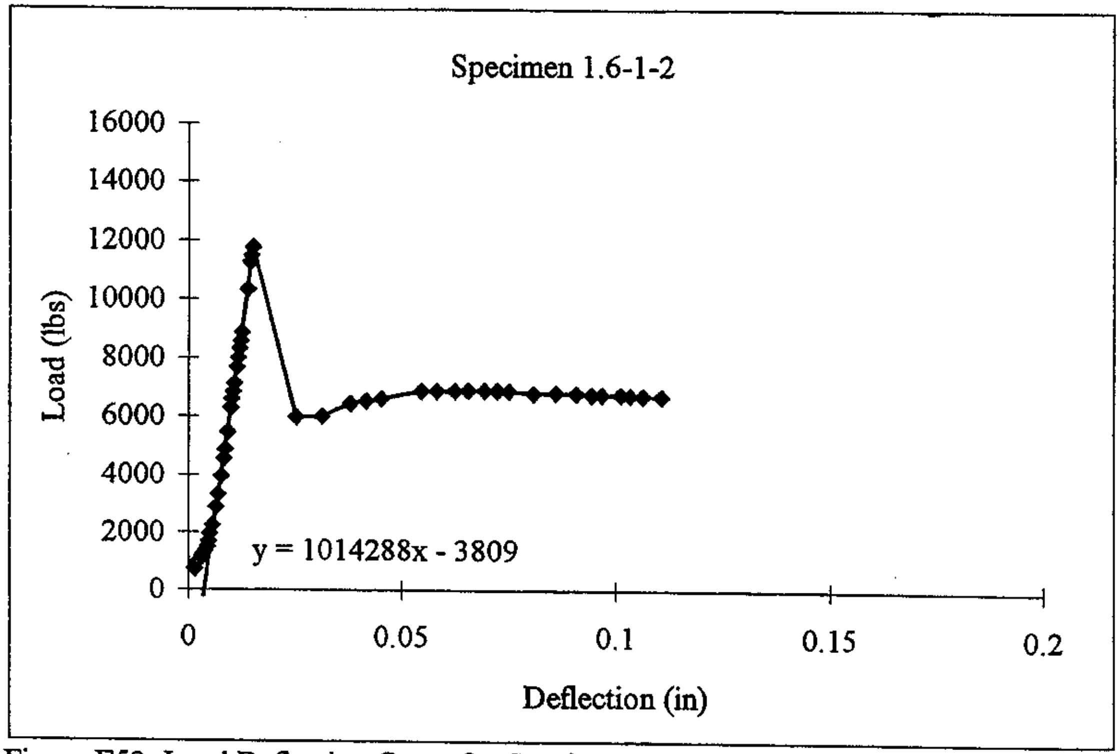

Figure E53: Load Deflection Curve for Specimen 1.6 - 1 - 2

Table E53: Load Deflection Data for Specimen 1.6 - 1 - 2

First Crack Load = 11,740 lbs
Midspan First Crack Deflection = 0.0114 in
Modulus of Rupture = 978.33 psi
First Crack Toughness = 66.92 lb-in

Specimen Type = Molded
Specimen Age =
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0038 in

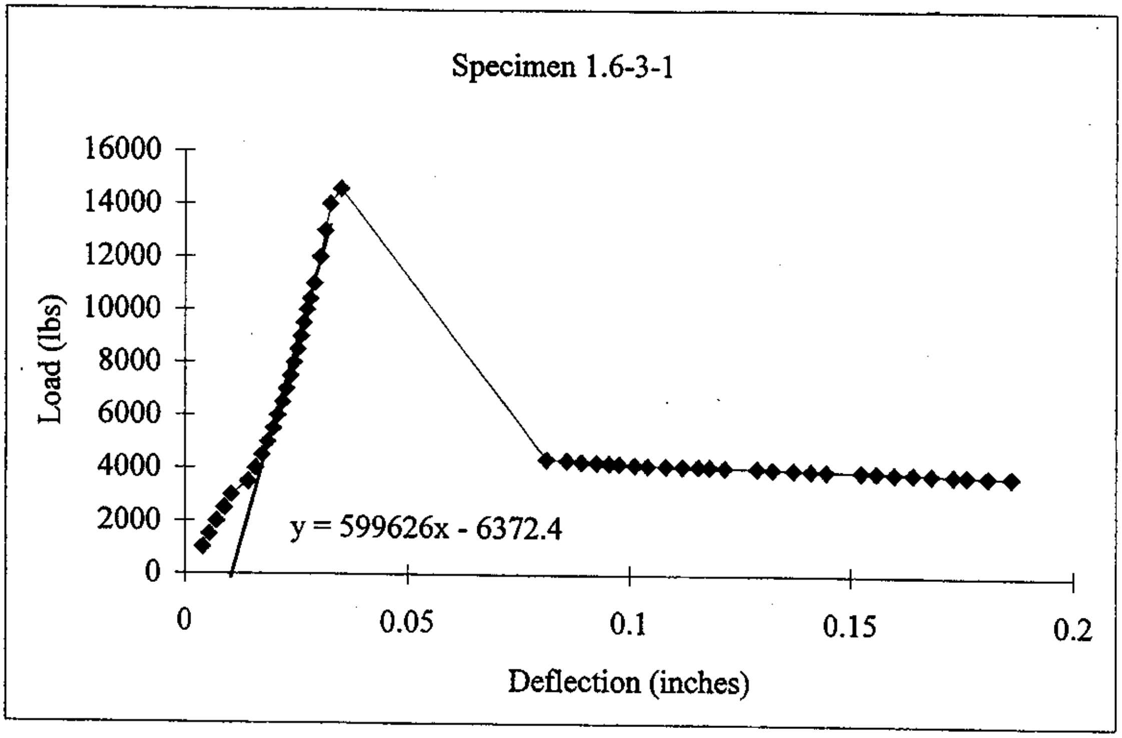

Figure E54: Load Deflection Curve for Specimen 1.6 - 3 - 1

Table E54: Load Deflection Data for Specimen 1.6 - 3 - 1

First Crack Load =	14,590	lbs
Midspan First Crack Deflection =	0.0244	in
Modulus of Rupture =	1176.61	psi
First Crack Toughness =	178.00	lb-in

Specimen Type =	Molded	
Specimen Age =	28	days
pecimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6.2	in
Depth =	6	in
Span Length =	18	in
O' =	0.0106	in

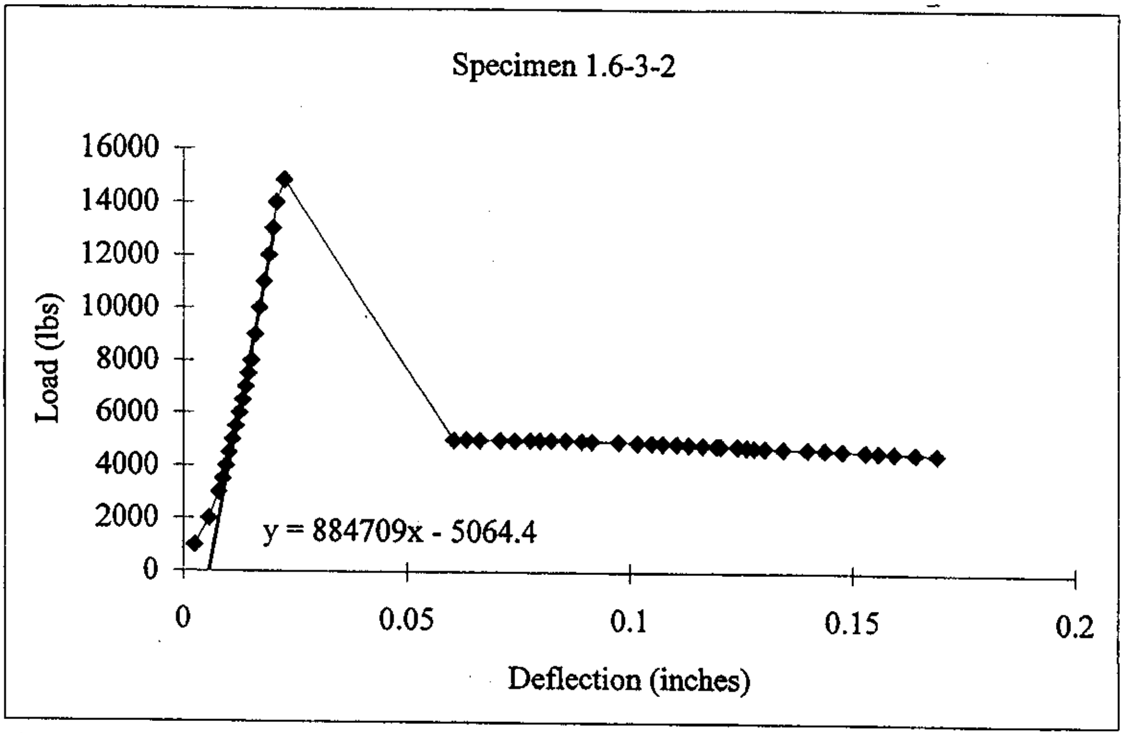

Figure E55: Load Deflection Curve for Specimen 1.6 - 3 - 2

Table E55: Load Deflection Data for Specimen 1.6 - 3 - 2

First Crack Load = 14,540 lbs
Midspan First Crack Deflection = 0.0151 in
Modulus of Rupture = 1172.58 psi
First Crack Toughness = 109.78 lb-in

Specimen Type = Molded
Specimen Age = 28 days
pecimen Abnormailities = None
Cure = Moist Room
Width = 6.2 in
Depth = 6 in
Span Length = 18 in
O' = 0.0057 in

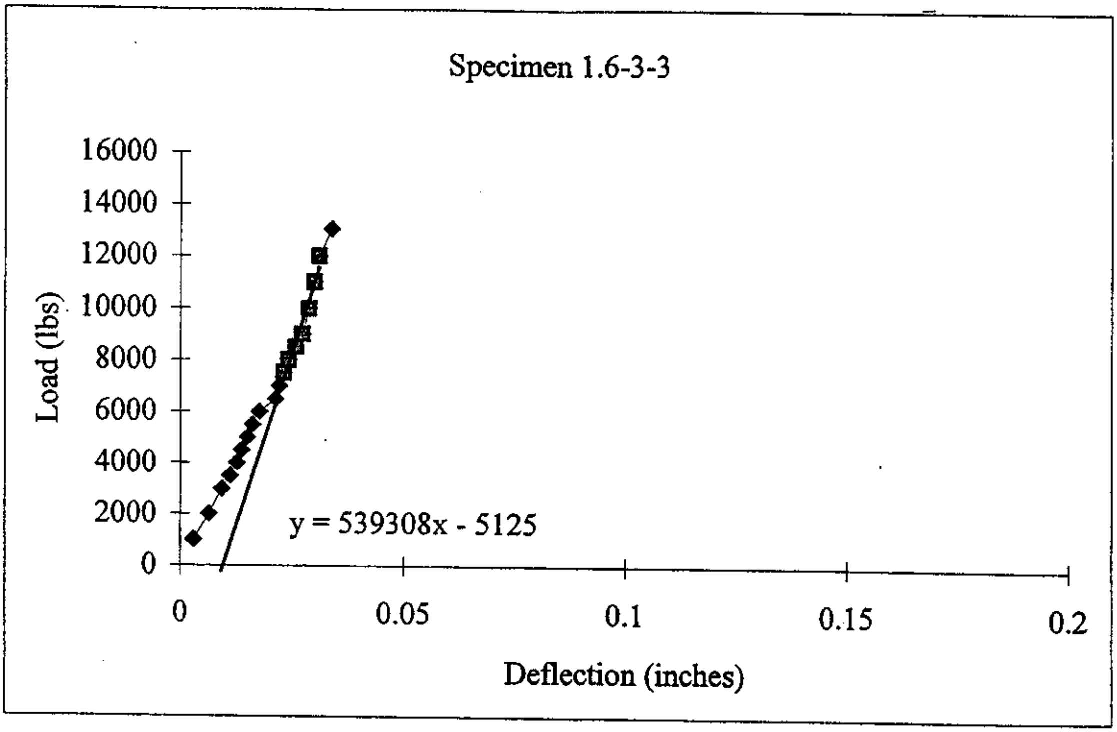

Figure E56: Load Deflection Curve for Specimen 1.6 - 3 - 3

Table E56: Load Deflection Data for Specimen 1.6 - 3 - 3

First Crack Load =	13,050	lbs
Midspan First Crack Deflection =	0.0242	in
Modulus of Rupture =	1052.42	psi
First Crack Toughness =	157.89	lb-in

Specimen Type = Molded
Specimen Age = 28 days
pecimen Abnormailities = None
Cure = Moist Room
Width = 6.2 in
Depth = 6 in
Span Length = 18 in
O' = 0.0095 in

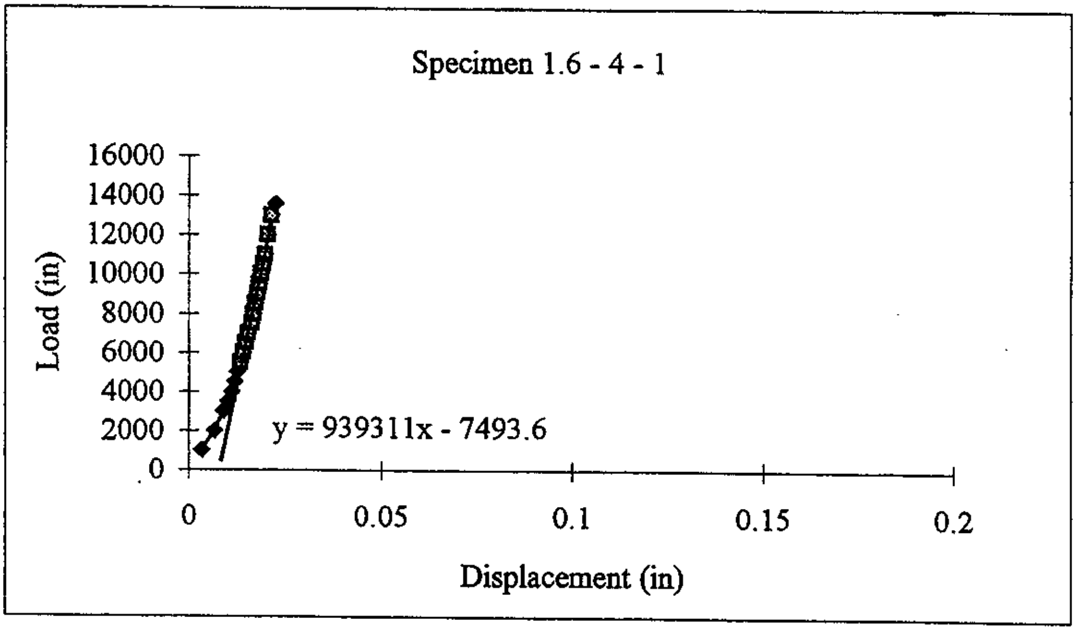

Figure E57: Load Deflection Curve for Specimen 1.6 - 4 - 1

Table E57: Load Deflection Data for Specimen 1.6 - 4 - 1

First Crack Load =	13,590	lbs
Midspan First Crack Deflection =	0.0144	in
Modulus of Rupture =	1132.5	psi
First Crack Toughness =	97.85	lb-in

Specimen Type =	Molded	
Specimen Age =	28	days
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.008	in

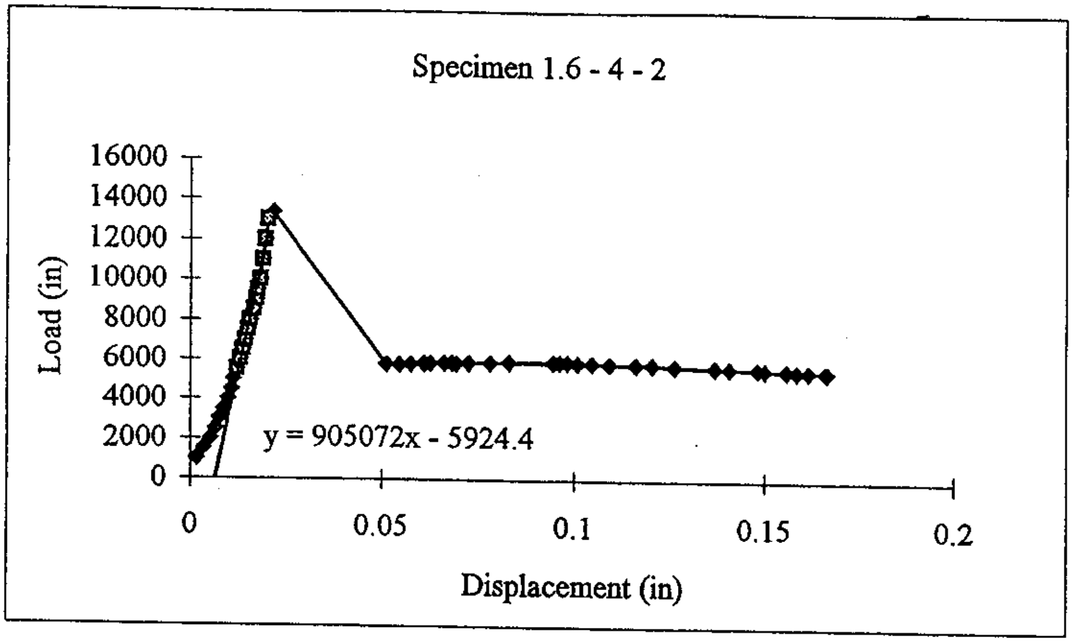

Figure E58: Load Deflection Curve for Specimen 1.6 - 4 - 2

Table E58: Load Deflection Data for Specimen 1.6 - 4 - 2

First Crack Load =	13,350	lbs
Midspan First Crack Deflection =	0.0148	in
Modulus of Rupture =	1112.5	psi
First Crack Toughness =	98.79	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0065 in

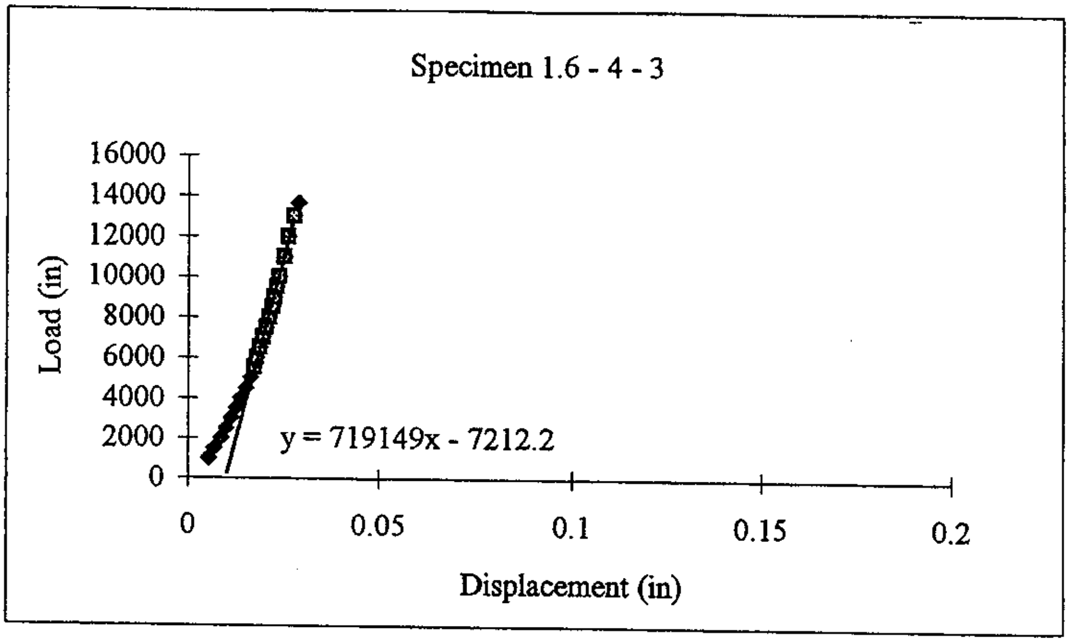

Figure E59: Load Deflection Curve for Specimen 1.6 - 4 - 3

Table E59: Load Deflection Data for Specimen 1.6 - 4 - 3

First Crack Load =	13,630	lbs
Midspan First Crack Deflection =		in
Modulus of Rupture =	1135.83	psi
First Crack Toughness =	0.0190	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.01 in

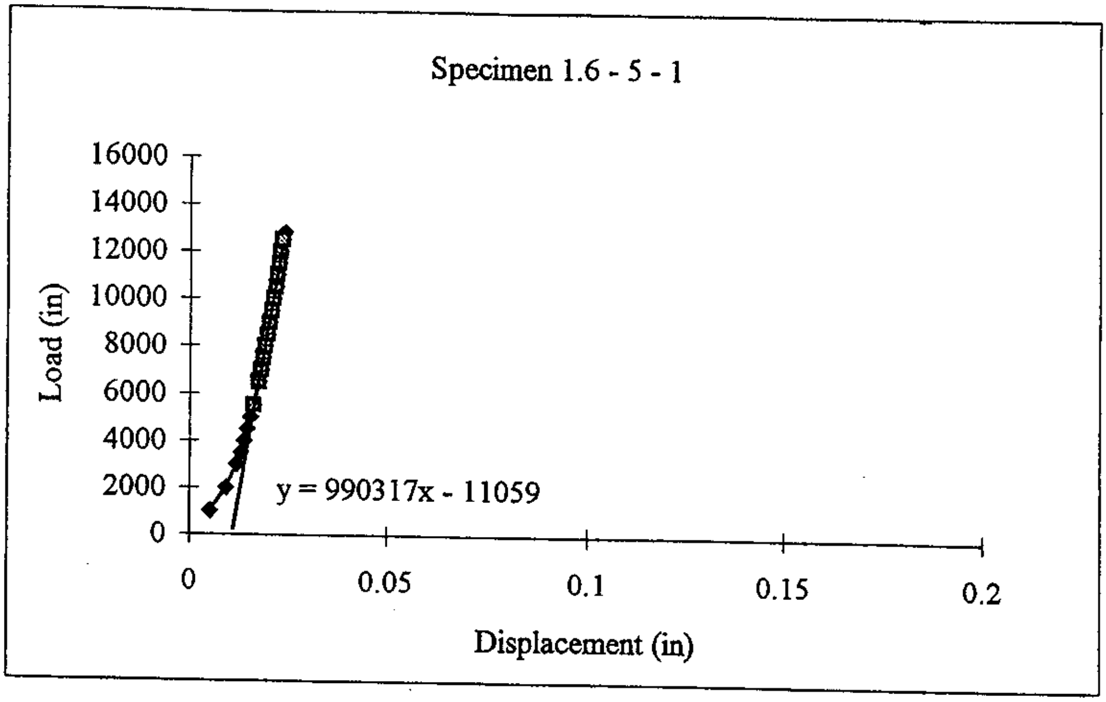

Figure E60: Load Deflection Curve for Specimen 1.6 - 5 - 1

Table E60: Load Deflection Data for Specimen 1.6 - 5 - 1

First Crack Load = 12,790 lbs
Midspan First Crack Deflection = 0.0129 in
Modulus of Rupture = 1065.83 psi
First Crack Toughness = 82.50 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0112 in

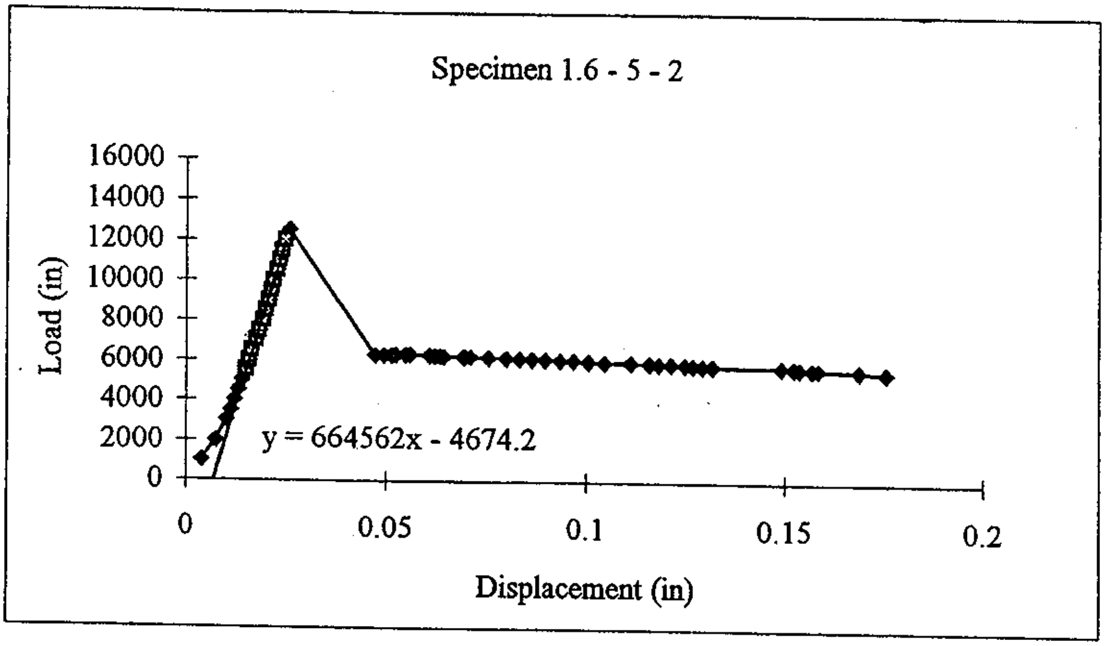

Figure E61: Load Deflection Curve for Specimen 1.6 - 5 - 2

Table E61: Load Deflection Data for Specimen 1.6 - 5 - 2

First Crack Load = 12,500 lbs
Midspan First Crack Deflection = 0.0188 in
Modulus of Rupture = 1041.67 psi
First Crack Toughness = 117.50 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.007 in

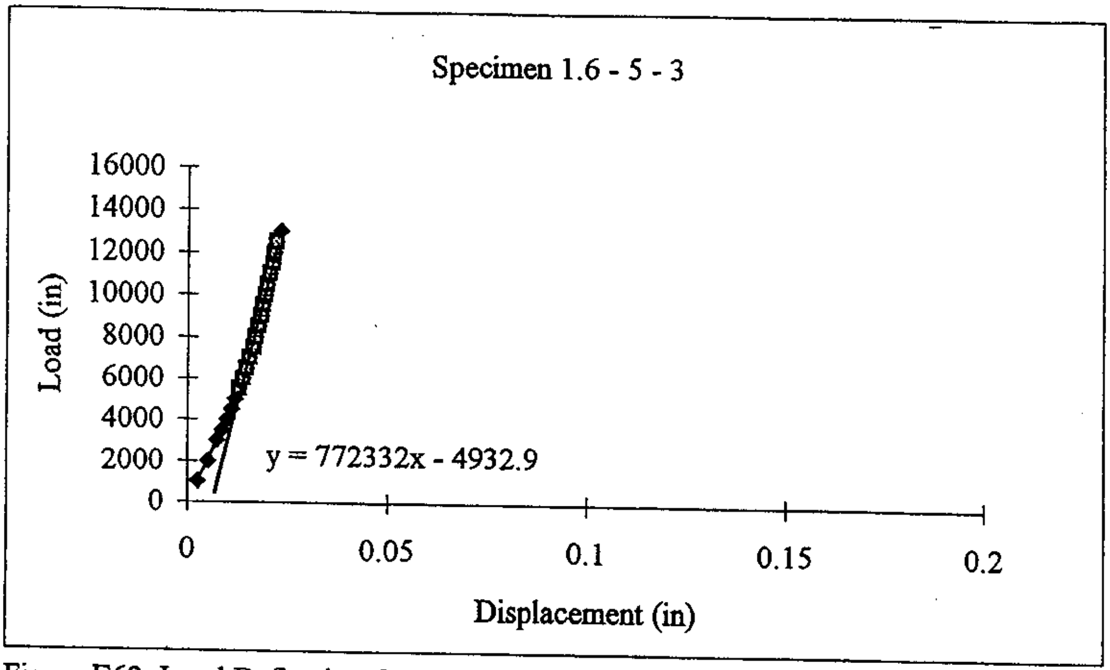

Figure E62: Load Deflection Curve for Specimen 1.6 - 5 - 3

Table E62: Load Deflection Data for Specimen 1.6 - 5 - 3

First Crack Load =	13,000	lbs
Midspan First Crack Deflection =	0.0168	in
Modulus of Rupture =	1083.33	psi
First Crack Toughness =	109.20	lb-in

Specimen Type =	Molded	
Specimen Age =	29	days
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.0064	in

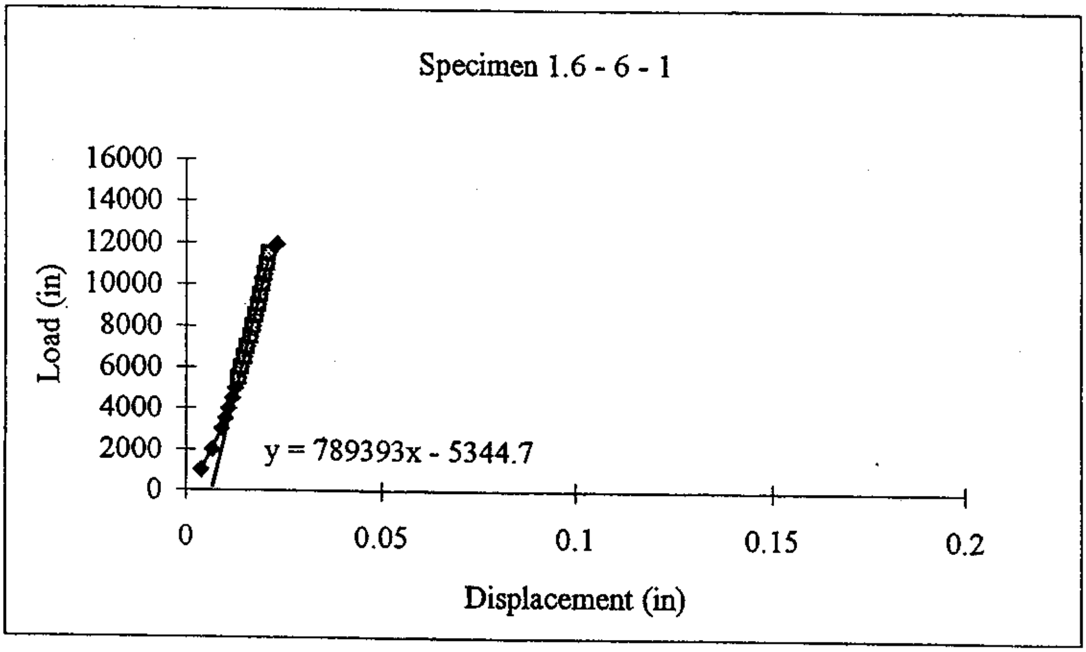

Figure E63: Load Deflection Curve for Specimen 1.6 - 6 - 1

Table E63: Load Deflection Data for Specimen 1.6 - 6 - 1

First Crack Load =	11,930	lbs
Midspan First Crack Deflection =	0.0162	in
Modulus of Rupture =	994.167	psi
First Crack Toughness =	96.63	lb-in

Specimen Type =	Molded	
Specimen Age =	28	days
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.0068	in

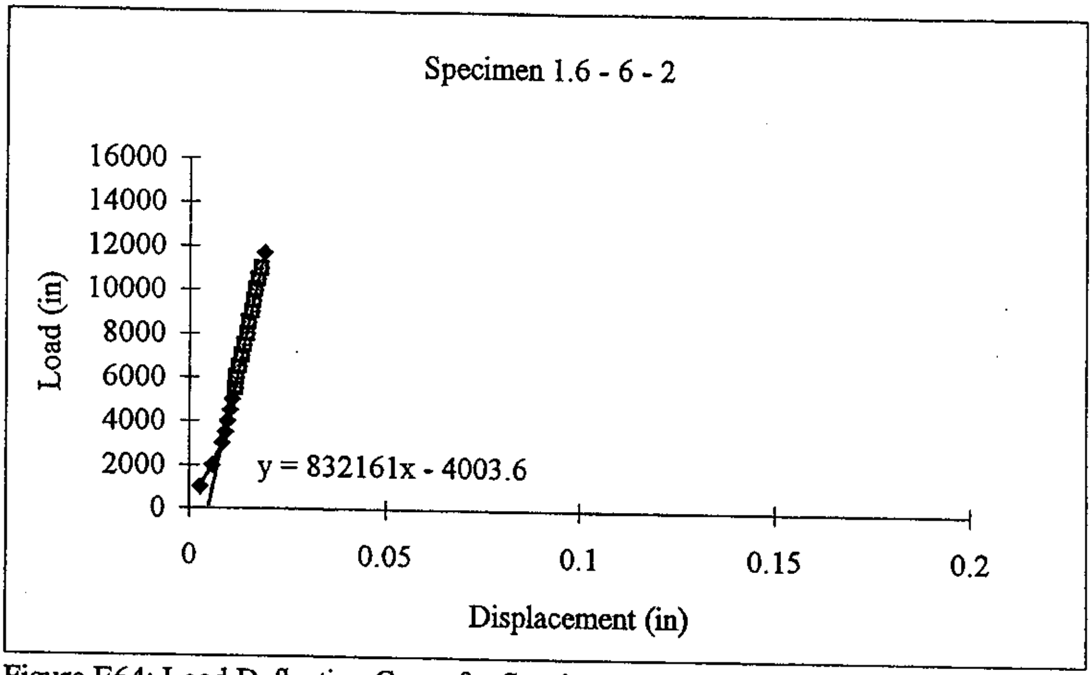

Figure E64: Load Deflection Curve for Specimen 1.6 - 6 - 2

Table E64: Load Deflection Data for Specimen 1.6 - 6 - 2

First Crack Load =	11,700	lbs
Midspan First Crack Deflection =	0.0141	in
Modulus of Rupture =	975	psi
First Crack Toughness =	82.49	lb-in

Specimen Type =	Molded	
Specimen Age =	28	days
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.0048	in

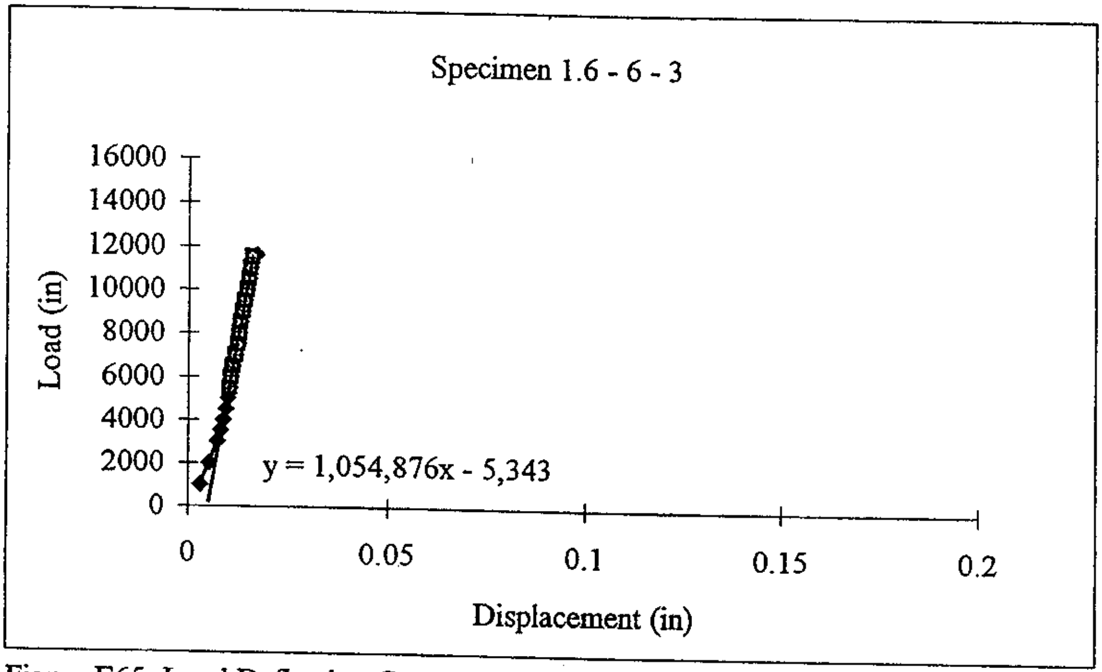

Figure E65: Load Deflection Curve for Specimen 1.6 - 6 - 3

Table E65: Load Deflection Data for Specimen 1.6 - 6 - 3

First Crack Load =	11,600	lbs
Midspan First Crack Deflection =	0.0116	in
Modulus of Rupture =	966.667	psi
First Crack Toughness =	67.28	lb-in

Specimen Type =	Molded	
Specimen Age =	28	days
Specimen Abnormailities =	None	
Cure =	Moist Room	
Width =	6	in
Depth =	6	in
Span Length =	18	in
O' =	0.0053	in

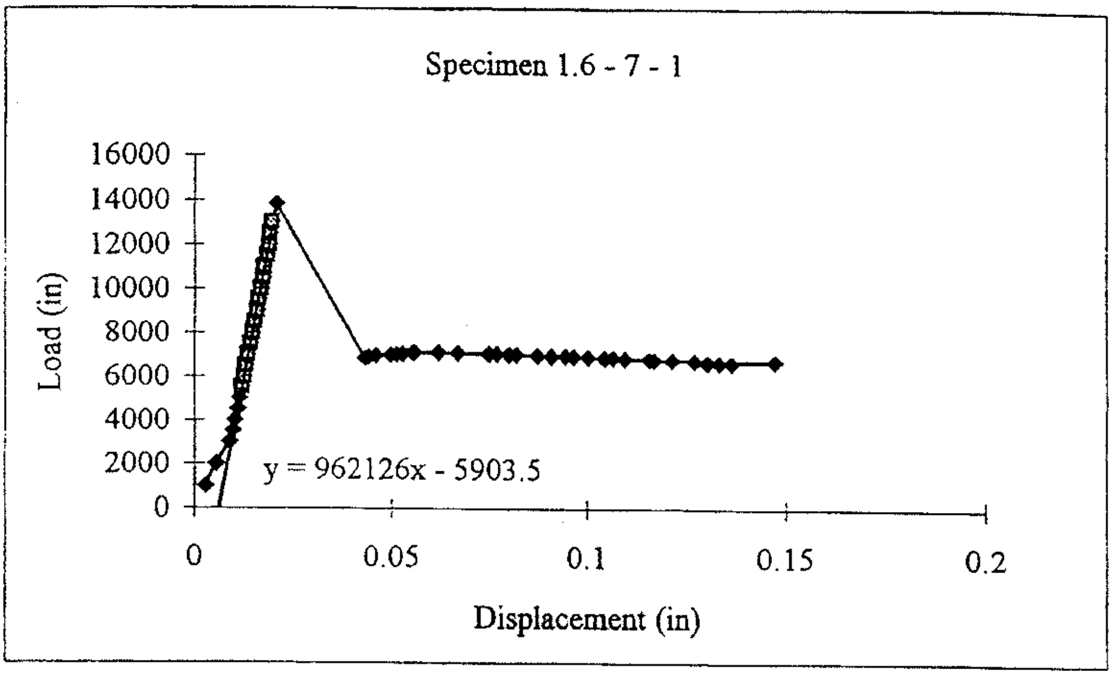

Figure E66: Load Deflection Curve for Specimen 1.6 – 7 – 1

Table E66: Load Deflection Data for Specimen 1.6 – 7 – 1

First Crack Load	=	13,810	lbs
Midspan First Crack Deflection	=	0.0144	in
Modulus of Rupture	=	1113.71	psi
First Crack Toughness	=	99.43	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormalities = None
Cure = Moist Room
Width = 6.2 in
Depth = 6 in
Span Length = 18 in
O' = 0.0061 in

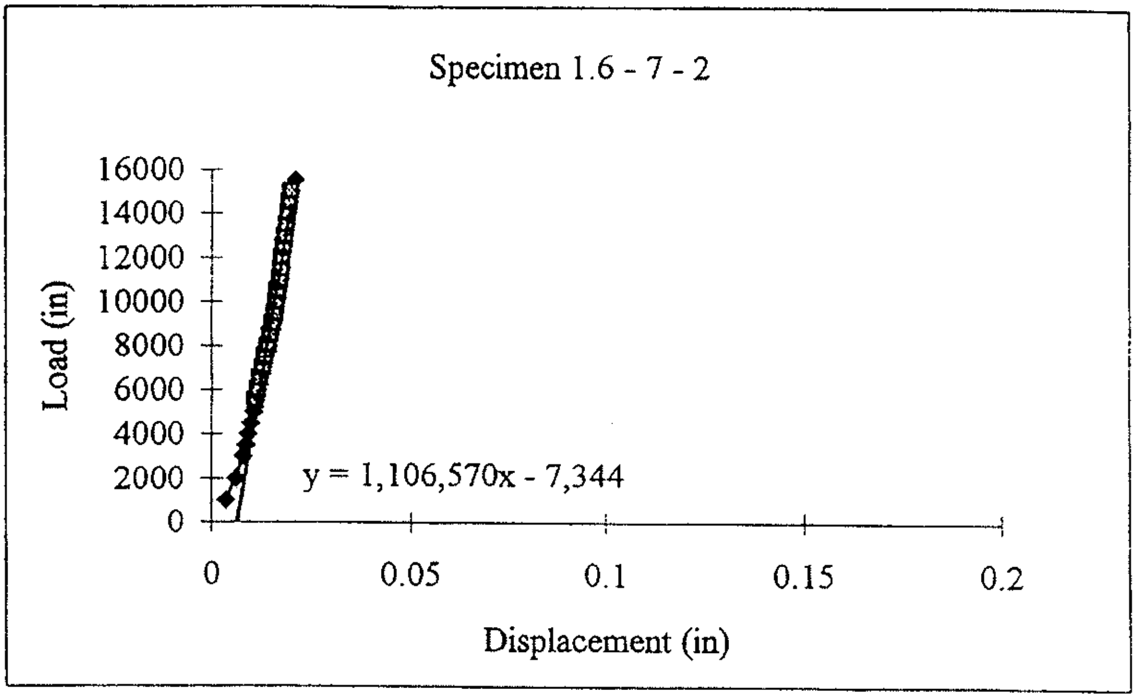

Figure E67: Load Deflection Curve for Specimen 1.6 – 7 – 2

Table E67: Load Deflection Data for Specimen 1.6 – 7 – 2

First Crack Load = 15,510 lbs
Midspan First Crack Deflection = 0.0141 in
Modulus of Rupture = 1230.95 psi
First Crack Toughness = 109.35 lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormalities = None
Cure = Moist Room
Width = 6.3 in
Depth = 6 in
Span Length = 18 in
O' = 0.0066 in

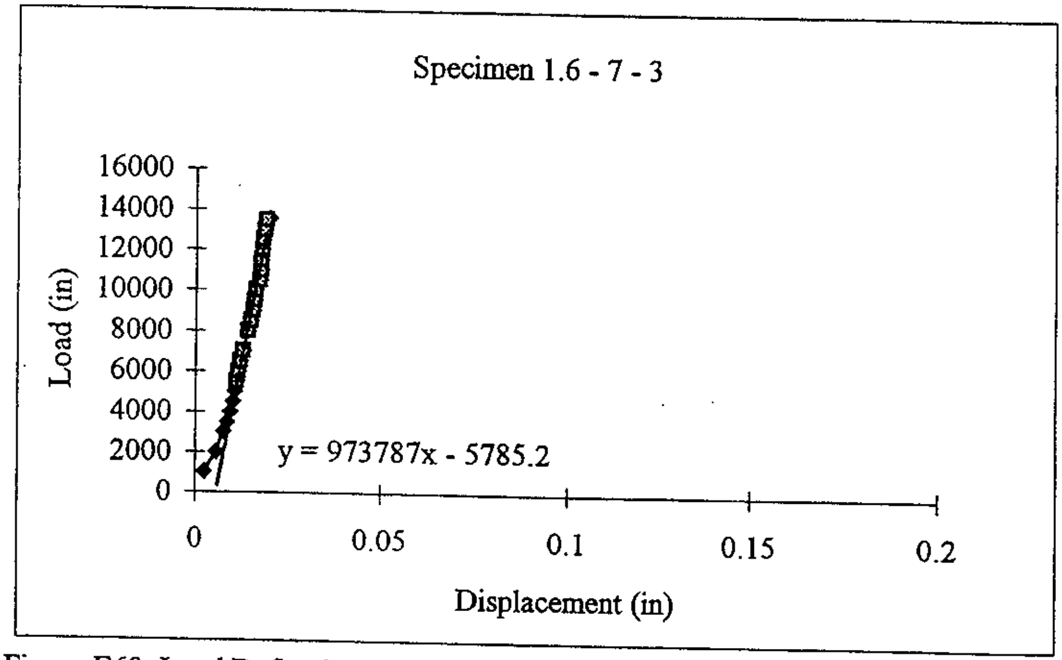

Figure E68: Load Deflection Curve for Specimen 1.6 - 7 - 3

Table E68: Load Deflection Data for Specimen 1.6 - 7 - 3

First Crack Load =	13,570	lbs
Midspan First Crack Deflection =	0.014	in
Modulus of Rupture =	1094.35	psi
First Crack Toughness =	94.99	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6.2 in
Depth = 6 in
Span Length = 18 in
O' = 0.0059 in

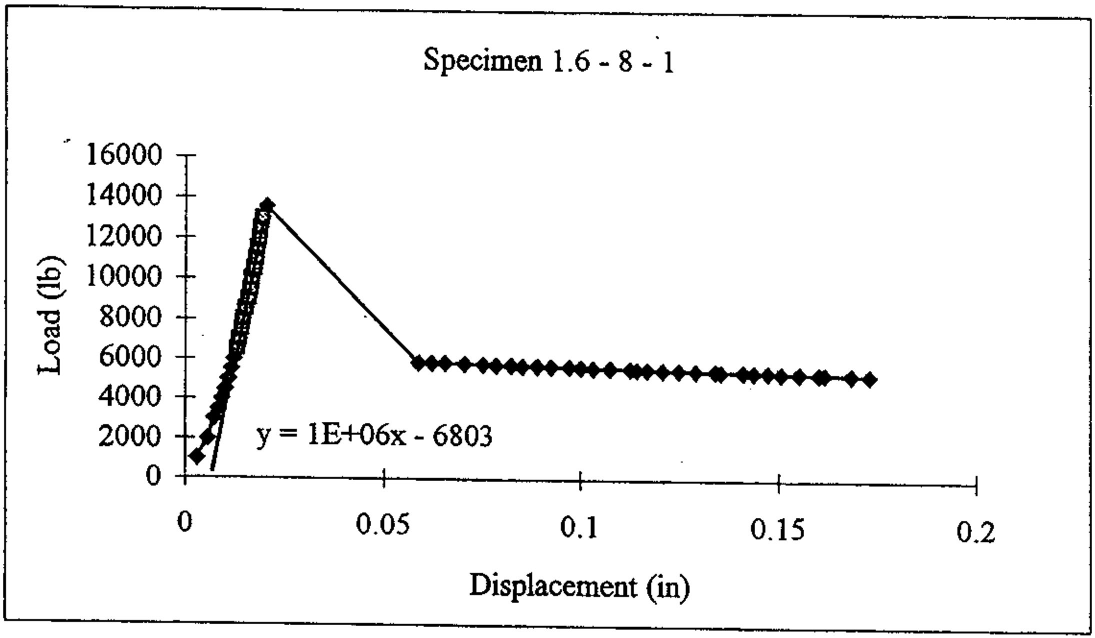

Figure E69: Load Deflection Curve for Specimen 1.6 - 8 - 1

Table E69: Load Deflection Data for Specimen 1.6 - 8 - 1

First Crack Load =	13,560	lbs
Midspan First Crack Deflection =	0.0136	in
Modulus of Rupture =	1130	psi
First Crack Toughness =	92.21	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0068 in

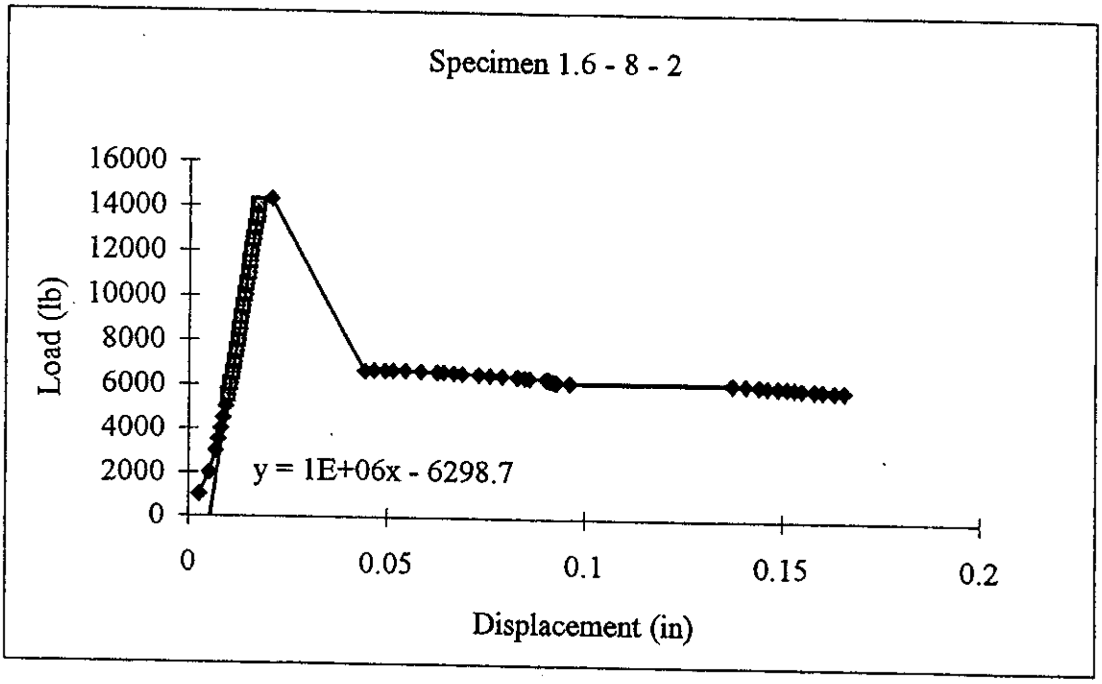

Figure E70: Load Deflection Curve for Specimen 1.6 - 8 - 2

Table E70: Load Deflection Data for Specimen 1.6 - 8 - 2

First Crack Load =	14,290	lbs
Midspan First Crack Deflection =	0.0143	in
Modulus of Rupture =	1190.83	psi
First Crack Toughness =	102.17	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0063 in

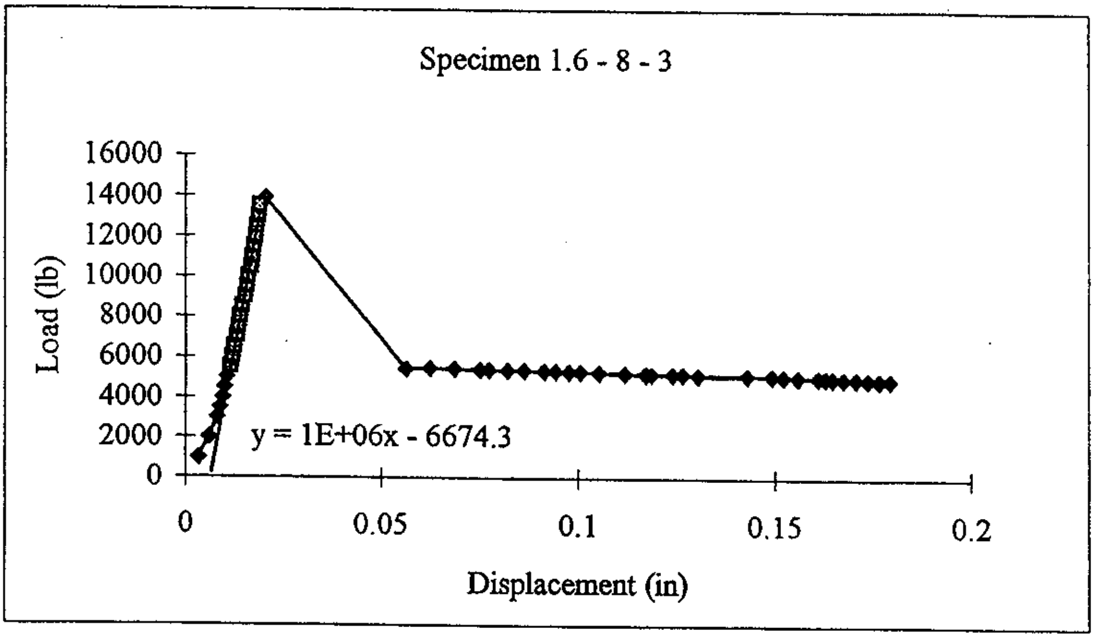

Figure E71: Load Deflection Curve for Specimen 1.6 - 8 - 3

Table E71: Load Deflection Data for Specimen 1.6 - 8 - 3

First Crack Load =	13,890	lbs
Midspan First Crack Deflection =	0.0139	in
Modulus of Rupture =	1157.5	psi
First Crack Toughness =	96.54	lb-in

Specimen Type = Molded
Specimen Age = 28 days
Specimen Abnormailities = None
Cure = Moist Room
Width = 6 in
Depth = 6 in
Span Length = 18 in
O' = 0.0067 in