Biaxial Loading of 4-Ply, Spliced, Nail Laminated Posts

By
David A. Strong B.A. B.Sc.

A Thesis Submitted to the Faculty of Graduate Studies
in Partial Fulfilment of the Requirements for the
Degree of Master of Science

Department of Biosystems Engineering
University of Manitoba
Winnipeg, MB, Canada R3T 5V6

0-612-32964-X

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Abstract

The purpose of this study was to determine the behaviour of biaxially loaded, 4-ply, spliced, nail laminated timber assemblies, under simply supported and fixed end support conditions. The study builds upon American work and utilizes the modern Canadian In-Grade Testing approach.

The study tested 33 commercially manufactured S-P-F # 2 grade timber assemblies built up from eight individual 2 x 8 sections with the splice region off-set towards the base of the post. The four test series conducted involved two point lateral loading and a simply supported condition, a fixed end condition, and a fixed end condition with the addition of two separate axial loads of 1000 lbs and 2000 lbs.

Results indicate that the support conditions had a very significant effect on post bending performance and that axial loading in this range had no effect. There was joint motion detected in all cases of the fixed end support condition by the design deflection limit. Conventional structural theory was used to develop simple modifiers for predicting similar post performance under both support conditions.

This study concludes, that current design values based on simply supported test conditions may be overly conservative, and that they do not fairly represent the capacity of a post in its probable end-use conditions.

Acknowledgments

I thank my advisor Dr. Ron Britton for his efforts on my behalf and for the opportunity to tackle such a major project so early in my engineering career. I also thank my other committee members, Dr. K. Dick and Dr. S. Riscalla, for their contributions and general review of my work.

I extend my appreciation to the outstanding technicians of our department; Jack Putnam, Matt McDonald, and Dale Bourns, for their significant work on this project.

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Introduction

Post frame construction is a common, practical, and economical method of producing agricultural and light industrial buildings in North America. In such a design, the posts are of critical importance, and there has been considerable research effort given to understanding their characteristics and performance. Initial research focussed on solid timbers, but as building scale grew and solid timber became more expensive and less available, the practical effectiveness of laminated posts became apparent and research shifted to this new and more complex area. These large section, long length timber assemblies, are built up from smaller laminates in such a way that they perform similar to, or even better than, a solid post. Whether mechanically or glue laminated, the process of engineering these assemblies promotes a greater control over the finished qualities of the post. This element of control is in direct contrast to the natural variability found in large section timbers that must simply be accepted, and dealt with in design limits. The positive economics of using laminated posts is well accepted, as demonstrated by their almost universal utilization by North American builders.

Post frame builders in Manitoba agree with the need for continued research into the performance of laminated posts, and three companies have joined together with the Department of Biosystems Engineering at the University of Manitoba to address this, and other questions, in timber design. In 1995, Olympic Building Systems, Newton Enterprises, and Goodon Industries have collaborated with elements of the university to create the Western Post Frame Buildings Association, and have provided it with funding to conduct research into timber design. These builders are interested in building stronger, more economical posts in longer lengths than they are currently using. Towards that end, this thesis is the association's first research project.

In the greater context of timber research, this work represents a new step in the research on mechanically laminated, spliced, timber assemblies. Mechanical lamination, as distinct from glue lamination, usually implies the use of nails alone to hold the different layers of an assembly together. Other means, such as bolts in conjunction with split rings, and toothed shear plates are also used but are generally not as common. Current work on mechanical lamination, done largely in the United States, has focussed on nail laminated, simply supported posts with symmetrically placed splices. The posts were loaded in bending under a two point load with no axial loads applied. The results of this work have been consolidated into an engineering practice on post design (ASAE 1995), for common use in the United States. In Canada, a different perspective has developed under the term In-Grade Testing, largely due to the work of Borg Madsen (1992). This approach focusses on practical testing procedures that simulate, as closely as possible, the realistic in-use conditions of the material or structure to be tested. The support conditions and actual loading pattern seen by a post in service for example, become important test parameters.

This present experiment builds upon the American work and, for the first time, applies the Canadian approach to the testing of mechanically laminated timber posts.

Objectives

The research followed the practical approach of the In - Grade testing philosophy with these specific objectives :

1. To determine the effects of combined axial and bending loads on four-ply, nail laminated posts.
2. To compare post performance under fixed end bending load and simply supported bending load conditions.
3. To compare fixed end post performance under biaxial loading and simple bending load conditions.
4. To compare experimental results with structural theory and develop a simple relationship between them that facilitates strength and stiffness predictions for design purposes.

Scope

The scope of this study included the following :

1. The experiment used commercially manufactured, 24', four-ply, spliced, nail-laminated, S-P-F posts, that were fabricated under normal working conditions.
2. Post design was based on a summary of American research presented in a draft copy of ASAE X559: Design Requirements And Bending Properties For Mechanically-Laminated Posts, October 1995 (ASAE 1995).

3. Ambient temperature and moisture conditions were measured and assumed to closely simulate in-service conditions.

4. The experiment and report utilize imperial units because they are the industry standard and the literature is largely American work. Analysis was done in SI units and converted to imperial for reporting, with the exception of temperature measurements and calculated E values.

Research Review

Principal Players

Relevant Canadian research in timber concerns the In-Grade Testing philosophy that is currently accepted in the National Building Code and championed by B. Madsen, a Professor Emeritus from the University of British Columbia. The research specifically done on nail laminated post behaviour has been done largely in the United States of America during the 1980's and 1990's. The people principally involved were: Professor D.R. Bohnhoff at the Agricultural Engineering Department, University of Wisconsin-Madison, R.C. Moody, a Supervisory Research Engineer, USDA Forest Service, Forest Products Research Laboratory, Madison, Wisconsin, Professor F.E. Woeste at Virginia Poly-Technical University, and Professor H.B. Manbeck, at Pennsylvania State University.

Canadian Research

In - Grade Testing

Current American and past Canadian research was dependent on traditional wood design values derived from testing methods first developed in the 1920's. In the 1980's, Canadian In-Grade Testing procedures were developed that were significantly different than past procedures, in both practice and intent. They were different to such an extent that this approach essentially forms a new philosophy for the development of wood design values. In essence, this more recent approach advocates full scale testing of wooden structural elements under loading and support conditions that reflect the end use of the product. Testing regimes are to be largely non-destructive and hence would allow large sample sizes, with the intent to produce a 5th percentile design value for each property of interest. This 'real life' testing contrasts directly with the abstractions of traditional wood design values.

In the conduct of full scale testing, traditional design values were derived from the extrapolated results of testing done on small, prepared, clear grain wood samples. A small piece of wood however, does not behave the same as a large piece of timber. " The two products - wood, in the sense of clear defect-free wood and timber, in the sense of commercial timber - have to be considered as two separate materials, and that must be respected when strength properties are developed for engineering purposes " (Madsen 1992). The results of traditional full scale testing are therefore predicated on an abstraction that may not accurately represent the reality of the material being tested.

When determining loading and support conditions for an experiment testing is usually conducted in accordance with well established standards set out by test agencies. These standard conditions do not however always accurately reflect the 'real life' conditions that a structural element may be subjected to. Another level of abstraction must therefore be introduced in compensation. With In-Grade Testing, " the test results should, as closely as possible, reflect the structural end use conditions to which the timber products would be subjected" (Madsen 1992). The timber should be tested as it is to be used. Current American research procedure is to test laminated poles as simply supported beams in bending under a two point load with no axial loading. This approach is effective in generating conservative design values, but it is simply not the loading reality the post is subjected to in actual use. The post is actually in a complex condition of composite loading and differential support conditions. In service use, in a post frame building for example, the post suffers both axial and bending loads simultaneously, with one end fixed, and the other end simply supported. A testing apparatus that closely simulates these conditions would adhere to the in-grade testing philosophy.

The practical approach of in-grade testing affects four other aspects of experimental procedure; rate of loading, moisture content, temperature, and proof loading.

Current American testing standards dictate a loading rate to produce failure in 5 - 15 minutes for wood samples. An extensive test program conducted by Madsen (1992) on rate of loading however, indicated that only strong timber had bending values sensitive to rate of loading. Weak timber members showed little sensitivity to rate of loading. At the 5^{th} percentile design value for strength, there was hardly any noticeable effect from differential loading rates. Testing programs can therefore be structured to produce sample failures in the practical time of one minute, and any small variations from that time will have no significant effect on results.

Moisture content and temperature are variables that are usually closely controlled under laboratory conditions because they can have a significant effect on timber properties (Desch and Dinwoodie 1996). Precisely controlled conditions, however, are not always practical to produce and do not reflect the variability of in-service use. There is also evidence (Madsen 1992), that moisture contents in the common in-service range of values may have virtually no effect on the design strengths of wood. With the pragmatic intent of the in-grade testing philosophy as a guide then , it would be acceptable to simply measure moisture content and temperature while conducting a test series in conditions that closely simulate in-service use.

The concept of proof loading is derived from the desire to conserve material, and the need to understand only how weak a material might be, and not how strong it could be. Design strength of a material or structural component is predicated on a reasonable guarantee of minimum strength, which in most cases is the 5^{th} percentile of strength distribution. This indicates that 95% of the material will be stronger than the given design value. In testing then, only 10% - 15% of a sample set need be loaded to failure in order to gain a clear indication of material behaviour at the 5^{th} percentile. By extending this idea to the area of service limits, where deflection restrictions are often the governing parameter in design that occur well before strength limits are approached, it is possible to develop an accurate understanding of deflection - load values at the 5^{th} percentile without extravagant testing to failure of numerous samples. Proof loading of the samples to an arbitrary deflection limit well beyond the accepted service limit, usually set at length (L) / 180, would not damage any but the very weakest members of a sample set and the bulk of the material could be returned for regular use. Experience has proven that the returned material suffers no ill effects from proof loading to the 10 - 15th percentile of strength distribution. (Madsen 1992).

Canadian Codes

Canadian design values for laminated posts are derived from a process that makes no attempt to account for possible variables in post design. The limit states design process in the Canadian Building Code (CSA 1994), states that the strength of built up members is simply 60% of an equivalently sized solid timber. Three layer, spliced, built-up columns are detailed in the standard, but there is no mention of four layer assemblies. The factored bending resistance in the splice region of a spliced member is defined to be simply 40% that of an unspliced, built-up beam. The performance and construction of composite members is a much more complex problem than is implied by these design criteria, and the building code must continue to be updated from ongoing research.

American Research

Principle Findings

Three ply post research results are summarized in Bohnhoff et al. (1991), and it is generally concluded that three ply, nail laminated posts are reasonably well understood assemblies. The research confirmed that lumber quality and lamination, splice length and arrangement, butt joint reinforcement, and nail pattern and type, all have an effect on post strength. This understanding of three ply post behaviour was used to guide further research into four ply post behaviour, which is generally regarded as being considerably more complex (Williams et al. 1992).

Research is ongoing into four ply post behaviour but there are several areas where conclusions can be drawn. It should be noted that all these conclusions are derived from testing done on simply supported posts in bending under a two point load, with the spliced region equidistant between supports. This test arrangement was used because of its inherent simplicity, and because " lateral (bending) loads, such as wind, can induce 75% or more of the maximum allowable fibre stress in a post" (Williams et al. 1992). A summary of these findings for design purposes can be found in the ASAE draft Engineering Practice X559: Design Requirements And Bending Properties For Mechanically - Laminated Posts, October, 1995 (ASAE 1995).

Lumber Quality and Lamination Effects

As might be expected, post "strength properties are related to lumber grade" (Bohnhoff et al 1991), and better grades of wood yield stronger posts. The process of lamination into a single assembly can however augment the effectiveness of lower grade timber. The multiple layers in the assembly compensate for local wood defects in any given layer and yield a "somewhat increased mean strength for lower grade lumber" (Bohnhoff et al 1991). Top grades of laminated timber however, showed no increase in mean strength over equivalent single members. The variability in strength and stiffness values for assemblies composed of all grades of lumber were significantly reduced when compared to solid member values. This results in a significant increase in the 5 th percentile allowable design values over those derived from an equivalent solid post (Bohnhoff et al. 1991).

The orientation of a mechanically laminated post is of critical importance to its load bearing capacity. Unlike solid or glue laminated assemblies which can bear reasonable loads from any direction, a mechanically laminated post must be loaded in a direction parallel to its laminations, an alignment referred to as a vertically laminated post (ASAE 1992). Sufficient lateral support for the weak bending axis is usually provided by blocking or girts as a regular part of the building design.

Preservative treatment is used on timber in contact with the ground or in wet service conditions to prevent rot and deter insect attack. In post frame construction, the section of post in, or close to the ground, is required by most building codes to be treated. Treated timber costs more than regular timber and hence a splice is often introduced into a post slightly above ground level to minimize the overall expense. In general "the treatment of timber with wood preservatives does not significantly affect its strength properties and can be ignored for design purposes " (Desch and Dinwoodie 1996). Taylor et al. (1992) found no significant difference between treated and untreated spliced posts made from yellow popular and red maple when they were treated with creosote. The Canadian National Building Code (NBC 1994), does not require any reduction in design strength for preservative treated lumber, but it does require a 10% design strength reduction for lumber treated with a chemical fire retardant.

Splice Length and Arrangement

Splicing a nail laminated post together between top and bottom sections will reduce its strength immensely from that of a solid or unspliced post of equivalent length. Results from four ply, unreinforced butt jointed, spliced post testing, demonstrated strength reductions ranging from 29 - 63 % of unspliced post strength (Williams et al. 1992). In the unreinforced three layer assemblies of a different test, spliced design strength values were found to be less than 45% of unspliced values, and mean stiffness values were only 60% of unspliced assemblies (Bohnhoff et al 1990). This strength and stiffness reduction is due to the unequal distribution of stresses between the laminae, and the much higher nail forces that develop within the splice area. In general terms then, it is apparent that approximated engineering design values for spliced posts should only be in the order of 50% of the maximum values currently calculated for unspliced posts.

Splice length is defined as the distance from first to last butt joint along the length of the post, and has significant effects on post strength. Shorter splices create greater lever forces acting within the splice itself, as the post in bending tries to "pivot" about the fulcrums that develop at each end of the spliced section (Williams et.al. 1993). These 'short arm of the lever' bending forces within the splice itself are resisted by the nails present, as they work to transfer the forces to an adjacent, solid, lamination. Failure is usually due to tension perpendicular to the grain, as nail shear forces work across the wood grain to resist bending forces in the post. Longer splices reduce the lever forces acting on the nails by lengthening the 'short arm of the lever', and by producing a larger surface area for the transfer of forces between laminae. A greater transfer area means more nails can be involved in load transfer, there is a reduction in shearing force per nail, and there is more wood material available to absorb the total applied load. The optimum splice length is a balance between minimum lengths with extreme nail forces, and practical maximums, limited by board length and economics. Recommended minimum overall splice lengths, (from first to last butt joint), are dependent on face width of the laminations and are presented in Table 1.

Table 1. Recommended overall splice lengths for four-ply, butt jointed posts.

Nominal Size	Splice Length
2 x 6	48"
2 x 8	60"
2 x 10	72"
2 x 12	96"

(ASAE 1995)

Splice arrangement in a spliced post is important for providing an even stress distribution across the post section. There is a natural tendency in all laminated posts for the central layers to be the most highly stressed because they have two connection planes, while the outer layers only have one. Testing has demonstrated that it is usually the center layers that fail, and specific splice arrangements are focussed on balancing the relative stiffness of this central region, with the variable stiffness of the outer layers. The outer butt joints may be left alone or reinforced and made stiffer by the addition of 18 or 20 gauge steel splice plates secured across the joints. Of the eight possible combinations of a four-ply post, two particular combinations were found the most effective (Williams et al. 1993). In

Fig. 1, post A is most effective when outside butt joint reinforcement is used, and post B is recommended for use without reinforcement. The longer centre splice of post A produces a stiff joint plane that will attract more of the load, unless it is balanced by reinforcing plates on the outside of the post. Post B is a balanced arrangement that produces an more even distribution of forces within the post, but its effectiveness is sensitive to proper splice length. A four foot splice length test of unreinforced 2 x 10's using arrangement B proved 30% weaker than arrangement A (Williams et. al. 1992).

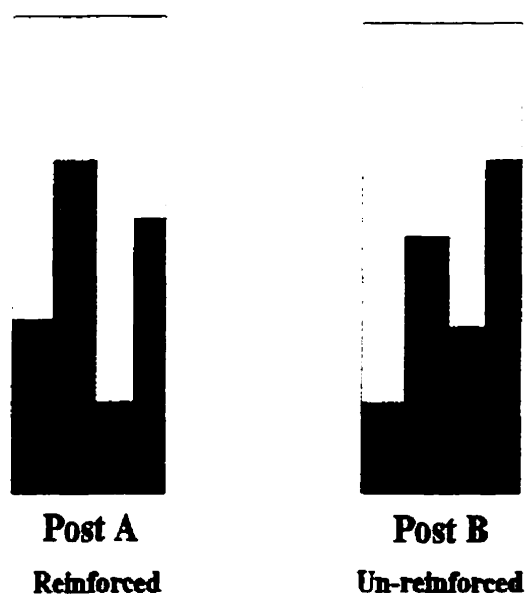

Figure 1. Best splice arrangements for a four-ply, spliced post (Williams et. al 1993).

Further testing at a six foot splice length however, indicated that arrangement B was preferable for unreinforced assemblies (Williams at al. 1993). Designing a post with at least the minimum suggested splice length will allow the joint to reach its maximum capacity with a distributed contribution from all layers.

Different splice arrangements will react in different ways to reinforcement, and some arrangements will receive more of a benefit than others. In testing conducted by Williams et al. (1992), post A demonstrated a 26% mean increase in bending strength when reinforced, but post B was not tested with reinforcement because it was considered a more balanced arrangement. In related three-ply post testing, reinforcing plates created a 14% increase in mean bending strength values with a 28% increase in design strength. Mean stiffness increased by 25% from unreinforced values (Bohnhoff et al 1991). A significant effect of reinforcing is a great reduction in variability of strength values with a resultant increase in allowable design values at the 5th percentile. Post arrangement A was found to have a 26% increase in mean post strength, and a 40% increase at the 5th percentile when it was reinforced with 16 gauge plates. The same post had a mean stiffness increase of 17% (Bohnhoff 1994).

Nail Pattern and Type

Mechanically laminated assemblies typically utilize nails for load transfer between individual post layers. Some research has been done on using shear transfer plates (a.k.a. metal truss plates), or bolts to connect the separate laminae, but nailing is the predominant commercial method of manufacture (Bohnhoff et. al. 1993). A proper nail pattern is intended to evenly distribute the load across the face width of the post with specific attention to the splice region. In an unspliced laminated post, the nails transfer little shear between the laminae and work essentially to hold the post together during loading. The assumption being that the different layers have the same modulus of elasticity and deflect to the same degree naturally. Any composite interaction within the post does not significantly effect mean strength values for any but low grade posts. The variability of both strength and stiffness results is, however, significantly reduced in comparison to single board values, and there is a subsequent increase in allowable design values that makes a laminated post 'greater than the sum of its parts' (Bohnhoff et al. 1991). In spliced posts however, the nails become critical components in the splice region, and nail forces must be balanced against wood resistance, particularly in tension perpendicular to grain. There are also certain minimum spacings to be observed in order to prevent splitting at end grain and between nails (ASAE 1992). Practical limits on nail density is another largely commercial concern that is not always reflected in some of the extremely dense nail patterns found in research. Recommended nail spacings related to nail diameter are found in Table 2. Nail length is dependent on whether nails are driven from both sides or only one. It is common practice to have the nails of sufficient length to penetrate at least three laminae and two planes of lamination. This geometry of double shear makes maximum use of the nail's resistance potential. Nail type and stiffness can significantly affect the performance of a laminated assembly (Woeste et al. 1989), and it is suggested that nail test results be reported with laminated post testing. Nail diameters of from 2/16" to 3/16", but not exceeding one eighth of the lamination thickness, are recommended (ASAE 1995). Larger nail diameters than these may split the wood, and diameters near the small end of the range should be checked for stiffness by the Morgan Impact Bend-Angle Nail Tester (MIBANT) (ASAE 1992).

Table 2. Recommended nail spacing for nail laminated assemblies.

End distance :	15 nail diameters
Edge distance :	10 nail diameters
Parallel-to-grain spacing :	20 nail diameters
Perpendicular-to-grain spacing	
- in-line rows :	10 nail diameters
- staggered rows :	5 nail diameters

(ASAE 1995)

Axial Loading

Observations from current bending research on spliced posts indicate failures are generally tension related, either wood splitting around nail holes, or reinforcing plate failure on the tension side of the post. The addition of axial loads to the bending loads may change the dynamic response of the posts in a significant way. "Although not substantiated by a test, it is quite likely that the addition of a small compressive force may actually increase the bending capacity of a spliced post, much like the addition of a small compressive load to a reinforced concrete member increases the bending capacity of the concrete member" (ASAE 1992). This axial force would decrease tension forces in general, and compress the butt joint gaps, allowing for greater load transfer across the joint and a more even distribution of load between the post layers. If such an increase in load bearing capacity occurs, then the existing design values and strength reductions for spliced posts would be overly conservative.

Materials and Methods

Materials

Test Frame

A full scale, bi-axial loading test frame was constructed for this research. The machine is illustrated in Fig. 2. A detailed description, engineering sketches, operating instructions, and the data control program are provided in Appendix B. The machine was designed to load a post simultaneously in bending and axial compression while recording deflection at a single point. Hydraulic systems and a centralized control cabinet allow the operator to visually monitor post performance and real time load-deflection data while operating the machine. The data recording rate can be changed within the control program code and data can be recorded to disk for later analysis. Machine capacity is limited to an 8" x 12" section post from 6' - 28' long. Maximum axial load is 8,000 lbs with two lateral point loads of 3000 lbs each. Loading force accuracy in both directions is ± 2% of load. Maximum measurable deflection, as recorded by a linear potentiometer, is restricted to 10" with an accuracy of ± 0.01". Rate of loading and flow balance between the two lateral load cylinders is controlled by manual flow controls using the procedures detailed in Appendix B. Lateral support was provided to the tested assembly by three Teflon lined braces located at quarter points along the span.

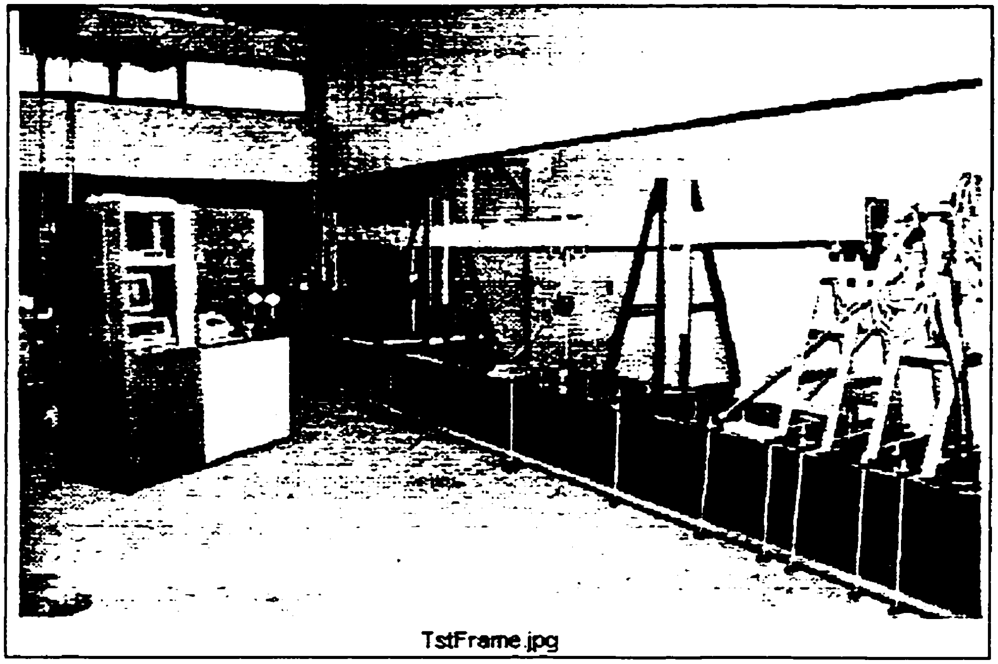

Figure 2. Biaxial loading test frame.

Data Acquisition System

The data acquisition system components are represented in Fig. 3. The automated part of the system includes two 3000 lb load cells, one 25000 lb load cell, a linear potentiometer, a Taurus One data acquisition system, and a 286 computer. The manual components of the system utilize ten pieces of 0.1" graph paper cards, black thread, a tri-square, and a metal ruler. The automated data readout was used to monitor centre span deflection and hence control the step loading procedure which is detailed below. The graph paper cards were tacked across the centerline of the post at 2' intervals along the length of the unsupported span of the post. All distances along the post were measured from the base, or fixed end of the post, and begin where the timber emerges from the metal of the support or directly over the simple support at that end. The thread was stretched taunt between nails driven into the centerline of the post directly above the simple supports, or as close as possible to the fixed end support. It was assumed that this thread would provide a constant reference line from which post deflection could be measured. The data recorded at each interval was rounded to the nearest 0.05" to account for thread thickness and estimation errors. The tri-square was placed on the post surface and extended out to the thread, thereby providing a sighting plane to reduce parallax errors in the deflection readings.

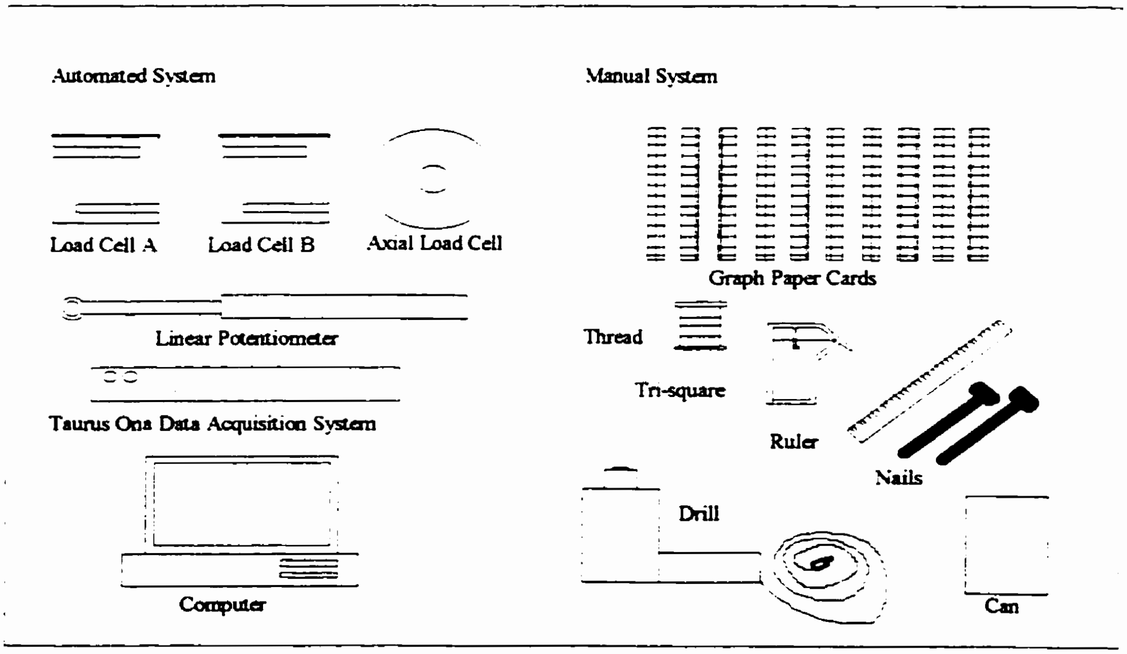

Figure 3. Data acquisition system components.

Moisture content sampling was done immediately following each test. The process used an electric drill and a 1" auger bit to drill horizontally through all four layers of the posts at once. The sampling hole was drilled through the approximate centre on the face width of the posts. The resulting wood chips were collected as they fell in a tin can and immediately taken for analysis.

Joint motion data were collected during each test by measuring top and bottom spacing of each joint with a metal ruler. Measurements were rounded to the nearest 1/16". Photographs of each joint were taken at the end of each test to record their final displaced arrangement and nail patterns.

Post Fabrication

Posts were fabricated of S-P-F No. 2 or better lumber by a commercial builder to the specifications in Fig. 4. No special conditions of manufacture were imposed. Fully 100% of the posts had at least one joint that could not be considered a closed butt joint and most of the posts arrived with significant variations in the nailing pattern. Primary changes in the nail pattern occurred when the manufacturer applied the original desired nail pattern to the wrong side of the post. Since all nails were hand driven 4" x 5/32" spiral nails, additional nails were added on site to the external joints, (J1 and J4), to standardize them as six nail joints. The two interior joints (J2 and J3), did not have the majority of their nails in double shear across two lamination planes because the nails only penetrated three laminations. Although this is a weaker joint than intended, it was felt to be sufficiently strong for experimental purposes and only the outside joints were reinforced on

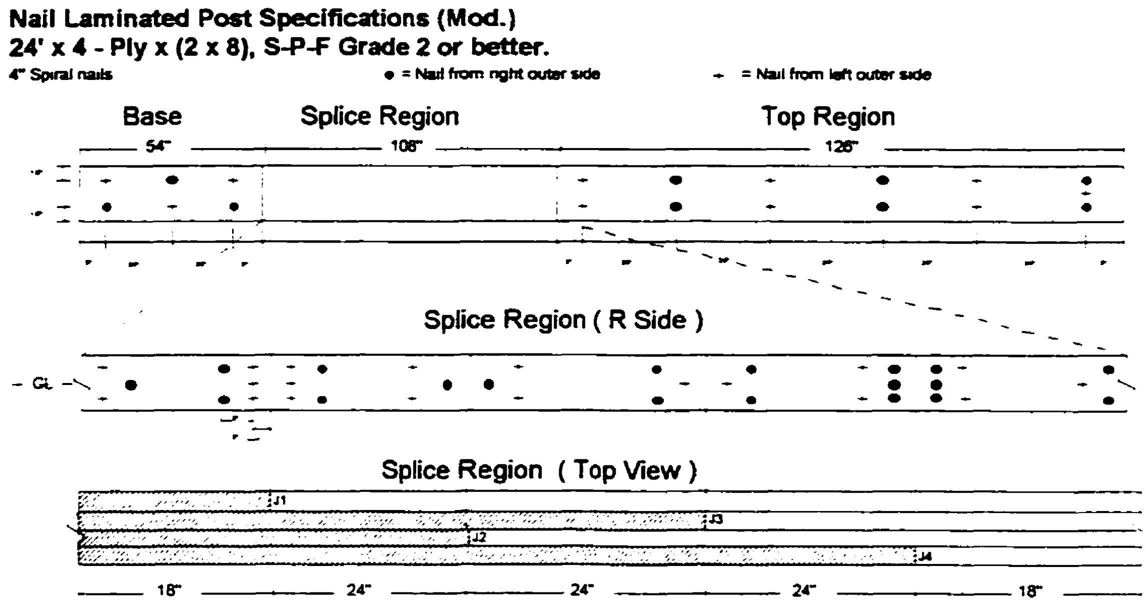

Figure 4. Post design specifications.

site. The nail pattern illustrated in Fig. 4 is the final, as tested, configuration. For axial loading both ends of each post were cut flush with a reciprocating saw and any slight variations were taken up by a ½" "buffalo board" pad placed between the loading faces and each post end. Variation also occurred at the point of contact between the simple supports and the posts where all four laminations did not always sit flush against the supporting plate. Since however, there were nails through the assembly in close proximity to the support which distributed forces across all four laminations, this detail was not considered to be a problem.

Methods

Experimental Program

There were three test series of ten posts each, and one series of 3 posts. Each series evaluated the posts under different loading and support conditions as illustrated in Fig. 5. Series A was considered a baseline set of data that closely simulated previous test conditions in earlier studies. These posts were simply supported and subjected to equal bending loads at third points along their span. The major unavoidable difference from earlier work was the offset splice region of these posts as compared with other work

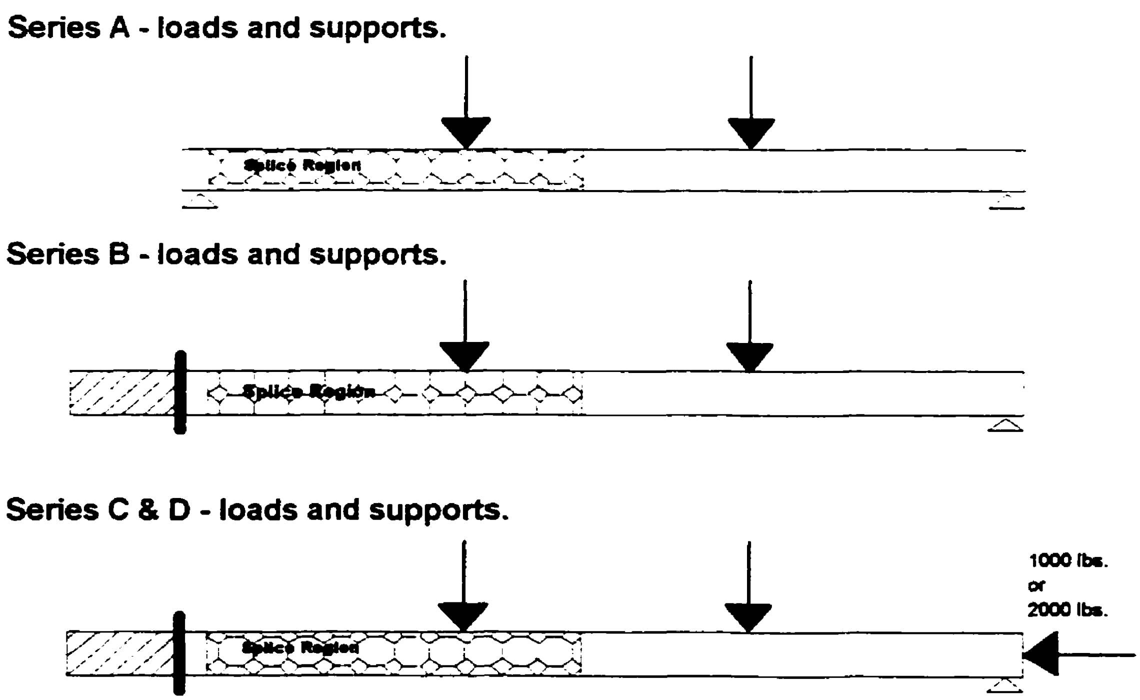

Figure 5. Experimental loading and support conditions.

having a symmetrically placed splice. Commercial posts have the splice region in the lower third section of the post to limit the length and expense of pressure treated lumber. This offset splice location was used in all testing series to allow comparison of results, and to satisfy the spirit of the in-grade testing philosophy. Series B was a fixed end, simply supported combination with similar bending loads applied. Note that series A and B had no axial loading. Series C was a fixed end, simply supported combination with the addition of a 1000 lb constant axial load. Series D was similar to Series C but with a 2000 lb axial load. Series D only had three posts tested because of sensing equipment failure. The results of series D however, were so consistent with other trends in the data that they were included for analysis with the other completed series.

The first three posts of each series, and all of Series D, were tested to failure to give an estimate of post behaviour throughout their entire range of deflection. The remaining seven posts in each series were tested to a 2" midpoint deflection. This midspan deflection limit was chosen to be well past the L / 180 limit, (of 1.4"), commonly accepted for structural member performance, yet it was not so much as to result in any permanent damage to the posts. Axial loads were chosen to be representative of moderate roof loads and are well below the critical structural load for such posts. An approximation of this critical load using Euler's column equation and the assumption of a solid cross section post is 43,000 lbs (see Appendix A6).

Procedure

Throughout the experiment and for 30 days prior, the lumber sat indoors at room temperatures of approximately 22°C. Temperature was not continually monitored, but the test room was in constant use during working hours throughout the test period. The lumber arrived with some apparent surface moisture on it but it maintained a relatively constant moisture content of 16.5%, dry basis, (db) with a standard deviation. (s.d) of 1.9, throughout the four months of testing.

Prior to loading, the machine had the fluid flow to both lateral load cylinders balanced by the method described in Appendix B. The post was then positioned in the machine and the ends secured as required for the individual test. Open span length was 21' for all test series. The initial 3' of each 24' post was fixed for series B, C, and D. The lateral load cylinders were positioned at third points across the open span of the post with their attached linkages containing load cell A at the 7' mark, and load cell B at the 14' mark. The clamp assemblies joining the post and load cell linkages were clamped tightly at 14', but left loose at the 7' mark because it was directly over the splice area. Preliminary testing indicated that a tight clamp in this area would restrict joint motion and artificially reinforce the area. There was no differential motion between the laminates at the 14' mark so this clamp was tightened to maintain positive control over the sample. The 10 graph paper cards were then tacked to the centerline of the post at 2' intervals. The card for the 14' mark was actually placed at the 14' 6" mark because of interference from the loading clamp in that area. The reference thread was then stretched between nails driven into the centerline of the post over the supports. Initial readings were taken at all 10 points and from the midpoint potentiometer. For axial loading tests, initial readings were taken before and after the axial load was applied. The setup was then complete and ready for the step-loading procedure of the test proper to begin.

The step loading procedure of each test involved operating the lateral load cylinders until the midspan linear potentiometer indicated a 0.02" increase in deflection from the previous reading. Loading was then stopped and manual readings were recorded at all of the 2' intervals along the beam. In the case of axial loading, adjustments were made to the axial loading cylinder as required to maintain a steady load. In no case did these axial adjustments have a measurable effect on deflection readings. This procedure was repeated until a midspan deflection of 2" was reached , or until failure for the first three of the 10 posts in each series.

Joint motion was measured when the post reached ½", 1", 1.4", and 2" midspan deflection. Photos were taken of each joint at the end of each test before unloading.

Moisture content sampling was done for each post on completion of testing by the core sampling method indicated above. The samples were analysed by the oven drying method on a dry mass basis as specified by ASTM D 2016. Drying time varied as convenient to the experiment, but due to the large surface area of the chipped sample, any time after three hours was sufficient to achieve steady state conditions at 130° C. Sample mass was determined to within the ± 0.2% accuracy required by the standard on an electronic laboratory scale with an accuracy of 0.005 g.

Analysis

Collected data was transferred to a Quattro Pro spreadsheet program for analysis and interpretation. Analysis was done at four values of midpoint deflection; 0.4", 1.0", 1.4", and 2.0". These points were chosen to yield a clear picture of post performance before, at, and after, the standard allowable deflection limit for a post of this length (ie. L / 180 = 1.4"). General observations and conclusions were drawn from the graphical interpretation of the data at other points of deflection as required. Standard deviations are recorded in Appendix A but not on any of the figures in the text. Generally, the standard deviations on all the data are less than the physical size of the symbols used to represent each data point, and graphical reporting of the deviations would confuse the figures.

For the analysis of series C and D, the off-centre bending moment effects from axial loading were ignored. A 2000 lb axial load for example, that is 2" off-centre due to midpoint deflection, would produce approximately 32 lbs of equivalent lateral load at midspan. This additional load is only a very small percentage of the total lateral load applied and was therefor assumed to have no independent effect.

Predictions relating to structural behaviour were derived from standard beam tables assuming the posts to be solid members with standard design values of S-P-F #2 grade timber (CWC 1995).

With the exception of temperature measurements and E values, the experiment was conducted and reported in imperial units because that is still the construction industry standard, and it allows direct comparison with previous research. Analysis was executed in SI units and converted where required to imperial units.

Results

A summary of results is included below with raw and analysed data reported in Appendices A1, A2, A3 and A4.

The simply supported test series A results are summarized graphically in Fig.6, Fig.7, and Fig.8. Figure 6 illustrates the significant difference between the mean load / deflection values of load cell A and load cell B. This result was expected due to the asymmetry of the splice region between the supports. Load cell A was located within the splice region of the post which was known to be the most flexible part, all other things being equal, and it did display a greater deflection for a given load. The analysis of variance (ANOVA) across series A detailed in Appendix A2, is a comparison between load cells A and B performed at the four deflection points of analysis. This analysis delivered an F - value well above the critical comparison value which not only confirms that loads at A and B are different, but that the trend between the two loads is to maintain a consistent difference between themselves. This consistency is also evident from the graphical interpretation of the data. A comparison of load values at the four deflection points chosen for analysis indicated that the mean of load A was a mean 15% less than the mean of load B after 1.0" midpoint deflection. Figure 7 and Fig. 8 indicate the load / deflection values for load cells A and B respectively. Series A is also represented in the post profiles of Fig. 9. The asymmetry of post deflection behaviour is evident from these figures. Measurement points on the splice end of the posts deflected more than those on the solid end for a given applied load, thus confirming that the splice region is the weakest section of the posts in bending.

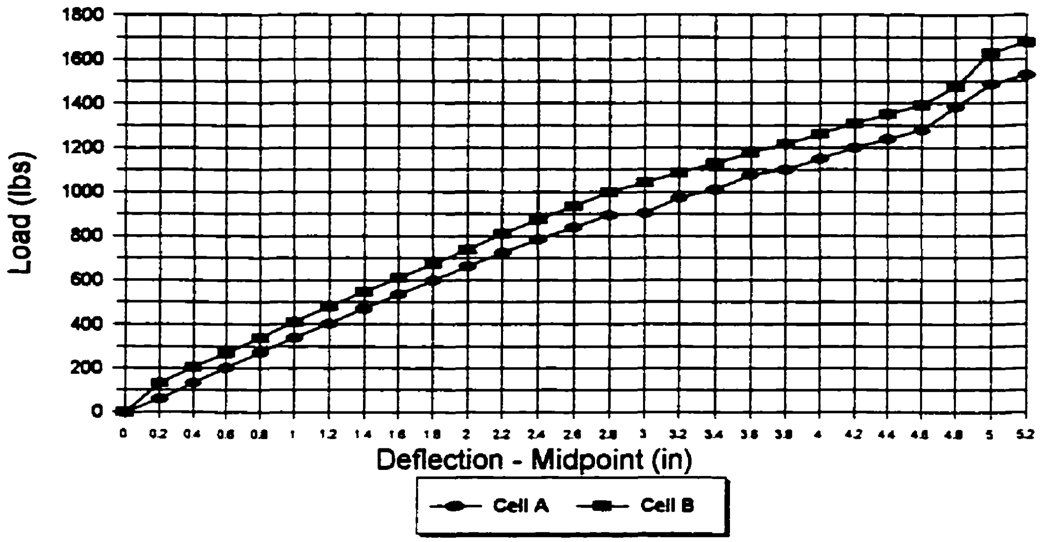

Figure 6. Simply supported bending, mean load deflection values of Series A.

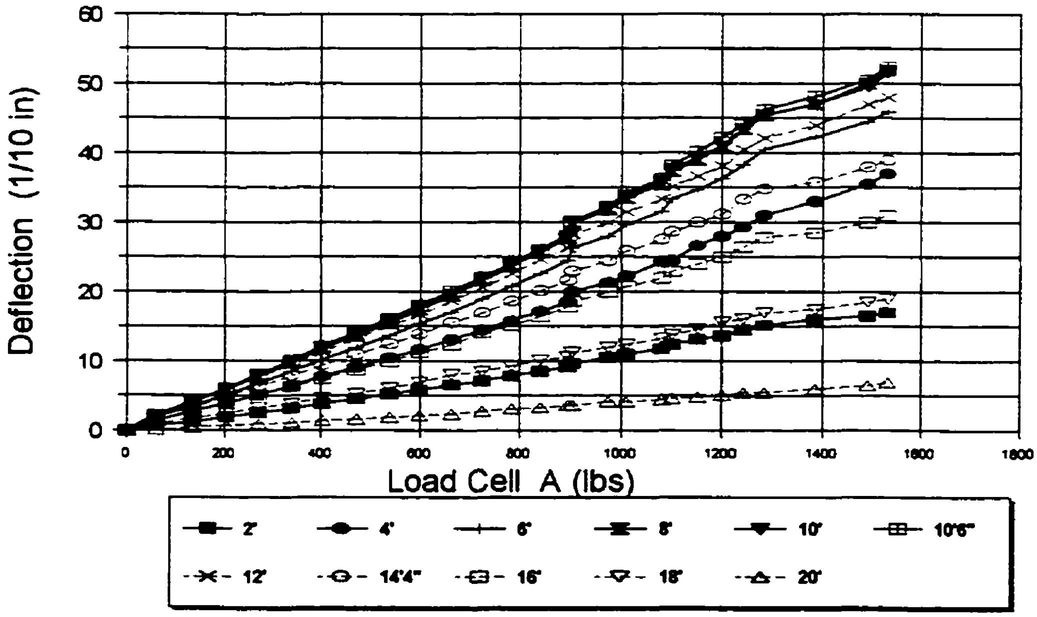

Figure 7. Simply supported bending - mean deflection vs load cell A values.

[1] Series are measured from base of post.

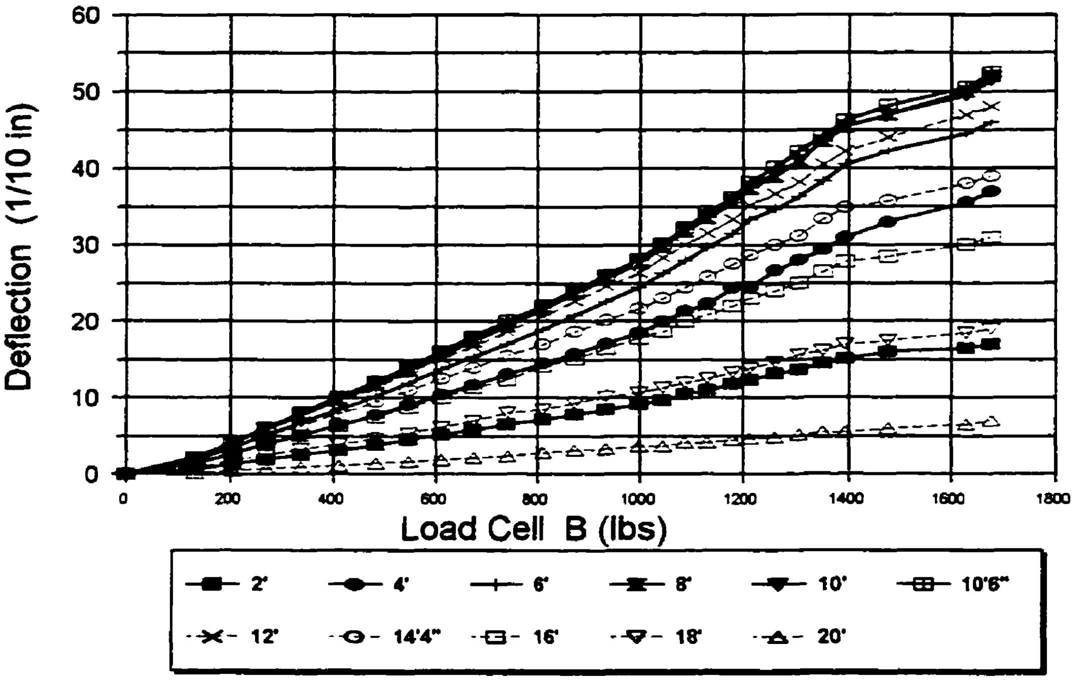

Figure 8. Simply supported bending - mean deflection vs load cell B values.

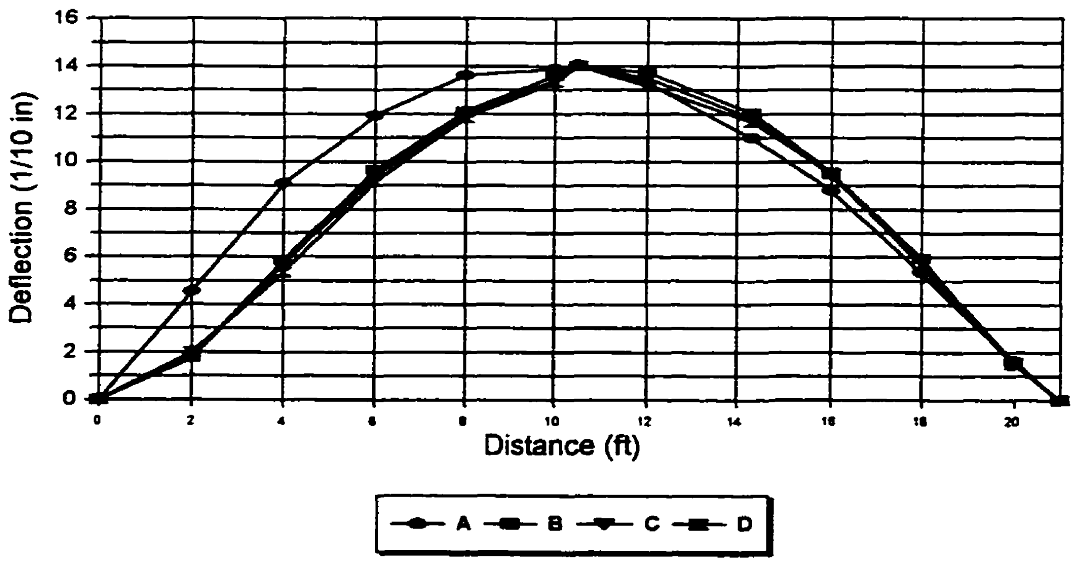

Figure 9. Post series profiles at 1.4" midpoint deflection.

The fixed end / simply supported series B and axially loaded series C and D had a different behaviour pattern between the load cell values than was found in series A. As illustrated in Fig 10 and calculated with ANOVA across all series in Appendix A2, there was no significant difference between load values within a series, or between all the series, for series B, C, and D. T-tests were conducted independently for load cell A and load cell B values at the four points of analysis with an alpha of 0.05. A significant difference was found however between series A load values and the corresponding values of series B, C, and D. An F-test conducted across all series for each load cell, using an alpha of 0.05, indicated that a difference existed between the series. This difference was confirmed between series A and each fixed end series with separate t-tests conducted at an alpha of 0.05. Table 3 lists the combined loads required to produce given midpoint deflections for all of the test series, and the percentage mean increase in loads due to the different support conditions. All of these results suggest that the most important element producing a strength or stiffness difference in the posts is the introduction of a fixed end condition.

Table 3. Combined load required for midpoint deflection (lbs).

Midpoint Deflection	Series A	B	C	D	Mean Increase (%)
0.4"	338	664	663	662	196
1.0"	753	1599	1533	1578	208
1.4"	1019	2203	2088	2162	211
2.0"	1403	3046	2909	3019	213

* Combined load of load cell A and load cell B values.

** Mean increase in load from simply supported condition to fixed end condition :

[(Mean (B-C-D)) / A] * 100

The addition of an axial load has virtually no apparent effect at the loads tested. The post profiles of series B, C, and D, in Fig. 9 graphically illustrate the stiffening effect in the splice region of the fixed end condition. The load / deflection values of series B in Fig. 11 and Fig. 10 are representative of all the fixed end series. After an initial stiffening effect of the support found in the first few feet of the post, the remaining deflection measurements are quite symmetrical about the midpoint of the post. Table 4 presents the difference in deflection of corresponding measurements along the posts of series B, C, and D at 1.4" midpoint deflection. This symmetrical relationship is true for all of the fixed end series at all four points of analysis. This symmetry may indicate that the fixed end, off-centre, spliced posts might behave in deflection as simply supported posts of shorter span.

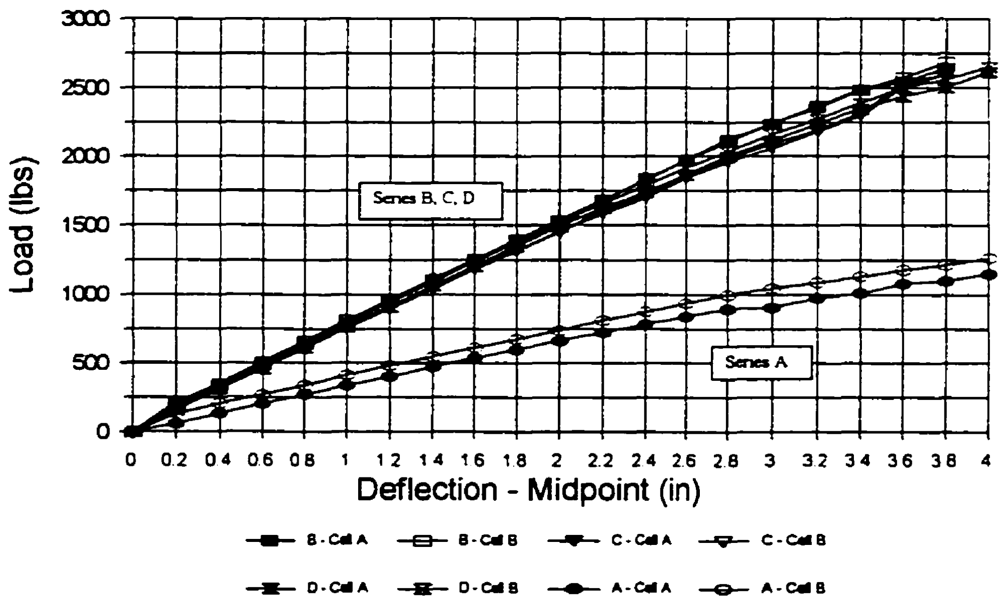

Figure 10. Fixed end series and simply supported series - load / deflection values.

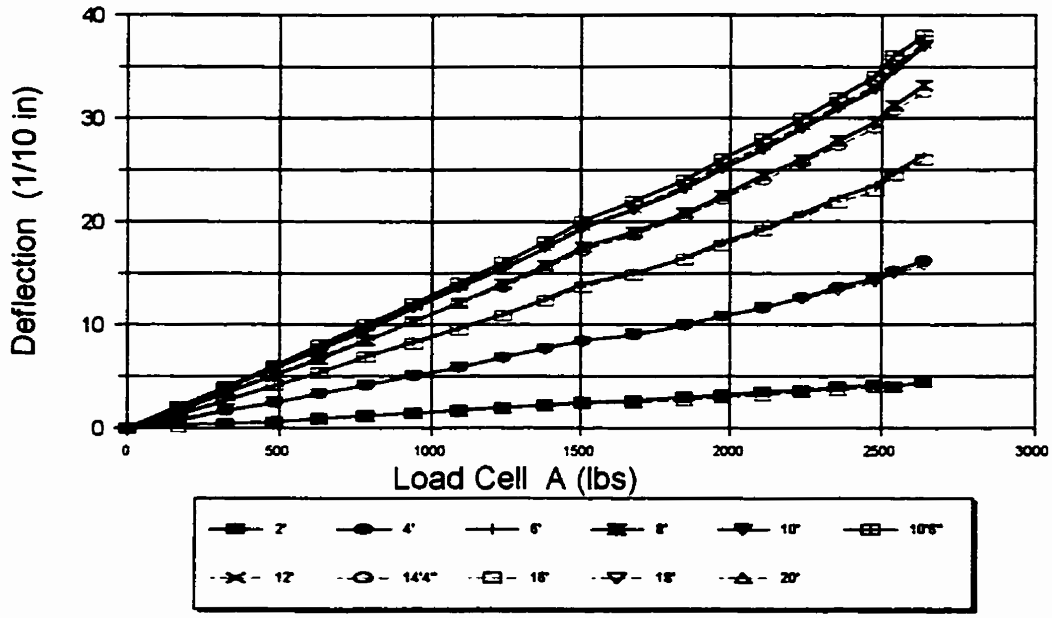

Figure 11. Fixed end series B - mean deflection vs load cell A.

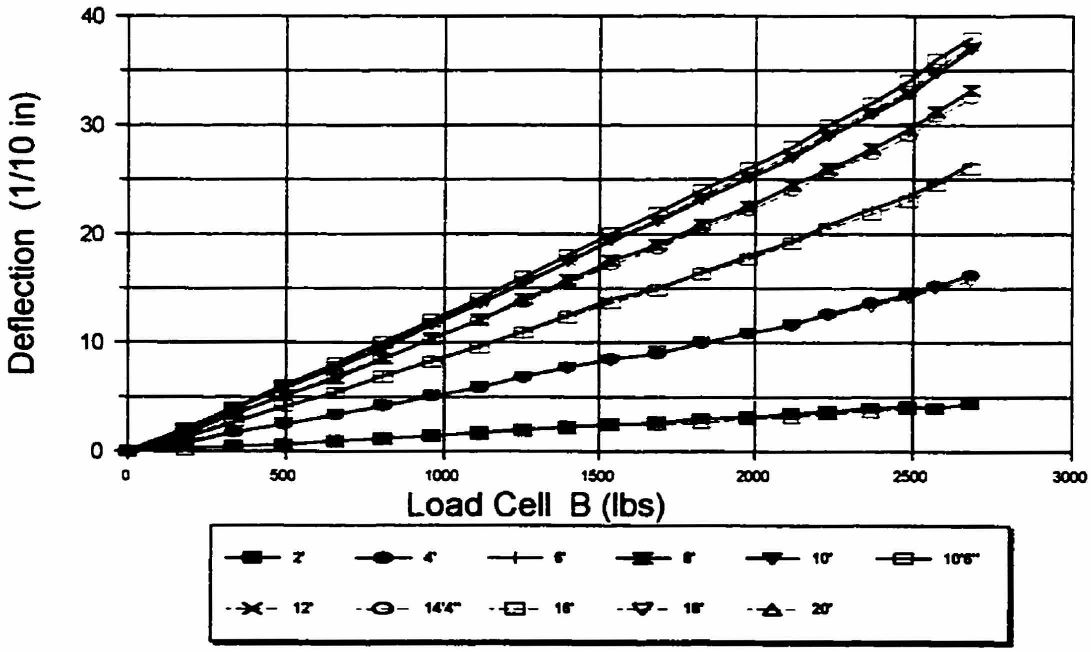

Figure 12. Fixed end series B - mean deflection vs load cell B.

Table 4. Deflection differences of corresponding measurements, series B, C, and D at 1.4" midpoint deflection (in).

Corresponding Position	Series B	Series C	Series D
2'- 20'	0.015	0.020	0.050
4' - 18'	-0.010	-0.025	-0.033
6' - 16'	0.010	0.000	-0.033
8' - 14' 4"	0.005	0.015	0.017
10' - 12'	-0.015	-0.010	0.017

The joint data are detailed in Appendix A3 and joint motion results are summarized at a midpoint deflection of 1.4" in Table 5. There were some minor differences between the series, but the primary result is that all of the fixed end condition posts showed noticeable joint motion in at least one joint when the post reached the design deflection limit. The simply supported series showed somewhat less motion at 1.4". midpoint deflection, but by 2.0", all the series A posts had shown significant joint motion as well. There was no general difference in joint performance between the axially loaded series C and D, and series B. This result, and general observations during testing, indicate that axial compression of the joints to form a tight butt joint did not occur. The predominant form of motion within the joints was rotation as illustrated in Fig. 13. This form of motion could have been restricted by clean and solid butt joints, but that quality of joint simply did not exist with any regularity in the commercially made posts that were tested. Nail slip or joint shear, as illustrated in Fig. 14, was the other form of observed motion that occurred with slightly less frequency than rotation. In approximately 5 % of the cases a distinctively predominant form of motion could not be defined and both nail slip and rotation were said to occur.

Table 5. Joint motion data summary.

Series A (8 samples*)

Total movement by 1.4 in deflection **

J1	J2	J3	J4
2 / 8	0 / 8	3 / 8	4 / 8
1 Rot[1]	0 Rot	2 Rot	2 Rot
1 NS[2]	0 NS	0 NS	2 NS

Motion distribution

J1	J2	J3	J4
22%	0	33%	44%

In total 9 / 24 joints moved = 38.00%

Rotation occurred in 5/24 joints = 21.00%
NS occurred in 3/24 joints = 12.50%
Both occurred in 1/24 joints = 4.00%

Series B, C, & D. (23 samples)

Total movement by 1.4 in deflection.

J1	J2	J3	J4
19 / 23	14 / 23	20 / 23	21 / 23
9 Rot	4 Rot	15 Rot	17 Rot
10 NS	10 NS	5 NS	0 NS

Motion distribution

J1	J2	J3	J4
26%	19%	27%	28%

In total 74 / 92 joints moved = 80.00%

Rotation occurred in 45/92 joints = 49.00%
NS occurred in 25/92 joints = 27.00%
Both occurred in 5/92 joints = 5.00%

* Sample A1 and A2 omitted due to lack of data.
** If both motions occur, motion is counted as NS.
[1] Rot refers to rotation. [2] NS refers to nail slip.

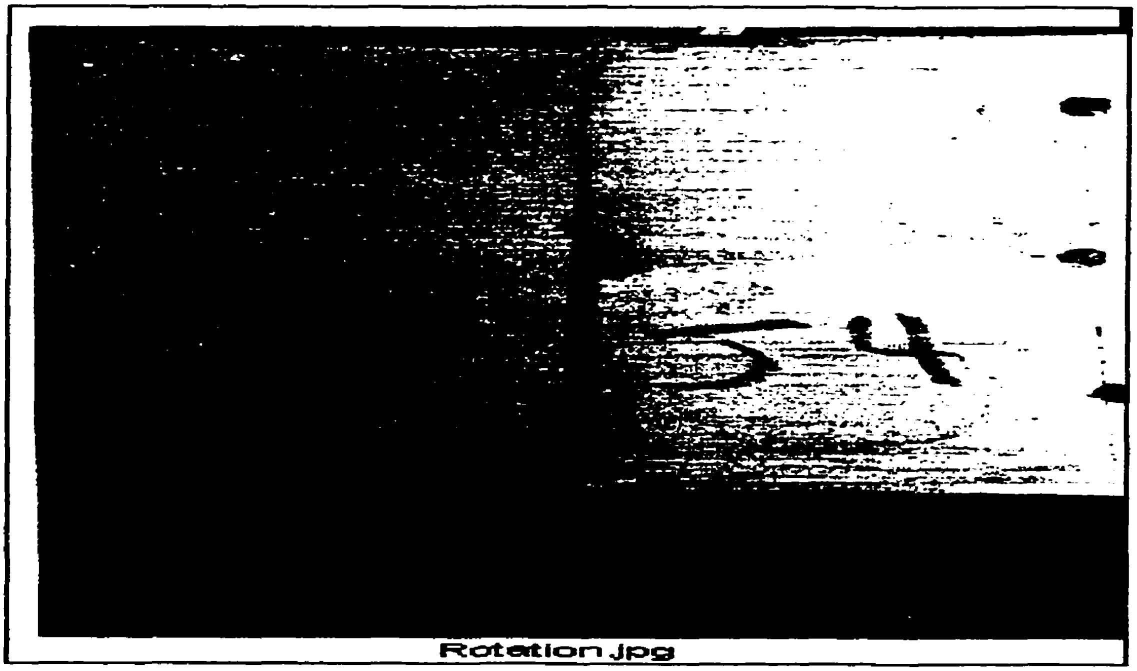

Figure 13. Example of joint motion - rotation.

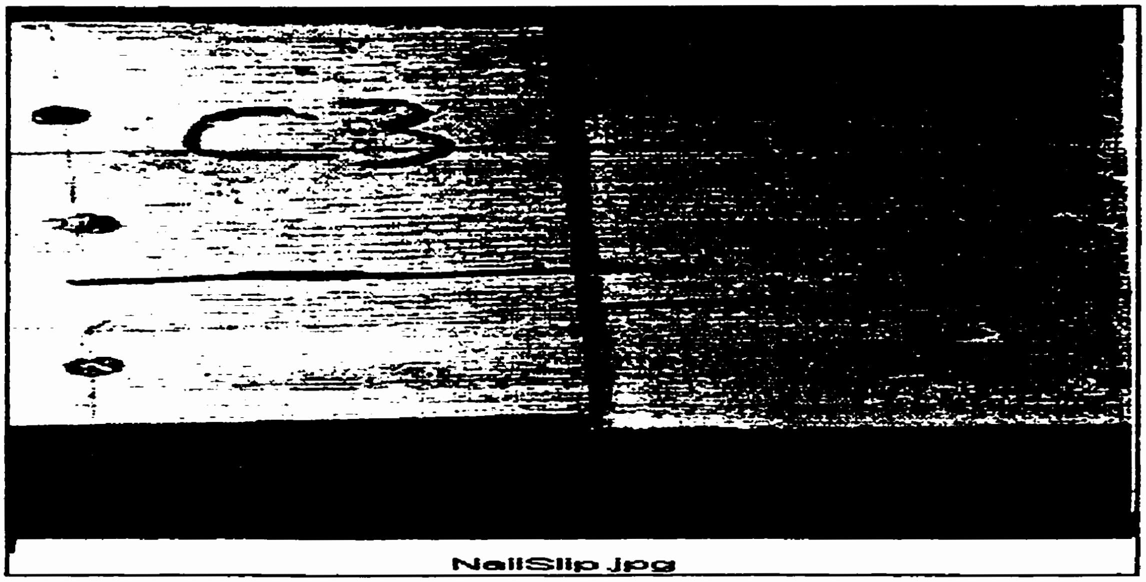

Figure 14. Example of joint motion - nail slip.

When considering individual joints, the fixed end series, as a combined set. demonstrated far more joint motion than the simply supported series. Approximately 80% of the joints in the fixed end series moved compared to about 38% of the joints in the simply supported series. This indicates that the joints of series B, C, and D, suffered higher stresses than series A, and that support conditions therefor have a major effect on joint performance. The stress distribution between the joints of a post was estimated by the statistical distribution of joint motion across the splice region - essentially, which of the joints, J1, J2, J3, or J4 moved the most often was taken to be indicative of which joint suffered the most stress. This motion distribution is presented in Table 5. Using this method, the stress distribution across the splice region was fairly even for the fixed end posts, but showed a distinct concentration of stresses towards the midpoint (J3 and J4), for the simply supported series. This concentration in the joint motion distribution correlates to the increased combination of moment and shear forces expected towards the centre of a simply supported post. The fixed end posts have a more complex feedback reaction from their fixed support, including a point of inflection between J1 and J2. This reaction serves to even out the joint stresses and to generally increase the forces present in the splice region due to the increased stiffness resulting from the fixed end support. The fixed end condition data indicates a pattern of joint motion mechanics indicative of what was expected in theory. Bending stresses, as indicated by rotation, predominate towards the centre of the post at J3 and J4, while shear stresses, indicated by nail slip, concentrate towards the fixed end at J1 and J2.

General observation of the weaker joint aberrations in the data, where nails were omitted or misplaced, (posts A9, B3, B4, and C9), does not indicate that they are particularly poor performers in comparison with other joints. The one different splice arrangement, post B10, was also not particularly outstanding from the other data in terms of joint motion or overall performance. The similarity of these accidental results with the overall results confirms the inherent variability of wooden assemblies, and suggests that the complexity of interactions within them may compensate for any minor variations in their structure.

The moisture content data (%db) are reported in Appendix A4. The moisture content mean of 16.5 %, with a standard deviation 1.9%, did not vary substantially over the four months of the test. This moisture content is within the normal range expected for this type of assembly and hence was not considered to have any unusual effect on the experiment.

Discussion

To fully understand the experimental results it is necessary to discuss the differences between the test series themselves, how the results and structural theory interrelate, and to comment on the effects of post geometry.

Inter - Test Comparisons

The two primary observations concerning the test series are the similarity of results among the fixed end posts, whether axially loaded or not, and the difference in performance of simply supported verses fixed end posts.

With no significant difference between any recorded deflection values in series B, C, and D, the addition of an axial load of up to 2000 lbs. had no effect on post performance. Although substantially less than the calculated critical column load of 43,400 lbs, (see Appendix A6), the axial load still represents a reasonable in-service load of 16 psf for a typical 60' wide building with posts 4' on centre. It was previously hypothesized that this type of loading would compress the butt joints in the splice region, and / or reduce the extreme fibre stresses in the tension side of the post. Both effects would have increased post strength, but such did not prove to be the case as there was no observable difference in post behaviour. For any joint compression to occur there would need to have been substantial deformation at the nail - wood interface for each nail along the entire length of the particular plies in question. The force required to effectively shear one ply relative to the other in the longitudinal direction would be dependant on nail number and shear capacity. Such a force would be quite substantial, and probably well beyond any design capacity of the post. The reduction of extreme fibre stress, though it may have occurred, had no observable effect, and again it may only be relevant at much higher axial loads where column instability becomes an issue.

The differences between the simply supported and fixed end conditions is immediately evident from an examination of Table 3 and Fig. 10. There is generally more than a 200% mean increase in the lateral load required to produce a desired deflection with a fixed end post when compared to a simply supported post. If the lateral loading criterion is the critical design parameter, as is suggested in the literature, then this finding has significant implications in engineering practice. To further investigate the different support conditions, they can be compared by looking at their effect on the relative stiffness of the post assemblies. Stiffness is generally defined as EI / L, where; E is the material modulus of elasticity, I is the cross section moment of inertia, and L is the exposed length of a member. A comparison of stiffness quickly becomes a comparison of the apparent E values for all the posts if other factors are held constant. The term 'apparent E value' is used to distinguish a derived value that refers to the composite assembly as a whole from the regular usage of E, which refers to a property of the material itself. The apparent E values calculated in Appendix A7 from the experimental load / deflection results are summarized in Table 6 and illustrated in Fig. 15.

Table 6. Summary of apparent E values in MPa (psi).*

	0.4 in	1.0 in	1.4 in.	2.0 in.
Series A	8689(60)	7775(54)	7506(52)	7242(50)
Series A wt [1]	4540(31)	3922(27)	3774(26)	3632(25)
Series B	7080 (49)	6834 (47)	6717 (46)	6508 (45)
Series C	7074 (49)	6552 (45)	6359 (44)	6206 (43)
Series D	7091 (49)	6766 (47)	6600 (46)	6451 (44)
Mean B,C,D	7082 (49)	6717 (46)	6559 (45)	6388 (44)
Ratio A wt / Mean	0.63	0.59	0.58	0.57

* # 2 or better S-P-F. E = 9500 MPa (65.5 psi) (CSA 1994).
[1] A wt = Series A weighted values.

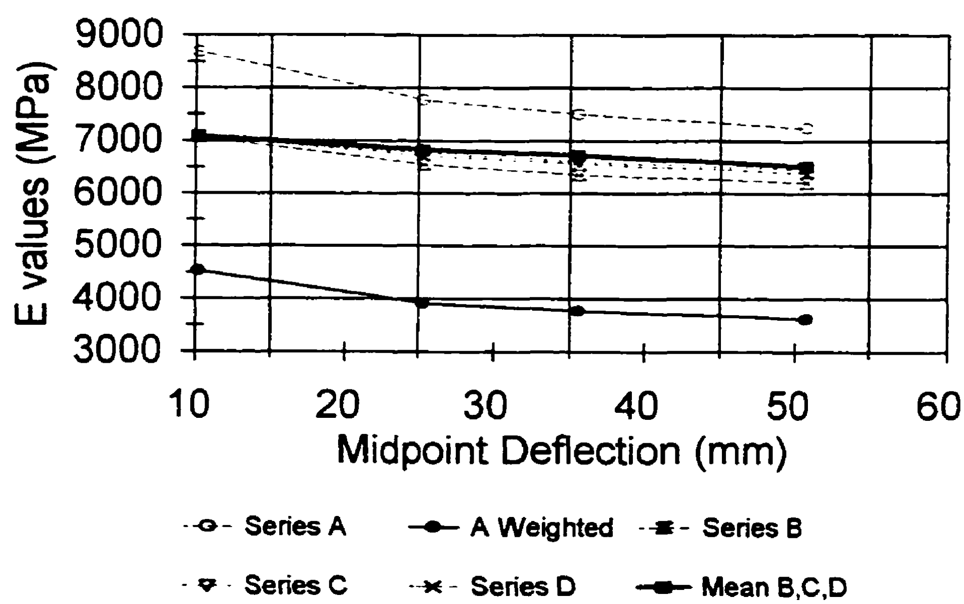

Figure 15. Calculated apparent E values.

The initial assumption for analysis was that each lateral (bending) point load, A and B, contributed equally to the midpoint deflection, and that axial loads were insignificant in effect. These assumptions worked well for the fixed end series but were not an effective simplification for the simply supported series. The testing in series A produced different values for load A and load B that were too distinct to simplify in this manner. The proportionality of the loads therefore was used to estimate each load point's contribution to a common midpoint deflection. Each load was said to produce as much of the total deflection as was its proportional contribution to the total load, regardless of its location on the beam. Load A was located over the splice region for example, but any effect from this was assumed to be insignificant. This approach was referred to as, Series A weighted. Both analysis approaches are reported in Table 6 and Fig.15 for comparison, but only the weighted analysis is used further because it is the more likely representation of reality. A ratio of series A weighted over the mean of series B, C, and D, suggests that the simply supported condition produces an assembly that is effectively only about 59% as stiff in bending as the fixed end condition. Such a result is to be expected from theory, but it confirms that the assembly behaves in a predictable manner. The significance of this result is to demonstrate again the differences between support conditions and their consequent effect on post performance. Existing design values based on simply supported testing may therefor be too conservative and may not adequately reflect the in-service capabilities of the posts.

Results vs Theory

The intentionally unsymmetrical splice region in these test series introduces a major departure from established testing procedure, where the spliced joints are expected to be wholly within the constant moment region of the post. By diverging from established practice in the effort to more closely simulate realistic conditions, it was necessary to develop a slightly different approach to facilitate analysis and develop a predictive capacity. Similar to what has been proposed in the ASAE X559 draft proposal, strength and stiffness modification factors were developed, but the ones presented here utilize a much simpler procedure. The modification factors derived are only directly applicable to the type and design of posts tested, but since these were designed by the guidelines of the above engineering practice, and built to a minimum commercial standard, the modification factors may be conservatively expanded to include other similar, if not identical, posts. The primary difference in approach from previous work was to treat the post as a single unit and not break it down into spliced and unspliced regions for analysis. Practical engineering design requirements are concerned with the ultimate performance of the post assembly as a whole and the demands of efficiency would see design values arrived at directly, in as few steps as possible. Although some precision will inevitably be lost with this simplification, it does follow the practical tenants of the in-grade testing philosophy, and produces a reasonable estimation of post behaviour.

Structural theory predictions of solid post behaviour under the different conditions tested are calculated in Appendix A8 and summarized with comparative experimental values in Table 7. These predictions are based on a solid post of similar dimensions

Table 7. Structural theory predictions and comparisons with actual values.

	Deflection at midspan from experimental loads (in).				Loads required for given midpoint deflection (lbs).			
	Analysis Points				Analysis Points			
	0.4"	1.0"	1.4"	2.0"	0.4"	1.0"	1.4"	2.0"
Simply Supported								
Predicted :	0.37	0.82	1.11	1.52	(145)(223)[2]	(415)(503)[2]	(595)(690)[2]	(872)(972)[2]
Actual (mean) :	0.4	1	1.4	2	(133)(205)	(340)(412)	(472)(547)	(663)(739)
(5 th percentile)[1]:					(89)(175)	(277)(357)	(397)(490)	(551)(652)
Ratio-Predicted /Actual								
(Mean) :	0.92	0.82	0.79	0.76	1.09 [3]	1.22 [3]	1.26 [3]	1.32 [3]
(5 th percentile mean)[1]:					1.39 [3]	1.45 [3]	1.45 [3]	1.53 [3]
Fixed End (Series B)								
Predicted :	0.30	0.72	0.99	1.37	(445)(445)[4]	(1115)(1115)[4]	(1560)(1560)[4]	(2230)(2230)[4]
Actual (mean) :	0.4	1	1.4	2	(325)(339)	(789)(810)	(1090)(1113)	(1506)(1540)
(5 th percentile mean)[1]:					(255)(300)	(668)(733)	(937)(990)	(1301)(1357)
Ratio - Predicted/Actual								
(Mean) :	0.74	0.72	0.71	0.68	1.34 [3]	1.40 [3]	1.42 [3]	1.46 [3]
(5 th percentile mean)[1]:					1.60 [3]	1.59 [3]	1.62 [3]	1.68 [3]

[1] Assumes normal distribution.
[2] (Load A)(LoadB) - predicted values maintain same difference ratio as measured mean values.
[3] Ratios calculated using mean load values of A and B.
[4] Assumes Load A = Load B

to the actual laminated posts. They use standard E values from the Joists and Planks Table 5.3.1A, S-P-F # 2 in section 086.1-94 of the NBC (CSA 1994), and they use standard beam tables found in the CWC Wood Design Manual, (1995). The prediction equations used two unequal loads located at third points along the span with the appropriate support conditions. Axial loading was ignored as it was found to be insignificant at the ranges tested and the posts essentially functioned as beams under similar restraint conditions. The ratio between predicted and actual performance forms the basis for the proposed modification factors. In Table 7, the corresponding ratios of deflection and mean load are the reciprocals of each other, and the 5 th percentiles of distribution for the experimental loads are derived values used for design purposes. The assumption of a normal distribution for this calculation may not be entirely accurate, (Madsen,1992), but it is a conservative assumption commonly used to simplify the analysis. All the ratios follow a trend that increases the distinction between the predicted and actual values with increasing midpoint deflection. This inaccuracy of prediction is explained by the decreasing of apparent E values with increasing midpoint deflection evident in Fig.15. The posts become proportionately less stiff as they continue to be loaded, probable due to local crushing of the wood around the nails with a consequent loss in holding power. For design purposes it is prudent to work from the weakest condition encountered, which in this experiment occurs at a midpoint deflection of 2.0" in all cases, so this is the ratio used to develop the modifiers. The deflection and load modification factors, summarized on Table 8, are simply the ratios of predicted to actual performance converted to an appropriate multiplier that can be applied to the structural beam table prediction equations.

Table 8. Deflection and load modifiers for tested posts using standard beam tables.

	Deflection	Load Capacity [1]
Simply supported :	1.32	0.65
Fixed End :	1.46	0.60

[1] Based on 5th percentile design loads.

The modifiers, are used as follows:

(Beam table predicted deflection) x (Deflection modifier) = (Actual deflection)

(Beam table predicted load capacity)

x (Load capacity modifier) = (Actual load capacity)

Simple beam theory anticipates an increase in load carrying capacity resulting from the fixed end condition over the simply supported condition. The comparison of total predicted and total actual loads, summarized in Table 9, indicates a more than two-fold increase in capacity that corroborates the direct link between simple beam theory and actual post behaviour.

Table 9. Bending load comparison between simply supported and fixed end posts using predicted and actual values.

	Analysis Points			
	0.4 in	**1.0 in**	**1.4 in**	**2.0 in**
Simply Supported				
Predicted (lbs)* :	368	918	1286	1844
Actual (lbs)** :	338	753	1019	1403
Fixed End* **				
Predicted (lbs)* :	890	2230	3120	4460
Actual (lbs)** :	664	1599	2203	3046
Ratio (FE / SS) :				
Predicted :	2.42	2.43	2.43	2.42
Actual :	1.96	2.12	2.16	2.17

*Total of loads A and B. Assumes solid wood section with E = 9500 Mpa (65.5 psi).
** Total of loads A and B, mean values.
*** Series B

The consistency of the comparison to the second decimal place is evident at the greater levels of midpoint deflection which are of greatest concern for design purposes. The actual magnitude of the capacity increase is less for the tested assemblies than theory would suggest. This could be due to the inherent weakness of a spliced post, and the fact that the fixed end condition has its greatest effect towards the base of the post where the offset splice region is located. The predicted values assume a solid, "full size", and continuous cross section, while the actual post is effectively only a 3/4 size section at each joint due to a discontinuity in one lamination. The influence of these four points of weakness may account for some of the difference between predicted and actual values, and it may also account for the restricted increase in actual post capacity between the simply supported and fixed end conditions. The difference between actual and predicted values appears to be consistent however, and the spread between them can be accounted for effectively with a simple modification factor. For posts of standard design under normal conditions then, the beam tables appear to be useable with a modification factor to directly predict post behaviour for design purposes in the critical deflection ranges with some degree of confidence.

Post Geometry

Post geometry includes a general discussion about joint motion and nail pattern, splice location effects, and the variability of the posts themselves.

The fact that virtually all of the posts showed joint motion by the design deflection limit is of significant concern. Although not investigated, such motion must involve localized wood fibre crushing, the enlarging of nail holes, and the progressive weakening of the joints, as indicated by the decreasing relative stiffness of the assembly under increasing deflection. Repetitive loading conditions, as would exist under service conditions, could only exacerbate this problem. The nail pattern tested, although perhaps not optimum, was still within reasonable design limits, yet it proved ineffective at preventing joint motion. A possible remedy for this situation, would be to reinforce all the joints with a greater nail density or perhaps with supplementary adhesive. Nail density has an upper limit, and the use of adhesive, either locally at each joint or throughout the splice region, may be the most effective option for improving performance. Adhesive might be most practically used in a prefabrication scenario, as a field application of it could prove difficult. A nail pattern that emphasizes the placing of nails in double shear across each particular joint, something that was not done in this work , would probably have increased the resistive capacity of the joints to some extent but it might have only a limited effect on post performance. Only the interior joints, (J2 and J3), would benefit from this arrangement, while the outer joints, (J1 and J4), would see no benefit at all because they cannot be created with nails in double shear. Examination of the data indicates that motion in either of these outer joints occurred in most of the posts tested, and hence the post as a whole would still suffer some joint motion.

The offsetting of the splice region that occurred in these experiments had a moderating effect on the forces acting on the joints. By moving the joints away from the region of maximum moment there is an effective increase in the capacity of the post as a whole, if the splices are rightly considered to be the weakest section of the post assembly. For the fixed end condition, the offset position allows the splice region to straddle a point of stress inflection theoretically located at approximately the 4' mark, between J1 and J2. Observation of the counter rotations in joint J1 and J2 support this theoretical location. By straddling a point of inflection, the set of joints themselves are subjected to a minimum of bending moment while the maximum moment occurs at the unspliced base of the post. For the simply supported condition, the offset position moves the splice region away from the maximum moment occurring at centre span. The offsetting does move the joints into a region of greater shearing forces, but shear is easier for the joints to deal with than moment forces. In shear, all nails in the affected region, including those on the central axis, will contribute their maximum resistance, whereas such is not the case in bending.

The variations in post geometry, such as warping, joint gaps, different nail patterns, different splice patterns, and other minor differences across all the samples did not produce any marked effect on the results. These minimum quality posts produced highly consistent results in virtually all areas of analysis. An explanation for this behaviour may be that these types of composite assemblies suffer complex stress distributions within themselves that result in a very consistent, averaged, external performance for the assembly as a whole. This consistency of results has been evident in previous research that utilized specially made posts, but it is significant to note that the results are also resilient to the effects of the many uncontrollable variables inherent in a commercially made post.

Conclusion

This experiment has taken another step in the analysis of mechanically laminated, spliced timber posts. After utilizing previous research to design and build commercial quality posts, it investigated their behaviour under a simulation of in-service conditions. The experiment introduced an unsymmetrical splice region and a fixed end condition, in addition to the usual simply supported testing procedure. No unspliced posts were tested. The posts were loaded in two point bending with moderate axial loads added in later test series. Force / deflection data were recorded and compared across support conditions and across axial loads. Joint motion data were collected and commented on in a qualitative manner. Data analysis connected the results with structural theory and developed a simplified procedure for predicting post performance under similar conditions. Based on the tests conducted, the following conclusions were reached:

1. Support conditions have a significant effect on post strength and realistic testing procedures are imperative to producing accurate design values. Fixed end verses simply supported conditions produced more than a 100% increase in resistive capacity.

2. Results indicate that current design values based on simply supported conditions are overly conservative.

3. Axial loading to a moderate level has little or no effect on post performance, and bending load capacity is the primary design parameter. Axial loading did not compress the butt joints or increase the strength of the splice region in any discernable way.

4. Some joint motion will invariably occur by the design deflection limit under fixed end conditions, even with a reasonably well designed nail pattern. With the given splice pattern, all joints showed a propensity to move and should be reinforced.

5. Standard structural theory can be simply adjusted with experimentally derived values to produce acceptable design values regarding the strength and deflection

performance of the posts. These modifiers can be conservatively applied beyond this test series to other posts of similar design and size.

6. Commercially produced post assemblies produced highly consistent results.

7. The practical in-grade testing philosophy of testing actual commercial products and assemblies, as produced, under realistic conditions, is appropriate and effective for testing this type of assembly.

Research Recommendations

This experiment challenged some existing assumptions and explored new procedures in the investigation of timber post behaviour. In doing so however, like all research, it invites still more questions and because of its uniqueness, requires further validation of its own procedures. Recommendations for continuing research would be:

1. Further testing of the same 4-ply, 2 x 8, posts at different lengths to obtain basic data and to validate the predictive capacity of 'the beam table equations with modifiers' approach.

2. Test full length, unspliced posts using finger-jointed lumber and compare the results with spliced values.

3. Increase the axial load significantly and investigate the effects on post performance.

4. Reduce the number of posts per test to three from the original ten. Statistical requirements not withstanding, the results were so consistent that much time and effort could be saved in the repetitive depth of a test series and invested into further new test series.

5. Limit deflection data collection to the midpoint only. Other measurement points along the post proportionately reflected midpoint motion and give a dynamic picture of the post during testing, but they are not required for further analysis.

6. Test other designs and sizes of posts for comparison purposes and to develop other modifiers.

7. Investigate the performance of joint reinforcement effects under realistic support conditions. The use of adhesives on each joint or throughout the splice region should be investigated.

8. Investigate the effects of cyclic loading on post performance and joint behaviour.

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Appendix A - Data and Analysis

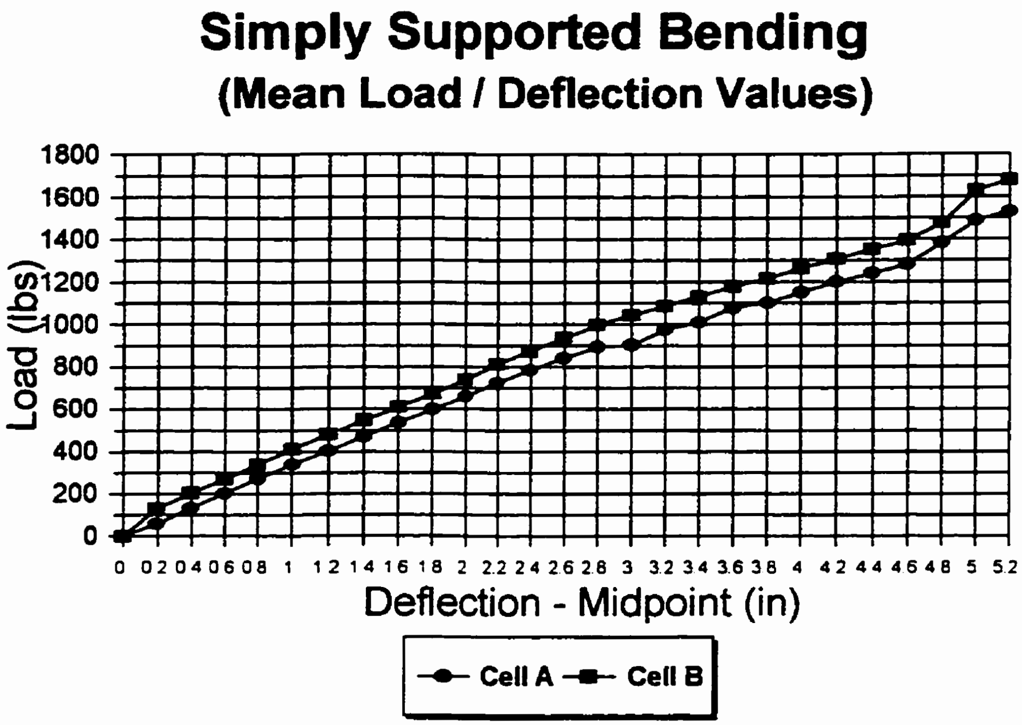


Figure A1 Series A - Measured load deflection values.

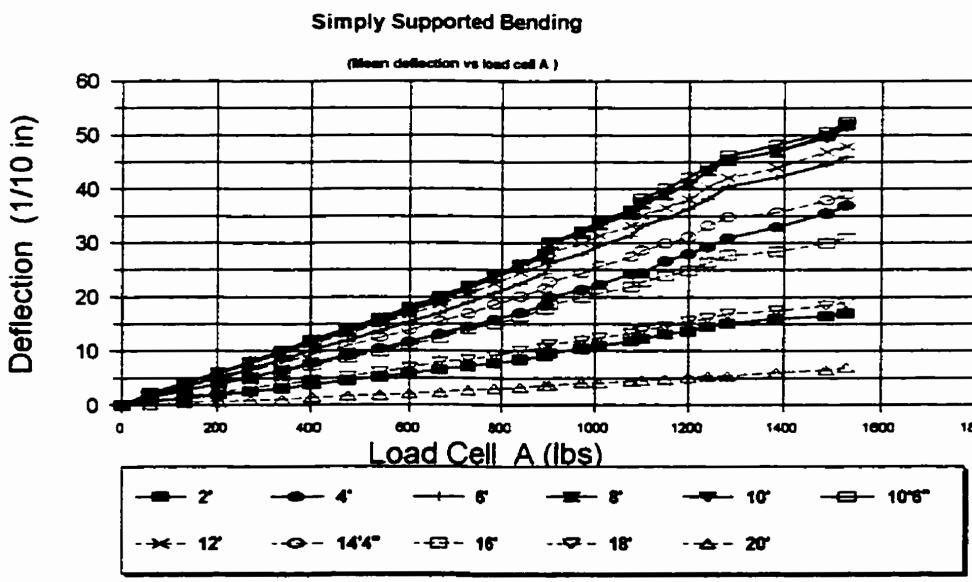


Figure A2 Series A - Measured deflection vs load cell A values.

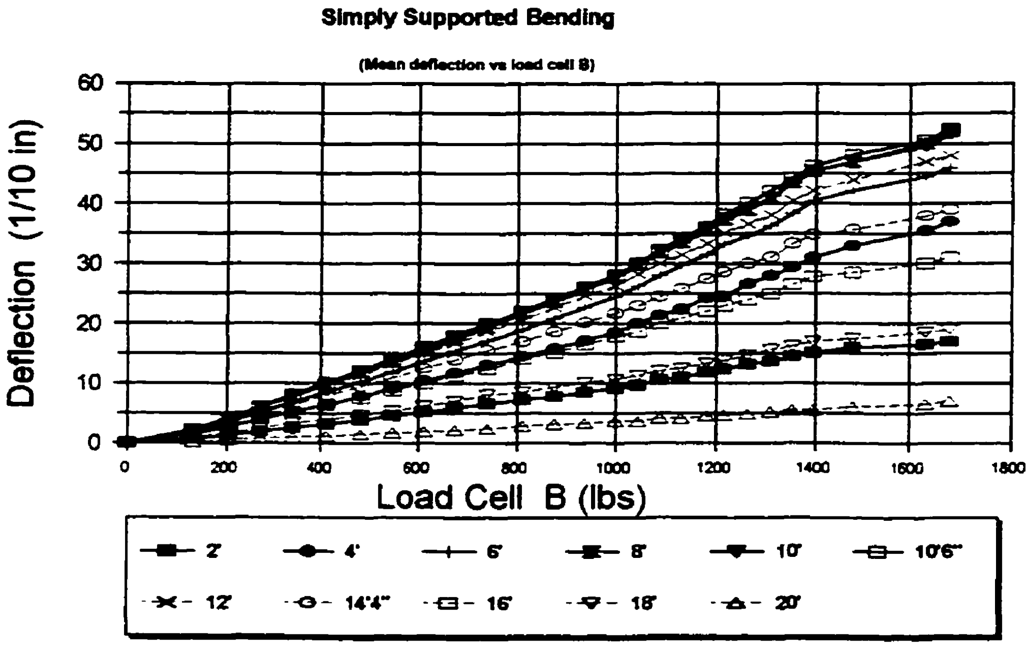


Figure A3 Series A - Measured deflection vs load cell B values.

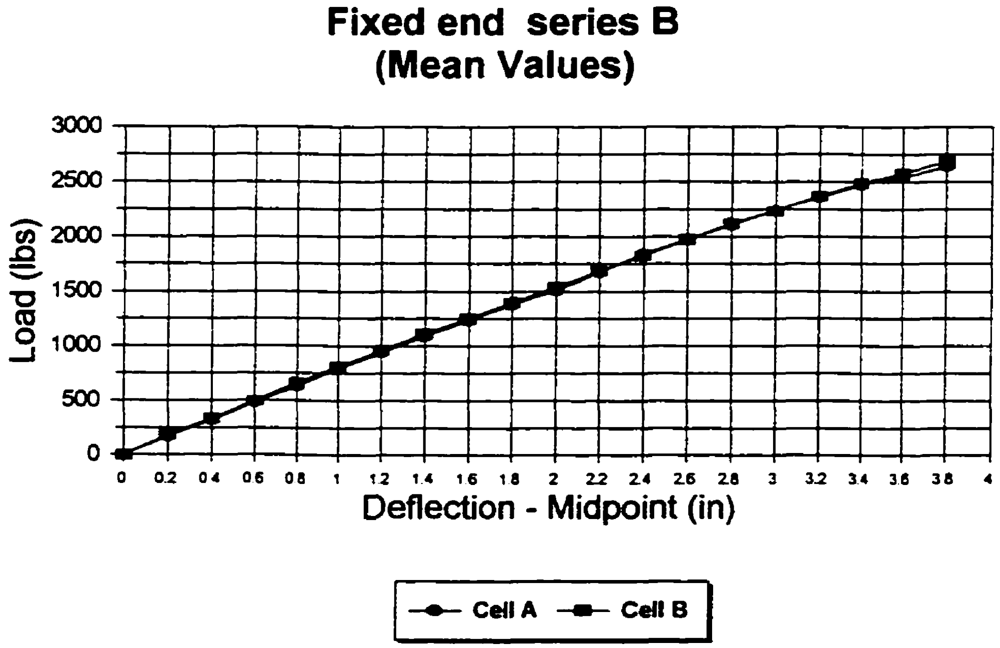


Figure A4 Series B - Measured load deflection values.

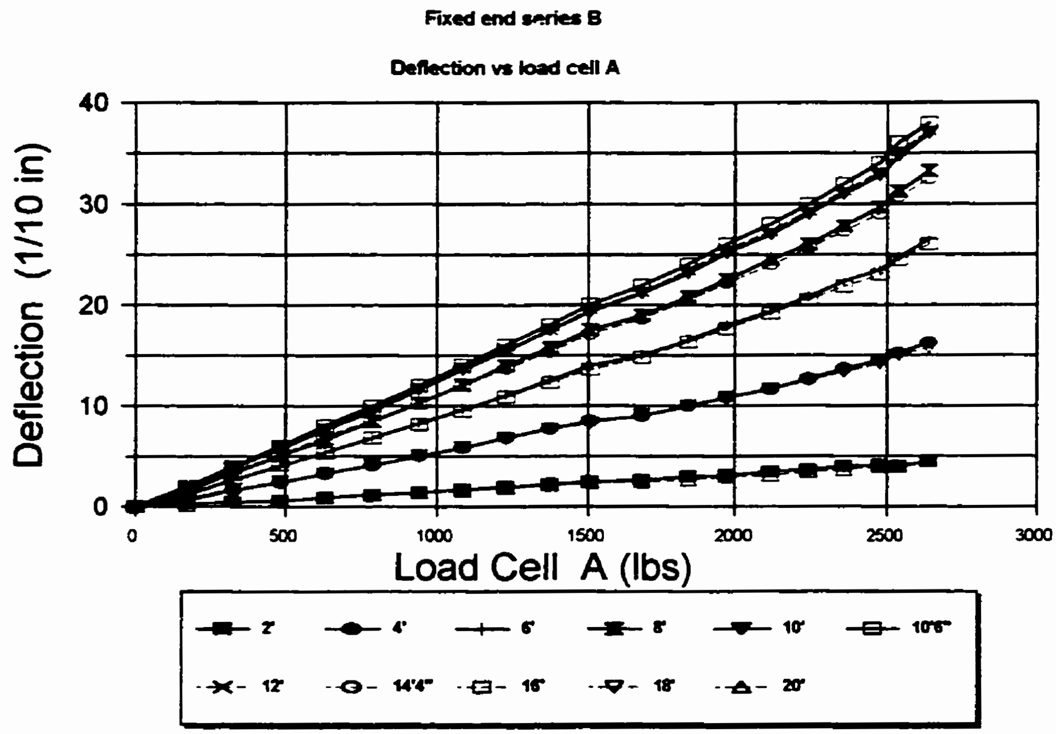


Figure A5 Series B - Measured deflection vs load cell A.

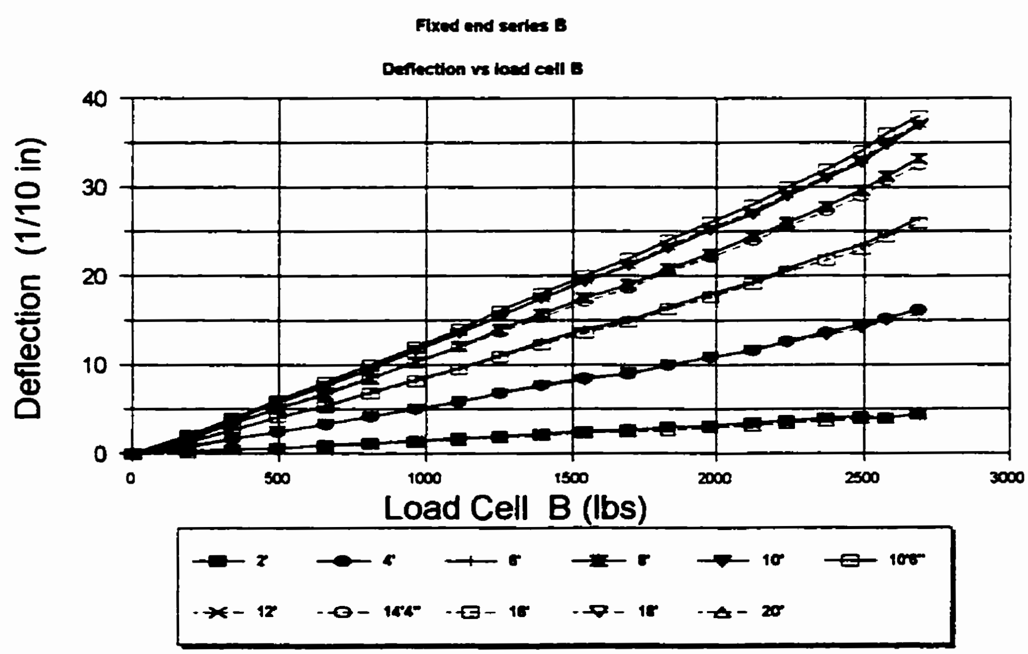


Figure A6 Series B - Measured deflection vs load cell B values.

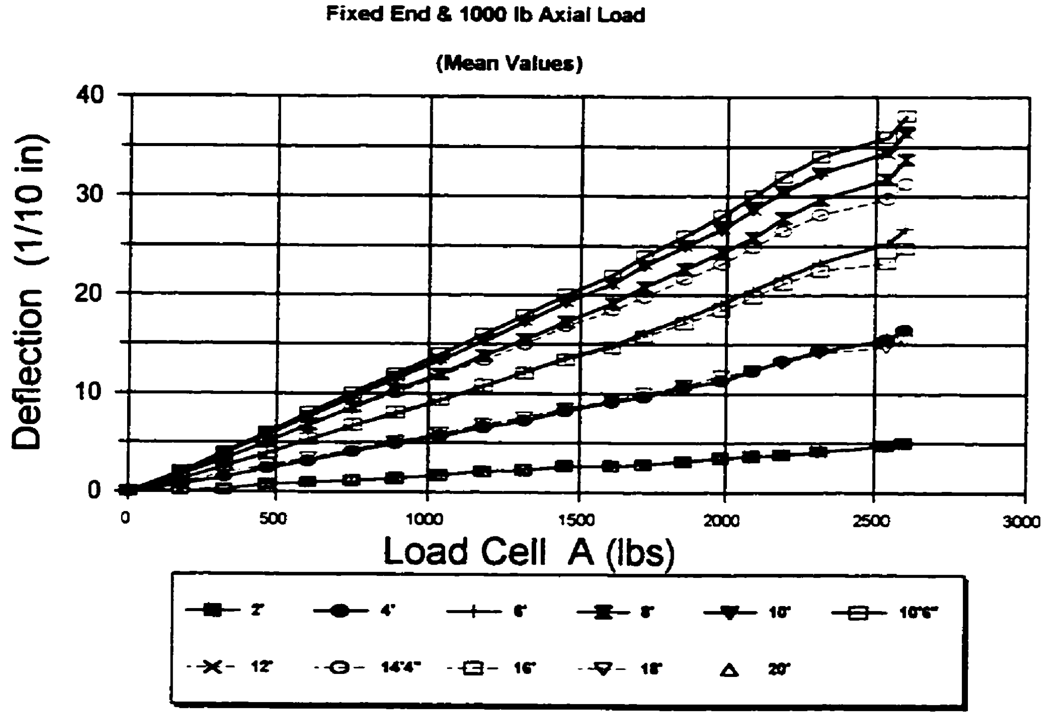


Figure A7 Series C - Measured deflection vs load cell A.

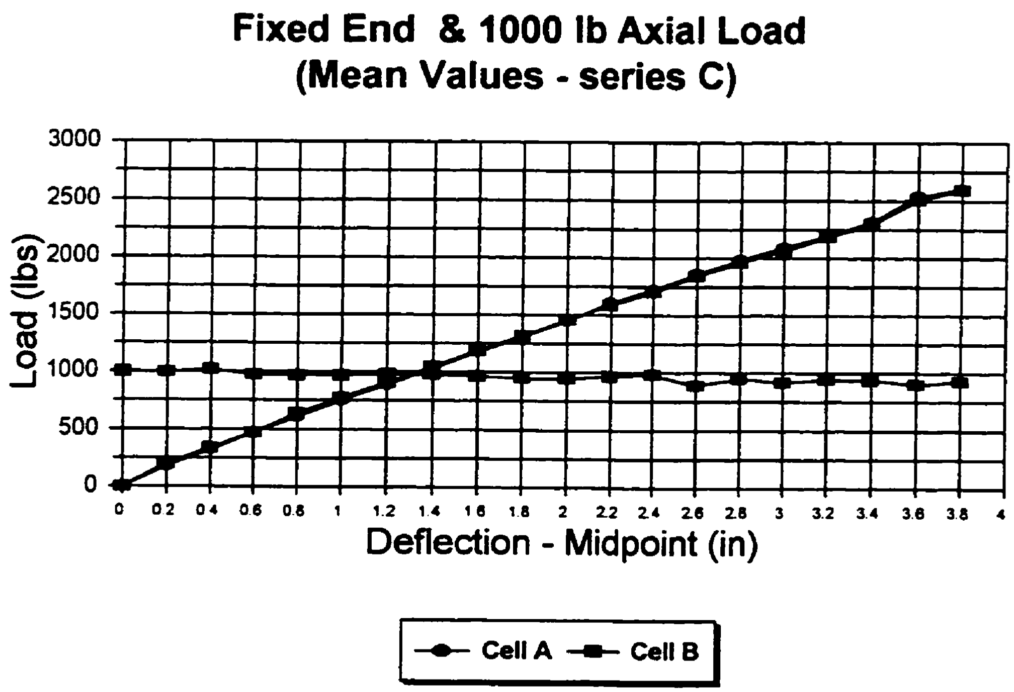


Figure A8 Series C - Measures load / deflection values.

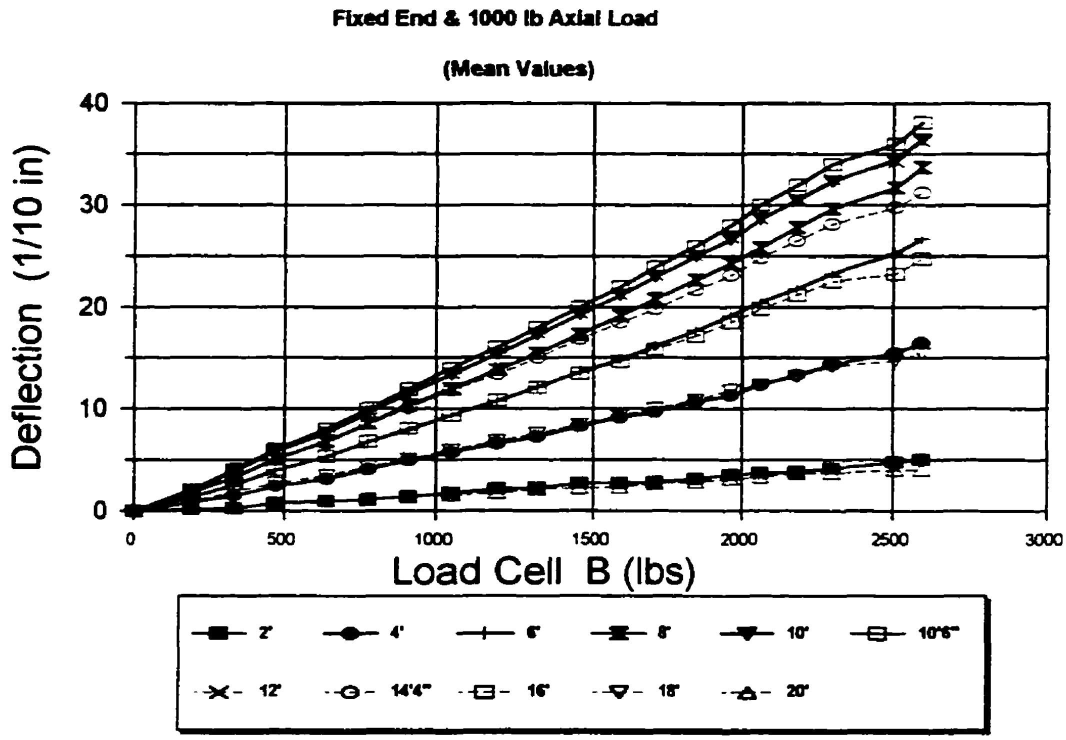


Figure A9 Series C - Measured deflection vs load cell B.

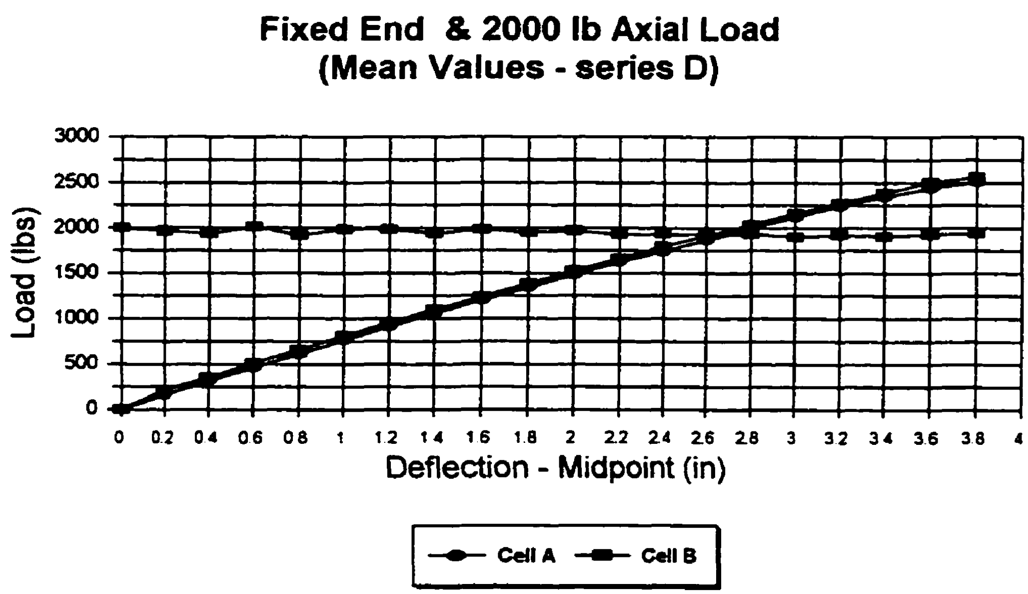


Figure A10 Series D - Measured load / deflection values.

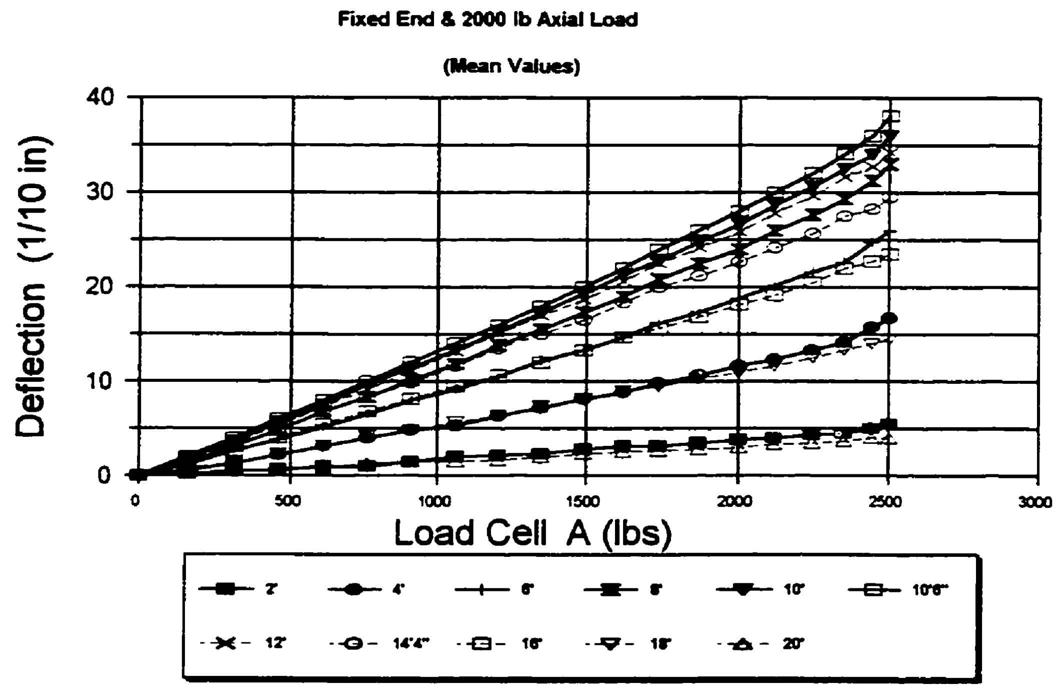


Figure A11 Series D - Measured deflection vs load cell A.

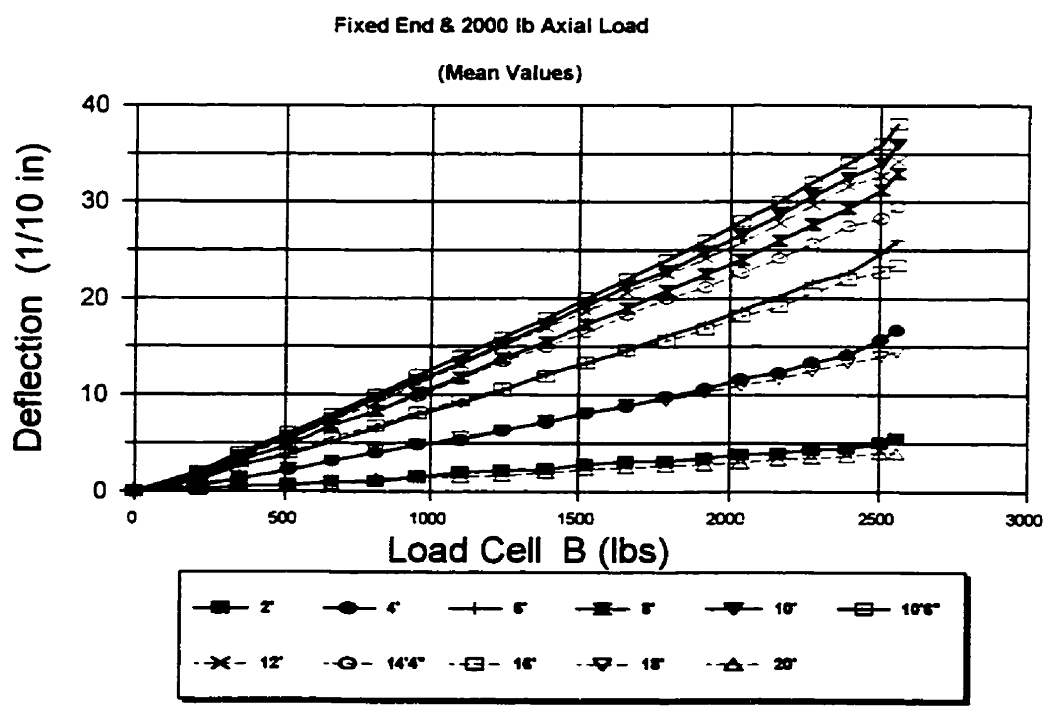


Figure A12 Series D - Measured deflection vs load cell B.

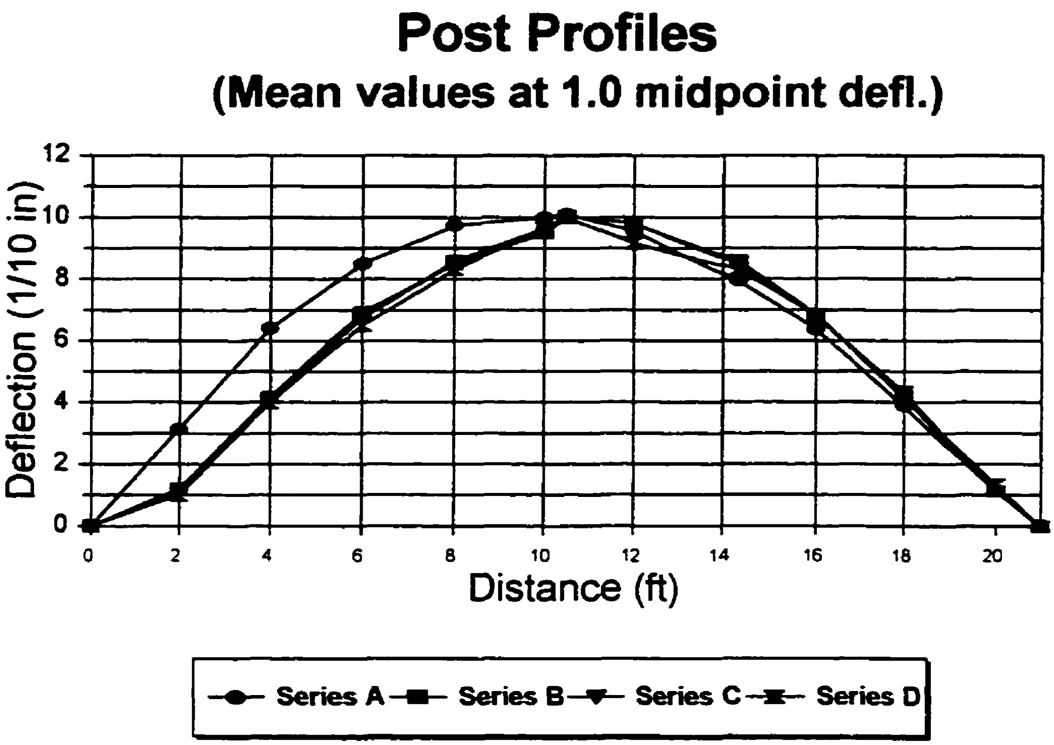


Figure A13 Composite series - post profiles at 1.0" midpoint deflection.

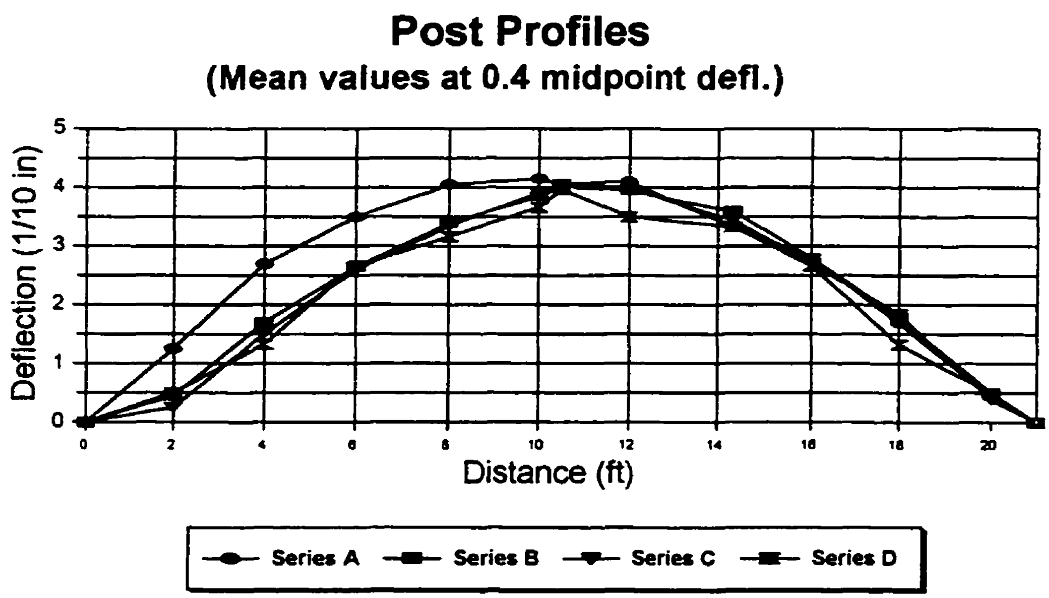


Figure A14 Composite of series - post profile at 0.4" midpoint deflection.

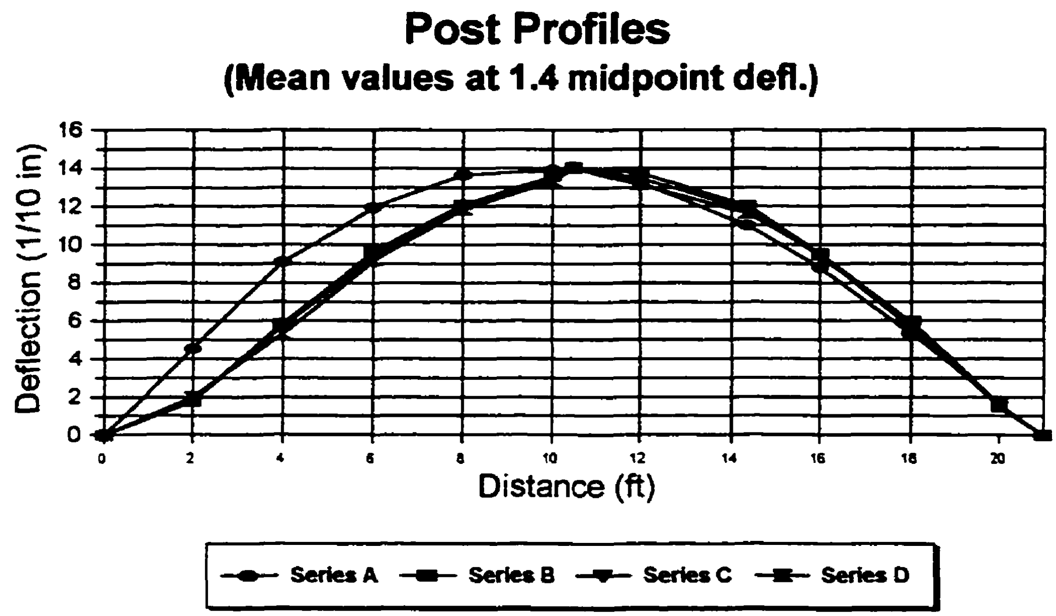


Figure A15 Composite series - post profiles at 1.4" midpoint deflection.

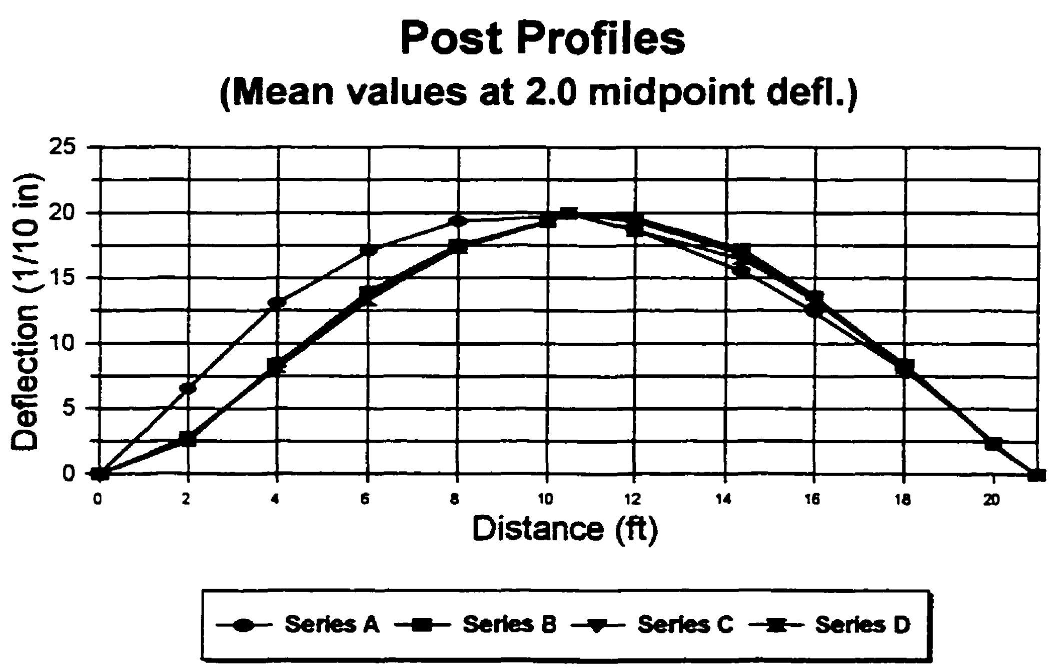


Figure A16 Composite series - post profiles at 2.0" midpoint deflection.

Statistics on Selected Displacements of A Series

Reading # 3 Delta = 0.4"

Test #	Load lbs A	(Delayed) lbs B	Deflection (Cor. from Initial) 2'	Units : 1/16 " 4'	6'	8'	10'	10'8"	12'	14'4"	16'	18'	20'
A1	188.00	208.00	1.00	3.00	3.50	4.00	4.50	4.10	4.00	3.50	2.50	1.50	0.50
A2	103.00	200.00	1.00	2.50	3.50	4.00	4.00	4.10	4.00	3.00	4.00	2.00	0.50
A3	160.00	237.00	1.50	3.50	4.00	5.00	4.50	4.20	5.00	3.50	3.00	2.00	1.00
A4	147.00	211.00	1.50	3.50	4.50	4.50	6.50	4.10	5.00	4.00	3.00	2.00	1.00
A5	128.00	193.00	1.50	2.50	3.50	4.00	4.00	4.10	4.00	3.50	2.00	1.50	0.00
A6	86.00	171.00	1.00	2.00	3.00	3.50	3.50	3.80	3.50	2.50	2.00	1.50	0.00
A7	130.00	197.00	1.00	2.50	3.50	3.50	4.00	4.10	4.00	3.50	3.50	2.00	0.50
A8	143.00	218.00	1.00	2.00	3.00	3.50	4.00	4.10	4.00	3.50	2.00	1.00	0.50
A9	112.00	184.00	1.50	2.50	3.00	4.00	3.50	4.00	3.50	2.50	2.50	1.50	0.00
A10	136.00	219.00	1.50	3.00	3.50	4.50	4.00	4.00	4.00	4.00	3.50	2.00	0.50
Mean	133.10	205.00	1.25	2.70	3.50	4.06	4.15	4.08	4.10	3.36	2.80	1.70	0.45
St. Dev	28.74	18.19	0.26	0.54	0.47	0.50	0.58	0.11	0.52	0.53	0.71	0.35	0.37
5 th %	85.80	174.89											
SE(Mean)	8.45	5.75	0.08	0.17	0.15	0.16	0.18	0.03	0.16	0.17	0.23	0.11	0.12
Coef. Var.	20.08	8.87	21.08	19.81	13.47	12.28	13.87	2.66	12.80	15.81	25.53	20.56	81.98

Reading # 6 Delta = 1.0"

Test #	Load lbs A	(Delayed) lbs B	Deflection (Cor. from Initial) 2'	Units : 1/16 " 4'	6'	8'	10'	10'8"	12'	14'4"	16'	18'	20'
A1	404.00	430.00	3.00	6.50	8.50	10.00	10.00	10.30	9.50	8.00	6.50	4.00	1.00
A2	315.00	401.00	3.00	6.00	9.00	10.00	10.00	10.10	10.00	8.00	7.20	4.00	1.50
A3	380.00	448.00	3.00	7.00	8.00	10.50	10.50	10.40	10.50	8.00	7.00	4.00	2.00
A4	382.00	435.00	3.50	7.50	8.50	10.50	11.50	10.10	10.50	9.00	6.50	4.50	1.50
A5	344.00	410.00	3.50	6.50	8.50	10.00	10.00	10.10	9.50	8.00	6.00	3.50	0.50
A6	286.00	365.00	3.00	5.50	7.50	9.00	9.00	9.80	8.50	7.00	5.50	3.50	1.00
A7	336.00	398.00	3.00	6.00	8.50	9.50	10.00	10.10	9.50	8.00	7.00	4.50	1.00
A8	358.00	412.00	3.00	6.00	7.50	9.50	9.50	10.10	9.00	7.50	5.50	3.50	1.00
A9	300.00	370.00	3.00	6.50	8.50	9.50	9.50	10.00	9.00	7.50	6.00	3.50	1.00
A10	382.00	483.00	3.50	6.50	8.50	10.00	10.00	10.00	9.50	8.50	6.50	4.00	1.00
Mean	340.70	412.00	3.15	6.40	8.50	9.75	10.00	10.10	9.55	7.95	6.37	3.90	1.15
St. Dev	38.75	33.24	0.24	0.57	0.62	0.63	0.67	0.16	0.64	0.55	0.61	0.39	0.41
5 th %	276.78	357.15											
SE(Mean)	12.25	10.51	0.08	0.18	0.20	0.20	0.21	0.05	0.20	0.17	0.19	0.12	0.13
Coef. Var.	11.37	8.07	7.67	8.87	7.34	6.51	6.67	1.62	6.74	6.92	9.54	10.11	35.79

Reading # 8 Delta = 1.4"

Test #	Load lbs A	(Delayed) lbs B	Deflection (Cor. from Initial) 2'	Units : 1/16 " 4'	6'	8'	10'	10'8"	12'	14'4"	16'	18'	20'
A1	485.00	561.00	4.50	9.00	12.00	13.50	14.00	14.00	13.00	11.00	8.50	5.00	1.50
A2	442.00	542.00	4.50	9.00	12.50	14.00	14.00	14.10	13.50	11.00	10.00	5.50	2.00
A3	487.00	581.00	4.50	9.50	12.00	14.50	14.50	14.30	14.00	11.00	9.00	5.50	2.00
A4	509.00	589.00	5.00	10.00	13.00	14.50	15.50	14.10	14.50	12.00	9.00	6.00	2.00
A5	484.00	562.00	5.00	9.00	12.00	13.50	14.00	14.10	13.50	11.00	8.50	5.00	1.00
A6	380.00	483.00	4.50	8.50	11.50	13.00	13.00	14.00	12.50	10.00	7.50	6.00	1.50
A7	480.00	538.00	4.00	9.00	11.50	13.00	13.50	14.10	13.00	11.50	9.50	6.00	2.00
A8	486.00	546.00	4.00	8.00	10.50	12.50	13.00	14.10	12.50	10.50	8.00	5.00	1.50
A9	426.00	502.00	4.50	8.50	12.00	13.50	13.50	14.00	13.00	10.50	8.50	5.00	1.50
A10	537.00	588.00	5.00	9.50	12.50	14.50	14.00	14.10	13.50	11.50	9.50	6.50	1.50
Mean	471.50	547.20	4.55	9.10	11.95	13.65	13.90	14.09	13.30	11.00	8.80	5.35	1.65
St. Dev	45.56	34.75	0.37	0.57	0.69	0.71	0.74	0.09	0.63	0.58	0.75	0.41	0.34
5 th %	396.32	489.86											
SE(Mean)	14.41	10.99	0.12	0.18	0.22	0.22	0.23	0.03	0.20	0.18	0.24	0.13	0.11
Coef. Var.	9.66	6.35	8.11	6.24	5.73	5.19	5.31	0.62	4.76	5.25	8.56	7.69	20.45

Reading # 11 Delta = 2.0"

Test #	Load lbs A	(Delayed) lbs B	Deflection (Cor. from Initial) 2'	Units : 1/16 " 4'	6'	8'	10'	10'8"	12'	14'4"	16'	18'	20'
A1	[illegible]	738.00	7.00	13.00	17.00	19.00	19.50	19.80	18.00	15.50	12.50	7.50	2.50
A2	630.00	739.00	6.50	13.00	18.00	20.00	20.00	20.10	19.00	16.00	14.00	8.00	2.50
A3	[illegible]	784.00	6.00	13.50	17.50	20.00	20.50	20.30	19.50	15.50	12.50	7.50	3.00
A4	727.00	791.00	7.00	14.00	18.00	20.00	21.00	20.10	20.00	16.50	12.50	8.00	3.00
A5	680.00	751.00	7.00	13.00	17.00	19.50	19.50	20.10	19.00	16.50	12.00	7.50	2.00
A6	636.00	624.00	6.50	12.50	16.50	18.50	18.50	19.90	17.50	14.00	11.00	7.00	2.00
A7	631.00	723.00	6.00	13.06	17.00	19.00	19.50	20.10	18.50	16.00	13.00	8.00	2.50
A8	703.00	745.00	6.00	12.00	16.56	18.00	19.00	20.10	18.00	15.00	11.50	7.00	2.00
A9	680.00	691.00	6.50	13.50	17.00	19.50	19.50	20.00	19.50	15.00	12.00	12.20	2.00
A10	788.00	808.00	7.00	13.50	17.50	20.50	20.00	20.10	19.00	18.50	13.00	8.00	2.50
Mean	683.20	738.30	6.55	13.11	17.11	19.40	19.70	20.07	18.70	15.55	12.40	8.07	2.40
St. Dev	69.43	52.80	0.44	0.57	0.73	0.77	0.71	0.12	0.75	0.76	0.84	1.50	0.39
5 th %	560.29	652.02											
SE(Mean)	21.64	16.73	0.14	0.18	0.23	0.24	0.23	0.04	0.24	0.24	0.27	0.48	0.12
Coef. Var.	10.32	7.15	6.69	4.33	4.24	3.98	3.63	0.59	4.03	4.90	6.80	18.83	16.43

Statistics on Selected Displacements of B Series

Reading # 3 Delta = 0.4"

Test #	Load lbs A	(Delayed) lbs B	Deflection (Cor. from initial) Units : 1/10 " 2'	4'	6'	8'	10'	10'6"	12'	14'4"	16'	18'	20'
B1	355.00	341.00	0.50	1.50	2.50	3.50	4.00	3.90	4.00	3.50	2.50	1.50	0.50
B2	325.00	330.00	0.50	1.50	3.00	3.50	4.00	4.00	3.50	3.50	3.00	1.50	0.50
B3	304.00	358.00	0.50	1.50	2.50	3.00	3.50	4.10	4.00	3.00	2.50	1.50	0.50
B4	244.00	303.00	0.50	2.50	3.00	3.50	4.00	4.10	4.00	3.50	3.00	1.50	0.50
B5	382.00	338.00	0.50	1.50	2.50	3.50	3.50	4.20	4.00	4.00	2.50	1.50	0.50
B6	288.00	319.00	0.50	1.50	2.50	3.00	4.00	4.30	3.50	3.50	2.50	2.00	0.50
B7	351.00	383.00	0.50	2.00	2.50	3.50	4.00	3.80	4.00	4.00	3.00	1.50	0.50
B8	310.00	353.00	0.00	1.50	2.50	3.00	3.50	4.30	3.50	3.50	2.50	2.00	0.50
B9	314.00	322.00	0.50	1.50	2.50	3.50	3.50	3.80	4.00	3.50	3.00	2.00	0.50
B10	379.00	338.00	0.50	2.00	3.00	4.00	4.50	4.00	5.00	4.00	1.50	3.00	0.50
Mean	325.20	338.10	0.45	1.70	2.65	3.40	3.85	4.01	3.95	3.60	2.60	1.80	0.50
St. Dev	42.76	23.48	0.16	0.35	0.24	0.32	0.34	0.10	0.44	0.32	0.35	0.48	0.00
5 th %	254.86	300.48											
SE(Mean)	13.52	7.42	0.05	0.11	0.08	0.10	0.11	0.03	0.14	0.10	0.11	0.15	0.00
Coef. Var.	13.15	6.92	35.14	20.58	9.11	9.30	8.77	2.48	11.08	8.78	12.49	26.84	0.00

Reading # 6 Delta = 1.0"

Test #	Load lbs A	(Delayed) lbs B	Deflection (Cor. from initial) Units : 1/10 " 2'	4'	6'	8'	10'	10'6"	12'	14'4"	16'	18'	20'
B1	832.00	820.00	1.50	4.00	7.00	8.50	9.50	9.90	9.50	8.50	6.50	4.00	1.00
B2	790.00	787.00	1.00	4.00	7.00	8.50	9.50	10.00	9.50	8.50	7.00	4.00	1.00
B3	754.00	849.00	1.00	4.00	6.50	8.00	9.00	10.00	8.50	8.00	5.50	4.00	1.00
B4	829.00	718.00	1.50	5.50	7.50	9.00	9.00	10.00	10.00	8.00	6.50	4.00	1.00
B5	841.00	790.00	1.00	4.00	6.50	8.50	9.50	10.20	10.00	8.70	6.50	4.00	1.50
B6	722.00	789.00	1.50	4.00	6.50	8.00	9.50	10.10	8.50	8.50	6.50	4.00	1.00
B7	840.00	884.00	1.00	4.50	7.00	8.50	10.00	9.90	10.00	9.00	7.50	4.50	1.00
B8	789.00	830.00	1.00	4.00	7.00	8.50	9.50	10.00	9.50	8.50	6.50	4.50	1.00
B9	728.00	808.00	1.00	3.50	6.50	8.50	9.50	10.10	10.00	9.00	7.50	4.00	1.50
B10	862.00	873.00	1.50	4.00	7.50	9.00	10.00	10.10	10.50	9.00	7.50	5.00	1.50
Mean	787.90	810.70	1.20	4.15	6.90	8.50	9.50	10.03	9.80	8.60	6.85	4.20	1.15
St. Dev	72.66	47.21	0.26	0.53	0.39	0.33	0.32	0.09	0.35	0.39	0.47	0.35	0.24
5 th %	668.17	733.22											
SE(Mean)	22.98	14.93	0.08	0.17	0.12	0.11	0.11	0.03	0.11	0.12	0.15	0.11	0.08
Coef. Var.	9.22	5.82	21.52	12.76	5.72	3.92	3.51	0.96	3.57	4.56	6.90	8.32	21.00

Reading # 8 Delta = 1.4"

Test #	Load lbs A	(Delayed) lbs B	Deflection (Cor. from initial) Units : 1/10 " 2'	4'	6'	8'	10'	10'6"	12'	14'4"	16'	18'	20'
B1	1172.00	1142.00	2.00	5.50	9.50	12.00	13.50	14.10	13.50	12.00	9.50	5.00	1.50
B2	1080.00	1073.00	1.50	5.50	9.50	12.00	14.00	14.10	14.00	12.00	9.50	6.00	1.50
B3	1058.00	1160.00	1.50	5.50	9.00	11.50	13.00	14.00	13.50	11.50	9.50	5.50	1.50
B4	882.00	973.00	2.00	6.00	10.50	12.50	14.00	14.00	13.50	11.50	9.00	5.50	1.50
B5	1138.00	1085.00	1.50	5.50	9.50	12.00	13.50	14.20	14.00	12.50	9.50	5.50	2.00
B6	1010.00	1047.00	2.00	5.50	9.00	12.00	13.00	13.90	13.00	11.50	9.00	5.50	1.50
B7	1158.00	1188.00	2.00	6.00	9.50	12.50	14.00	14.30	14.00	12.50	10.00	6.50	1.50
B8	1100.00	1141.00	1.50	5.50	10.00	12.00	13.50	14.10	13.50	12.00	9.00	6.00	1.50
B9	1089.00	1129.00	1.50	5.50	9.50	12.00	13.50	14.00	14.00	12.50	10.00	6.00	1.50
B10	1207.00	1231.00	2.00	6.00	10.50	12.50	14.00	14.10	14.50	12.50	10.50	7.00	2.00
Mean	1090.20	1113.20	1.75	5.65	9.65	12.10	13.60	14.35	13.75	12.05	9.55	5.85	1.60
St. Dev	93.17	74.51	0.26	0.78	0.53	0.32	0.36	0.08	0.42	0.44	0.50	0.50	0.21
5 th %	938.94	990.46											
SE(Mean)	29.46	23.56	0.08	0.25	0.17	0.10	0.12	0.03	0.13	0.14	0.16	0.16	0.07
Coef. Var.	8.55	6.70	15.02	13.39	5.49	2.61	2.80	0.60	3.08	3.63	5.21	8.58	13.18

Reading # 11 Delta = 2.0"

Test #	Load lbs A	(Delayed) lbs B	Deflection (Cor. from initial) Units : 1/10 " 2'	4'	6'	8'	10'	10'6"	12'	14'4"	16'	18'	20'
B1	1625.00	1595.00	2.50	8.00	14.00	17.50	19.00	19.90	19.50	17.00	13.50	8.00	2.50
B2	1495.00	1487.00	2.50	8.00	14.00	17.50	18.50	20.10	20.00	17.50	14.00	8.50	2.00
B3	1501.00	1608.00	2.50	8.00	13.50	16.50	19.00	20.00	19.50	17.00	13.50	8.00	2.00
B4	1241.00	1338.00	2.50	11.00	15.00	18.00	19.50	20.00	19.00	16.00	13.00	7.50	2.50
B5	1434.00	1439.00	2.50	8.50	13.50	17.00	19.50	20.20	20.00	18.00	13.50	8.00	2.50
B6	1445.00	1483.00	2.50	8.00	13.50	17.00	19.00	20.00	19.00	16.50	13.50	8.50	2.50
B7	1633.00	1628.00	2.50	9.00	14.00	18.00	20.00	20.00	20.00	18.00	14.00	8.50	2.50
B8	1508.00	1593.00	2.00	8.50	14.00	18.00	19.00	20.00	19.00	16.50	13.00	8.50	2.50
B9	1501.00	1529.00	2.50	8.00	13.50	17.50	19.50	20.10	20.00	17.50	14.00	8.50	2.50
B10	1683.00	1720.00	3.00	8.00	15.00	18.50	20.00	20.10	20.50	18.00	14.50	8.50	2.50
Mean	1508.70	1539.70	2.50	8.50	14.00	17.55	19.40	20.04	19.65	17.20	13.65	8.35	2.40
St. Dev	125.13	111.07	0.24	0.84	0.58	0.60	0.39	0.08	0.53	0.71	0.47	0.53	0.21
5 th %	1300.86	1358.96											
SE(Mean)	39.57	35.12	0.07	0.30	0.18	0.19	0.12	0.03	0.17	0.23	0.15	0.17	0.07
Coef. Var.	8.31	7.21	9.43	11.09	4.12	3.41	2.03	0.42	2.70	4.16	3.48	6.34	8.78

Statistics on Selected Displacements of C Series

Reading #3 Delta = 0.4"

Test #	Load lbs A	(Delayed) lbs B	Axial	Deflection (Cor. from Initial) Units 1/10" 2"	4"	6"	8"	10"	10'6"	12"	14'4"	16"	18"	20"
C1	328.00	313.00	1000.00	0.00	1.50	3.00	3.50	4.00	4.00	4.00	3.00	3.00	2.00	0.50
C2	348.00	408.00	1000.00	0.50	1.00	2.50	3.50	4.00	4.10	4.00	3.50	2.50	2.00	3.50
C3	386.00	380.00	1080.00	0.00	1.50	3.00	3.00	4.00	4.20	4.00	3.50	2.50	2.00	3.50
C4	386.00	317.00	1054.00	0.50	1.50	2.50	3.00	4.00	4.10	4.00	3.50	2.50	2.00	0.80
C5	280.00	283.00	1040.00	0.50	1.50	2.00	3.00	3.50	3.80	3.50	3.50	3.00	2.20	0.50
C6	322.00	388.00	1013.00	0.00	1.50	2.50	3.50	4.00	4.30	4.00	3.50	3.00	1.50	3.50
C7	321.00	315.00	873.00	0.50	2.00	2.50	3.50	3.50	3.80	4.00	3.20	3.00	1.00	3.50
C8	384.00	387.00	1000.00	0.50	1.50	2.50	3.50	3.50	3.80	4.00	3.50	2.50	2.00	0.00
C9	330.00	388.00	1040.00	0.00	1.50	2.50	3.50	4.00	4.10	4.00	4.00	2.50	2.00	3.50
C10	380.00	317.30	1027.00	0.00	1.50	3.00	3.50	4.50	4.20	4.50	3.50	2.50	2.00	2.00
Mean	336.70	328.10	1022.70	0.25	1.58	2.60	3.38	3.80	4.08	4.00	3.46	2.70	1.88	0.40
St. Dev	38.81	38.30	31.81	0.28	0.24	0.32	0.24	0.32	0.14	0.24	0.28	0.28	0.34	0.21
5th %	288.27	282.88												
SE(Mean)	12.58	10.88	9.88	0.09	0.07	0.10	0.08	0.10	0.04	0.07	0.08	0.09	0.11	0.07
Coef. Var.	12.28	10.12	3.08	108.41	15.71	12.16	7.21	8.11	3.34	5.88	8.23	9.58	18.24	52.70

Reading #6 Delta = 1.0"

Test #	Load lbs A	(Delayed) lbs B	Axial	Deflection (Cor. from Initial) Units 1/10" 2"	4"	6"	8"	10"	10'6"	12"	14'4"	16"	18"	20"
C1	750.00	712.00	1013.00	1.00	4.00	6.50	8.50	10.00	10.00	10.00	8.50	7.00	4.50	1.50
C2	778.00	808.00	948.00	1.00	4.00	7.00	8.00	10.00	10.00	10.00	8.50	6.50	4.50	1.00
C3	830.00	823.00	1027.00	1.00	4.00	7.00	8.00	8.50	10.00	10.00	6.50	6.50	4.00	1.00
C4	[illegible]	805.00	819.00	1.50	4.00	8.50	8.00	10.00	10.10	10.00	6.50	7.00	4.50	1.50
C5	[illegible]	[illegible]	[illegible]	1.50	4.00	6.50	6.50	8.50	6.80	6.50	3.50	1.00	4.50	1.00
C6	771.00	824.00	948.00	1.00	4.00	6.50	6.50	8.50	10.20	10.00	8.50	6.50	4.50	1.50
C7	778.00	747.00	1000.00	1.50	4.50	7.00	8.00	4.50	4.80	8.50	8.00	7.00	4.00	1.00
C8	710.00	780.00	948.00	1.00	4.00	7.00	8.50	8.00	8.80	8.50	6.50	8.50	4.50	1.00
C9	775.00	822.00	1013.00	1.00	4.00	9.50	8.00	4.50	10.10	6.50	8.00	7.00	4.00	1.00
C10	804.00	712.00	948.00	1.00	4.50	7.00	8.00	10.00	10.00	10.00	8.50	7.00	4.50	1.00
Mean	758.70	778.20	974.20	1.15	4.10	8.75	8.80	8.80	10.04	8.80	8.50	6.80	4.35	1.15
St. Dev	67.86	54.05	37.76	0.24	0.21	0.28	0.38	0.34	0.13	0.28	0.34	0.28	0.24	0.24
5th %	644.63	687.28												
SE(Mean)	21.46	17.08	11.94	0.08	0.07	0.06	0.12	0.11	0.04	0.08	0.07	0.09	0.08	0.08
Coef. Var.	8.80	6.88	3.88	21.00	5.14	3.90	4.58	3.50	1.34	2.83	2.77	3.80	5.56	21.00

Reading #8 Delta = 1.4"

Test #	Load lbs A	(Delayed) lbs B	Axial	Deflection (Cor. from Initial) Units 1/10" 2"	4"	6"	8"	10"	10'6"	12"	14'4"	16"	18"	20"
C1	1007.00	858.00	1027.00	1.50	5.50	8.00	12.00	13.50	14.00	13.50	12.00	8.50	6.00	1.50
C2	1080.00	1111.00	888.00	2.00	5.50	8.50	12.50	14.00	14.00	14.00	12.00	8.00	6.00	1.50
C3	1138.00	1112.00	1013.00	1.50	6.00	6.50	11.50	13.00	14.00	13.50	12.00	6.00	6.00	1.50
C4	1131.00	1118.00	888.00	2.00	5.50	8.50	11.50	13.50	14.00	13.50	12.00	6.50	6.50	1.50
C5	908.00	940.00	1000.00	2.00	5.50	8.00	11.50	13.00	13.80	13.00	11.50	8.50	6.00	1.50
C6	1083.00	1111.00	857.00	1.50	6.00	8.50	12.00	13.50	14.30	14.00	12.00	8.50	5.50	2.00
C7	1088.00	1000.00	888.00	2.00	6.00	10.00	12.50	13.00	13.80	13.00	11.50	8.50	5.50	1.50
C8	978.00	1058.00	858.00	2.00	5.50	8.50	12.00	13.00	13.80	13.00	11.50	6.50	6.00	1.50
C9	1081.00	1080.00	1013.00	1.50	5.50	8.00	12.00	13.50	14.00	13.50	12.00	8.50	6.00	1.50
C10	808.00	874.00	948.00	1.50	6.00	4.50	12.50	14.00	14.70	14.00	12.00	8.50	6.00	1.50
Mean	1035.00	1048.00	981.80	1.75	5.70	8.40	12.00	13.40	14.00	13.50	11.85	8.40	5.85	1.56
St. Dev	78.38	88.46	38.43	0.28	0.28	0.32	0.41	0.38	0.12	0.41	0.24	0.21	0.28	0.16
5th %	810.04	834.88												
SE(Mean)	24.79	21.88	8.31	0.08	0.08	0.10	0.13	0.12	0.04	0.13	0.08	0.07	0.08	0.05
Coef. Var.	7.54	8.60	3.00	15.08	4.93	3.38	1.40	2.84	3.86	3.02	2.04	2.24	4.77	10.00

Reading #11 Delta = 2.0"

Test #	Load lbs A	(Delayed) lbs B	Axial	Deflection (Cor. from Initial) Units 1/10" 2"	4"	6"	8"	10"	10'6"	12"	14'4"	16"	18"	20"
C1	1325.00	1380.00	1027.00	2.00	8.00	13.00	17.00	19.00	20.00	18.00	17.00	14.00	8.00	2.50
C2	1534.00	1528.00	873.00	2.50	8.00	14.00	18.00	20.00	20.00	19.50	17.00	13.00	8.50	2.00
C3	1581.00	1537.00	888.00	2.50	8.50	13.50	18.50	18.50	20.00	19.00	18.50	13.00	8.00	2.00
C4	1638.00	1688.00	818.00	3.00	8.00	13.50	17.00	19.00	20.00	18.50	17.00	13.50	8.50	3.00
C5	1307.00	1303.00	883.00	3.00	8.00	13.00	17.00	18.00	18.80	18.00	17.30	13.50	8.00	2.50
C6	1480.00	1534.00	948.00	2.50	8.50	13.50	17.00	18.50	20.20	20.00	17.00	13.50	8.00	2.50
C7	1485.00	1448.00	1013.00	3.00	8.00	14.00	19.00	18.50	20.00	19.00	18.50	13.50	8.00	2.00
C8	1386.00	1441.00	808.00	3.00	8.00	14.00	17.50	19.00	19.80	19.00	19.50	13.50	8.50	2.00
C9	1520.00	1612.00	808.00	2.50	8.00	13.50	17.50	19.50	20.10	19.50	17.50	13.50	8.50	2.50
C10	1380.00	1386.00	883.00	2.50	8.50	14.00	17.50	20.20	20.20	20.00	17.00	13.50	8.50	2.00
Mean	1461.80	1468.80	888.20	2.88	8.25	13.80	17.30	19.30	20.03	19.28	18.00	13.40	8.48	2.25
St. Dev	118.40	82.38	44.28	0.34	0.38	0.38	0.48	0.48	0.11	0.41	0.32	0.28	0.37	0.28
5th %	1257.04	1304.87												
SE(Mean)	37.44	28.22	14.00	0.11	0.11	0.12	0.15	0.15	0.03	0.13	0.10	0.08	0.12	0.08
Coef. Var.	8.10	6.34	4.88	12.73	4.28	2.80	2.79	2.50	0.53	2.13	1.87	2.11	4.37	11.71

Statistics on Selected Displacements of D Series

Reading # 3 Delta = 0.4"

Test #	Load lbs A	(Delayed) lbs B	Axial	Deflection (Cor. from initial) Units : 1/10 " 2'	4'	6'	8'	10'	10'6"	12'	14'4"	16'	18'	20'
D1	290.00	343.00	1813.00	1.00	1.50	2.50	3.00	3.50	4.00	3.50	3.00	2.50	1.50	0.50
D2	336.00	350.00	1840.00	0.00	1.00	2.50	3.00	4.00	4.00	3.50	3.50	2.50	1.00	0.50
D3	314.00	354.00	1854.00	0.50	1.50	3.00	3.50	3.50	3.90	3.50	3.50	3.00	1.50	0.50
Mean	313.33	349.00	1835.67	0.50	1.33	2.67	3.17	3.67	3.97	3.50	3.33	2.67	1.33	0.50
St. Dev	23.01	5.57	20.84	0.50	0.29	0.29	0.29	0.29	0.06	0.00	0.29	0.29	0.29	0.00
5 th %	275.49	339.84												
SE(Mean)	7.28	1.76	6.59	0.16	0.09	0.09	0.09	0.09	0.02	0.00	0.09	0.09	0.09	0.00
Coef. Var.	7.34	1.60	1.08	100.00	21.65	10.83	9.12	7.87	1.46	0.00	8.66	10.83	21.65	0.00

Reading # 6 Delta = 1.0"

Test #	Load lbs A	(Delayed) lbs B	Axial	Deflection (Cor. from initial) Units : 1/10 " 2'	4'	6'	8'	10'	10'6"	12'	14'4"	16'	18'	20'
D1	709.00	740.00	2030.00	1.50	4.00	6.00	8.00	9.50	10.00	8.50	7.50	6.50	4.50	1.50
D2	807.00	852.00	1987.00	0.50	4.00	6.50	8.50	10.00	10.00	9.50	9.00	7.00	3.50	1.00
D3	776.00	850.00	1954.00	1.00	4.00	7.00	8.50	9.50	10.00	9.50	8.50	7.00	4.50	1.50
Mean	764.00	814.00	1983.67	1.00	4.00	6.50	8.33	9.67	10.00	9.17	8.33	6.83	4.17	1.33
St. Dev	50.09	64.09	40.65	0.50	0.00	0.50	0.29	0.29	0.00	0.58	0.76	0.29	0.58	0.29
5 th %	681.60	708.57												
SE(Mean)	15.84	20.27	12.85	0.16	0.00	0.16	0.09	0.09	0.00	0.18	0.24	0.09	0.18	0.09
Coef. Var.	6.56	7.87	2.05	50.00	0.00	7.69	3.46	2.99	0.00	6.30	9.17	4.22	13.86	21.65

Reading # 8 Delta = 1.4"

Test #	Load lbs A	(Delayed) lbs B	Axial	Deflection (Cor. from initial) Units : 1/10 " 2'	4'	6'	8'	10'	10'6"	12'	14'4"	16'	18'	20'
D1	978.00	988.00	1940.00	2.50	5.50	9.00	11.50	13.00	14.00	12.50	11.00	9.00	5.50	1.50
D2	1113.00	1153.00	1913.00	1.50	5.00	9.00	12.00	13.50	14.10	13.50	12.00	9.50	5.50	1.50
D3	1094.00	1161.00	1981.00	2.00	5.50	9.50	12.00	13.50	14.00	13.50	12.00	10.00	6.00	1.50
Mean	1061.67	1100.67	1944.67	2.00	5.33	9.17	11.83	13.33	14.03	13.17	11.67	9.50	5.67	1.50
St. Dev	73.08	97.65	34.24	0.50	0.29	0.29	0.29	0.29	0.06	0.58	0.58	0.50	0.29	0.00
5 th %	941.45	940.03												
SE(Mean)	23.11	30.88	10.83	0.16	0.09	0.09	0.09	0.09	0.02	0.18	0.18	0.16	0.09	0.00
Coef. Var.	6.88	8.87	1.76	25.00	5.41	3.15	2.44	2.17	0.41	4.38	4.95	5.26	5.09	0.00

Reading # 11 Delta = 2.0"

Test #	Load lbs A	(Delayed) lbs B	Axial	Deflection (Cor. from initial) Units : 1/10 " 2'	4'	6'	8'	10'	10'6"	12'	14'4"	16'	18'	20'
D1	1380.00	1369.00	2034.00	3.50	8.00	13.00	17.00	19.00	20.00	17.50	15.50	12.50	8.00	2.00
D2	1545.00	1573.00	1940.00	2.00	8.00	13.00	17.50	19.50	19.90	18.50	17.00	13.50	8.00	2.50
D3	1550.00	1639.00	1940.00	3.00	8.50	14.00	17.50	19.50	20.10	19.00	17.00	14.00	8.50	2.50
Mean	1491.67	1527.00	1971.33	2.83	8.17	13.33	17.33	19.33	20.00	18.67	16.50	13.33	8.17	2.33
St. Dev	96.74	140.78	54.27	0.76	0.29	0.58	0.29	0.29	0.10	1.04	0.87	0.76	0.29	0.29
5 th %	1332.53	1295.46												
SE(Mean)	30.59	44.51	17.16	0.24	0.09	0.18	0.09	0.09	0.03	0.33	0.27	0.24	0.09	0.09
Coef. Var.	6.49	9.22	2.75	26.96	3.53	4.33	1.67	1.49	0.50	5.58	5.25	5.73	3.53	12.37

Analysis of Varience on Loads
Comparisons Across Series A : Load A vs Load B

Summary 0.4 in Defl. Loads
Analyses of Variance:One Way

Groups	*Count*	*Sum*	*Average*	*Variance*
A Cell	10	1331	133.1	714.7667
B Cell	10	2050	205	330.8889

Analyses of Variance

Source of Variation

	SS	*df*	*MS*	*F*	*P-value*	*F-crit*
Between Groups	25848.05	1	25848.05	49.43894	1.5E-06	4.413873
Within Groups	9410.9	18	522.8278			
Total	35258.95	19				

Therefore - there IS a diff between load A and B.

Note : Very high F value indicates rejection of null hyp that means are equal.
(Probability of getting same value 95% of the time is very low.)

Summary 1.0 in Defl Loads
Analyses of Variance:One Way

Groups	*Count*	*Sum*	*Average*	*Variance*
A Cell	10	3407	340.7	1501.789
B Cell	10	4120	412	1104.889

Analyses of Variance

Source of Variation

	SS	*df*	*MS*	*F*	*P-value*	*F-crit*
Between Groups	25418.45	1	25418.45	19.50256	0.000333	4.413873
Within Groups	23460.1	18	1303.339			
Total	48878.55	19				

Therefore - there IS a diff between load A and B

Summary 1.4 in Defl. Load
Analyses of Variance:One Way

Groups	*Count*	*Sum*	*Average*	*Variance*
A Cell	10	4715	471.5	2075.833
B Cell	10	5472	547.2	1207.733

Analyses of Variance

Source of Variation

	SS	*df*	*MS*	*F*	*P-value*	*F-crit*
Between Groups	28652.45	1	28652.45	17.45203	0.000566	4.413873
Within Groups	29552.1	18	1641.783			
Total	58204.55	19				

Therefore - there IS a diff between load A and B

Summary 2.0 in Defl. Load
Analyses of Variance:One Way

Groups	*Count*	*Sum*	*Average*	*Variance*
A Cell	10	6632	663.2	4683.067
B Cell	10	7383	738.3	2798.011

Analyses of Variance

Source of Variation

	SS	*df*	*MS*	*F*	*P-value*	*F-crit*
Between Groups	28956.05	1	28956.05	7.741144	0.012294	4.413873
Within Groups	67329.7	18	3740.539			
Total	96285.75	19				

Therefore - there IS a diff between load A and B.

Analysis of Variance on Loads
Comparisons Across All Series at Given Deflections.

ANOVA : Load Cell A - Delta = 0.4 in.
Ho = There is NO difference between sample means.

Analysis of Variance One Way - Load Cell A

Summary

Groups	Count	Sum	Average	Variance
A	10.000	1331.000	133.100	714.767
B	10.000	3252.000	325.200	1828.622
C	10.000	3247.000	324.700	1584.900
D	3.000	940.000	313.333	529.333

Analysis of Variance

Source of Variation

	SS	df	MS	F	P-value	F-crit
Between Groups	454544.600	3.000	151514.867	22.318	2.4345927E-08	2.86626555154116
Within Groups	244386.900	36.000	6788.517			
Total	698931.500	39.000				

Reject Ho so therefore there is a difference between at least two means at Alpha = 0.05

t Test Two-Sample Assuming Unequal Variances

	A	B
Mean	133.100	325.200
Variance	714.767	1828.622
Observations	10.000	10.000
Pearson Correlation	0.135	
Pooled Variance	1271.694	
df	15.000	
t	12.045	
P(T<=t) one tail	0.000	
t Critical one tail	1.753	
P(T<=t) two tail	0.000	
t Critical two tail	2.131	

Mean of Sample A differs from mean of Sample B at Alpha = 0.05

t Test Two-Sample Assuming Unequal Variances

	A	C
Mean	133.100	324.700
Variance	714.767	1584.900
Observations	10.000	10.000
Pearson Correlation	0.082	
Pooled Variance	1149.833	
df	16.000	
t	12.835	
P(T<=t) one tail	0.000	
t Critical one tail	1.746	
P(T<=t) two tail	0.000	
t Critical two tail	2.120	

Mean of Sample A differs from mean of Sample C at Alpha = 0.05

t Test Two-Sample Assuming Unequal Variances

	A	D
Mean	133.100	313.333
Variance	714.767	529.333
Observations	10.000	3.000
Pearson Correlation	NA	
Pooled Variance	681.052	
df	4.000	
t	-11.467	
P(T<=t) one tail	0.000	
t Critical one tail	2.132	
P(T<=t) two tail	0.000	
t Critical two tail	2.776	

Mean of Sample A differs from mean of Sample D at Alpha = 0.05

t Test Two-Sample Assuming Unequal Variances

	B	C
Mean	325.200	324.700
Variance	1828.622	1584.900
Observations	10.000	10.000
Pearson Correlation	0.741	
Pooled Variance	1706.761	
df	18.000	
t	0.027	
P(T<=t) one tail	0.489	
t Critical one tail	1.734	
P(T<=t) two tail	0.979	
t Critical two tail	2.101	

Mean of Sample B DOES NOT DIFFER from mean of Sample C at Alpha = 0.05

t Test Two-Sample Assuming Unequal Variances

	B	D
Mean	325.200	313.333
Variance	1828.622	529.333
Observations	10.000	3.000
Pearson Correlation	NA	
Pooled Variance	1592.386	
df	7.000	
t	0.826	
P(T<=t) one tail	0.278	
t Critical one tail	1.895	
P(T<=t) two tail	0.551	
t Critical two tail	2.365	

Mean of Sample B DOES NOT DIFFER from mean of Sample D at Alpha = 0.05

Assumptions
1. Populations are normally distributed
2. Variances of populations are approximately equal
3. Samples are random of population

Notes
F - test : Null hypothesis assumes means are the same. Therefor the alternate is that at least two means differ.
If the returned F - value is greater than F - critical then means differ. (Reject Ho if F > Fc)

Load Cell A

A	B	C	D
198.00	355.00	329.00	296.00
103.00	325.00	348.00	330.00
150.00	304.00	385.00	314.00
147.00	244.00	385.00	
128.00	342.00	290.00	
85.00	299.00	322.00	
130.00	351.00	321.00	
143.00	310.00	284.00	
112.00	314.00	333.00	
135.00	378.00	250.00	

t Test Two-Sample Assuming Unequal Variances

	C	D
Mean	324.700	##############
Variance	1584.900	##############
Observations	10.000	3
Pearson Correlation	NA	
Pooled Variance	1382.978	
df	8.000	
t	0.821	
P(T<=t) one tail	0.278	
t Critical one tail	1.943	
P(T<=t) two tail	0.557	
t Critical two tail	2.447	

Mean of Sample C DOES NOT DIFFER from mean of Sample D at Alpha = 0.05

ANOVA : Load Cell B - Delta = 0.4 in.
Ho = There is NO difference between sample means.

Analysis of Variance One Way

Summary

Groups	Count	Sum	Average	Variance
A	10.000	2050.000	205.000	330.889
B	10.000	3391.000	339.100	551.211
C	10.000	3391.000	339.100	1176.544
D	3.000	1047.000	349.000	31.000

Analysis of Variance

Source of Variation

	SS	df	MS	F	P-value	F-crit
Between Groups	389781.075	3.000	129927.025	17.148	4.08141 E-07	2.8852...
Within Groups	274371.800	38.000	7621.442			
Total	664152.875	39.000				

Reject Ho so therefore there is a difference between at least two means at Alpha = 0.05

Load Cell B

A	B	C	D
200.00	341.00	315.00	343.00
200.00	330.00	408.00	350.00
217.00	358.00	350.00	354.00
211.00	303.00	317.00	
193.00	335.00	293.00	
171.00	310.00	358.00	
197.00	343.00	315.00	
219.00	303.00	352.00	
184.00	322.00	368.00	
219.00	330.00	317.00	

t Test Two Sample Assuming Unequal Variances

	A	B
Mean	205.000	339.100
Variance	330.889	551.211
Observations	10.000	10.000
Pearson Correlation	0.339	
Pooled Variance	441.050	
df	17.000	
t	14.278	
P(T<=t) one tail	0.000	
t Critical one tail	1.740	
P(T<=t) two tail	0.000	
t Critical two tail	2.110	

Mean of Sample A differs from mean of Sample B at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	A	C
Mean	205.000	339.100
Variance	330.889	1176.544
Observations	10.000	10.000
Pearson Correlation	-0.103	
Pooled Variance	753.717	
df	14.000	
t	10.922	
P(T<=t) one tail	0.000	
t Critical one tail	1.761	
P(T<=t) two tail	0.000	
t Critical two tail	2.145	

Mean of Sample A differs from mean of Sample C at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	A	D
Mean	205.000	349.000
Variance	330.889	31.000
Observations	10.000	3.000
Pearson Correlation	NA	
Pooled Variance	278.304	
df	11.000	
t	21.853	
P(T<=t) one tail	0.000	
t Critical one tail	1.796	
P(T<=t) two tail	0.000	
t Critical two tail	2.201	

Mean of Sample A differs from mean of Sample D at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	B	C
Mean	339.100	339.100
Variance	551.211	1176.544
Observations	10.000	10.000
Pearson Correlation	-0.150	
Pooled Variance	863.878	
df	16.000	
t	0.000	
P(T<=t) one tail	0.500	
t Critical one tail	1.746	
P(T<=t) two tail	1.000	
t Critical two tail	2.120	

Mean of Sample B DOES NOT DIFFER from mean of Sample C at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	B	D
Mean	339.100	349.000
Variance	551.211	31.000
Observations	10.000	3.000
Pearson Correlation	NA	
Pooled Variance	456.627	
df	11.000	
t	1.224	
P(T<=t) one tail	0.123	
t Critical one tail	1.796	
P(T<=t) two tail	0.247	
t Critical two tail	2.201	

Mean of Sample B DOES NOT DIFFER from mean of Sample D at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	C	D
Mean	339.100	349
Variance	1176.544	31
Observations	10.000	3
Pearson Correlation	NA	
Pooled Variance	898.204	
df	10.000	
t	-0.875	
P(T<=t) one tail	0.201	
t Critical one tail	1.812	
P(T<=t) two tail	0.402	
t Critical two tail	2.228	

Mean of Sample C DOES NOT DIFFER from mean of Sample D at Alpha = 0.05

ANOVA : Load Cell A - Delta = 1.0 in.

Ho = There is NO difference between sample means.

Analysis of Variance One Way

Summary

Groups	Count	Sum	Average	Variance
A	10.000	3407.000	340.700	1601.79
B	10.000	7879.000	787.900	6279.43
C	10.000	7762.000	776.200	2921.29
D	3.000	2442.000	814.000	4108.00

Analysis of Variance

Source of Variation

	SS	df	MS	F	P-value	F-crit
Between Groups	2444327.300	3.000	814775.767	19.73	0.000	2.866
Within Groups	1486990.200	36.000	41305.283			
Total	3931317.500	39.000				

Reject Ho so therefore there is a difference between at least two means at Alpha = 0.05

Load Cell A

A	B	C	D
404.00	836.00	712.00	740.00
316.00	790.00	836.00	862.00
360.00	764.00	823.00	860.00
362.00	829.00	806.00	
344.00	841.00	699.00	
286.00	722.00	824.00	
336.00	840.00	747.00	
366.00	789.00	780.00	
300.00	786.00	822.00	
362.00	862.00	712.00	

t-Test: Two-Sample Assuming Unequal Variances

	A	B
Mean	340.700	787.900
Variance	1601.789	6279.433
Observations	10.000	10.000
Pearson Correlation	0.217	
Pooled Variance	3390.611	
df	14.000	
t	-17.173	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.761	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.145	

Mean of Sample A differs from mean of Sample B at Alpha = 0.05

t-Test: Two-Sample Assuming Unequal Variances

	B	C
Mean	787.900	776.200
Variance	6279.433	2921.289
Observations	10.000	10.000
Pearson Correlation	-0.867	
Pooled Variance	4100.361	
df	17.000	
t	0.409	
P(T<=t) one-tail	0.344	
t Critical one-tail	1.740	
P(T<=t) two-tail	0.688	
t Critical two-tail	2.110	

Mean of Sample B DOES NOT DIFFER from mean of Sample C at Alpha = 0.05

t-Test: Two-Sample Assuming Unequal Variances

	C	D
Mean	776.200	814.000
Variance	2921.289	4108.000
Observations	10.000	3.000
Pearson Correlation	NA	
Pooled Variance	3137.066	
df	3.000	
t	-0.927	
P(T<=t) one-tail	0.211	
t Critical one-tail	2.353	
P(T<=t) two-tail	0.422	
t Critical two-tail	3.182	

Mean of Sample C DOES NOT DIFFER from mean of Sample D at Alpha = 0.05

t-Test: Two-Sample Assuming Unequal Variances

	A	C
Mean	340.700	776.200
Variance	1601.789	2921.289
Observations	10.000	10.000
Pearson Correlation	-0.883	
Pooled Variance	2211.539	
df	16.000	
t	-20.707	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.746	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.120	

Mean of Sample A differs from mean of Sample C at Alpha = 0.05

t-Test: Two-Sample Assuming Unequal Variances

	B	D
Mean	787.900	814.000
Variance	6279.433	4108.000
Observations	10.000	3.000
Pearson Correlation	NA	
Pooled Variance	46056.482	
df	3.000	
t	0.869	
P(T<=t) one-tail	0.221	
t Critical one-tail	2.353	
P(T<=t) two-tail	0.443	
t Critical two-tail	3.182	

Mean of Sample B DOES NOT DIFFER from mean of Sample D at Alpha = 0.05

t-Test: Two-Sample Assuming Unequal Variances

	A	D
Mean	340.700	814.000
Variance	1601.789	4108.000
Observations	10.000	3.000
Pearson Correlation	NA	
Pooled Variance	1978.846	
df	2.000	
t	-12.142	
P(T<=t) one-tail	0.003	
t Critical one-tail	2.920	
P(T<=t) two-tail	0.007	
t Critical two-tail	4.303	

Mean of Sample A differs from mean of Sample D at Alpha = 0.05

ANOVA : Load Cell B - Delta = 1.0 In.
Ho = There is NO difference between sample means.

Analysis of Variance One Way

Summary

Groups	Count	Sum	Average	Variance
A	10.000	4120.000	412.000	1104.89
B	10.000	8107.000	810.700	2229.12
C	10.000	7762.000	776.200	2921.29
D	3.000	2442.000	814.000	4108.00

Analysis of Variance

Source of Variation

	SS	df	MS	F	P-value	F-crit
Between Groups	2312241.675	3.000	770747.225	19.06	0.000	2.866
Within Groups	1455965.300	36.000	40443.481			
Total	3768206.975	39.000				

Reject Ho so therefore there is a difference between at least two means at Alpha = 0.05

Load Cell B

A	B	C	D
432.00	820.00	712.00	740.00
401.00	781.00	838.00	852.00
446.00	849.00	823.00	850.00
435.00	718.00	805.00	
410.00	780.00	699.00	
355.00	798.00	824.00	
396.00	854.00	747.00	
412.00	810.00	780.00	
370.00	824.00	822.00	
463.00	873.00	712.00	

t Test Two Sample Assuming Unequal Variances

	A	B
Mean	412.000	810.700
Variance	1104.889	2229.122
Observations	10.000	10.000
Pearson Correlation	0.327	
Pooled Variance	1667.005	
df	16.000	
t	21.835	
P(T<=t) one tail	0.000	
t Critical one tail	1.746	
P(T<=t) two tail	0.000	
t Critical two tail	2.120	

Mean of Sample A differs from mean of Sample B at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	B	C
Mean	810.700	776.200
Variance	2229.122	2921.289
Observations	10.000	10.000
Pearson Correlation	0.361	
Pooled Variance	2575.205	
df	18.000	
t	1.520	
P(T<=t) one tail	0.073	
t Critical one tail	1.734	
P(T<=t) two tail	0.146	
t Critical two tail	2.101	

Mean of Sample B DOES NOT DIFFER from mean of Sample C at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	C	D
Mean	776.200	814.000
Variance	2921.289	4108.000
Observations	10.000	3.000
Pearson Correlation	NA	
Pooled Variance	3137.055	
df	3.000	
t	0.927	
P(T<=t) one tail	0.211	
t Critical one tail	2.353	
P(T<=t) two tail	0.422	
t Critical two tail	3.182	

Mean of Sample C DOES NOT DIFFER from mean of Sample D at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	A	C
Mean	412.000	776.200
Variance	1104.889	2921.289
Observations	10.000	10.000
Pearson Correlation	-0.429	
Pooled Variance	2013.089	
df	15.000	
t	18.151	
P(T<=t) one tail	0.000	
t Critical one tail	1.753	
P(T<=t) two tail	0.000	
t Critical two tail	2.131	

Mean of Sample A differs from mean of Sample C at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	B	D
Mean	810.700	814.000
Variance	2229.122	4108.000
Observations	10.000	3.000
Pearson Correlation	NA	
Pooled Variance	2570.135	
df	3.000	
t	0.083	
P(T<=t) one tail	0.470	
t Critical one tail	2.353	
P(T<=t) two tail	0.939	
t Critical two tail	3.182	

Mean of Sample B DOES NOT DIFFER from mean of Sample D at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	A	D
Mean	412.000	814.000
Variance	1104.889	4108.000
Observations	10.000	3.000
Pearson Correlation	NA	
Pooled Variance	1850.808	
df	2.000	
t	10.450	
P(T<=t) one tail	0.005	
t Critical one tail	2.920	
P(T<=t) two tail	0.009	
t Critical two tail	4.303	

Mean of Sample A differs from mean of Sample D at Alpha = 0.05

ANOVA : Load Cell A - Delta = 1.4 in.
Ho = There is NO difference between sample means.

Analysis of Variance One Way

Summary

Groups	Count	Sum	Average	Variance
A	10.000	4715.000	471.500	2075.833
B	10.000	10902.000	1090.200	8580.178
C	10.000	10390.000	1039.000	6145.333
D	3.000	3185.000	1061.667	5340.333

Analysis of Variance

Source of Variation

	SS	df	MS	F	P-value	F-crit
Between Groups	4613703.800	3.000	1537901.267	21.885	3.05524E-08	2.866265515158716
Within Groups	2529778.600	36.000	70271.626			
Total	7143482.400	39.000				

Reject Ho so therefore there is a difference between at least two means at Alpha = 0.05

Load Cell A

A	B	C	D
485.00	1172.00	1007.00	978.00
442.00	1080.00	1080.00	1113.00
497.00	1058.00	1136.00	1094.00
509.00	882.00	1131.00	
484.00	1138.00	938.00	
380.00	1010.00	1053.00	
460.00	1158.00	1078.00	
495.00	1100.00	978.00	
426.00	1090.00	1081.00	
537.00	1207.00	908.00	

t-Test: Two-Sample Assuming Unequal Variances

	A	B
Mean	471.500	1090.200
Variance	2075.833	8580.178
Observations	10.000	10.000
Pearson Correlation	0.183	
Pooled Variance	5378.006	
df	13.000	
t	18.855	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.771	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.160	

Mean of Sample A differs from mean of Sample B at Alpha = 0.05

t-Test: Two-Sample Assuming Unequal Variances

	A	C
Mean	471.500	1039.000
Variance	2075.833	6145.333
Observations	10.000	10.000
Pearson Correlation	0.358	
Pooled Variance	4110.583	
df	14.000	
t	18.702	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.761	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.145	

Mean of Sample A differs from mean of Sample C at Alpha = 0.05

t-Test: Two-Sample Assuming Unequal Variances

	A	D
Mean	471.500	1061.667
Variance	2075.833	5340.333
Observations	10.000	3.000
Pearson Correlation	NA	
Pooled Variance	2896.378	
df	2.000	
t	13.237	
P(T<=t) one-tail	0.003	
t Critical one-tail	2.920	
P(T<=t) two-tail	0.006	
t Critical two-tail	4.303	

Mean of Sample A differs from mean of Sample D at Alpha = 0.05

t-Test: Two-Sample Assuming Unequal Variances

	B	C
Mean	1090.2	1039
Variance	8580.177778	6145.333333
Observations	10	10
Pearson Correlation	0.09346311	
Pooled Variance	7412.755556	
df	17	
t	1.329135072	
P(T<=t) one-tail	0.10058004	
t Critical one-tail	1.739606724	
P(T<=t) two-tail	0.201173279	
t Critical two-tail	2.109815577	

Mean of Sample B DOES NOT DIFFER from mean of Sample C at Alpha = 0.05

t-Test: Two-Sample Assuming Unequal Variances

	B	D
Mean	1090.2	1061.666667
Variance	8580.177778	5340.333333
Observations	10	3
Pearson Correlation	NA	
Pooled Variance	8072.933333	
df	4	
t	0.554478252	
P(T<=t) one-tail	0.304308372	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.608782745	
t Critical two-tail	2.776445105	

Mean of Sample B DOES NOT DIFFER from mean of Sample D at Alpha = 0.05

t-Test: Two-Sample Assuming Unequal Variances

	C	D
Mean	1039	1061.666667
Variance	6145.333333	5340.333333
Observations	10	3
Pearson Correlation	NA	
Pooled Variance	5958.969697	
df	4	
t	0.461188494	
P(T<=t) one-tail	0.333651182	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.667302323	
t Critical two-tail	2.776445105	

Mean of Sample C DOES NOT DIFFER from mean of Sample D at Alpha = 0.05

ANOVA : Load Cell B - Delta = 1.4 in.
Ho = There is NO difference between sample means.

Analysis of Variance One Way

Summary

Groups	Count	Sum	Average	Variance
A	10.000	5472.000	547.200	1207.733
B	10.000	11132.000	1113.200	5567.067
C	10.000	10492.000	1049.200	4823.733
D	3.000	3302.000	1100.667	9530.333

Analysis of Variance

Source of Variation

	SS	df	MS	F	P-value	F-crit
Between Groups	4383987.500	3.000	1461329.167	19.721	[illegible]	[illegible]
Within Groups	2667540.400	36.000	74098.344			
Total	7051527.900	39.000				

Reject Ho so therefore there is a difference between at least two means at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	A	B
Mean	547.200	1113.200
Variance	1207.733	5567.067
Observations	10.000	10.000
Pearson Correlation	0.168	
Pooled Variance	3387.400	
df	13.000	
t	-21.745	
P(T<=t) one tail	0.000	
t Critical one tail	1.771	
P(T<=t) two tail	0.000	
t Critical two tail	2.160	

Mean of Sample A differs from mean of Sample B at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	A	C
Mean	547.200	1049.200
Variance	1207.733	4823.733
Observations	10.000	10.000
Pearson Correlation	0.216	
Pooled Variance	3015.733	
df	13.000	
t	-20.441	
P(T<=t) one tail	0.000	
t Critical one tail	1.771	
P(T<=t) two tail	0.000	
t Critical two tail	2.160	

Mean of Sample A differs from mean of Sample C at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	A	D
Mean	547.200	1100.667
Variance	1207.733	9530.333
Observations	10.000	3.000
Pearson Correlation	NA	
Pooled Variance	2722.024	
df	2.000	
t	9.635	
P(T<=t) one tail	0.005	
t Critical one tail	2.920	
P(T<=t) two tail	0.011	
t Critical two tail	4.303	

Mean of Sample A differs from mean of Sample C at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	B	C
Mean	1113.2	1049.2
Variance	5567.066667	4823.733333
Observations	10	10
Pearson Correlation	0.42716221	
Pooled Variance	5195.4	
df	18	
t	1.98563412	
P(T<=t) one tail	0.03127321	
t Critical one tail	1.73406364	
P(T<=t) two tail	0.06254658	
t Critical two tail	2.10092204	

Mean of Sample B DOES NOT DIFFER from mean of Sample C at Alpha = 0.05

t Test Two Sample Assuming Unequal Variances

	B	D
Mean	1113.2	1100.666667
Variance	5567.066667	9530.333333
Observations	10	3
Pearson Correlation	NA	
Pooled Variance	6288.751515	
df	3	
t	0.205095747	
P(T<=t) one tail	0.42532313	
t Critical one tail	2.353363434	
P(T<=t) two tail	0.85064626	
t Critical two tail	3.182446305	

Mean of Sample B DOES NOT DIFFER from mean of Sample D at Alpha = 0.05

Load Cell B

A	B	C	D
551.00	1112.00	958.00	988.00
542.00	1073.00	1111.00	1153.00
581.00	1190.00	1112.00	1161.00
589.00	973.00	1116.00	
552.00	1055.00	940.00	
483.00	1047.00	1111.00	
538.00	1195.00	1032.00	
549.00	1141.00	1055.00	
502.00	1129.00	1083.00	
588.00	1237.00	974.00	

t Test Two Sample Assuming Unequal Variances

	C	D
Mean	1049.20	1100.67
Variance	4823.73	9530.33
Observations	10	3
Pearson Correlation	NA	
Pooled Variance	5080.956097	
df	3	
t	0.85058401	
P(T<=t) one tail	0.2288	
t Critical one tail	2.3534	
P(T<=t) two tail	0.4575	
t Critical two tail	3.1824	

Mean of Sample C DOES NOT DIFFER from mean of Sample D at Alpha = 0.05

ANOVA : Load Cell A - Delta = 2.0 in.

Ho = There is NO difference between sample means.

Analysis of Variance One Way

Summary

Groups	Count	Sum	Average	Variance
A	10.000	6632.000	663.200	4483.067
B	10.000	16067.000	1606.700	18668.233
C	10.000	14618.000	1461.800	14017.966
D	3.000	4476.000	1491.867	9368.333

Analysis of Variance

Source of Variation

	SS	df	MS	F	P-value	F-crit
Between Groups	8783614.800	3.000	2927871.633	21.078	4.66823E-06	2.866266666100718
Within Groups	5000596.800	36.000	138906.433			
Total	13784210.400	39.000				

Reject Ho so therefore there is a difference between at least two means at Alpha = 0.05

Load Cell A

A	B	C	D
669.00	1825.00	1326.00	1380.00
630.00	1496.00	1624.00	1648.00
680.00	1601.00	1861.00	1550.00
727.00	1241.00	1628.00	
690.00	1434.00	1307.00	
636.00	1448.00	1480.00	
631.00	1633.00	1496.00	
703.00	1609.00	1386.00	
690.00	1601.00	1620.00	
789.00	1683.00	1293.00	

t-Test Two-Sample Assuming Unequal Variances

	A	B
Mean	663.200	1606.700
Variance	4483.067	18668.233
Observations	10.000	10.000
Pearson Correlation	0.068	
Pooled Variance	10170.650	
df	14.000	
t	-18.702	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.761	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.145	

Mean of Sample A differs from mean of Sample B at Alpha = 0.05

t-Test Two-Sample Assuming Unequal Variances

	B	C
Mean	1606.7	1461.8
Variance	18668.23333	14017.95666
Observations	10	10
Pearson Correlation	-0.69967296	
Pooled Variance	14838.09444	
df	18	
t	1.007786906	
P(T<=t) one-tail	0.163486777	
t Critical one-tail	1.734063604	
P(T<=t) two-tail	0.326913566	
t Critical two-tail	2.10092204	

Mean of Sample B DOES NOT DIFFER from mean of Sample C at Alpha = 0.05

t-Test Two-Sample Assuming Unequal Variances

	C	D
Mean	1461.8	1491.866667
Variance	14017.95666	9368.333333
Observations	10	3
Pearson Correlation	NA	
Pooled Variance	13170.78182	
df	4	
t	-0.59299990	
P(T<=t) one-tail	0.292872403	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.686144806	
t Critical two-tail	2.776445106	

Mean of Sample C DOES NOT DIFFER from mean of Sample D at Alpha = 0.05

t-Test Two-Sample Assuming Unequal Variances

	A	C
Mean	663.200	1461.800
Variance	4483.067	14017.966
Observations	10.000	10.000
Pearson Correlation	-0.341	
Pooled Variance	9350.511	
df	14.000	
t	-18.236	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.761	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.145	

Mean of Sample A differs from mean of Sample C at Alpha = 0.05

t-Test Two-Sample Assuming Unequal Variances

	B	D
Mean	1606.7	1491.866667
Variance	18668.23333	9368.333333
Observations	10	3
Pearson Correlation	NA	
Pooled Variance	14612.79697	
df	4	
t	0.219626186	
P(T<=t) one-tail	0.418456748	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.836913496	
t Critical two-tail	2.776445106	

Mean of Sample B DOES NOT DIFFER from mean of Sample D at Alpha = 0.05

t-Test Two-Sample Assuming Unequal Variances

	A	D
Mean	663.200	1491.867
Variance	4483.067	9368.333
Observations	10.000	3.000
Pearson Correlation	NA	
Pooled Variance	5633.115	
df	3.000	
t	-13.831	
P(T<=t) one-tail	0.000	
t Critical one-tail	2.353	
P(T<=t) two-tail	0.001	
t Critical two-tail	3.182	

Mean of Sample A differs from mean of Sample D at Alpha = 0.05

ANOVA : Load Cell B - Delta = 2.8 in.
Ho = There is NO difference between sample means.

Analysis of Variance One Way

Summary

Groups	Count	Sum	Average	Variance
A	10 000	7383 000	738 300	2798 011
B	10 000	15387 000	1538 700	12338 233
C	10 000	14509 000	1450 900	8530 767
D	3 000	4581 000	1527 000	19812 000

Analysis of Variance

Source of Variation

	SS	df	MS	F	P-value	F-crit
Between Groups	8522448 000	3 000	2840816 000	19 861	9 1141E-08	2 866265551587
Within Groups	5149294 000	36 000	143035 944			
Total	13671742 000	39 000				

Reject Ho so therefore there is a difference between at least two means at Alpha = 0 05

t Test Two Sample Assuming Unequal Variances

	A	B
Mean	738 300	1538 700
Variance	2798 011	12338 233
Observations	10 000	10 000
Pearson Correlation	0 174	
Pooled Variance	7567 122	
df	13 000	
t	20 574	
P(T<=t) one tail	0 000	
t Critical one tail	1 771	
P(T<=t) two tail	0 000	
t Critical two tail	2 160	

Mean of Sample A differs from mean of Sample B at Alpha = 0 05

t-Test Two Sample Assuming Unequal Variances

	A	C
Mean	738 300	1450 900
Variance	2798 011	8530 767
Observations	10 000	10 000
Pearson Correlation	0 250	
Pooled Variance	5007 389	
df	14 000	
t	21 315	
P(T<=t) one tail	0 000	
t Critical one tail	1 761	
P(T<=t) two tail	0 000	
t Critical two tail	2 145	

Mean of Sample A differs from mean of Sample C at Alpha = 0 05

t Test Two Sample Assuming Unequal Variances

	A	D
Mean	738 300	1527 000
Variance	2798 011	19812 000
Observations	10 000	3 000
Pearson Correlation	NA	
Pooled Variance	5891 404	
df	2 000	
t	9 494	
P(T<=t) one tail	0 005	
t Critical one tail	2 920	
P(T<=t) two tail	0 011	
t Critical two tail	4 303	

Mean of Sample A differs from mean of Sample D at Alpha = 0 05

t Test Two Sample Assuming Unequal Variances

	B	C
Mean	1538 7	1450 9
Variance	12338 23333	8530 766667
Observations	10	10
Pearson Correlation	0 39008944	
Pooled Variance	10435 5	
df	17	
t	1 81233250	
P(T<=t) one tail	0 04381 7363	
t Critical one tail	1 73960 6724	
P(T<=t) two tail	0 08763 4727	
t Critical two tail	2 109815577	

Mean of Sample B DOES NOT DIFFER from mean of Sample C at Alpha = 0 05

t Test Two Sample Assuming Unequal Variances

	B	D
Mean	1538 7	1527
Variance	12338 23333	19812
Observations	10	3
Pearson Correlation	NA	
Pooled Variance	13895 46394	
df	3	
t	0 14345 9925	
P(T<=t) one tail	0 44751 2893	
t Critical one tail	2 353363434	
P(T<=t) two tail	0 89502 5787	
t Critical two tail	3 182446305	

Mean of Sample B DOES NOT DIFFER from mean of Sample D at Alpha = 0 05

Load Cell B

A	B	C	D
739 00	1585 00	1350 00	1369 00
739 00	1467 00	1529 00	1573 00
784 00	1609 00	1557 00	1639 00
781 00	1335 00	1558 00	
751 00	1638 00	1303 00	
624 00	1683 00	1534 00	
723 00	1629 00	1449 00	
745 00	1591 00	1441 00	
691 00	1529 00	1512 00	
[illegible]	1720 00	1355 00	

t Test Two Sample Assuming Unequal Variances

	C	D
Mean	1450 9	1527
Variance	8530 766667	19812
Observations	10	3
Pearson Correlation	NA	
Pooled Variance	10588 80802	
df	3	
t	-0 81173858	
P(T<=t) one tail	0 238183845	
t Critical one tail	2 353363434	
P(T<=t) two tail	0 476367689	
t Critical two tail	3 182446305	

Mean of Sample C DOES NOT DIFFER from mean of Sample D at Alpha = 0 05

Joint Motion Data

Joint motion involved rotation and/or vertical slip
Values listed are for the largest space across the joint gap, in units of 1/16 ", rounded off to show trends
Since most joints rotate, whether the largest gap is across the top or bottom of the post profile
is dependent on relative joint location. Gap value given could decrease if rotation evens out top/bottom spacing
Rotation evident from change in values (gap size)
Non-obvious rotations are indicated by - Rotat - annotation
NS (Nail slip). Indicates first detection of vertical motion at joint, either relative between butted boards
or comparatively vs adjacent piles
Non-observed data is omitted or repeated from last reading to indicate no change (conservative assumption)

Largest Gap Spacing (units of 1/16 ")

Initial Spacing

	J1	J2	J3	J4
A1	-	-	-	-
A2	1	0	0	1
A3	1	1	1	2
A4	1	1	1	1
A5	1	1	1	1
A6	1	0	1	2
A7	1	2	1	1
A8	0	0	0	3
A9[1]	2	0	0	1
A10	1	1	1	2

0.4 " Midpoint Deflection

	J1	J2	J3	J4
A1	-	-	-	-
A2	-	-	-	-
A3	1	(1 NS)	1	2
A4	1	1	1	1
A5	1	1	1	1
A6	1	0	1	2
A7	1	2	1	1
A8	0	0	0	3
A9[1]	2	0	0	1
A10	1	1	1	2

1.0 " Midpoint Deflection

	J1	J2	J3	J4
A1	-	-	-	-
A2	-	-	-	-
A3	1	1	1	(3)
A4	1	1	1	1
A5	1	1	1	1
A6	(2)	0	1	(2 NS)
A7	1	2	1	(2)
A8	0	0	1	3
A9[1]	(1 NS)	0	1	(1 NS)
A10	1	1	1	2

1.4 " Midpoint Deflection

	J1	J2	J3	J4
A1	-	-	-	-
A2	(1)	(1)	-	(1)
A3	1	2	1	3
A4	1	1	1	1
A5	1	1	1	1
A6	2	0	1	2
A7	1	2	2	2
A8	0	0	1	3
A9[1]	1	0	1	2
A10	1	1	1	2

2.0" Midpoint Deflection

	J1	J2	J3	J4
A1	-	-	-	-
A2	1	(1)	(2)	(3)
A3	(1 NS)	2	1	3
A4	1	(2 NS)	(2)	(3 NS)
A5	1	(2 NS)	1	(2)
A6	2 NS	0	1	2
A7	1	(3 NS)	3	2 NS
A8	(0 NS)	(1)	1	(4 NS)
A9[1]	1	(1 NS)	2	3
A10	1	(2)	(2)	2 NS

(val) = First detected motion in joint - either rotation or nail slip
[1] Only 2 nails / side in J4

Initial Spacing

	J1	J2	J3	J4
B1	2	0	0	1
B2	2	1	0	1
B3[1]	1	1	1	1
B4[2]	2	1	2	1
B5	3	1	1	1
B6	0	0	0	3
B7	2	0	1	1
B8	3	0	1	2
B9	2	1	0	1
B10[3]	1	0	0	0

0.4 " Midpoint Deflection

	J1	J2	J3	J4
B1	2	0	0	1
B2	2	1	0	1
B3[1]	1	1	1	1
B4[2]	2	1	2	1
B5	3	1	1	1
B6	0	0	0	3
B7	2	0	1	1
B8	3	0	1	2
B9	2	1	0	1
B10[3]	1	0	0	0

1.0 " Midpoint Deflection

	J1	J2	J3	J4
B1	2	(0 NS)	0	(2)
B2	2	(1 NS)	0	(2)
B3[1]	(1 NS)	(1 NS)	1	(2)
B4[2]	(2 NS)	1	(1 NS)	(2)
B5	(4)	(2 NS)	(2)	(2)
B6	0	0	(1)	3
B7	2	0	1	(0)
B8	(3NS)	(1)	(1NS)	2
B9	2	1	0	(2)
B10[3]	(0NS)	(0NS)	(1)	(1)

1.4 " Midpoint Deflection

	J1	J2	J3	J4
B1	2	0	(0 NS)	2
B2	(1)	1	(1)	2
B3[1]	1	1	1	2
B4[2]	1	(2)	1	2
B5	4	2	2	2
B6	(0 NS)	(0 NS)	2	(2)
B7	(2 NS)	0	1	1
B8	3	1	1	2
B9	(2NS)	1	(1)	2
B10[3]	0	1	1	1

2.0" Midpoint Deflection

	J1	J2	J3	J4
B1	2	0	0	2
B2	1	1	1	2
B3[1]	2	1	1	2
B4[2]	1	2	2	2
B5	4 NS	2	2	3 NS
B6	0	0	2	2
B7	2	(0 NS)	(2)	1
B8	3	1	2	(3)
B9	2	(1NS)	1	3NS
B10[3]	0	1	1	1

[1] J2 only has 2 nails / side
[2] J1 and J3 only have 1 nail / side
[3] Off splice arrangement

Initial Spacing

	J1	J2	J3	J4
C1	0	0	2	2
C2	1	1	1	1
C3	1	1	1	1
C4	1	0	0	1
C5	1	1	1	1
C6	1	1	2	1
C7	2	0	2	1
C8	2	1	0	1
C9[1]	1	1	2	1
C10	1	0	1	1

0.4 " Midpoint Deflection

	J1	J2	J3	J4
C1	0	0	2	2
C2	1	1	1	1
C3	1	1	1	1
C4	1	0	0	1
C5	1	1	1	1
C6	1	1	2	1
C7	2	0	2	1
C8	2	1	0	1
C9[1]	1	1	2	1
C10	1	0	1	1

1.0 " Midpoint Deflection

	J1	J2	J3	J4
C1	0	0	2	2
C2	(2)	1	1	(0)
C3	(2)	(2)	1	1
C4	1	0	(1)	1
C5	1	1	1	(2)
C6	(2)	1	(1)	(2)
C7	(3)	0	(1)	(0)
C8	2	(1 NS)	(1)	(2)
C9[1]	(1 NS)	(1 NS)	(1)	(1 Rotat)
C10	(0)	0	(2 NS)	(1 Rotat)

1.4 " Midpoint Deflection

	J1	J2	J3	J4
C1	0	0	(1)	2
C2	2	(0)	(0)	1
C3	2 NS	2	(2)	(2)
C4	1	0	1	(2)
C5	1	(1 NS)	1	2
C6	2	1	1	2
C7	3	(0 NS)	1	1
C8	(3 NS)	1	2	2
C9[1]	1	0	1	1
C10	0 NS	0	2	1

2.0" Midpoint Deflection

	J1	J2	J3	J4
C1	(1)	0	2	(2 Rotat)
C2	2	0 NS	0	2
C3	2	2 NS	3	2
C4	(2)	0	2	2
C5	1	1	(2)	2
C6	2 NS	1	1	2
C7	3	0	1	2
C8	3	2	2	2
C9[1]	1	0	1	2
C10	0	(0 NS)	3	2

[1] J3 nail pattern off

Initial Spacing

	J1	J2	J3	J4
D1[1]	1	0	2	0
D2	1	0	1	2
D3	1	0	2	1

0.4 " Midpoint Deflection

	J1	J2	J3	J4
D1[1]	1	0	2	0
D2	1	0	1	2
D3	1	0	2	1

1.0 " Midpoint Deflection

	J1	J2	J3	J4
D1[1]	(0 NS)	0	(1)	0
D2	(2)	0	(1 NS)	(1)
D3	(2)	0	(2 Rotat)	(2)

1.4 " Midpoint Deflection

	J1	J2	J3	J4
D1[1]	0	0	2	(1)
D2	2	0	2	1
D3	2	0	2	2

2.0" Midpoint Deflection

	J1	J2	J3	J4
D1[1]	1	0	2	1
D2	2 NS	0	2	2
D3	2 NS	(1)	3 NS	2

Joint Motion Summary

Summary on 31 posts - A1 and A2 omitted due to lack of data.

A Series : 75% of posts showed some joint motion by 1.4" midpoint def. (100% by 2.0" def.)
B Series : 100% of posts showed some joint motion by 1.4" midpoint def.
C Series : 100% of posts showed some joint motion by 1.4" midpoint def.
D Series : 100% of posts showed some joint motion by 1.4" midpoint def.

Breakdown by Joints

A Series :	9 / 24 joints showed initial motion by 1.4 " def.	37.50%
B Series :	34 / 40 joints showed initial motion by 1.4 " def.	85%
C Series :	31 / 40 joints showed initial motion by 1.4 " def.	77.50%
D Series :	9 / 12 joints showed initial motion by 1.4 " def.	75%

Series A (8 samples)

If both motions occur, motion is counted as NS.

1 in. deflection

J1	J2	J3	J4
1 Rot	0 Rot	2 Rot	2 Rot
1 NS	0 NS	0 NS	2 NS
(1 both)			

1.4 in. Deflection

J1	J2	J3	J4
0	0	1 Rot	0

Total movement by 1.4 in deflection.

J1	J2	J3	J4
2 / 8	0 / 8	3 / 8	4 / 8
1 Rot	0 Rot	2 Rot	2 Rot
1 NS	0 NS	0 NS	2 NS

Motion distribution

22%	0	33%	44%

In total 9 / 24 joints moved = 38.00%
Type : 5 Rot, 3 NS, 1 Both.

Rotation occurred in 5/24 joints = 21.00%
NS occurred in 3/24 joints = 12.50%

Series B, C, & D. (23 samples)

1 in. deflection

J1	J2	J3	J4
8 Rot	2 Rot	10 Rot	17 Rot
6 NS	7 NS	4 NS	0 NS
(1 both)	(1 both)	(2 both)	

1.4 in. Deflection

J1	J2	J3	J4
1 Rot	2 Rot	5 Rot	4 Rot
4 NS	3 NS	1 NS	0 NS
(1 both)			

Total movement by 1.4 in deflection.

J1	J2	J3	J4
19 / 23	14 / 23	20 / 23	21 / 23
9 Rot	4 Rot	15 Rot	17 Rot
10 NS	10 NS	5 NS	0 NS

Motion distribution

26%	19%	27%	28%

In total 74 / 92 joints moved = 80.00%
Type : 45 Rot, 25 NS, 5 Both.

Rotation occurred in 45/92 joints = 49.00%
NS occurred in 25/92 joints = 27.00%

Conclusions

All joint arrangements were ineffective at preventing significant joint motion by the design deflection limit under realistic loading and support conditions.

Rotation at a joint is the predominant form of motion. This could be restricted by clean and solid butt joints, but these simply do not occur with any regularity in commercial posts.

Nail slip (shear), is a much more significant factor in joint motion under fixed end conditions.

The joint stresses are much more evenly distributed in the fixed end posts.

Bending stresses (as indicated by rotation) predominate towards the centre of the post at J3 and J4, while shear stresses (as indicated by nail slip), concentrate towards the base of the post at J1 and J2.

Increasing axial loading may reduce joint motion slightly, but it has little practical effect because the majority of joints still incur some motion.

General observation of the weaker joint aberrations in the data (A9, B3, B4, C9), do not indicate that they are particularly poor performer compared to the other joints. The one different splice arrangement (B10), is also not particularly outstanding from the other data.

Moisture Content of All Test Series
Species : S-P-F #2

Series A - Dec / 97

Sample	MC (%db)	Notes
A1	16.2	6 hrs
A2	15.4	6 hrs
A3	16.7	7 hrs
A4	16.1	5 hrs
A5	16.9	5 hrs
A6	16.9	20 hrs
A7	17.8	7.3 hrs
A8	15.5	7.3 hrs
A9	15.7	22 hrs
A10	18.4	2 weeks

Note 3 - 4 hrs of drying time is acceptable.

A Series MC%	
Mean	16.56
Standard Error	0.31
Median	16.45
Mode	16.90
Standard Deviation	0.98
Variance	0.97
Kurtosis	-0.27
Skewness	0.68
Range	3.00
Minimum	15.40
Maximum	18.40
Sum	165.60
Count	10.00
Confidence Level(0.95)	0.61

Series B - Jan / 98

Sample	MC (%db)	Notes
B1	15.06	24 hrs
B2	19.08	28 hrs
B3	16.8	6 hrs
B4	17.2	4.5 hrs
B5	17.5	23.5 hrs
B6	14.9	24.5 hrs
B7	14.4	5.5 hrs
B8	16.7	4.5 hrs
B9	17.8	25 hrs
B10	14.2	22.5 hrs

B Series MC%	
Mean	16.36
Standard Error	0.52
Median	16.75
Mode	NA
Standard Deviation	1.63
Variance	2.67
Kurtosis	-1.17
Skewness	0.06
Range	4.88
Minimum	14.20
Maximum	19.08
Sum	163.61
Count	10.00
Confidence Level(0.95)	1.01

Series C - Feb / 98

Sample	MC (%db)	Notes
C1	13	
C2	22.4	25.5 hrs
C3	15.9	
C4	17.9	
C5	17	
C6	15.9	
C7	15.4	
C8	18.6	
C9	18.7	5 days
C10	16.1	2 days

C Series MC%	
Mean	17.09
Standard Error	0.80
Median	16.55
Mode	15.90
Standard Deviation	2.52
Variance	6.36
Kurtosis	1.62
Skewness	0.70
Range	9.40
Minimum	13.00
Maximum	22.40
Sum	170.90
Count	10.00
Confidence Level(0.95)	1.56

Series D - March / 98

Sample	MC (%db)	Notes
D1	11.5	24.5 hrs
D2	16.9	5 days
D3	17.4	23 hrs

D Series MC%	
Mean	15.27
Standard Error	1.89
Median	16.90
Mode	NA
Standard Deviation	3.27
Variance	10.70
Kurtosis	ERR
Skewness	-1.69
Range	5.90
Minimum	11.50
Maximum	17.40
Sum	45.80
Count	3.00
Confidence Level(0.95)	3.70

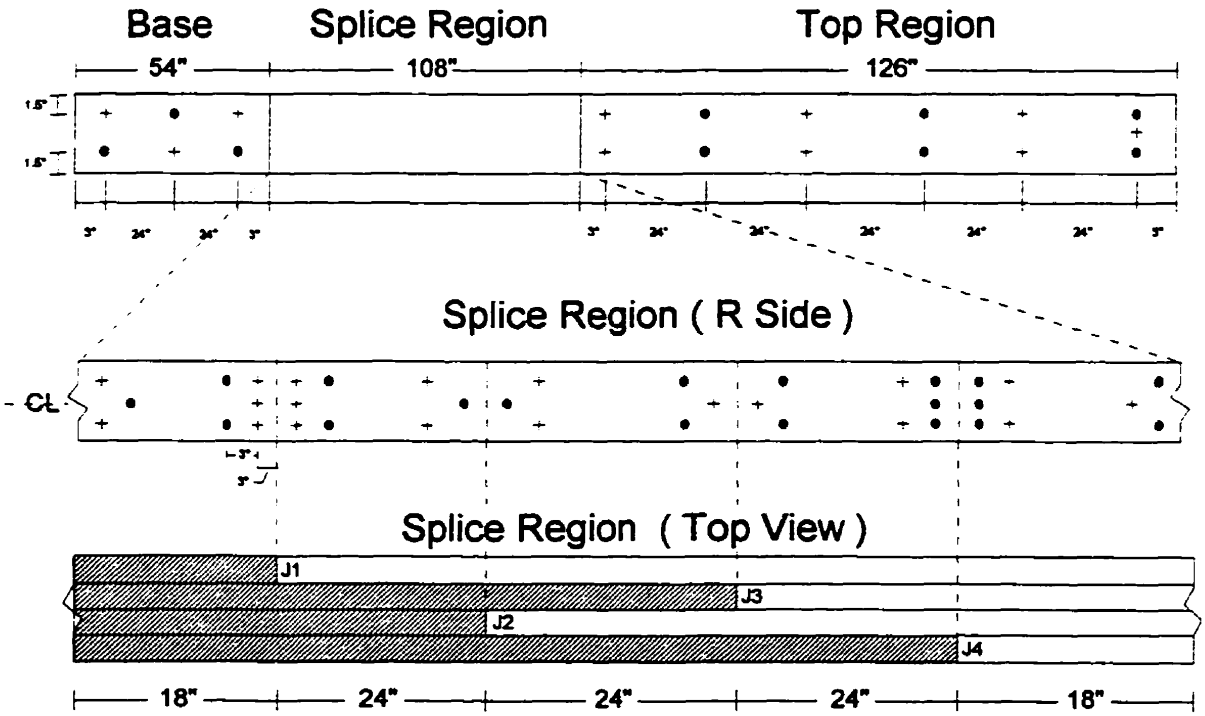
Total MC %
16.2
15.4
16.7
16.1
16.9
16.9
17.8
15.5
15.7
18.4
15.06
19.08
16.8
17.2
17.5
14.9
14.4
16.7
17.8
14.2
13
22.4
15.9
17.9
17
15.9
15.4
18.6
18.7
16.1
11.5
16.9
17.4

Total Series MC%	
Mean	16.543
Standard Error	0.33641
Median	16.7
Mode	16.9
Standard Deviation	1.9325
Variance	3.73456
Kurtosis	2.51366
Skewness	0.19343
Range	10.9
Minimum	11.5
Maximum	22.4
Sum	545.91
Count	33
Confidence Level(0.95)	0.66

CV = 11.7 %

Nail Laminated Post Specifications (Mod.)
24' x 4 - Ply x (2 x 8), S-P-F Grade 2 or better.

4" Spiral nails • = Nail from right outer side + = Nail from left outer side



Slender Column Axial Load Analysis

Column Length - L (mm) :	6400	E_{05} Value (MPa) :	6500
Column Width - b (mm):	152	I value (mm^4) :	78907051
Depth - h (mm):	184		
Effective Length - Le (mm):	5120		

E_{05} for S-P-F # 2 = 6500 MPa
Ref: Wood Design Manual, 1995

End Conditions
Pinned: Le = L
Pin / Rigid: Le = 0.8L
Rigid/Rigid: Le = 0.65L
Free/Rigid: Le = 2L
Ref: CSA 086.1-94 Tbl. A5.5.6.1

Radius of Gyration - r : 53.1 mm
r = SQR (I / A)
(r for rect. x section = 0.29h)

Slenderness ratio : 96.4
SR = Le / r
(Must be < 170 for wood)
Ref: Structural Basis of Architecture, 1992

Slenderness ratio : 27.8
SR = Le / h :
(Must be < 50 - column restrained laterally)
Ref: CSA 086.1- 94 5.5.6.2

Euler Load Equation (N)

P critical : 1.93E+05 N
$P_{kr} = Pi^2 * E*I / Le^2$

Euler Stress (N / mm ^{2})
Breaking Stress : 6.90 MPa
Stress = P_{kr} / Area :

Critical load in kg : 19684 kg
Critical load in lbs of force : 43409 lbs

Beam Formula Solver
Simply Supported
Two unequal concentrated loads unsymmetrically placed.

Determining E values from given loads and midpoint deflections.

Formula :

EI * y = [Pb / 6L]*[x³ - (L / b)*(x - a)³ - (L² - b²) *x]	for : a < x < L	(P2 = Load A)
EI * y = [Pb / 6L]*[x³ - (L² - b²) * x]	for : 0 < x < a	(P1 = Load B)

Ref . Schaum's Strength of Materials, 3/ed

Midpoint deflection (Y_{Total}), of simply supported beam under point load P_1, at distance a from from the left support and load P_2 which is additive to the first load. ie. Deflections $Y_1 + Y_2 = Y_{Total}$ and $Y_1 = Y_2$
Weighted E values use the assumption of proportional contributions to deflection based the proportion of loads. ie. Load A produces A / (A + B) of the deflection.
Distances a + b = L along beam. Coordinate x = 0 is at the left end of beam and Y is positive above the x-axis.

General Inputs :

L (mm) =	6400	
P_{2a} (mm) =	2134	P_2 distance from left end.
P_{1a} (mm) =	4266	P_1 distance from left end.
Midpoint x (mm) =	3200	
I (mm⁴) =	7.89E+07	

Results :

Series A:

Defl = 0.4 in.
Y_{Tot} (mm) = -10.2

P_1 (N) =	911	P_2 (N) =	592
a_1 (mm) =	4266	a_2 (mm) =	2134
b_1 (mm) =	2134	b_2 (mm) =	4266
E (MPa) =	**8689**	**Weighted :**	**4540**

Defl = 1.0 in.
Y_{Tot} (mm) = -25.4

P_1 (N) =	1833	P_2 (N) =	1516
a_1 (mm) =	4266	a_2 (mm) =	2134
b_1 (mm) =	2134	b_2 (mm) =	4266
E (MPa) =	**7775**	**Weighted :**	**3922**

Defl = 1.4 in.
Y_{Tot} (mm) = -35.6

P_1 (N) =	2434	P_2 (N) =	2097
a_1 (mm) =	4266	a_2 (mm) =	2134
b_1 (mm) =	2134	b_2 (mm) =	4266
E (MPa) =	**7506**	**Weighted :**	**3774**

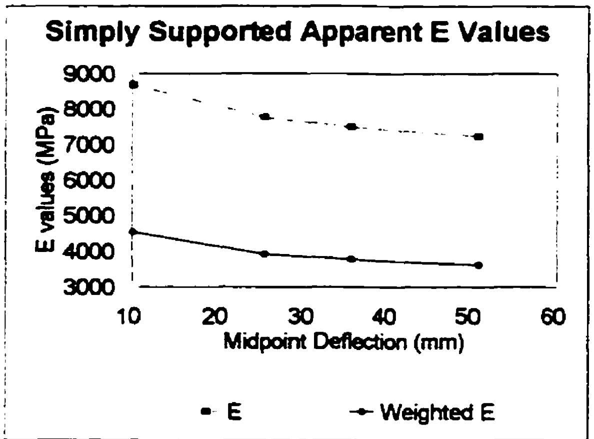
Defl = 2.0 in.
Y_{Tot} (mm) = -50.8

P_1 (N) =	3289	P_2 (N) =	2950
a_1 (mm) =	4266	a_2 (mm) =	2134
b_1 (mm) =	2134	b_2 (mm) =	4266
E (MPa) =	**7242**	**Weighted :**	**3832**

Summary

Defl	Load A	Load B	E	Weighted E
10.2	592	911	8689	4540
25.4	1516	1833	7775	3922
35.6	2097	2434	7506	3774
50.8	2950	3289	7242	3832

Analysis	E Values	Weighted E
Mean	7803.19	3967.10
Standard Error	314.82	200.12
Median	7640.40	3848.00
Mode	NA	NA
Standard Deviation	629.64	400.23
Variance	396444.43	160184.58
Kurtosis	1.85	2.36
Skewness	1.32	1.49
Range	1447.02	908.54
Minimum	7242.47	3631.93
Maximum	8689.49	4540.46
Sum	31212.77	15868.38
Count	4.00	4.00
Confidence Level(0.95)	617.03	392.22
CV	0.081	0.101



Beam Formula Solver
Fixed End - Simply Supported
Two unequal loads unsymmetrically placed.

Determining E values from given loads and midpoint deflections.

Formula :

Y = [P b² x / (12EI L³)] * (3aL² - 2L a² - a x²) for x < a (P₁ = Load A)
Y = [P a / (12EI L³)] * (L - x)² * (3L² x - a² x - 2a² L) for x > a (P₂ = Load B)

Ref: CWC Wood Design Manual 1995

Midpoint deflection $Y_{mid} = Y_1 + Y_2$ from load A and B. Assume $Y_1 + Y_2$
[illegible]

General Inputs :

L [mm] =	6400	
P_1, a [mm] =	4266	P_1 distance from simple support
P_2, a [mm] =	2134	P_2 distance from simple support
Midpoint x [mm] =	3200	
I [mm⁴] =	[illegible]	

Results :

Series B :

Defl = 0.4 in		Defl = 1.0 in		Defl = 1.4 in		Defl = 2.0 in	
Y_{mid} [mm] =	10.2	Y_{mid} [mm] =	25.4	Y_{mid} [mm] =	35.6	Y_{mid} [mm] =	50.8
E (MPa) =	7080	E (MPa) =	6834	E (MPa) =	6717	E (MPa) =	[illegible]

Series C :

Defl = 0.4 in		Defl = 1.0 in		Defl = 1.4 in		Defl = 2.0 in	
Y_{mid} [mm] =	10.2	Y_{mid} [mm] =	25.4	Y_{mid} [mm] =	35.6	Y_{mid} [mm] =	50.8
E (MPa) =	7074	E (MPa) =	6662	E (MPa) =	[illegible]	E (MPa) =	[illegible]

Series D :

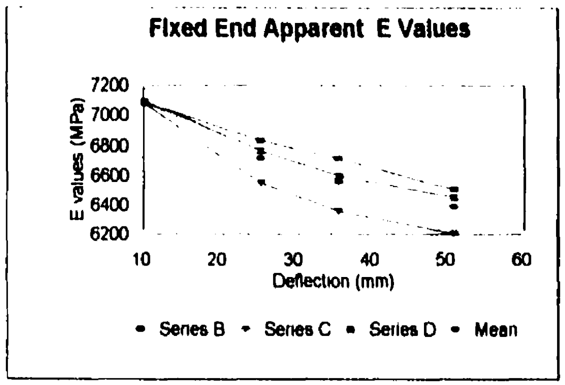
Defl = 0.4 in		Defl = 1.0 in		Defl = 1.4 in		Defl = 2.0 in	
Y_{mid} [mm] =	10.2	Y_{mid} [mm] =	25.4	Y_{mid} [mm] =	35.6	Y_{mid} [mm] =	50.8
E (MPa) =	7081	E (MPa) =	[illegible]	E (MPa) =	[illegible]	E (MPa) =	6461

E Values Summary

	Deflection (mm)			
	10.2	25.4	35.6	50.8
Series B	7080	6834	6717	[illegible]
Series C	7074	6662	[illegible]	[illegible]
Series D	7081	[illegible]	[illegible]	6461
Mean	[illegible]	6717	[illegible]	[illegible]

E Values Summary Analysis

Deflection (mm)	10.2		25.4		35.6		50.8
Mean	7082?	Mean	6717	Mean	[illegible]	Mean	[illegible]
Standard Error	[illegible]	Standard Error	[illegible]	Standard Error	[illegible]	Standard Error	[illegible]
Median	[illegible]	Median	[illegible]	Median	[illegible]	Median	[illegible]
Mode	NA	Mode	NA	Mode	NA	Mode	NA
St. Dev	[illegible]	St. Dev	147.30?	St. Dev	[illegible]	St. Dev	[illegible]
Variance	[illegible]	Variance	[illegible]	Variance	[illegible]	Variance	[illegible]
Kurtosis	[illegible]	Kurtosis	[illegible]	Kurtosis	[illegible]	Kurtosis	[illegible]
Skewness	[illegible]	Skewness	[illegible]	Skewness	[illegible]	Skewness	[illegible]
Range	[illegible]	Range	[illegible]	Range	[illegible]	Range	[illegible]
Minimum	[illegible]	Minimum	[illegible]	Minimum	[illegible]	Minimum	[illegible]
Maximum	[illegible]	Maximum	[illegible]	Maximum	[illegible]	Maximum	[illegible]
Sum	[illegible]	Sum	[illegible]	Sum	[illegible]	Sum	[illegible]
Count	3.00	Count	3.00	Count	3.00	Count	3.00
Confidence Level(95.0%)	[illegible]	Confidence Level(95.0%)	[illegible]	Confidence Level(95.0%)	[illegible]	Confidence Level(95.0%)	[illegible]
CV	0.001		0.022		[illegible]		[illegible]



Beam Formula Solver

Simply Supported

Two unequal concentrated loads unsymetrically placed.

Inputs : 0.4 in. midpoint deflection

Load A (P1)(N) =	592	E (MPa) =	9500
Load B (P2)(N) =	912		
L (mm) =	6400	I (mm⁴) =	7.88E+07
a (mm) =	2134		
b (mm) =	2134	Load A at position a from left end	
x (mm) =	3200	Load B at position b from right end	

Results :

$R_1 = V_1$:	808	N
$R_2 = V_2$:	905	N
V_x (when x > a & < (L - b))	107	N
M_1 (Max when $R_1 > P_1$)	1.49E+06	N * mm (kN * m)
M_2 (Max when $R_2 > P_2$) :	1.72E+06	N * mm (kN * m)
M_x (when x < a)	2.34E+06	N * mm (kN * m)
M_x (when x > a & < (L-b))	1.60E+06	N * mm (kN * m)

Ref: Beam Diagrams and Formulae. Wood Design Manual. 1995

Notes:

1 N = 0.2248 pounds force

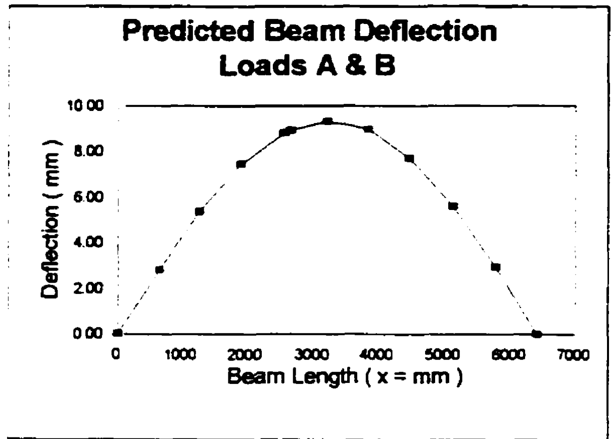
Rectangular Moment of Inertia: I = bd³ / 12 (mm⁴)

Modulus of Elasticity

Joists and Planks: 386.1.94 Tbl 5.3.1A

S-P-F #2: E = 9500 MPa

Ref: Wood Design Manual. 1995



Predicted Deflection *

Deflection (y) of simply supported beam under point load P at a distance a from from the left support.

* Note: Coordinate change. Distances a + b = L along beam. Coordinate x = 0 is at the left end of beam.

Ref: Schaum's Strength of Materials. 3rd

EI * y = [illegible] for 0 < x < a

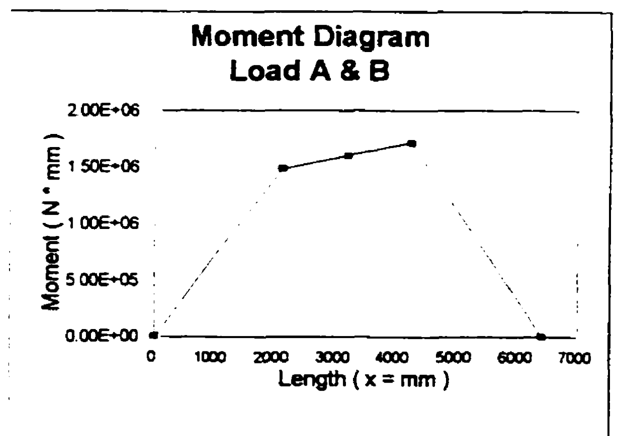
EI * y = [illegible] for a < x < L

		P1			P2			Total Deflection
		P1 a (mm)	P1 b (mm)	Beam Length (mm)	P2 a (mm)	P2 b (mm)		(P1 + P2)
		2134	4266	6400	4266	2134		(Pos values)
		Deflection (mm)		Actual Def.	Deflection (mm)		Actual Def.	
Length along beam	X Values(mm)	0 < x < a	a < x < L	Y1	0 < x < a	a < x < L	Y2	(mm)
[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00
[illegible]	640	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.81
[illegible]	1280	[illegible]	[illegible]	[illegible]	3	[illegible]	3	5.39
[illegible]	1920	3	3	3	-4	[illegible]	-4	7.46
[illegible]	2560	-4	-4	-4	[illegible]	-4	5	8.82
[illegible]	[illegible]	-4	-4	-4	[illegible]	-4	[illegible]	8.94
[illegible]	3200	-4	-4	-4	-6	5	-6	9.34
[illegible]	3840	[illegible]	[illegible]	[illegible]	-6	-6	[illegible]	8.98
[illegible]	4480	[illegible]	[illegible]	[illegible]	5	-5	[illegible]	7.71
[illegible]	5120	[illegible]	[illegible]	[illegible]	-4	-4	-4	5.81
[illegible]	5760	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.84
[illegible]	6400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00

Predicted Moment

Length along beam	X Values(mm)	Moment (N * mm)
[illegible]	0	0.00E+00
[illegible]	2134	1.49E+06
[illegible]	3200	1.60E+06
[illegible]	4266	1.72E+06
[illegible]	6400	0.00E+00

* When (when x > a & < (L-b))



Beam Formula Solver
Simply Supported
Two unequal concentrated loads unsymetrically placed.

Inputs : 1.8 in. midpoint deflection

Load A (P1)(N)=	1516	E (MPa) =	9500
Load B (P2)(N)=	1833		
L (mm) =	6400	I (mm⁴) =	7.88E+07
a (mm) =	2134		
b (mm) =	2134	Load A at position a from left end	
x (mm) =	3200	Load B at position b from right end	

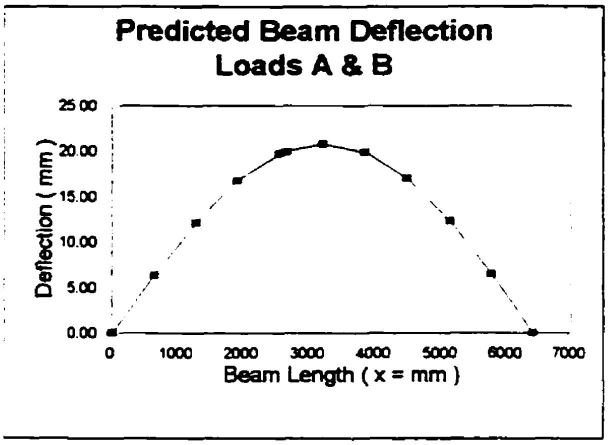
Results :

$R_1 = V_1 =$	1622	N
$R_2 = V_2 =$	1727	N
V_x (when x > a & < (L - b))	106	N
M_1 (Max when $R_1 < P_1$)	3.46E+06	N * mm (kN * m)
M_2 (Max when $R_2 < P_2$)	3.68E+06	N * mm (kN * m)
M_x (when x < a)	5.19E+06	N * mm (kN * m)
M_x (when x > a & < (L-b))	3.57E+06	N * mm (kN * m)

Ref: Beam Diagrams and Formulas. Wood Design Manual 1995

Notes:
1 N = 0.2248 pounds force
Rectangular Moment of Inertia I = bd^3 / 12 ([illegible])

Modulus of Elasticity
Joists and Planks 388 1.34 Tbl 5.3.1A
S-P-F #2 E = 9500 MPa
Ref: Wood Design Manual 1995



Predicted Deflection *

Deflection (y) of simply supported beam under point load P at a distance a from from the left support
* Note: Coordinate change. Distances a + b = L along beam. Coordinate x = 0 is at the left end of beam
Ref: Schaum's Strength of Materials 3ed

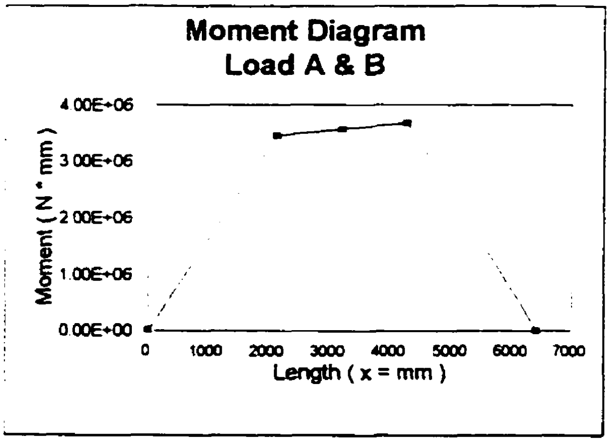
E * I * y = (Pb / 6L)[(L² - b²) * x] for 0 < x < a
E * I * y = (Pb / 6L)[(L/b)(x - a)³ + (L² - b²) x] for a < x < L

		P_1			P_2			Total
		P_1 a (mm)	P_1 b (mm)	Beam Length (mm)	P_2 a (mm)	P_2 b (mm)		Deflection
		2134	4266	6400	4266	2134		(P_1 + P_2)
		Deflection (mm)		Actual Def.	Deflection (mm)		Actual Def.	(Pos values)
Length along beam	X Values(mm)	0 < x < a	a < x < L	Y_1	0 < x < a	a < x < L	Y_2	(mm)
L*0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00
L*0.1	640	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.34
L*0.2	1280	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.12
L*0.3	1920	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16.77
L*0.4	2560	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19.73
[illegible]	2880	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.00
L*0.5	3200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.79
L*0.6	3840	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19.89
L*0.7	4480	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.01
L*0.8	5120	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.36
L*0.9	5760	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.48
L*1	6400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		0.00

Predicted Moment

Length along beam	X Values(mm)	Moment (N * mm)
L*0	0	0.00E+00
L*a	2134	3.46E+06
L*x *	3200	3.57E+06
L*b	4266	3.68E+06
L*L	6400	0.00E+00

* When (when x > a & < (L-b))



Beam Formula Solver
Simply Supported
Two unequal concentrated loads unsymetrically placed.

Inputs : 1.4 in. midpoint deflection

Load A (P1)(N) =	2087	E (MPa) =	9500
Load B (P2)(N) =	2433		
L (mm) =	6400	I (mm⁴) =	7.88E+07
a (mm) =	2134		
b (mm) =	2134	Load A at position a from left end	
x (mm) =	3200	Load B at position b from right end	

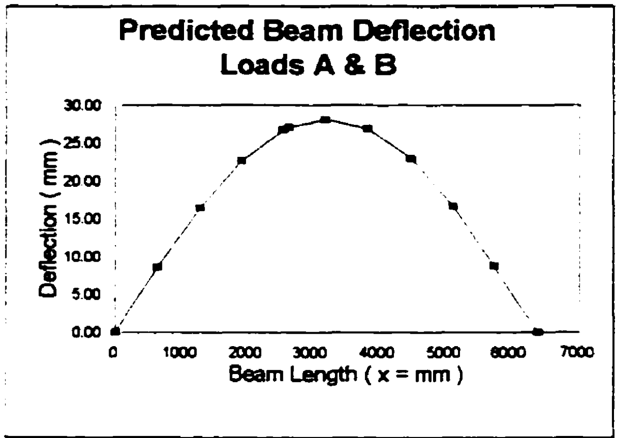
Results :

$R_1 = V_1$ =	2209	N
$R_2 = V_2$ =	2321	N
V_x (when x > a & < (L - b))	112	N
M_1 (Max when $R_1 < P_1$)	4.71E+06	N * mm (kN * m)
M_2 (Max when $R_2 < P_2$)	4.95E+06	N * mm (kN * m)
M_x (when x < a)	1.07E+06	N * mm (kN * m)
M_x (when x > a & < (L-b))	4.83E+06	N * mm (kN * m)

Ref: Beam Diagrams and Formulae. Wood Design Manual. 1995

Notes:
1 N = 0.2248 pounds force
Rectangular Moment of Inertia I = bd³ / 12 (mm⁴)

Modulus of Elasticity
Jones and Pierce 1996 1.94 To 5.3.1A
S-P-F #2 E = 9500 MPa
Ref: Wood Design Manual 1995



Predicted Deflection *

Deflection (y) of simply supported beam under point load P at a distance a from from the left support
* Note: Coordinate change. Distances a + b = L along beam. Coordinate x = 0 is at the left end of beam
Ref: Schaum's Strength of Materials 3ed

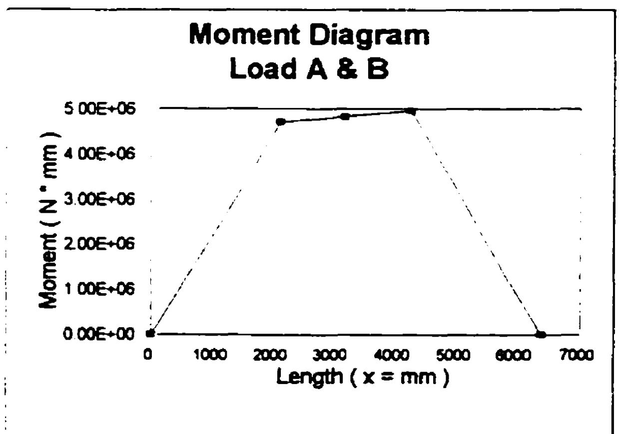
EI * y = [illegible] for 0 < x < a
EI * y = [illegible] for a < x < L

		P1			P2			Total Deflection
		P1 a (mm)	P1 b (mm)	Beam Length (mm)	P2 a (mm)	P2 b (mm)		(P1 + P2)
		2134	4266	6400	4266	2134		(Pos values)
		Deflection (mm)		Actual Def.	Deflection (mm)		Actual Def.	
Length along beam	X Values (mm)	0 < x < a	a < x < L	Y_1	0 < x < a	a < x < L	Y_2	(mm)
L*0	0	0	5	0	0	42	0	0.00
L*0.1	640	4	3	4	4	22	4	8.80
L*0.2	1280	8	8	8	8	5	8	16.43
L*0.3	1920	11	11	11	11	4	11	22.71
L*0.4	2560	13	13	13	14	11	14	26.72
L*0.414	2880	13	13	13	14	12	14	27.07
L*0.5	3200	12	13	13	15	14	15	28.12
L*0.6	3840	10	12	12	15	15	15	26.88
L*0.7	4480	4	10	10	13	13	13	22.87
L*0.8	5120	5	7	7	8	10	10	16.67
L*0.9	5760	19	4	4	3	5	5	8.74
L*1	6400	36	0	0	4	0	0	0.00

Predicted Moment

Length along beam	X Values (mm)	Moment (N * mm)
L=0	0	0.00E+00
L=a	2134	4.71E+06
L=x*	3200	4.83E+06
L=c	4266	4.95E+06
L=L	6400	0.00E+00

* When (when x > a & < (L-b))



Beam Formula Solver

Simply Supported

Two unequal concentrated loads unsymmetrically placed.

Inputs : 2.8 in. midpoint deflection

Load A (P1)(N)=	2850	E (MPa) =	9500
Load B (P2)(N)=	3287		
L (mm) =	6400	I (mm⁴) =	7.88E+07
a (mm) =	2134		
b (mm) =	2134	Load A at position a from left end	
x (mm) =	3200	Load B at position b from right end	

Results :

$R_1 = V_1 =$	3062	N
$R_2 = V_2 =$	3175	N
V_x (when x > a & < (L-b))	112	N
M_1 (Max when $R_1 < P_1$)	6.54E+06	N * mm (kN * m)
M_2 (Max when $R_2 < P_2$)	6.77E+06	N * mm (kN * m)
M_x (when x < a)	5.80E+06	N * mm (kN * m)
M_x (when x > a & < (L-b))	6.65E+06	N * mm (kN * m)

Ref. Beam Diagrams and Formulas. Wood Design Manual 1995

Notes:

1 N = 0.2248 pounds force

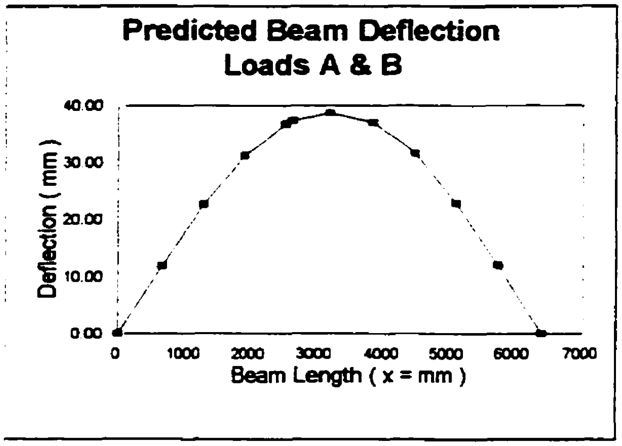
Rectangular Moment of Inertia I = bd³ / 12 (mm⁴)

Modulus of Elasticity

Joists and Planks: O86.1-94 Table 5.3.1A

S-P-F #2: E = 9500 MPa

Ref. Wood Design Manual 1995



Predicted Deflection *

Deflection (y) of simply supported beam under point load P at a distance a from from the left support

* Note: Coordinate change: Distances a + b = L along beam. Coordinate x = 0 is at the left end of beam

Ref: Schaum's Strength of Materials 3ed

EI * y = (Pb / 6L)[x³ - (L² - b²) x] for 0 < x < a

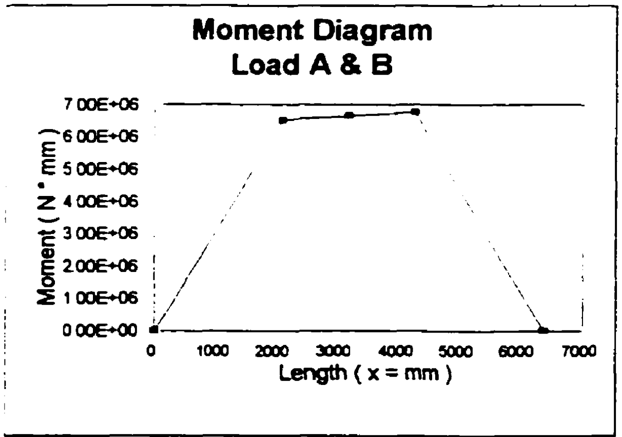
EI * y = (Pb / 6L)[(L/b)(x - a)³ - (L² - b²) x] for a < x < L

		P1			P2			Total
		P1 a (mm)	P1 b (mm)	Beam Length (mm)	P2 a (mm)	P2 b (mm)		Deflection
		2134	4266	6400	4266	2134		(P1 + P2)
		Deflection (mm)		Actual Def.	Deflection (mm)		Actual Def	(Pos values)
Length along beam	X Values (mm)	0 < x < a	a < x < L	Y1	0 < x < a	a < x < L	Y2	(mm)
L*0.0	0	0	5	0	0	57	0	0.00
L*0.1	640	6	4	6	6	29	6	11.87
L*0.2	1280	12	11	12	11	[illegible]	11	22.86
L*0.3	1920	16	16	16	15	6	15	31.32
L*0.4	2560	19	18	19	19	15	19	35.81
L*0.414	2650	16	19	18	19	16	19	37.30
L*0.5	3200	18	18	19	20	20	20	38.72
L*0.6	3840	13	17	17	20	20	20	36.86
L*0.7	4480	5	14	14	18	19	18	31.88
L*0.8	5120	9	10	10	13	13	13	22.80
L*0.9	5760	26	5	5	5	7	7	12.01
L*1	6400	51	0	0	[illegible]	0	0	0.00

Predicted Moment

Length along beam	X Values (mm)	Moment (N * mm)
L*0	0	0.00E+00
L*a	2134	6.54E+06
L*x*	3200	6.65E+06
L*b	4266	6.77E+06
L*L	6400	0.00E+00

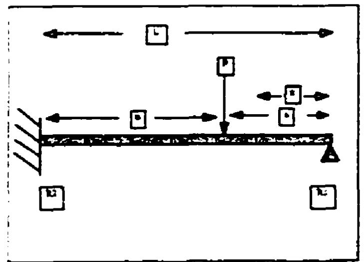
* When (when x > a & < (L-b))



Beam Formula Solver
Fixed End - Simply Supported
Concentrated Load @ Any Point

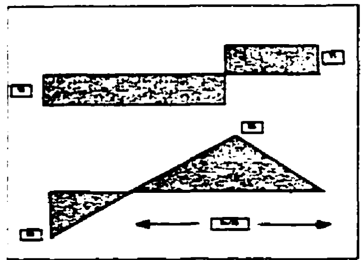
Inputs : Load A

P (N) =	1446	E (MPa) =	9500
L (mm) =	6400	I (mm⁴) =	7.88E+07
a (mm) =	2134		
b (mm) =	4266		
x (mm) =	3200		



Results :

R1 = V1 =	749.58	N
R2 = V2 =	696.42	N
M1 (@ Point Ld) =	1.60E+06	N * mm (kN * m)
M2 (@ Fixed end) =	1.37E+06	N * mm (kN * m)
Mx (x < a) =	2.40E+06	N * mm (kN * m)
Mx (x > a) =	8.57E+05	N * mm (kN * m)
Def max. (a<0.414L @ x = *)	4.73	mm
Def. max.(a>0.414L @ x = **)	4.72	mm
Def @ a =	4.63	mm
Def @ x (x < a) =	3.90	mm
Def @ x (x > a) =	4.29	mm
Point of Inflection: * Pa / R2 =	4430.88	mm
* x = L * ((L² + a²) / (3*L² - a²))	2461.75	mm
** x = L * (SQRT(a / (2*L + a)))	2419.30	mm



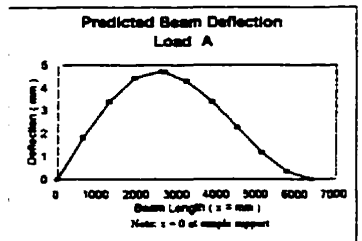
Notes:
X = 0 at simple support
1 N = 0.2248 pounds force
Rectangular Moment of Inertia I = bd³ / 12 (mm⁴)

Modulus of Elasticity
Joists and Planks O86 1-84 Tbl. 5.3.1A
S-P-F #3 E = 9500 MPa
Ref: Wood Design Manual, 1995

Predicted Deflection

Beam Length : 6400 Value of a = 2134

Length along beam	X Value(mm)	Deflection (mm) (x < a)	(x > a)	Actual Deflect (mm)
L * 0	0	0.00	-3.12	0.00
L * 0.1	640	1.83	0.76	1.83
L * 0.2	1280	3.40	3.20	3.40
L * 0.3	1920	4.44	4.44	4.44
L * 0.4	2560	4.70	4.72	4.72
L * 0.414	2650	4.66	4.70	4.70
L * 0.5	3200	3.90	4.29	4.29
L * 0.6	3840	1.80	3.40	3.40
L * 0.7	4480	-1.86	2.28	2.28
L * 0.8	5120	-7.38	1.17	1.17
L * 0.9	5760	-14.99	0.33	0.33
L * 1	6400	-24.95	0.00	0.00



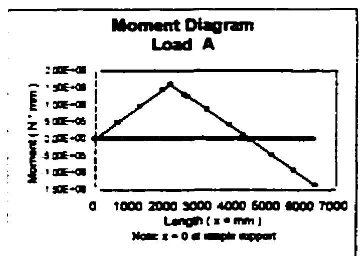
Predicted Moment

Beam Length : 6400 Value of a = 2134

Length along beam	X Value(mm)	Moment (N mm) (x < a)	(x > a)	Actual Moment
L * 0	0	0.00E+00	3.08E+06	0.00E+00
L * 0.1	640	4.80E+05	2.64E+06	4.80E+05
L * 0.2	1280	9.58E+05	2.19E+06	9.58E+05
L * 0.3	1920	1.44E+06	1.75E+06	1.44E+06
L * 0.4	2560	1.92E+06	1.30E+06	1.30E+06
L * 0.414	2650	1.99E+06	1.24E+06	1.24E+06
L * 0.5	3200	2.40E+06	8.57E+05	8.57E+05
L * 0.6	3840	2.88E+06	4.11E+05	4.11E+05
L * 0.7	4480	3.36E+06	-3.42E+04	-3.42E+04
L * 0.8	5120	3.84E+06	-4.80E+05	-4.80E+05
L * 0.9	5760	4.32E+06	-8.28E+05	-8.28E+05
L * 1 (Fixed End - M1)	6400	4.80E+06	-1.37E+06	-1.37E+06
L @ a (Point of load - M2)	2134	1.60E+06	1.80E+06	1.80E+06
L @ x2 (From second force)	4266	3.20E+06	1.15E+06	1.15E+05

Sorted Moments (N mm)

X Value(mm)	Actual Moment	Zero Series
0	0.00E+00	0
640	4.80E+05	0
1280	9.58E+05	0
1920	1.44E+06	0
2134	1.80E+06	0
2560	1.30E+06	0
2650	1.24E+06	0
3200	8.57E+05	0
3840	4.11E+05	0
4266	1.15E+05	0
4480	-3.42E+04	0
5120	-4.80E+05	0
5760	-8.28E+05	0
6400	-1.37E+06	0



Point of Inflection and Zero Moment (X) 4431 mm

Max. Moment @ Point X = a 1.80E+06 N * mm

Beam Formula Solver
Fixed End - Simply Supported
Concentrated Load @ Any Point

Inputs : Load B

P (N) =	1500	E (MPa) =	9500
L (mm) =	6400	I (mm^4) =	1.88E+07
a (mm) =	4286		
b (mm) =	2134		
x (mm) =	3200		

Results :

R1 = V1 =	223.54	N
R2 = V2 =	1284.46	N
M1 (@ Point Ld	9.54E+05	N * mm (kN * m)
M2 (@ Fixed end	1.79E+06	N * mm (kN * m)
Mx (x < a) =	7.15E+05	N * mm (kN * m)
Mx (x > a) =	2.32E+05	N * mm (kN * m)
Def max (a<0.414	3.08	mm
Def max (a>0.414	3.28	mm
Def @ a =	2.65	mm
Def @ x (x < a)	3.28	mm
Def @ x (x > a)	2.65	mm
Point of inflection	5008.42	mm
* x = L* ((L^2 + a^2)	3516.85	mm
** x = L * (SQRT(x	3199.81	mm

Notes:
x = 0 at simple support
1 N = 0.2248 pounds force
Rectangular Moment of inertia I = bd^3 / 12 (mm^4)

Modulus of Elasticity
Joists and Planks 38 * 64 To 51 *A
S-P-F #3 E = 9500 MPa
Ref: Wood Design Manual 1995

Predicted Deflection

Beam Length 6400 Value of a = 4286

Length along bea	X Value(mm)	Deflection (mm) (x < a)	(x > a)	Actual Deflection (mm)
L * 0	0	0.00	[illegible]	0.00
L * 0.1	640	0.98	15.02	0.98
L * 0.2	1280	1.85	7.38	1.85
L * 0.3	1920	2.58	1.75	2.58
L * 0.4	2560	3.07	1.41	3.07
L * 0.414	2650	3.12	1.70	3.12
L * 0.5	3200	3.28	2.65	3.28
L * 0.6	3840	3.05	3.02	3.05
L * 0.7	4480	2.37	2.37	2.37
L * 0.8	5120	1.15	1.35	1.35
L * 0.9	5760	-0.70	0.41	0.41
L * 1	6400	3.75	0.00	0.00

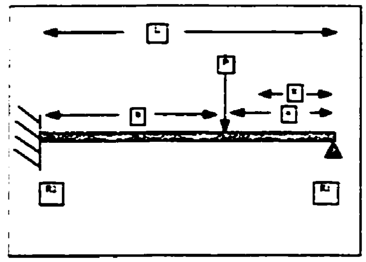
Predicted Moment

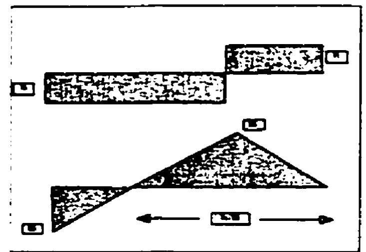
Beam Length 6400 Value of a = 4286

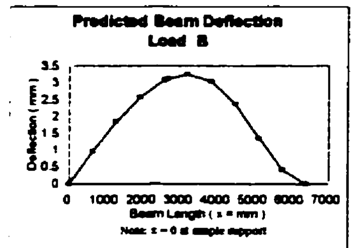
Length along bea	X Value(mm)	Moment (N mm) (x < a)	(x > a)	Actual Moment	Sorted Moments (N mm) X Value(mm)	Actual Moment	Zero Series
L * 0	0	0.00E+00	6.43E+05	0.00E+00	0	0.00E+00	0
L * 0.1	640	1.43E+05	5.61E+05	1.43E+05	640	1.43E+05	0
L * 0.2	1280	2.86E+05	4.79E+05	2.86E+05	1280	2.86E+05	0
L * 0.3	1920	4.29E+05	3.97E+05	4.29E+05	1920	4.29E+05	0
L * 0.4	2560	5.72E+05	3.14E+05	5.72E+05	2134	4.77E+05	0
L * 0.414	2650	5.92E+05	3.03E+05	5.92E+05	2560	5.72E+05	0
L * 0.5	3200	7.15E+05	2.32E+05	7.15E+05	2650	5.92E+05	0
L * 0.6	3840	8.58E+05	1.50E+05	8.58E+05	3200	7.15E+05	0
L * 0.7	4480	1.00E+06	6.79E+05	6.79E+05	3840	8.58E+05	0
L * 0.8	5120	1.14E+06	-1.43E+05	-1.43E+05	4286	9.54E+05	0
L * 0.9	5760	1.29E+06	-9.65E+05	-9.65E+05	4480	6.79E+05	0
L * 1 (Fixed End	6400	1.43E+06	-1.79E+06	-1.79E+06	5120	-1.43E+05	0
L @ a Point of a	4286	9.54E+05	9.54E+05	9.54E+05	5760	-9.65E+05	0
L @ a' (From fix	2134	4.77E+05	3.69E+05	4.77E+05	6400	-1.79E+06	0

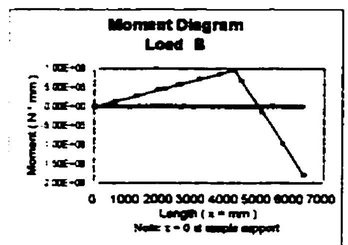
Point of inflection and
Zero Moment (x 5008 mm

Max. Moment @ P 9.54E+05 N * mm









Beam Formula Solver
Fixed End - Simply Supported
Summary of Two Concentrated Loads

Inputs :

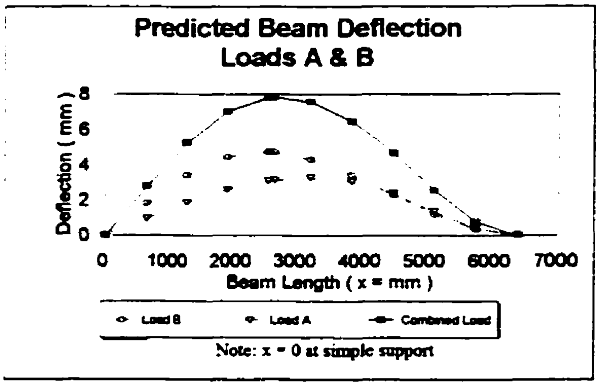
Senes B
Point load A. 1446 N Point load B: 1506 N
Values at 0.4 in midpoint deflection.

Results :

R1 = V1 =	973.12 N
R2 = V2 =	1960 68 N
M2 (@ Fixed end) =	3.16E+06 N * mm (kN * m)
Mx (x < a) =	3.11E+06 N * mm (kN * m)
Mx (x > a) =	3.18E+06 N * mm (kN * m)
Def max. (a<0.414L @ x = ")	7.81 mm
Def max.(a>0.414L @ x = "")	7.98 mm
Def @ x (x < a) =	7.16 mm
Def @ x (x > a) =	7.14 mm

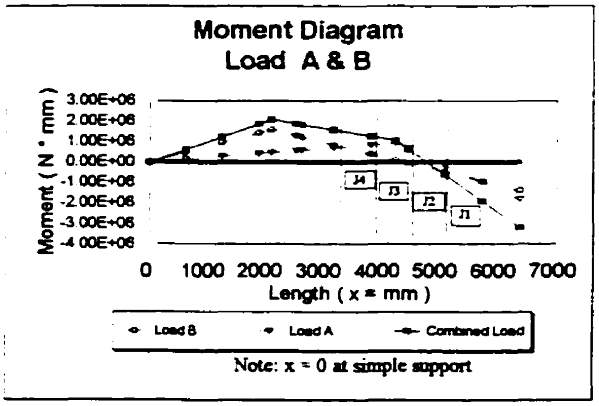
Deflection Sum

X Value(mm)	Sum (mm)
0	0 00
640	2.79
1280	5.25
1920	7.02
2560	7.79
2850	7.82
3200	7.55
3840	6.44
4480	4.65
5120	2.53
5760	0.75
6400	0.00



Moment Sum

X Value(mm)	Sum	Zero Series
0	0.00E+00	0
640	6.23E+05	0
1280	1.25E+06	0
1920	1.87E+06	0
2134	2.08E+06	0
2560	1.88E+06	0
2850	1.83E+06	0
3200	1.57E+06	0
3840	1.27E+06	0
4266	1.07E+06	0
4480	6.45E+05	0
5120	-6.23E+05	0
5760	-1.89E+06	0
6400	-3.16E+06	0



Beam Formula Solver
Fixed End - Simply Supported
Summary of Two Concentrated Loads

Inputs :

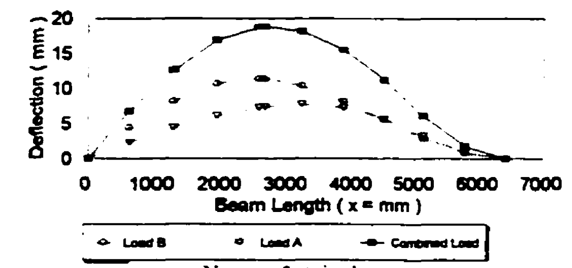
Series B
Point load A. 3505 N   Point load B: 3607 N
Values at 1.0 in midpoint deflection.

Results :

R1 = V1 =	2351 60 N
R2 = V2 =	4760 40 N
M2 (@ Fixed end) =	7.60E+06 N * mm (kN * m)
Mx (x < a) =	7.53E+06 N * mm (kN * m)
Mx (x > a) =	7.63E+06 N * mm (kN * m)
Def max. (a<0.414L @ x = *)	18.83 mm
Def. max.(a>0.414L @ x = **)	19.23 mm
Def @ x (x < a) =	17.25 mm
Def @ x (x > a) =	17.22 mm

Deflection Sum

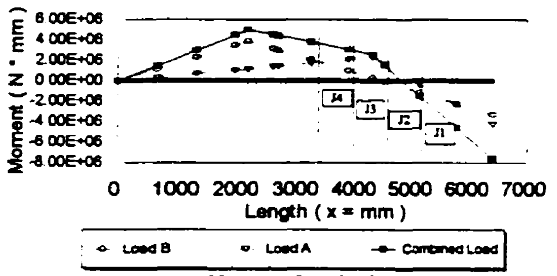
X Value(mm)	Sum (mm)
0	0.00
640	6.74
1280	12.66
1920	16.93
2560	18.80
2650	18.85
3200	18.19
3840	15.52
4480	11.19
5120	6.09
5760	1.80
6400	0.00



Note: x = 0 at simple support

Moment Sum

X Value(mm)	Sum	Zero Series
0	0.00E+00	0
640	1.51E+06	0
1280	3.01E+06	0
1920	4.52E+06	0
2134	5.02E+06	0
2560	4.53E+06	0
2650	4.42E+06	0
3200	3.79E+06	0
3840	3.05E+06	0
4266	2.56E+06	0
4480	1.54E+06	0
5120	-1.51E+06	0
5760	-4.55E+06	0
6400	-7.60E+06	0



Note: x = 0 at simple support

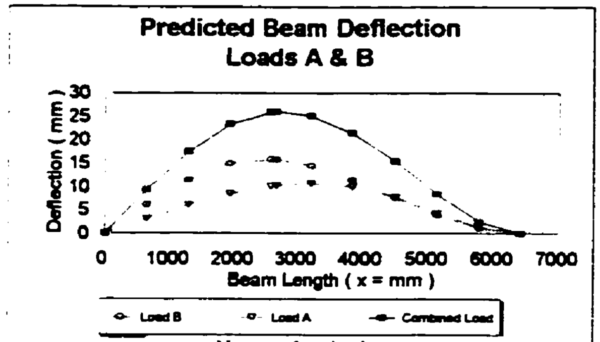
Beam Formula Solver
Fixed End - Simply Supported
Summary of Two Concentrated Loads

Inputs :

Senes B
Point load A: 4849 N   Point load B: 4951 N
Values at 1.4 in midpoint deflection.

Results :

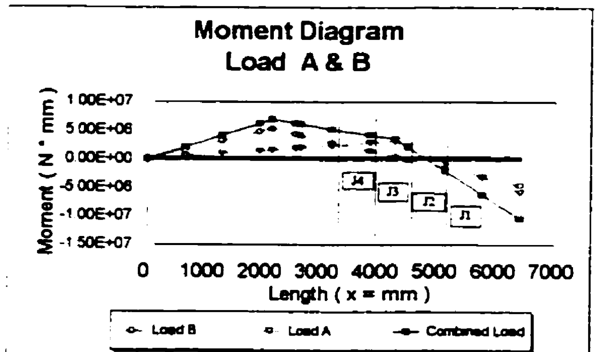
R1 = V1 =	3247.53	N
R2 = V2 =	6552.47	N
M2 (@ Fixed end) =	1.05E+07	N * mm (kN * m)
Mx (x < a) =	1.04E+07	N * mm (kN * m)
Mx (x > a) =	1.05E+07	N * mm (kN * m)
Def max. (a<0.414L @ x = *)	25.96	mm
Def. max.(a>0.414L @ x = **)	26.52	mm
Def @ x (x < a) =	23.78	mm
Def @ x (x > a) =	23.75	mm



Note: x = 0 at simple support

Deflection Sum

X Value(mm)	Sum (mm)
0	0.00
640	9.30
1280	17.46
1920	23.35
2560	25.92
2650	26.00
3200	25.09
3840	21.40
4480	15.43
5120	8.38
5760	2.48
6400	0.00



Note: x = 0 at simple support

Moment Sum

X Value(mm)	Sum	Zero Series
0	0.00E+00	0
640	2.08E+06	0
1280	4.16E+06	0
1920	6.24E+06	0
2134	6.93E+06	0
2560	6.25E+06	0
2650	6.10E+06	0
3200	5.22E+06	0
3840	4.20E+06	0
4266	3.52E+06	0
4480	2.11E+06	0
5120	-2.08E+06	0
5760	-6.27E+06	0
6400	-1.05E+07	0

Beam Formula Solver
Fixed End - Simply Supported
Summary of Two Concentrated Loads

Inputs :

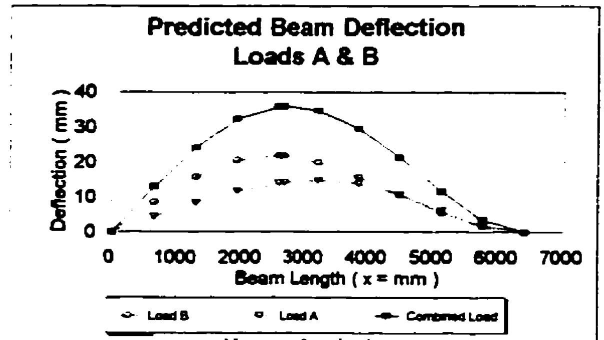
Series B
Point load A. 6702 N   Point load B: 6849 N
Values at 2.0 in midpoint deflection.

Results :

R1 = V1 =	4489.44 N
R2 = V2 =	9061.56 N
M2 (@ Fixed end) =	1.45E+07 N * mm (kN * m)
Mx (x < a) =	1.44E+07 N * mm (kN * m)
Mx (x > a) =	1.45E+07 N * mm (kN * m)
Def max. (a<0.414L @ x = ")	35.90 mm
Def. max (a>0.414L @ x = "")	36.67 mm
Def @ x (x < a) =	32.88 mm
Def @ x (x > a) =	32.84 mm

Deflection Sum

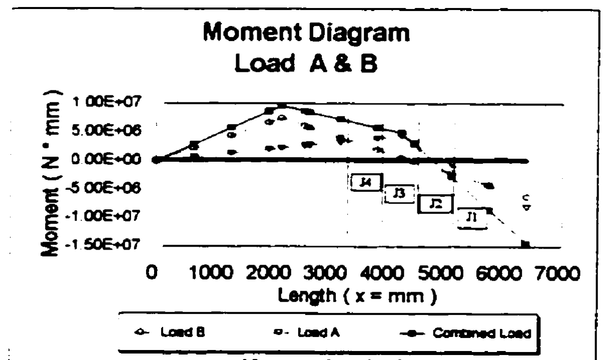
X Value(mm)	Sum (mm)
0	0.00
640	12.86
1280	24.14
1920	32.29
2560	35.84
2650	35.95
3200	34.69
3840	29.59
4480	21.33
5120	11.59
5760	3.43
6400	0.00



Note: x = 0 at simple support

Moment Sum

X Value(mm)	Sum	Zero Series
0	0.00E+00	0
640	2.87E+06	0
1280	5.75E+06	0
1920	8.62E+06	0
2134	9.58E+06	0
2560	8.64E+06	0
2650	8.44E+06	0
3200	7.22E+06	0
3840	5.81E+06	0
4266	4.86E+06	0
4480	2.92E+06	0
5120	-2.88E+06	0
5760	-8.67E+06	0
6400	-1.45E+07	0



Note: x = 0 at simple support

Appendix B - Biaxial Loading Test Frame

Biaxial Test Frame Description and Design Notes

Machine Description

The biaxial loading test frame is 30' long, 4' wide, by 7' high, and weighs approximately 3000 lbs. It is designed to apply axial and bending loads simultaneously to a test sample while recording load / deflection results. It was created to test post or beam type assemblies under simply supported or fixed end conditions, but it could be easily modified to other configurations. The spine of the machine is fixed and levelled in place, but all other elements are flexible and can be adjusted as required for different test scenarios. Sketch drawings of the different structural elements, linkage details, and hydraulic circuits, are illustrated in Appendix B2.

Major Components

1. Steel spine and superstructure.
2. Loading cylinders: 6 "∅ x 6" throw axial compression cylinder, 2 x 3" ∅ x 20 " throw tension bending cylinders.
3. Oildyne series 500 hydraulic power unit, (bidirectional motor, pump, and reservoir).
4. Oildyne flow control valve (micrometer controlled).
5. Preexisting hydraulic circuit for axial compression that includes a motor, pump, flow control, filter, and an electrically operated directional valve.
6. Strainsert 25,000 lb universal flat load cell.
7. Strainsert 3,000 lb S-shaped load cells (x 2).
8. Linear potentiometer (10" maximum deflection).
9. Taurus One eight channel data acquisition system.
10. Signal amplifier and interpretation circuit.
11. 80286 computer and amber monitor.

Machine Capacity and Limitations

1. Axial load capacity of 8000 lbs. This maximum is limited by slip and deformation of the restraining bar clamp under a tension load. Ultimate capacity would be limited by the capacity of the load cell and the coupling nuts on the reinforcing tension rods.

2. Bending load capacity of 2 x 3000 lbs. is limited by the S - shaped load cells. Ultimate capacity could be greatly expanded and limited only by system pressure and the cylinder diameter. A single load point using only one tension cylinder is easily arranged.

3. Sample length may vary from a few feet to 28' .

4. Cross sectional size of 12 in. high by 8 in. wide is limited by the size of the butt plate on the end support sleeve and the clamps on the tension cylinders. Spacer blocks may be required in the end support sleeve to raise the centre line of small samples in order to prevent eccentric axial loading. The simple support structure is vertically adjustable a few inches up and down.

5. Lateral support provided by three movable frames is limited to a 14 in. depth measured from the base of the end support sleeve.

6. Deflection measurements are limited to 10 in. and considered accurate to 0.01 ".

7. Axial load measurements are compression only and considered accurate to +/- 1.5%, with a minimum load of 35 lbs. Best accuracy from occurs from 100 - 8000 lbs.

8. Bending loads can be tension only and are considered accurate to +/- 2.0 %,

with a minimum load of 25 lbs. Best accuracy occurs from 100 - 2500 lbs.

Project Budget

The project was developed with the assistance of industrial funding from the Western Post Frame Builders Association. Major materials purchased were valued at $10,000. Several major items were available from existing resources and have been acquired at no direct cost to the project. These items include: computer and monitor, Taurus One data acquisition system, both 3,000 lb load cells, the instrument cabinet, and the entire hydraulic compression circuit less cylinder. The estimated value of these components is $ 3,000. A very conservative estimate of design and construction time is 18 months. The designer's salary and substantial technician time during this period is estimated at $25,000. Total projected cost in a commercial environment would therefore be not less than $37,000.

Designer 's Notes

Hydraulic Systems

1. Both the compression and tension systems are designed to 3000 psi. with the exception of the tension system flow rate calibration (pressure), gages. These are equipped with cutoff valves for use only in unloaded conditions. Usual operating pressure for these experiments was up to 800 psi in compression and 850 psi in tension, but both systems are variable by set screws up to the system maximum.

2. Oil temperature in the compression system is not a problem, but the tension system reaches 80 $^{\circ}$C fairly quickly under continuous operation due to the severe

restrictions in flow required for slow cylinder motion. No apparent problems exist during short term or step loading types of operation. High temperature hydraulic fluid (87 $^{\circ}$C) is available for the system if required.

3. Differential friction forces in the two tension cylinders complicated the issue of symmetric loading with parallel cylinders. Not only was there a difference between the cylinders, but there was a difference within each cylinder depending on its immediate position. This differential friction would be further aggravated by changing hydraulic fluid conditions. Simple flow controls and pressure gages set to maintain a predetermined pressure differential were tried but not found to be accurately repeatable. The gages presently on the tension circuit are therefor of limited use. The solution for this work was to set the overall flow, and then balance the cylinders manually across the desired range of motion with a bubble level. This calibration was combined with a short spurt, step loading process to minimize heat buildup in the circuit. These two processes together produced a workable, accurate, and repeatable procedure for applying the desired loads.

4. Future uses of the machine may demand that the two tension cylinders produce a similar and uniform displacement. This can be easily accomplished by linking the cylinders in series with appropriate resizing of the second cylinder.

5. Maintaining constant pressure from the axial compression cylinder during sample bending was of concern do to end rotation and retraction across the simple support. Such motion away from the load face did occur and regular adjustments were required on the axial cylinder. The step loading procedure followed facilitated this adjustment very well. A constant pressure valve installed in the circuit at a future time could alleviate this problem.

Structural System

1. The axial loads are limited by deformation of the restraining clamps that secure the tension rods to the main beams. These clamps fail at 8,500 lbs of axial load and severely reduce the capacity of the machine, which could be at the 25, 000 lb limit of the axial load cell. The clamps slide along the beam and rotate due to eccentric loading. Reinforcing these clamps should be the first modification done on the machine to enhance its performance. If these clamps function properly, the coupling nuts on the reinforcing rods are the next weakest link because they are made of only mild steel. The rods themselves are of high tensile steel, (120,000 psi), but no high capacity coupling nuts were locally available.

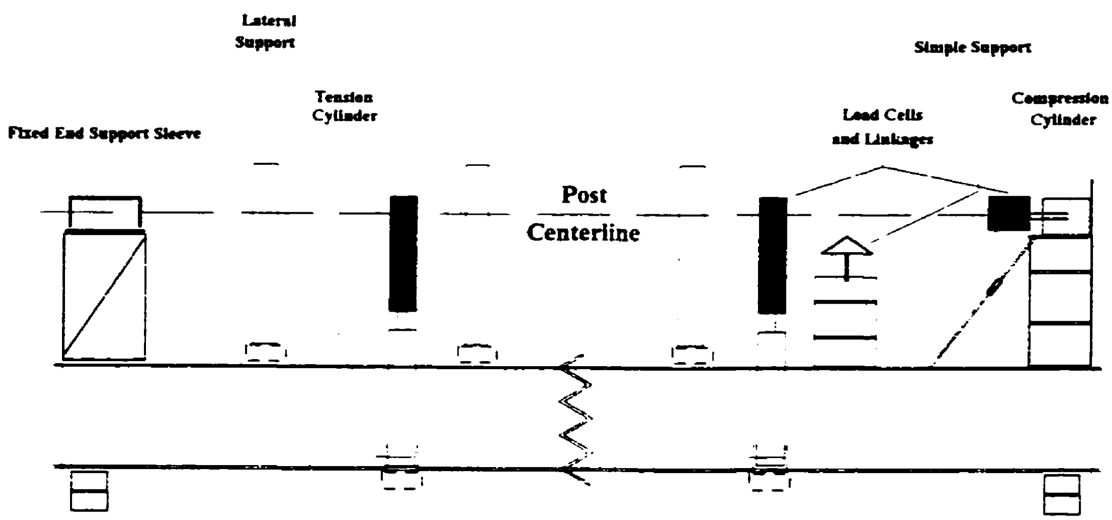
2. The lateral supports functioned well but they could be reinforced if required by tying them together across their tops.

3. An expansion plate may be required to raise the axis of the compression cylinder for centerline loading of larger samples. Such a plate would bolt through the existing slots and vertically extend the compression cylinder end brace.

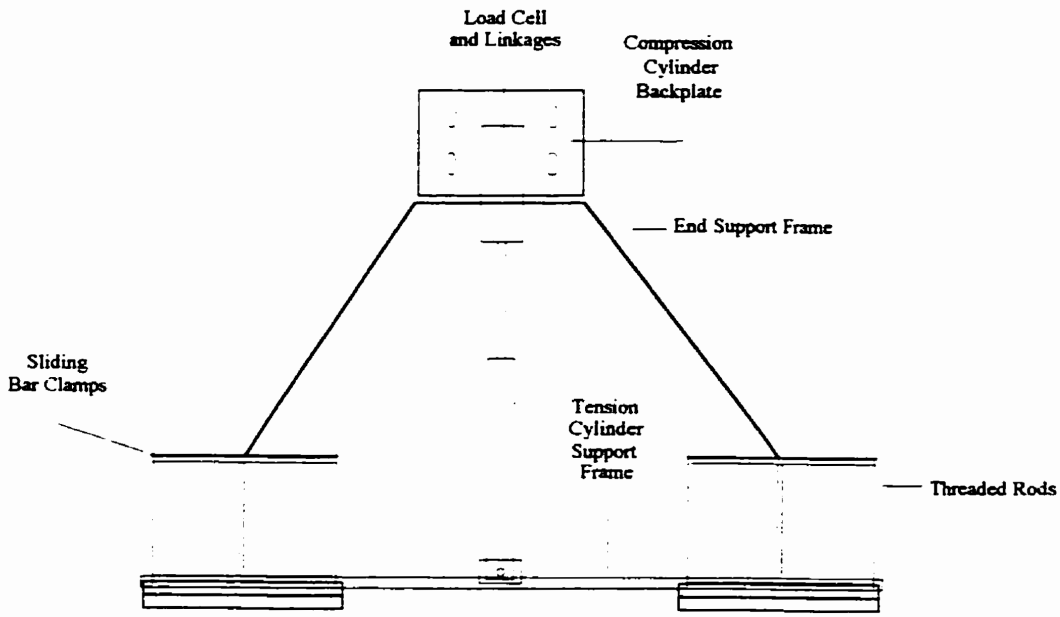
Software Control Program

Appendix B4 is a printout of the software program ' CONTROL1'. It is written in QBasic to interpret the data acquisition system output into meaningful values for the machine operator. The program displays and records data on force, deflection, and time on a continuos basis. Archiving data to a selected text file is an option for exporting data to be analysed. The program is a passive read only program and has no feedback to the machine's physical operation in any way. 'CONTROL1' is not compiled but runs from the QBasic program within any DOS computer. The sampling rate may be changed by manually adjusting a time delay DO LOOP within the main body of the program.

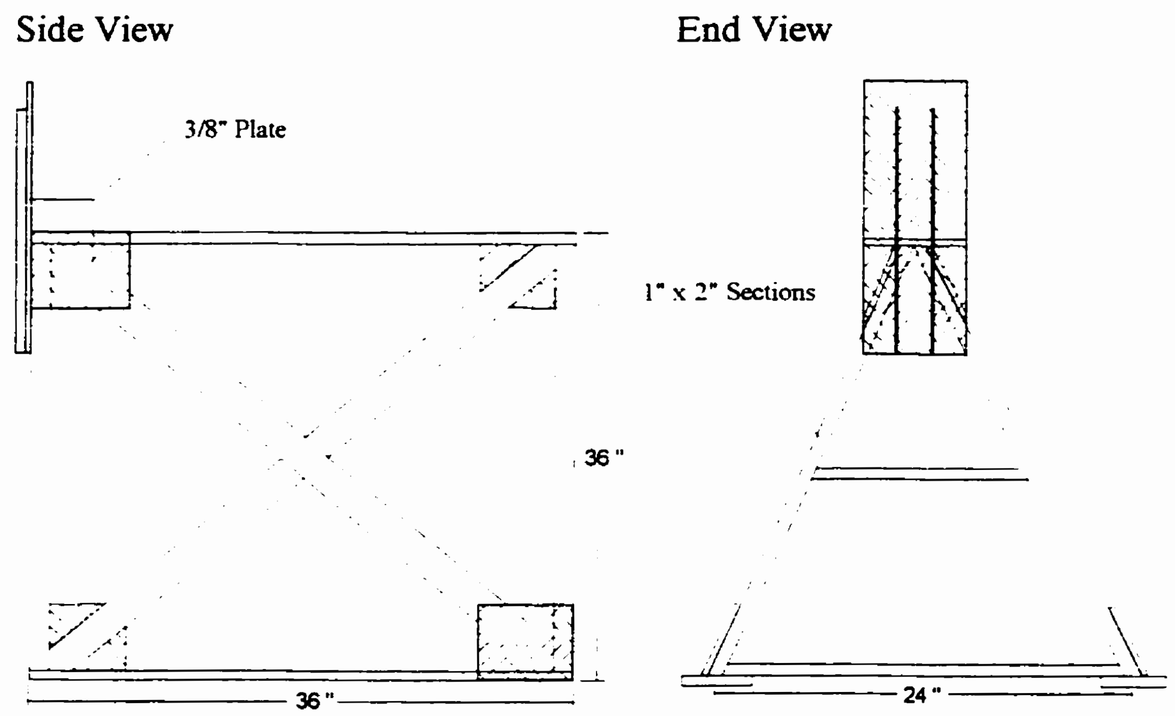
Biaxial Loading Test Frame
Outline (Simplified)



Biaxial Loading Test Frame
End View (R) (Simplified)

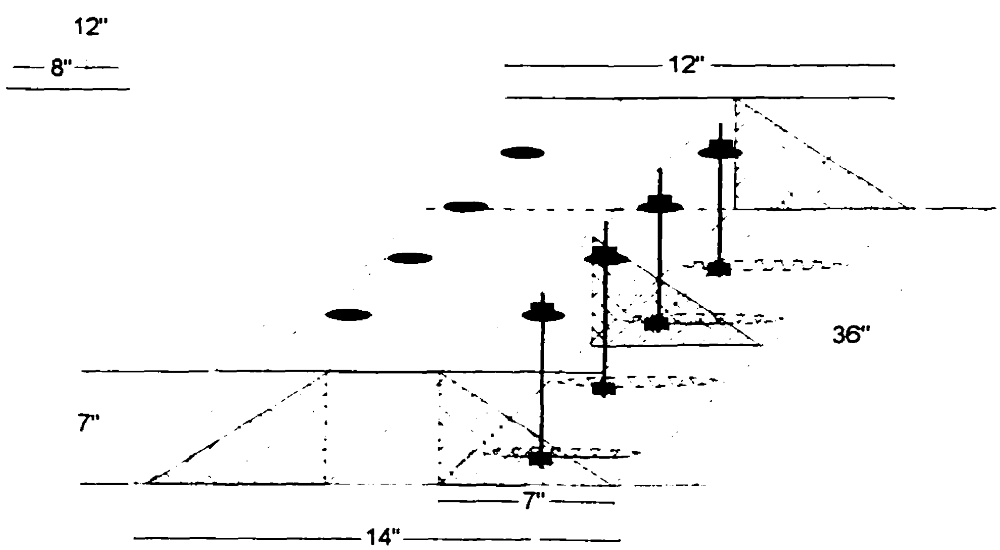


Biaxial Loading Test Frame
Detail : End Frame

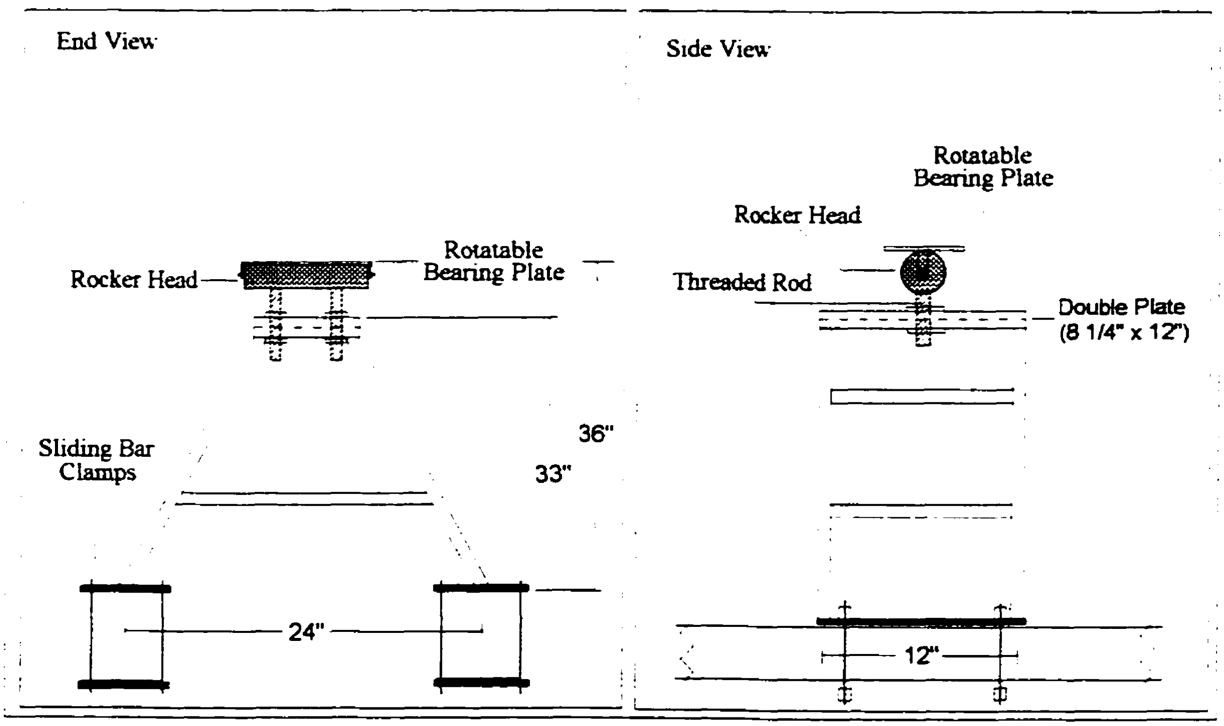


Biaxial Loading Test Frame
Detail : Fixed End Support for End Frame

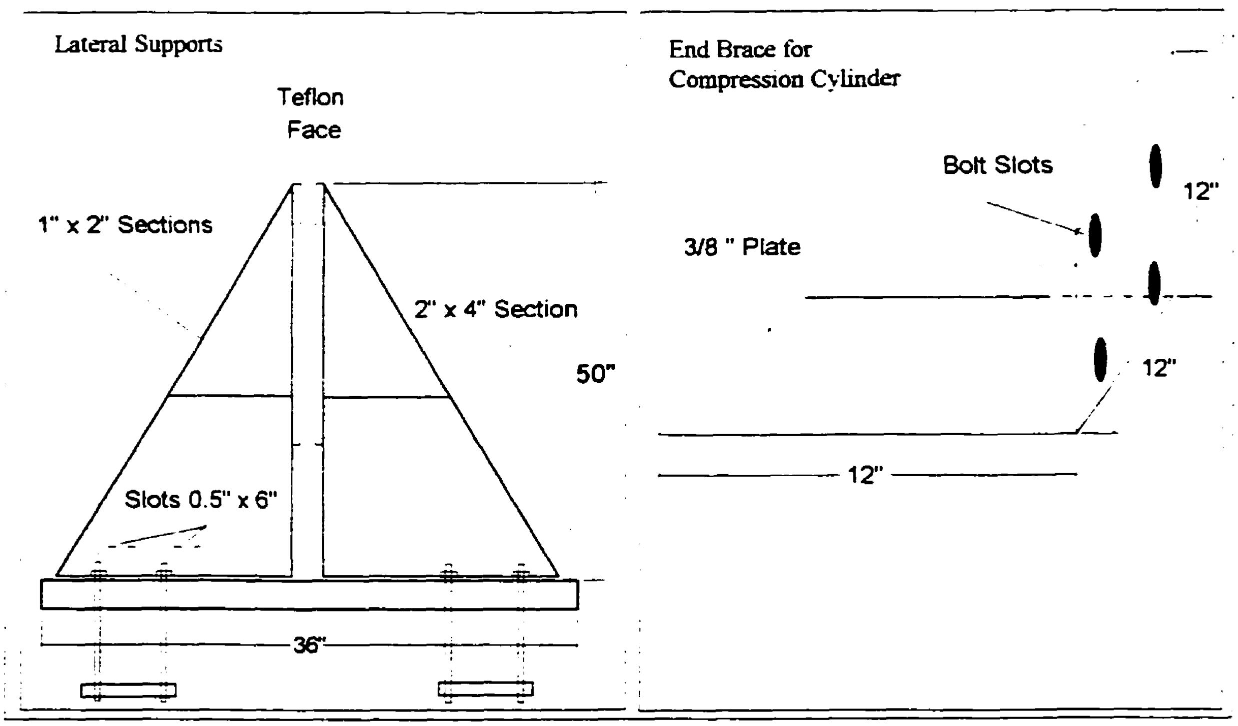
Capacity



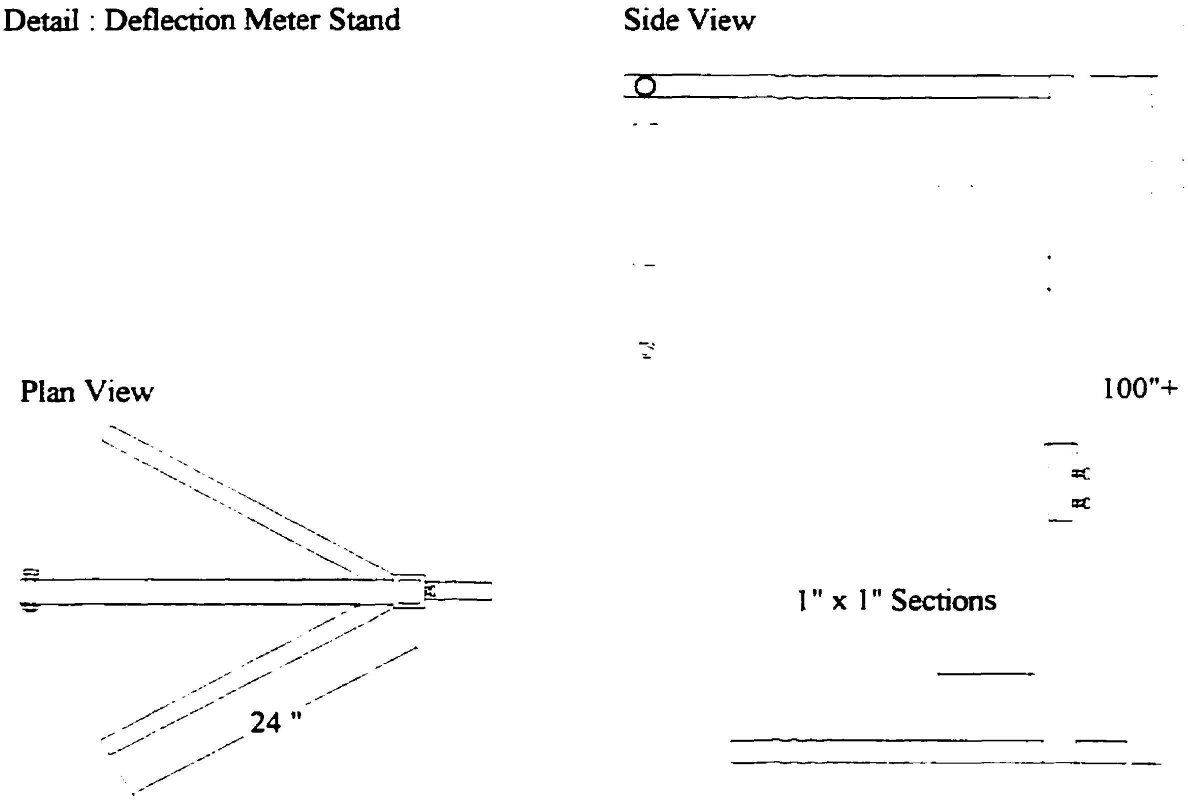
Biaxial Loading Test Frame
Detail : Simple Support



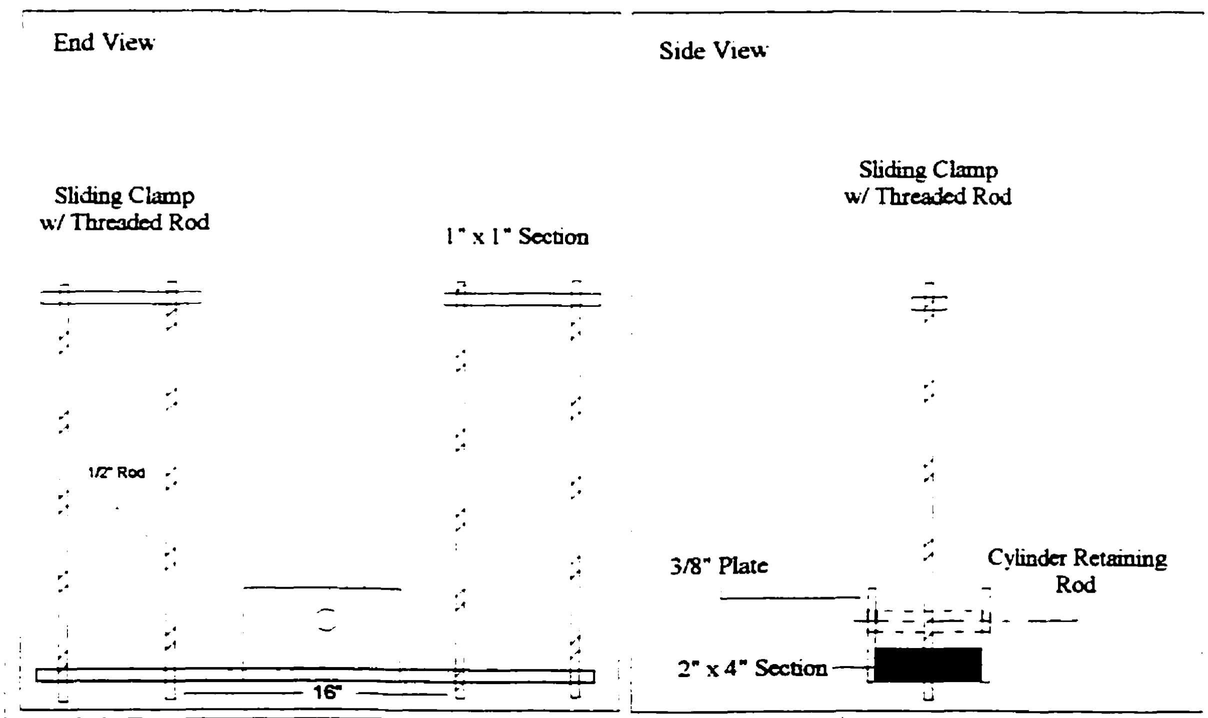
Biaxial Loading Test Frame
Detail : Lateral Supports and End Brace



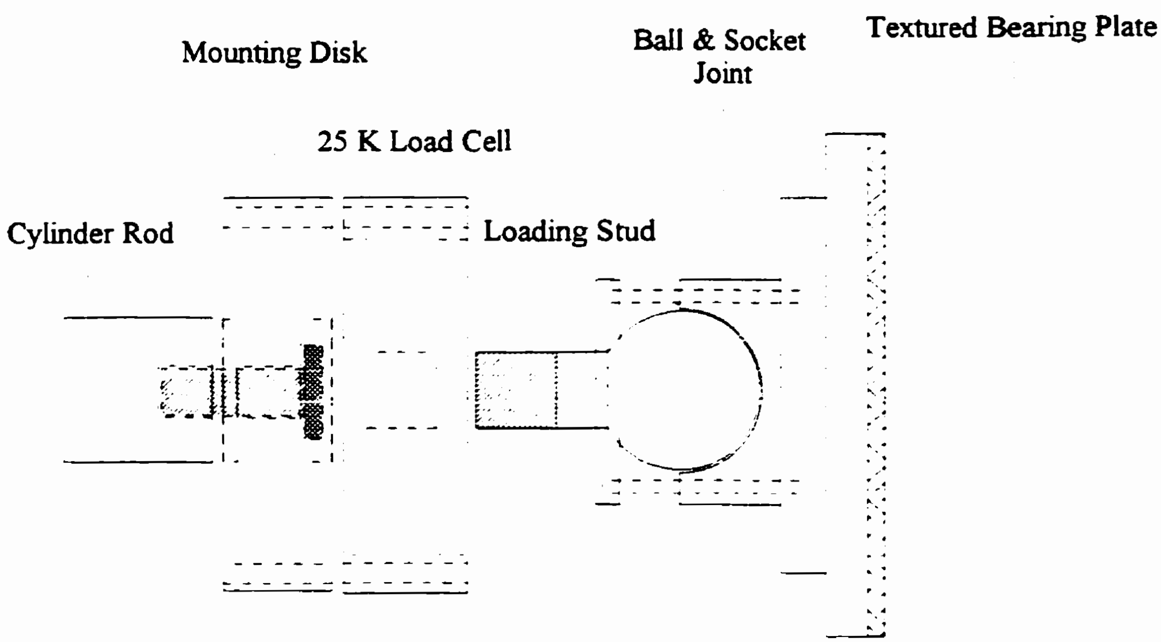
Biaxial Loading Test Frame
Detail : Deflection Meter Stand



Biaxial Loading Test Frame
Detail : Tension Cylinder Support

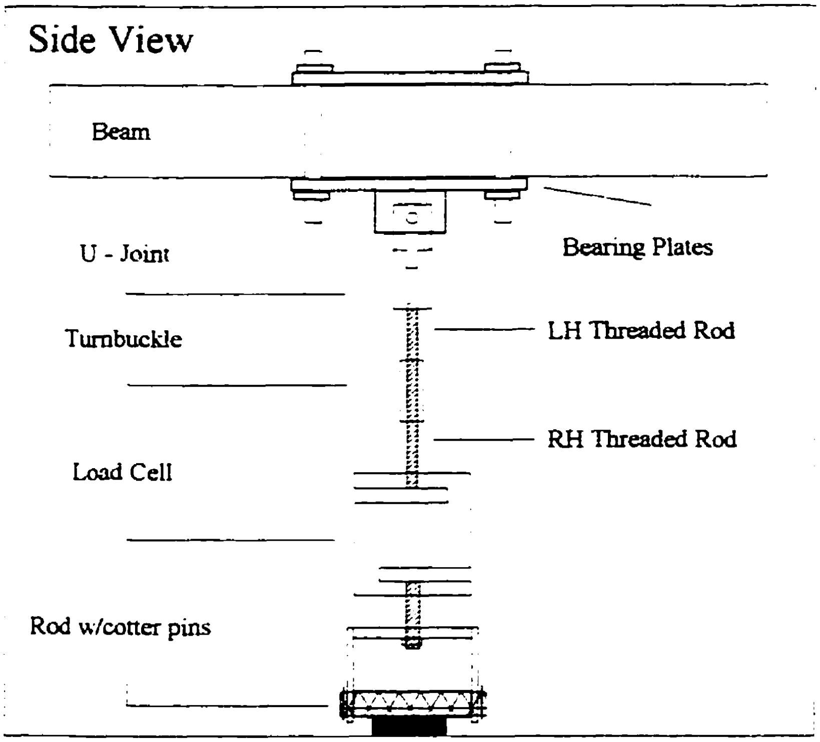


Biaxial Loading Test Frame
Detail : Load Cell and Linkage - Compression Cylinder

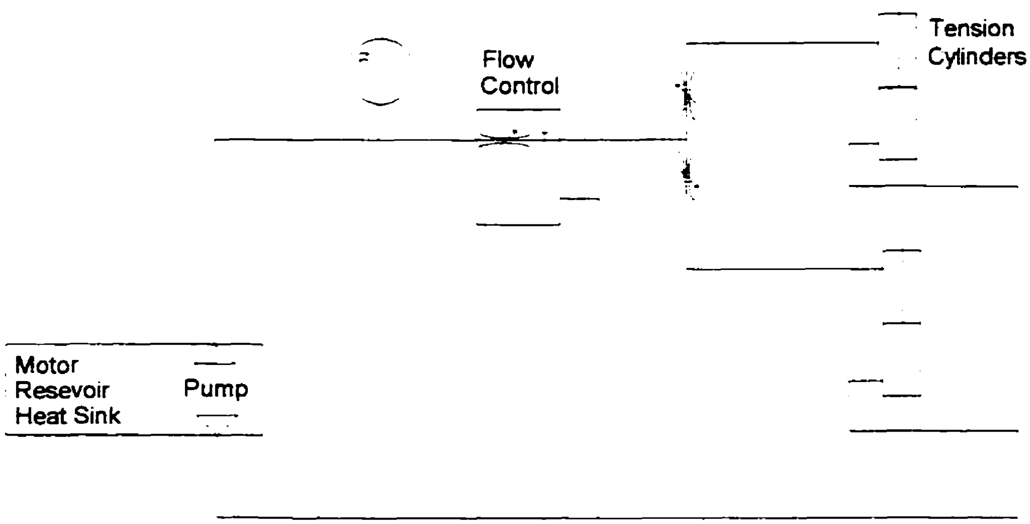


Biaxial Loading Test Frame

Detail : Load Cell and Linkage - Tension Cylinder

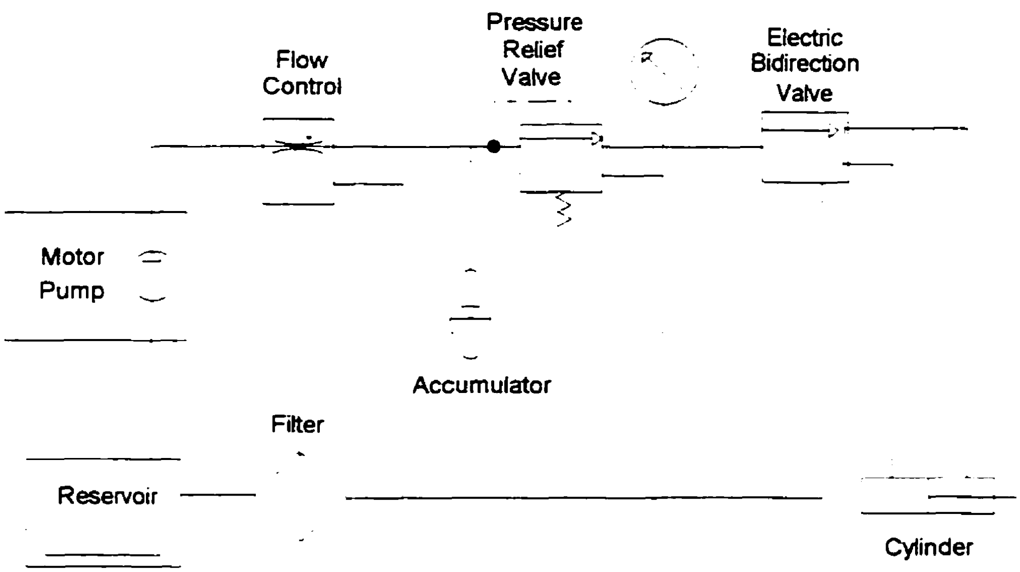


Biaxial Loading Test Frame
Hydraulic Circuit - Tension Cylinders



Seperate electrical switch for power and direction.

Composite Loading Test Frame
Hydraulic Circuit - Compression Cylinder



Operating Instructions

These operating instructions offer guidance on the use of the biaxial loading test frame. Due to the unique, prototypical nature of the machine, new procedures may evolve with time but these were found to be successful for the experiments conducted. The primary concern is that THERE ARE NO SAFETY STOPS ON THE MACHINE. It is easily possible to overload the instruments or bend the axial loading assembly if care is not taken to monitor load and deflection levels as they are being applied. Aside from that, there are no 'hidden gremlins' in the machine and it is generally easy to use and works well.

General

1. Engage main power switch. (Computer, data acquisition system, tension cylinder circuit, compression circuit has its own power).
2. Enter QBasic environment and load CONTROL1. Follow program through intro screens until instructed to 'press any key to begin data recording'.
3. Load sample and align machine for testing. Simple supports may be used or the fixed end clamp assembly installed on the end support frame. Buffalo board inserts on both ends of the post ensure good axial contact if required. Lateral supports may be placed as desired along the sample length. At least one bending load clamp should be firmly attached to ensure positive control of the sample.
4. Run program.
5. Manually operate loading cylinders until desired load or deflection is obtained. Limits of loading are determined from observation of sample and observation of continuous data readout. DO NOT quickly flip the bidirectional cylinder control switches back and forth or they may burn out.

6. Stop program (F1), and archive data run to desired file name if required.
7. Manually operate cylinders to unload the sample. DO NOT overextend the tension loading cylinders and 'push up' the sample. The linkages were designed for tension only and may be easily damaged by compression loads.
8. The pump and control cabinet may be disconnected and moved easily by unplugging the power cables, the instrument cables, and uncoupling the hydraulic lines.

Calibrating Tension Cylinders

This method was utilized with a step loading procedure which avoided the major difficulties associated with heat build up in the hydraulic fluid. It addresses the difficulties concerning differential friction between the cylinders and compensates for differential friction within the throw of each cylinder by only using the displacement range required for the experiment.

1. Ensure pressure gages are closed off from the system and run both cylinders out to full extension. NOTE: The large pressure gages attached to the tension circuit are not used in this procedure and would be damaged by maximum system pressures.

2. Set the primary Oildyne flow control valve to desired setting. This setting is determined by experimentation and will remain set for the entire experimental series. This setting is generally determined by disconnecting one cylinder and timing the displacement of the contracting cylinder to determine loading rate. Ensure that secondary flow controls are fully open. Slow this measured rate by one half when both cylinders are to be used.

3. Place a bubble level with wooden extension across both cylinder heads and tape in position.

4. Begin contraction of cylinders to beginning of desired test range. Rough balancing of the cylinders can be done at this point with the two secondary flow controls located on the edge of the control cabinet. Balancing is done by observing the position of the bubble and opening or closing the flow controls as required. Generally it is simplest to leave one flow control set and adjust the other one to centre the bubble.

5. Fine adjustment of the flow balance between the cylinders occurs just before the desired range of deflection. If the deflection range is short, (ie. 2"), then the cylinders will remained balanced through the entire range. Larger ranges will not necessarily be balanced, but load forces will generally overtake friction forces at greater deflections and consequently the friction forces become irrelevant.

6. Final fine adjustment of up to 1 ½ " is made with the turnbuckle of the tension linkage. This is useful as it allows flexibility as to the exact 'beginning' of the testing range.

Biaxial Loading Test Frame Data Control Program

```
'    ----- Bi-Axial Loading Test Frame Data Control Program -----
'    ---- Created by :  David A Strong,    14 August 1996 ----------
'    ----- Utilizes: Taurus One Data Acquisition System  -----------
'                  8086 Computer System w/hard disk
'                  Q Basic
'                  Title : CONTROL1.BAS
'                  ( Last amended : 29 Oct 97 )
'------------------------------------------------------------------------------------------
'              ----- Preliminary Intro Screens  -----
'

Begin:
CLS : stopchk = 0: ' SCREEN 9: COLOR 7, 1
PRINT : PRINT "  Composite Loading Test Frame Data Control Program"
PRINT "  --------------------------------------------"
PRINT : PRINT "  Program will collect data at 2.0 sec. intervals until"
PRINT "  F1 is pressed or the auto stop occurs. "
PRINT "  ( When there is no further deflection for 5 sec.)"
PRINT : PRINT "  There is an option to store the current data run onto the"
PRINT "  hard disk under any given name."
PRINT "  Data will be stored as a comma delimited text file. ( *.TXT) "
PRINT : PRINT : PRINT "  Press any key to continue."
DO: LOOP WHILE INKEY$ = ""
CLS
LOCATE 5, 1
PRINT "  Align machine for testing.": PRINT
```

```
PRINT "  Press F1 anytime to stop data recording": PRINT
PRINT "  Press any key to begin recording data at 2.0 sec. intervals."
PRINT
DO: LOOP WHILE INKEY$ = ""
'
'                  ----- MAIN PROGRAM -----
'
OPEN "COM1:9600,N,8,1,RS" FOR RANDOM AS #1   '  Open Taurus com port
PRINT #1, "$A0 1 UC CA (18,10)" '          Set message terminator
LINE INPUT #1, TANS$ '                 Taurus return message goes here
PRINT #1, " $A0 1 AS CL (0,0,4)"  '         Analog Setup of Channel 1-4
LINE INPUT #1, TANS$
OPEN "testdata" FOR OUTPUT AS #2:          '  Taurus Data goes to this file
KEY(1) ON: ON KEY(1) GOSUB Endchoice
ON ERROR GOTO Errortrap
CLS : LOCATE 5, 1                          '  Header printout
PRINT "DATA READOUT FROM TAURUS ONE"
PRINT "----------------------------": PRINT
PRINT "____LPOT____3Ka_____3Kb_____25K_____TIME___"
PRINT "   (in)  (lbs)  (lbs)  (lbs)  (sec) "
LOCATE 22, 1
PRINT " Press F1 to stop data recording."
Timestart = TIMER
DO
 Start! = TIMER
GOSUB Readdata
GOSUB Convert
GOSUB Endcheck
GOSUB Writedata
```

```
GOSUB Printdata
DO: '                        - Time delay set for 2.0 sec.
 Finish! = TIMER
LOOP WHILE (Finish! - Start! <= 1.971)
LOOP
Final:
CLOSE
END

'               ---- SUBROUTINES ----

Readdata: '                   - Reading data from Taurus system
PRINT #1, "$A0 1 AA (1,0)" ' Comd to Taurus to send data - Analog Acquisition
LINE INPUT #1, TANS$: LINE INPUT #1, TANS$
PRINT #1, "$A0 1 AR NU (4)" '        Analog Report
INPUT #1, id$, A$, B$, C$, D$, NUL$ ' Data returned as string var.
data1 = VAL(D$) '              Data1 = LVDT
data2 = VAL(A$) '              Data2 = 3Ka
data3 = VAL(B$) '              Data3 = 3Kb
data4 = VAL(C$) '              Data4 = 25K
data5 = TIMER - Timestart
RETURN

Convert: '                    -Converts returning mV signals to pound
'                              and displacement values.(data1a etc.)
data1a = (1947 - data1) / 194.4
data2b = (-data2 + 10.6124) / .73999 '    2 step conversion of mv to lbs.
data2a = (.02109 * data2b) - 12.5455 + data2b
data3a = (-data3 + 5.21959) / .72689 '        Min load of 100# +/- 2%
```

```
data4a = (data4 - 30.5847) / .07443'          Min load of 100# +/- 1.5%
IF data1a <= .09 THEN data1a = 0 '            Zero's output to screen
IF data2a <= 15 THEN data2a = 0'              and file for start of curve
IF data3a <= 15 THEN data3a = 0
IF data4a <= 44 THEN data4a = 0
data1a = (CINT(data1a * 100)) / 100 ' Rounds off at 2 decimals
data2a = (CINT(data2a))
data3a = (CINT(data3a))
data4a = (CINT(data4a))
data5a = (CINT(data5 * 10)) / 10
RETURN

Printdata: '                    -Prints converted data to screen
'PRINT
LOCATE 11, 1
PRINT USING "#####.##"; data1a;
PRINT USING "#######"; data2a; data3a;
PRINT USING "#########"; data4a;
PRINT USING "#######.#"; data5a
RETURN

Endcheck: '                   -Checks end condition - if displacement
'                              variable (data1a) has not changed in
'                              10 repetitions of the data reading
'                              cycle. (ie. for 5 sec.)
IF (stopchk = 9) THEN
     PRINT : PRINT "  Program terminated"
     GOTO Endchoice
ELSEIF (Olddata - INT(data1a * 10) = 0) THEN
```

```
'       stopchk = stopchk + 1:  '      Continous run loop if this line deleted
        RETURN
END IF
Olddata = INT(data1a * 10)
stopchk = 0
RETURN

Writedata: '                        -Writes data sequentially (with commas)
'                               to file #2
WRITE #2, data1a, data2a, data3a, data4a, data5a
RETURN

Archivedata: '                      -Optional storage of data to hard disk.
Archive:
PRINT : CLOSE
INPUT "  Do you want to store this data run on disk (Y/N)"; ans$
IF ((ASC(ans$) = 89) OR (ASC(ans$) = 121)) THEN
        PRINT : INPUT "  What Filename do you want on drive c:\ "; dskfile$
        OPEN "c:\" + dskfile$ + ".TXT" FOR OUTPUT AS #9
        OPEN "testdata" FOR INPUT AS #3
        DO UNTIL EOF(3)
                INPUT #3, data1b, data2b, data3b, data4b, data5a
                WRITE #9, data1b, data2b, data3b, data4b, data5a
        LOOP
        PRINT
        PRINT "  Data transfer complete to file c:\"; dskfile$; ".TXT"
        GOTO Endchoice
ELSE IF ((ASC(ans$) = 78) OR (ASC(ans$) = 110)) THEN GOTO Endchoice
END IF
```

```
PRINT :
PRINT "  Invalid Choice"
GOTO Archive
RETURN

Endchoice: '                    -Options to end program.
Choice: PRINT
INPUT "  Do you wish to End, Restart, or Archive Data. (E,R,A) "; e$
SELECT CASE (UCASE$(e$))
    CASE "E"
        CLS : CLOSE
        LOCATE 12, 29
        PRINT "Program Terminated"
        GOTO Final
    CASE "R"
        CLS : CLOSE
        GOTO Begin
    CASE "A"
        CLS
        GOSUB Archivedata
        GOTO Choice
    CASE ELSE
        PRINT
        PRINT "  Invalid Choice"
        GOTO Choice
END SELECT
RETURN
```

```
Errortrap: '                    -Error trapping - ie. when "return"is
'                              used but letter is required for input.
PRINT : PRINT "  Error in Program, data may still be safe.": PRINT
RESUME Choice
RETURN

'              ---- END ----
'-----------------------------------------------------------------------
```

IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6"

APPLIED IMAGE . Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989