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STRENGTH TESTING OF BOAT CLEATS

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In Partial Fulfillment

of the Requirements for the Degree of

Bachelor of Science in Mechanical Engineering

by

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On my honor as a University student, on this assignment I have neither given nor received unauthorized aid as defined by the Honor Guidelines for Papers in Humanities Courses.

Michael C. Drew

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(Signature)

Approved: Professor Soudek T.H. Soudek
(Signature)

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FOREWORD

This thesis was offered to me by Professor T.C. Scott in connection with the Boat U.S. Foundation which requested the University of Virginia to perform cleat strength tests. I was attracted to this project because it was based on strength-of-materials and machine design principles which I have concentrated on in my course work. Although the results of this thesis are not as conclusive as I had hoped, the overall project was a success. I would like to thank Lewis Steva for helping fabricate my cleat mounts, the Boat U.S. Foundation for their financial support, and most importantly, Professor T.C. Scott, who's encouragement and aid helped me complete this project.

M.C.D.

Table of Contents

APPENDIXES:

ABSTRACT

The strength capabilities of eleven types of cleats were investigated for the Boat U.S. Foundation. Each cleat was tested in four loading orientations which simulated real-world applications of the cleats. This was accomplished using a hydraulic press which applied force on each cleat with a 1/4" steel cable until the cleat broke. Two mounts were designed and created to hold the cleats at the bottom of the press in the proper position for testing. The data for each test included breaking force, loading orientation and failure mode. The results of the tests varied significantly. Although mounting screw breakage was the most common mode of failure for the cleats, several of the cleats suffered from mounting hole and main body failure. Two stress analyses were performed following the testing in an attempt to provide a simple method of predicting cleat strength and performance capabilities. A simple analysis provided vague and inaccurate results. The second, more complex analysis, produced a better understanding of the stresses experienced in the loaded cleat system, but many uncertainties were still prevalent. Predicting the exact failure force and mode from a stringent analysis would be a monumental task. Complexities such as stress concentrations, manufacturing inconsistencies, and loading irregularities make such an analysis useless for the typical boat owner. Therefore, the analysis was only capable of providing broad statements about poor and efficient cleat designs. One cleat type was broken in the same method four times with a breaking force spread of about 1000 pounds. This revealed the inaccuracies involved in testing and analyzing the cleats.

CHAPTER 1

INTRODUCTION

The Boat U.S. Foundation asked the University of Virginia to perform strength tests of various boat cleat designs. The cleats were thoroughly tested with a hydraulic press in order to present valuable data to boat owners who purchase cleats. The goal of the project was to combine force analysis techniques with actual laboratory data to differentiate between good and bad cleat designs, and to predict the failure force and mode of current cleat designs.

Each cleat tested in this study was analyzed in four basic loading conditions. A force was applied to each cleat until either the mounting screws or the cleat itself broke, and then the breaking force and mode of failure (screws, cleat feet, cleat leg, or cleat body) was recorded. According to force and stress theory, one should be able to predict the mode and force of failure knowing the dimensions, loading direction and force, and structural material of the cleat and screws. The basic concept involved in this analysis is stress which is calculated as force divided by area. There are two main types of stress: tensile stress, which is a stress normal to the cross sectional area; and shear stress, which is a stress parallel to the cross sectional area. Theoretically, the cleats should fail where this simple ratio of force and area exceeds the maximum capable stress of the material. However, even the irregularities present in a system as simple as the loaded cleat can introduce an incredible amount of uncertainty.

Some of these irregularities include stress concentrations from sharp corners and screw holes, friction from the mounting surface, and basic manufacturing flaws which lower the stress limits of the material. Yet, even with these problems, an attempt was made to reasonably predict the failure force and mode for each type of cleat. The characteristics of good (strong) and bad (weak) cleat designs were also identified.

There has been very little effort put forth to document and publicize cleat performance data. Therefore, the literature search for this project was virtually nonexistent. Some cleat testing was performed by the Attwood company, which manufactures boat cleats, and the data was given to the university from Boat U.S. However, Boat U.S. desired a more thorough investigation because the Attwood results were rather vague.

Boat cleats are essential components on any water vessel because they are used for securing a boat to a dock when not in use. The strength capabilities of the cleat become important when the restrained vessel is subjected to stormy conditions. If the cleats fail during these high stress situations, the boat can be damaged or destroyed. A boat or yacht owner may need to purchase cleats to protect his or her investment, but it is difficult to judge the strength and quality of the many cleats available because most do not indicate loading capabilities. Furthermore, the mere appearance of a cleat can be quite deceiving. Although some cleats may look rather durable because of their size and finish, they may actually have some attribute which severely limits their performance. The literature from previous cleat testing is very limited, so an in-depth study of cleat strength will be very helpful to boat and yacht owners alike. Boat U.S. would like to publish the results from these tests to assist their subscribers in making educated cleat purchases.

This report provides detailed information about the testing procedures, and describes the approach taken for the force and stress analysis. The assumptions made for the analysis are listed. A simplified stress analysis is presented first, followed by a more complex investigation into the forces and stresses within the cleat system. Even the complex analysis did not accurately predict failure force because of the prevalent irregularities in the system, and the limits of such an analysis are discussed. The characteristics of good and bad cleat designs are discussed in the conclusion section, and the successes and failures of the project are reviewed.

CHAPTER 2

DESIGN OF CLEAT MOUNTS

CHAPTER 2: DESIGN OF CLEAT MOUNTS

A suitable mount was designed in order to test the cleats in the various loading directions on the hydraulic press.

2.1 Initial Design Considerations

Before testing the cleats with the hydraulic press, a mounting system had to be designed and fabricated. Eleven different shaped cleats had to be tested in four loading orientations, so the system had to be flexible. The mount had to be strong enough to withstand high testing forces, but also had to be compact to fit the dimensions of the press. The first idea was to create a fully adjustable mount with hinges to allow angular and position adjustment. However, there were only four standard loading positions, so full adjustability was not necessary. Therefore, this idea was rejected because of its complexity and size. The next design considered was a modular mount that would conveniently allow multiple orientation testing for the eleven different cleat dimensions.

2.2 Creation and Performance of the Mount

The designs for the modular mount were drafted and given to the shop technicians for fabrication. (See Figure 2.1) No cleat mounting holes were specified in the mounting plate, so that I could personally drill the proper holes for various cleats when necessary. The 3/8-inch thick mounting plate contained 3, 1/2-inch holes drilled in the proper locations at the edge of the plate to allow testing of the cleats at 0°, 45°, and 90° in the vertical plane. One 1/2-inch hole was drilled in the center of the plate to hold the cleats 45° in both the horizontal and vertical planes (hereafter referred to as the 45°/45° position). The mounting plate fit into the slot on the modular base, and a 1/2-inch bolt was used to secure the connection. The 45°/45° orientation required the use of a different base and a threaded bolt, but the same plate could be used.

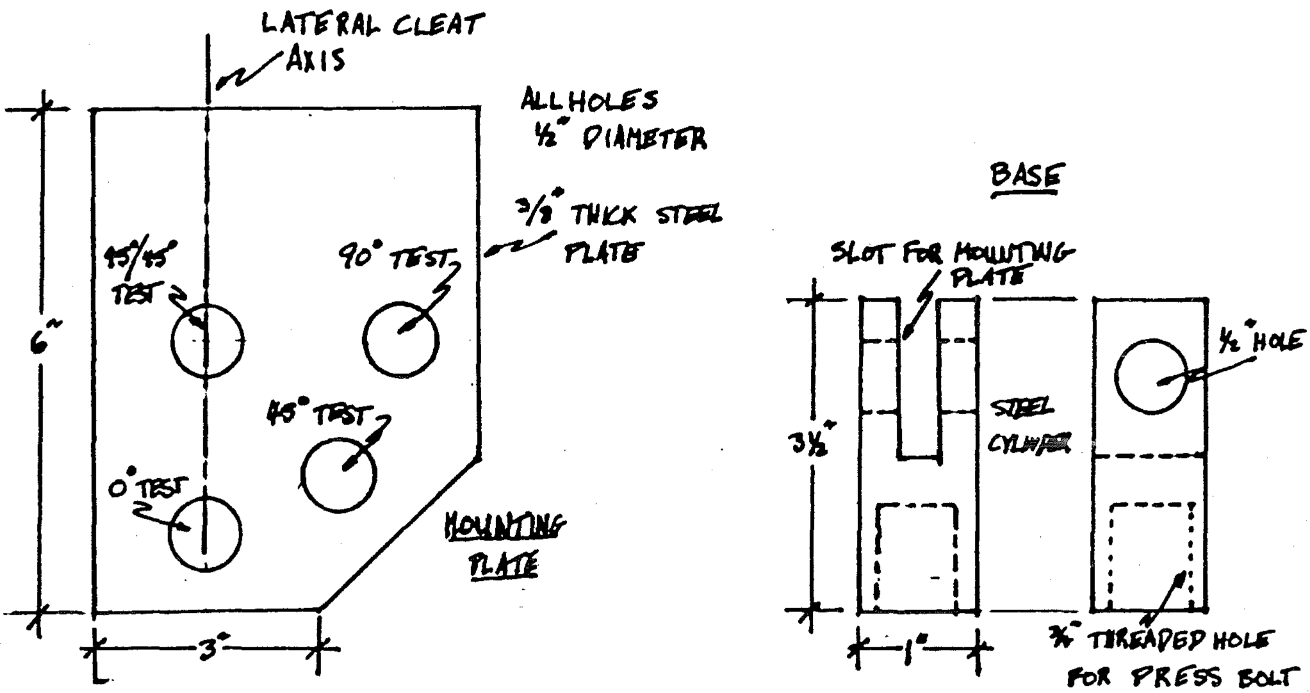


Figure 2.1

This was a convenient design because it was only necessary to drill each cleat's screw holes once. The system worked well for the three mounting orientations of 0°, 45°, and 90°, however, when the 45°/45° mount was assembled and used, it introduced a great deal of complications. Another design was necessary, but in the meantime, all the testing in the first three positions was completed.

2.3 Mounting Problems Faced During Testing

Overall, the modular system worked well for the 0°, 45°, and 90° orientations, but the mounting plate quickly became cluttered with holes because the eleven cleat types all had different mounting screw positions. Soon, it was no longer possible to drill holes in the plate for new cleat types. Therefore, another basic plate was created that was identical to the first so that the remainder of the cleats could be tested.

The problems involved with the 45°/45° designed were much more severe. Originally, the design seemed practical and elegant, but the first test in the 45°/45° direction completely sheared off the fastening bolt. A replacement bolt would have to handle very large combined shear and tensile stresses, and no such capable bolts were available. Yet, there was another problem involved with the 45°/45° mount. The angled face of the base obstructed the mounting screws for many of the cleats, and reducing the area of the face would drastically increase the stresses in the fastening bolt.

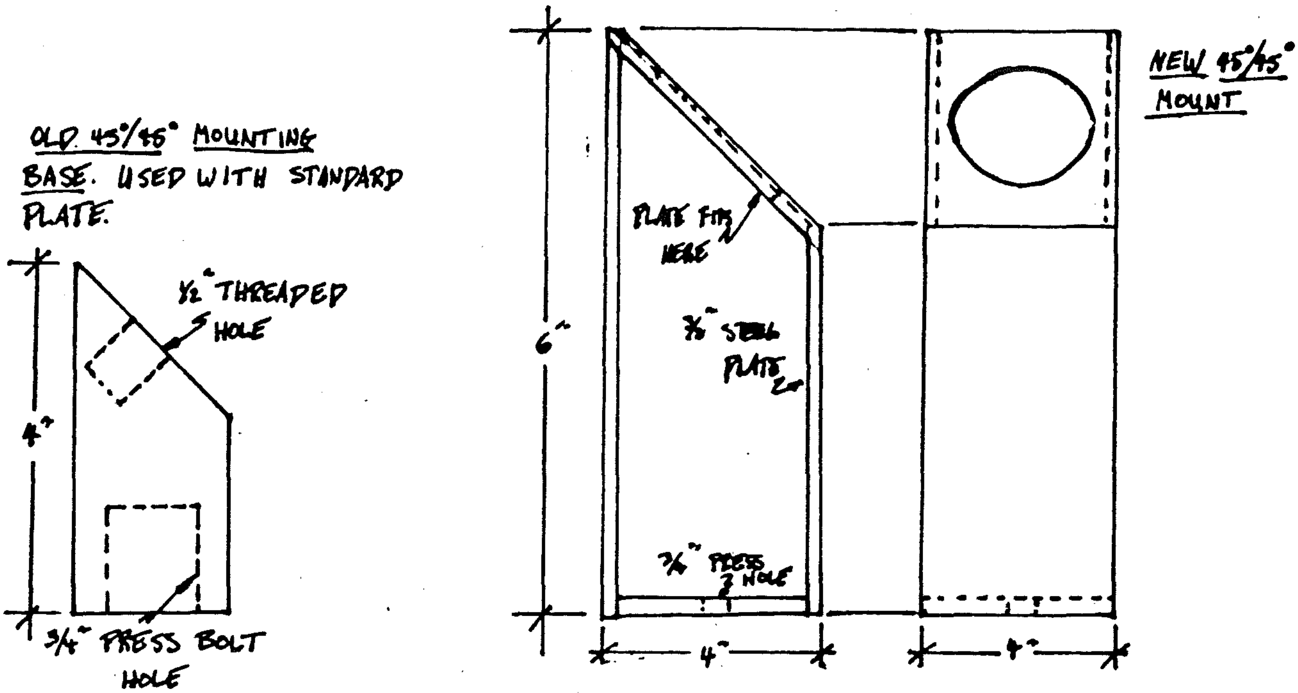


Figure 2.2

2.3 Redesigning the 45°/45° Mount

The problems with the 45°/45° mount were solved by designing an entirely new mount specifically for this orientation. (See Figure 2.2) A frame was created out of

3/8-inch steel with a 45° sloped panel on the top. Each cleat was fastened to a 1/4-inch plate 45° in the vertical plane which fit under the sloped panel. There was a 4-inch hole cut into the panel so that the cleat could protrude through the top. This design, although rather inconvenient in use, performed well, and the remainder of the cleats could then be tested.

CHAPTER 3

THE TESTING PROCESS

CHAPTER 3: THE TESTING PROCESS

The testing process required several steps to insure consistency and accuracy among all tests.

3.1 Torquing the Cleat Mounting Screws

When the cleats were attached to the mounting plates with the correct size of stainless steel screw, a torque wrench was used to insure that all nuts were torqued the proper amount. This was a very important step, because improper torque settings could cause noticeable variation in the results. As a nut is tightened on a screw or bolt, it squeezes the cleat and the mounting plate together. This, in turn, introduces a permanent, internal load on the screw known as preload. As the torque is increased on the nut, the preload in the screw increases, and the tendency for the cleat to separate from the plate decreases. If a cleat separates from the plate, static loading conditions would change immediately. This is undesirable because the assumptions and models used for the analysis would no longer be valid among all tests. However, the preload introduces an internal tensile stress on the screw which can cause material weakening and/or failure of the screw if the torque is set too high.

3.1.1 Determining Torque Values

In an attempt to determine the proper torque settings for the screws used in the experiment, the maximum allowable torque was calculated from theoretical textbook equations. The maximum torque value determined from the calculations (shown in Appendix A) for a stainless steel 1/4-20 screw was 32.2 lb-in. Yet, after some experimentation in the laboratory, 50 lb-in was found to work well for the 1/4-20 screws and 100 lb-in was used for the 10-32 stainless steel screws. The torque wrench used was not very accurate at such low values, but this was not important. The inconsistencies caused by friction and surface quality outweighed the gained accuracy of an expensive torque wrench. The basic idea was to tighten the screws as tight as possible before yielding commenced. After some experience was gained, the screws could be tightened based mostly on feel rather than on wrench indication.

3.2 Using the Hydraulic Press

A hydraulic press operates by pumping hydraulic fluid into a piston. As more fluid is delivered to the piston chamber, the moving part of the press raises. As the press encounters resistance to this upward motion, the moving arm requires a higher fluid pressure to continue its motion. The pump on a hydraulic press is capable of pumping fluid at very high pressures at varying rates of speed. The pump that was used for this experiment had a pressure gauge located on the intake fluid line of the piston chamber. Since the pressure in the fluid system is virtually identical at all locations, the loading force of the press can be calculated by subtracting 50 psi from the displayed pressure (from the pressure required to lift the moving arm of the press), and multiplying by the cross-sectional area of the piston. The diameter of the piston was displayed as 1.125 inches on the side of the press so the force calculation was simple and accurate, assuming the pressure gauge was correct. This assumption, however, had to be validated to guarantee accurate data acquisition.

3.2.1 Calibrating the Pressure Gauge

The pressure gauge was calibrated using a dead weight calibrator. This machine consisted of a two-sided hydraulic fluid line. The pressure gauge was attached to one side of the line, and a small piston chamber was located on the other side. Special iron weights of varying pressure denominations (the weights indicated pressures because they were specifically designed for the corresponding piston area) were stacked on a piston inserted into the chamber, and the pressure in the fluid line was increased with a hand pump until the piston lifted the weights. The pressure indicated on the gauge was compared to the known pressure caused by the weights for increments of 100 psi from 100 to 2000 psi. When the press gauge was tested, there was very little deviation between actual and indicated pressure. The variation that did exist (between 25 and 50 psi) could be neglected as experimental error. Therefore, the gauge used in the cleat tests was reliable and accurate for the tests.

3.3 Loading the Cleats

After a cleat was fastened to the mount with the correct torque setting, and the mount was secured to the base of the press, a 1/4-inch plastic-coated steel cable was used to apply the breaking force. The cable was looped around the prongs of the cleats and secured to the moving arm at the top of the press. Although cleats are typically used with nylon rope, 1/4-inch plastic-coated steel cable was chosen so that the cleats would break prior to cord failure. The cable was thick enough to simulate the rope, and the plastic coating reduced scratching and abrading of the cleats.

3.3.1 Special Loading Considerations

Before testing began, two cleats were broken in order to get a feel for the experiment. The mount and cleat in the 0°, 45°, and 90° loading configurations tended to tip backwards due to the applied force. This was not good because it caused a horizontal force vector on the cleat that should not exist for the 0°, same-plane loading. The 3/4-inch securing bolt at the bottom of the press is designed to act as a pinned ball-joint which pivots so that the loads in the bolt become entirely tensile. (See Figure 3.1) This is desirable for most tensile tests, but not for a cleat test. The force that is applied to the cleat/mount system creates a rotational moment that causes the observed tipping of the mount.

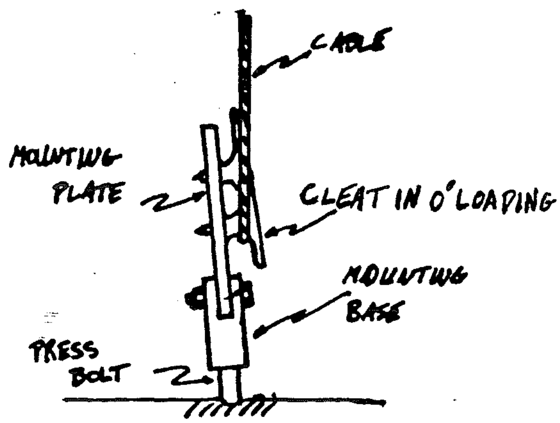


Figure 3.1

There was not much that could be done to remedy the situation except in the 0° loading configuration. In this position, the cable was wrapped around the bottom leg of the cleat and then threaded around the top leg. This modification did not change the force distribution by any appreciable amount, but it did prevent the tipping of the system. Fortunately, the tipping was not excessive, and even though the 45° and 90° tests could not easily be altered, the tipping in these positions was not as extreme to begin with. (See Figure 3.2)

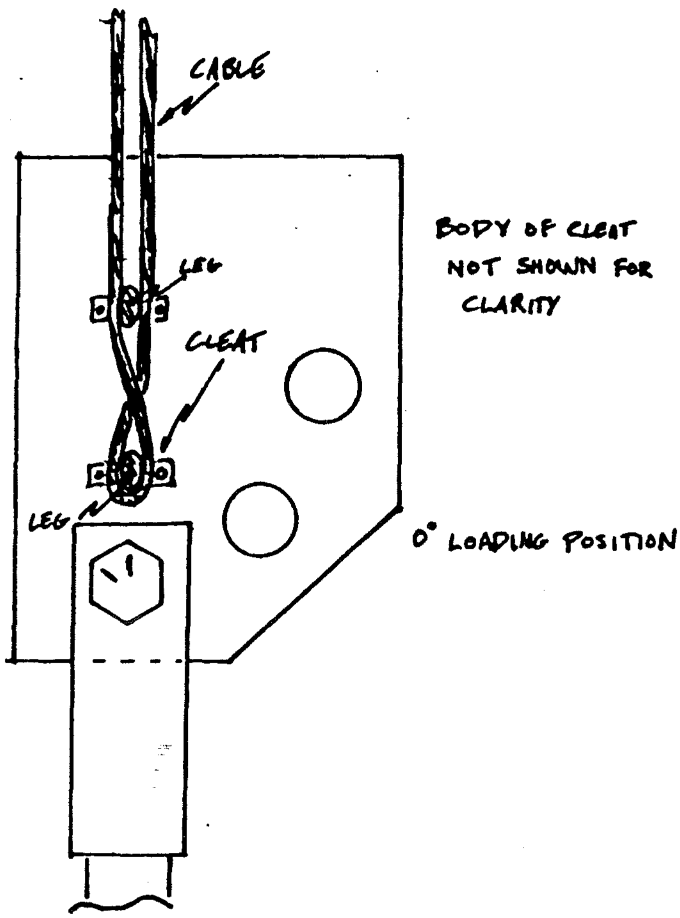


Figure 3.2

3.4 Recording the Data

For each test, the cleat was mounted as discussed above, and the press was turned on to draw the cable upward at a slow, but steady speed. The fluid pressure increased non-linearly with time as the press loaded the cleat, and the pressure at the first sign of failure was recorded. A cleat was considered to "fail" when any part of the cleat or the cleat's mounting screws broke. The press was usually stopped at this point, although sometimes a test was allowed to continue so that the successive modes of failure could be observed. Failure was defined at the first sign of fracture, because any further force necessary to continue breakage is usually less than or equal to the first force of fracture. A cleat is *effectively* destroyed and useless at this point.

After each test was complete, the cleat and its pieces were placed inside an envelope for later analysis, and the failure pressure and cleat type was recorded on the outside. Also, all the tests were recorded on video tape so that the failure modes of each cleat could be reviewed if necessary.

CHAPTER 4

DATA EVALUATION AND ANALYSIS

Chapter 4: DATA EVALUATION AND ANALYSIS

The data must be evaluated and processed so that it reveals valuable information to boat cleat users.

4.1 Complicating Factors For the Stress Analysis

When materials are subjected to loads and stresses, there can be more involved than what meets the eye. Even the loaded cleat system, which seemed quite simple at first appearance, was riddled with complications and uncertainties which distorted the results. An understanding of some basic material properties and characteristics can help make sense out of the findings of this experiment.

4.1.1 Failure Modes

When a cleat failed, it broke in one or more of four failure modes. The screws were the most common mode of failure, followed by the screw holes, or feet, of the cleat. Some of the tests broke a leg of the cleat (this is the part of the cleat which extends from the feet up to the main body), and sometimes the body itself fractured violently. Most of the analysis concentrated on the screws and the feet of the cleat because they were consistently the weakest part of the system.

4.1.2 Stress Concentration Factors

When an item with a complicated shape is loaded, the stresses are not accurately predicted from the standard force to area relationship. At sharp edges, or holes, stress concentrations exist which can drastically increases actual stress. The actual stress can be anywhere from above 1, to 4 or 5 times the nominal stress (force divided by cross-sectional area). This explains why so many things break at edges or holes, and this behavior was particularly noticed in the cleat tests where feet failure was the second most prevalent failure mode. The cleats had sharp edges between the feet and the legs, and each foot contained a counter-sunk screw hole with a complex geometry.

Actual stress can be calculated from the nominal stress by multiplying by a *stress concentration factor*. These values are determined from empirical values displayed in charts and graphs of most strength-of-materials text books. The factors are related to the extremity of an edge, or the relative size of a hole compared to the entire cross-sectional width. Each cleat exhibited complex feet geometries which made finding exact concentration factors a nearly impossible task.

4.1.3 Screw Stress Concentrations

When the holes are drilled in the mounting plate for each cleat, the alignment will not be perfect. Therefore, one of the screws will be more snug against the top of the mounting plate hole than another. This causes inconsistencies in the load distribution among the screws because one of the screws will carry more than its theoretical share of the load. The tensile loads for many loading orientations are theoretically predicted to vary among screws, but the shear load is assumed to be equally distributed. Also, when the four-screw cleats are loaded in the 0° and 90° directions, tensile loads are assumed constant among the two top and bottom screws. Yet, testing in these directions often resulted in one of the screws breaking first instead of both breaking at the same time. Thus stress concentration among the screws is another factor that must be considered during the analysis.

4.1.4 Manufacturing Irregularities

The final main factor that could have caused variation in the test results is the possibility of manufacturing irregularities. When a cleat or screw is produced, there is always some variation in the shape and material quality of the item. Small irregularities in either of the components could have caused a noticeable variation in the data. These irregularities tend to weaken the system, so variation is expected to err on the low side of the expected material strength.

The screws represent the most consistent components in the system. Both the 1/4-20 and the #10-32 stainless steel screws were strength tested on the press, and the stress required to break them was 80,000 psi ±10%. This was well within the listed range of tensile strength for stainless steel, so there is little doubt that the tests were accurate.

4.2 The Test Data

The Data recorded from the cleat tests is shown below in Table 4.1. Both failure force (measured in pounds force) and mode are shown.

Some additional tests were run on cleat L because it was not broken or seriously bent during the first tests. The cleat was tested four additional times in the 90° orientation in order to investigate the variation of the tests. The screws were the most consistent components in the

Failure Mode: **1 = Screws Failed**
2 = Feet Failed
3 = Leg Failed
4 = Body Failed

ITEM	**No. Screws and size**	**Failure Load and Failure Type For:** 0°	45°	90°	45°/45°
A	2/#10-32	2780/1	1390/1	1590/1	2380/4
B	2/¼-20	3780/1	3860/1	3800/1	4000/1
C	2/¼-20	2500/1	3890/1	3700/1	4770/1
D	2/¼-20	3580/1,4	3380/1,4	3970/1	4760/1
E	2/¼-20	4970/1,2	3780/2	4170/2	5360/1
F	4/¼-20	4170/2,4	1190/2	1790/2	4770/2
G	4/¼-20	7160/1	6760/3	6720/1	5370/3,4
H	4/#10-32	3380/2	2920/2	2380/2	3180/4
J	4/#10-32	3180/3	2780/2	2880/2	3970/2
K	4/¼-20	6660/1	6800/1	7550/1	6560/1
L	4/#10-32	3180/1	3990/1	3970/1	4570/3

Table 4.1

Original Reported Load	= 3970 lb
Additional Tests....	3380 lb
	4370 lb
	4070 lb
	3875 lb

Average = 3930 lb
Spread = 4370 - 3380 = 990 lb

Table 4.2

test rig, and yet, even in this loading configuration where the screws failed first, the data spread was about 1000 lbs. (See Table 4.2) This data indicated that test variations were rampant, and were a definite cause of concern for the project.

4.3 The Simple Analysis

After all testing was complete, a simple analysis was performed on all eleven cleats. The first step in this analysis was to measure and calculate the smallest areas (since breakage will occur at the smallest section) of the four basic parts of a cleat: screws, feet, legs, and body. Next, these cross-sectional areas were multiplied by the material tensile strength of the part to determine the tensile force required for breakage. The hope was that a ratio of the actual cleat failure load (divided equally amount the screws and feet) to the load required to break the part, might give an indication of the weakest part of the assembly. Hopefully, a ratio of around one or greater, would indicate the part that actually failed.

4.3.1 Assumptions of the Simple Analysis

Before examining the precision of the simple analysis, there were many assumptions made that must be discussed. The most obvious is the assumption that the forces were shared equally among all screws and cleats. Probably the most noteworthy weakness of this analysis, however, is that combined shear and tensile loads were not considered. Each screw and foot caries a tensile and shear load during testing, and this analysis assumed that the entire breaking force could be divided equally among the screws and feet as a shear load.

Obviously, stress concentrations were not considered in this analysis, however, as discussed above, determining the correct factors for each cleat would virtually be impossible. Nevertheless, the failure load to tensile load ratio of the feet for all four-screw cleats was compared. (See Appendix B Page 1) Although concentration factors were not known, perhaps a minimum value of this ratio for cleats with feet failure could be found. However, the data was not very conclusive, and besides, nobody would want to go through these calculations in a boat hardware store anyway.

4.3.2 Accuracy of the Simple Analysis

The problems with predicting feet failure with the simple analysis has already been discussed. However, a quick glance at the results indicates that no real conclusions can be made about *any* of the cleats, or their failure modes. Even the ratios for the parts that failed are very rarely greater than one. This is because the assumption neglected combined shear and tensile loading, and assumed that the loads were distributed equally among all screws and feet. This is a dangerous set of assumptions, because although shear forces should theoretically be distributed equally, tensile loads are definitely not equally shared. For the cleats which suffered from screw failure, the screw ratio is often the largest. However, the ratio for feet would frequently be just as large if the appropriate concentration factors were applied. Overall, this analysis did not lead to any conclusions about boat cleat performance. Therefore, another, more intricate analysis was required before any relevant statements could be made.

4.4 The Complex Analysis

For the complex study, a static loading analysis was performed for both two and four-screw cleats in all four loading directions. A diagram of the cleat with all forces applied in equilibrium (known as a free body diagram, or FBD) was used to determine both shear and tensile forces at the mounting screw locations. These forces could be thought to act on the screws and on the foot of the particular screw. Although the listed calculations are for screw stress, they can be used to find the forces on the feet if the area variable is removed. (See Appendices C-F for calculations.)

The FBDs for many of the analyses were statically indeterminate, so a deflection analysis was used to provide another relationship between forces. (See Appendix C Page 1) This does not necessarily imply that the cleat separated from the mounting plate. However, as the cleats are loaded, there is a small amount of deflection in the which is proportionally related to the tensile force of the screws. Thus, even if the cleat does not separate from the plate, this part of the analysis is still theoretically valid.

4.4.1 Complex Analysis Assumptions

4.4.1.1 Frictional Assumptions

There were some assumptions made in the complex analysis which could have caused variation of the results. The FBD analysis for all the loading methods assumes that there was a certain amount of friction between the cleat and the mounting plate. Friction would tend to reduce the shear stress on the screws and feet, because the entire surface (or part of the surface - friction force is independent of area) would take some of the load.

The friction force between two surfaces is proportional to the normal force (perpendicular to the surface face) between the surfaces. The proportionality constant is μ, the coefficient of friction. This coefficient varies depending on material and surface conditions, and is determined experimentally. However, real values of μ are very inconsistent, so one cannot always rely on textbook values. The value of μ chosen for this project was 0.2.

4.4.1.2 The Assumption of Rigidity

One assumption that was made for both the simple and complex analysis is that the cleat is rigid. This implies that the cleat itself did not flex or deform (until failure) and that the forces could be distributed properly among all feet and screws.

If we analyze the 0° test of a two-legged cleat, we assume that the shear force is equally shared by the top and bottom feet and screws. The force of the cable was applied at the bottom leg, so we assume that half of the shear force is carried by the bottom of the cleat, and half is carried by the top. However, if the body of the cleat is not capable of handling the bending stress imposed by half the shearing force, the majority of the force will be carried by the bottom of the cleat. One can imagine a cleat with a styrofoam body. When tested, the top of the cleat will carry almost no shear load, because the top is not *rigidly* attached to the bottom, and a component of the bottom will fail. (The styrofoam would then break in half.)

Some of the cleats that were tested may have lacked rigidity, but it is nearly impossible to tell based on the test results. The bottom feet or screws of the cleats typically failed first for most of the tests, but this was probably caused by the tensile loads which were significantly higher on the lower parts of the cleats, and equations of the complex analysis predicted this occurrence.

4.4.1.3 Force Vector Location/Direction Assumptions

The last important assumption that was made concerned the locations and directions of the force vectors. The complex analysis assumed that the forces applied to the cleats were exactly 0°, 45°, or 90° in the vertical plane, or 45° in both the vertical and horizontal planes. This assumption is not entirely correct, as some variation did occur. This was briefly discussed in the testing process chapter. Furthermore, the force vectors were presumed to originate at the lateral center on the leg of each cleat. Obviously, the cable was looped *around* the leg of each cleat so the locations of the vectors were partially offset.

4.4.2 Combining Shear and Tensile Stress: Mohr's Circle

The one assumption that the complex analysis did not make was the neglect of combined shear and tensile loads.

When a component possess both shear and tensile loads, the actual maximum stress is higher than either the shear or tensile stress. This is because both tensile and shear stress is measure in a relative vertical and horizontal axis. Maximum stress occurs on a different axis within the component, and the method of Mohr's Circle is utilized to find these maximum stresses. (See Appendix C Page 2) Although both maximum tensile and shear stresses can be found, the tensile stress is the highest, and is therefore, the critical stress.

4.4.3 Accuracy of the Complex Analysis

Even though the complex analysis had its own set of assumptions, it should have been more accurate than the simple analysis. This analysis took the dimensions of each cleat into account, and as stated above, included a detailed analysis of force.

After the equations were derived, the first step in performing this analysis involved measuring several dimensions for all eleven cleats. (See Appendix G) Then, the cleat tests were divided into eight groups: two-screw cleats in the four loading directions, and four-screw cleats in the four loading directions. Quatro Pro was used to calculate the stresses based on the derived equations, the measured dimensions, and the recorded failure force of each cleat.

4.4.3.1 Analyzing Screw Stress

Mohr's Circle equations were also calculated on Quatro Pro to find the maximum tensile stresses in each screw. Since screw failure was the most prevalent failure mode in the tests, the calculated screw stresses were compared to the screw tensile strength (80,000 psi) for those cleats that exhibited screw failure. This was done to check the validity and accuracy of the equations. Figures 4.1 - 4.4 show graphs of the maximum screw stress for each type of cleat. The screw location with the maximum stress was plotted for each cleat because this is where failure was most likely to occur. In Figures 4.1 - 4.3, the average screw stresses of the cleats with screw failure are indeed close to 80,000 psi. However, there is a large amount of data spread, particularly in Figure 4.1. The failed-screw stresses varied mostly on the low side of 80,000 psi. This is an interesting fact that was explained quite easily. As discussed above, the screws will not all share the loads equally as they were assumed to do in the analysis, and one screw will break before the average load reaches 80,000 psi.

For some unknown reason, the stresses calculated for the 45°/45° were considerably higher than those calculated for the other analyses. To remedy this situation, the average of the failed-screw stresses was divided by 80,000 psi to obtain a value of 1.905. This ratio, or "fudge factor", was then used to scale down *all* of the calculated stresses for this loading direction. Such empirical factors are often used in many scientific formulae when a system is too complex to model with theoretical principles. The resulting graph is shown in Figure 4.5, and the data spread was found to be similar to the other graphs.

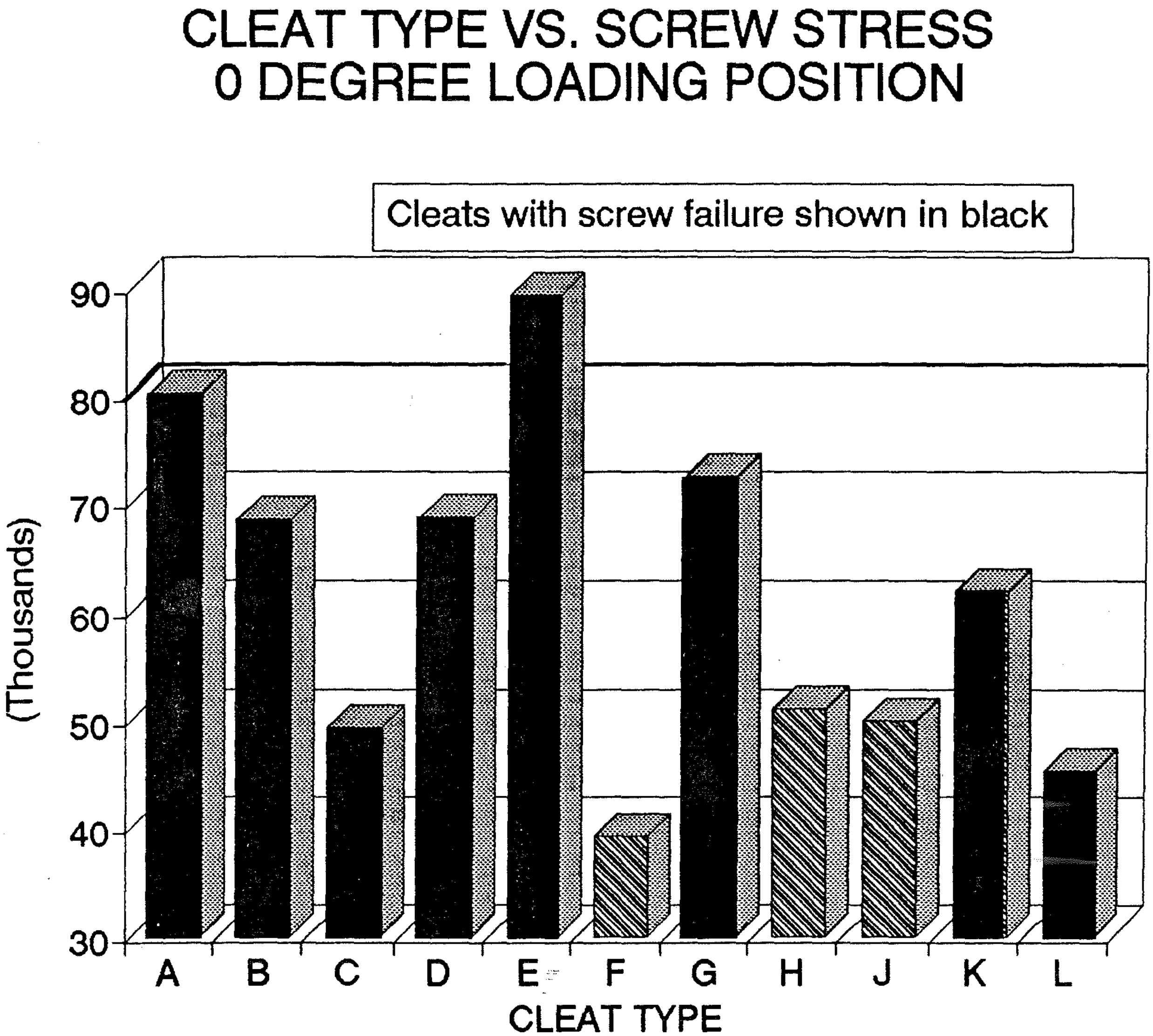
4.4.3.2 Analyzing Feet Stress

Solving the problem of predicting foot stress seemed like an impossible task, but the complex analysis predicted forces more accurately, so another foot analysis was performed. The main problem with foot stress is the complex shape of the hole. The shear force on the bolt acted as a tensile force on the cross-section of the hole, but the tensile force of the screw acts on the conical face of the countersunk hole in a rather complex fashion. Since this force distribution was not understood, the foot analysis neglected this force and only dealt with the shear force of the screw.

Using Quatro Pro, the *tensile* stress of the feet was found by multiplying the area of the screw by the *shear* stress on the screw, and dividing this value by the minimum cross-sectional area of the foot. This value was then divided by the tensile strength of the cleat's material. This is essentially the same kind of ratio used for the simple analysis, and unfortunately, the same uncertainty was noticed. (See Appendix H) There seemed to be no way of predicting foot failure without performing a computer-generated finite element analysis, and such an analysis would be unwarranted for boat cleats.

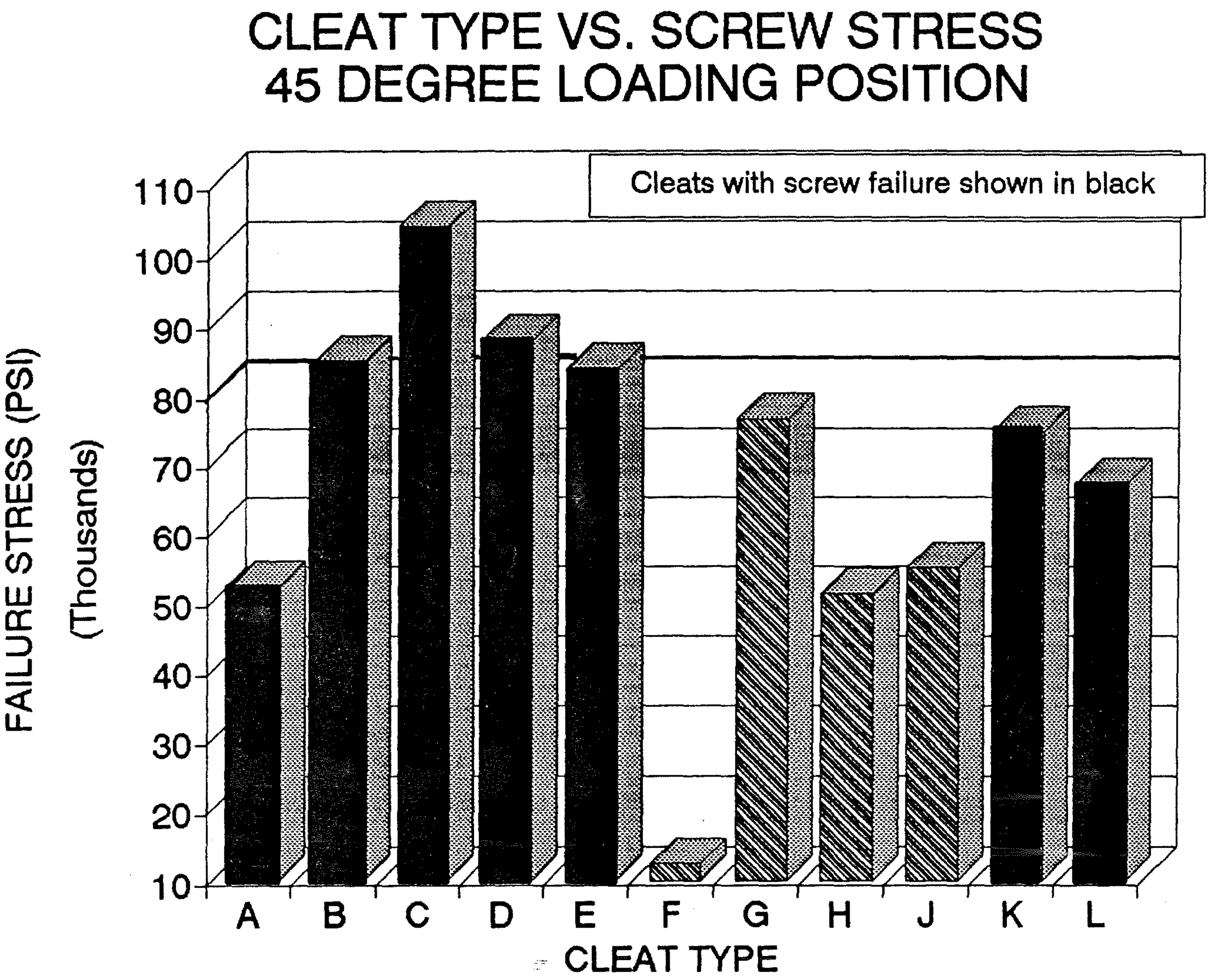
4.4.4 Final Notes of the Complex Analysis

The failure modes of body and leg were not considered in the complex analysis. This is partially due to the perplexity of such an analysis, and also the rarity of these failure modes. Also, cleats that failed in these modes, failed at smaller forces with different modes in other orientations. Since only the weakest modes among all loading orientations should be considered when publishing performance capabilities of a cleat, leg and body failure do not require analysis.



CLEAT TYPE VS. SCREW STRESS
0 DEGREE LOADING POSITION
Cleats with screw failure shown in black
(Thousands)
90
80
70
60
50
40
30
A
B
C
D
E
F
G
H
J
K
L
CLEAT TYPE

Figure 4.1



CLEAT TYPE VS. SCREW STRESS
45 DEGREE LOADING POSITION
Cleats with screw failure shown in black
FAILURE STRESS (PSI)
(Thousands)
110
100
90
80
70
60
50
40
30
20
10
A
B
C
D
E
F
G
H
J
K
L
CLEAT TYPE

Figure 4.2

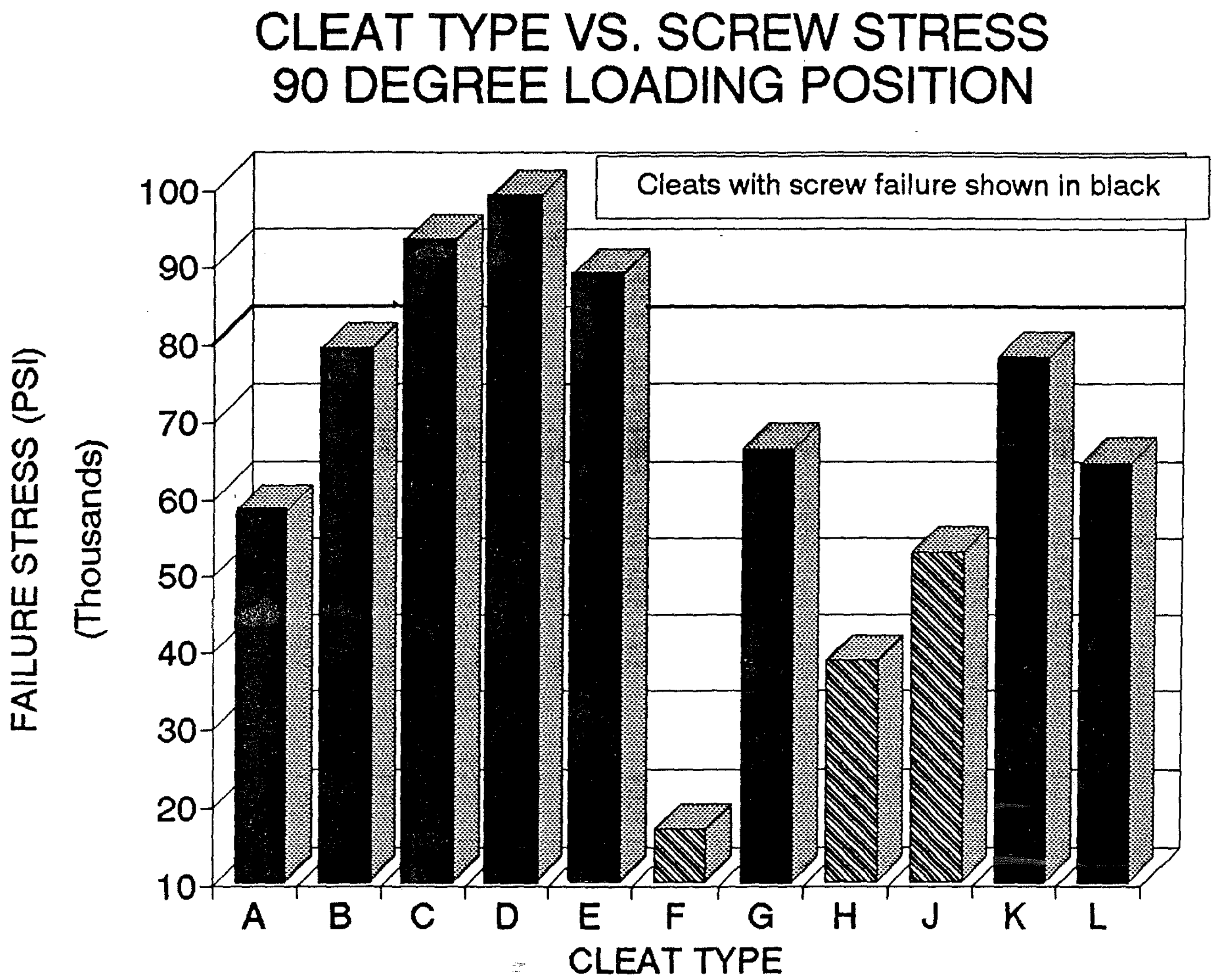

CLEAT TYPE VS. SCREW STRESS
90 DEGREE LOADING POSITION
Cleats with screw failure shown in black
FAILURE STRESS (PSI)
(Thousands)
100
90
80
70
60
50
40
30
20
10
A
B
C
D
E
F
G
H
J
K
L
CLEAT TYPE

Figure 4.3

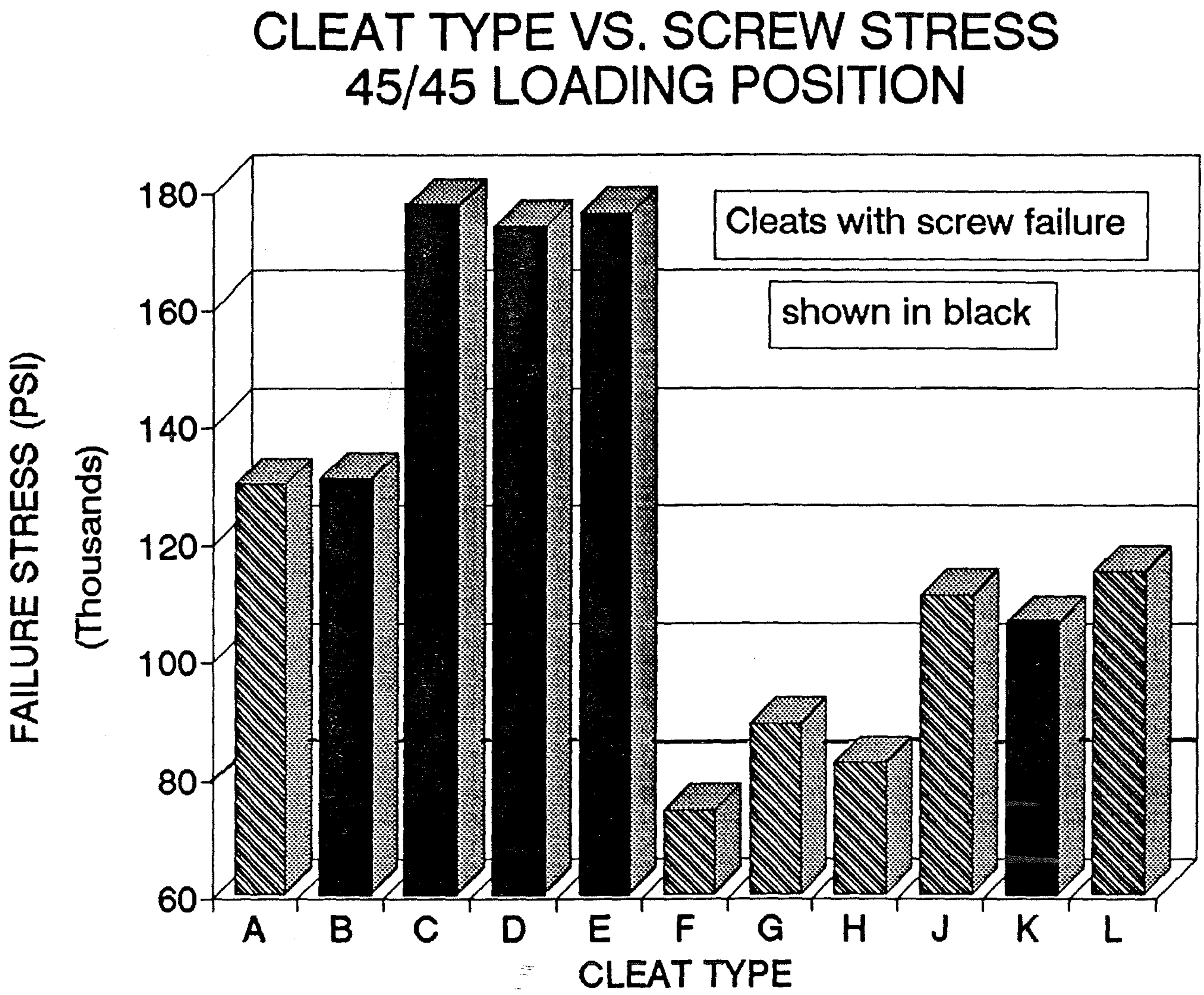

CLEAT TYPE VS. SCREW STRESS
45/45 LOADING POSITION
Cleats with screw failure
shown in black
FAILURE STRESS (PSI)
(Thousands)
180
160
140
120
100
80
60
A
B
C
D
E
F
G
H
J
K
L
CLEAT TYPE

Figure 4.4

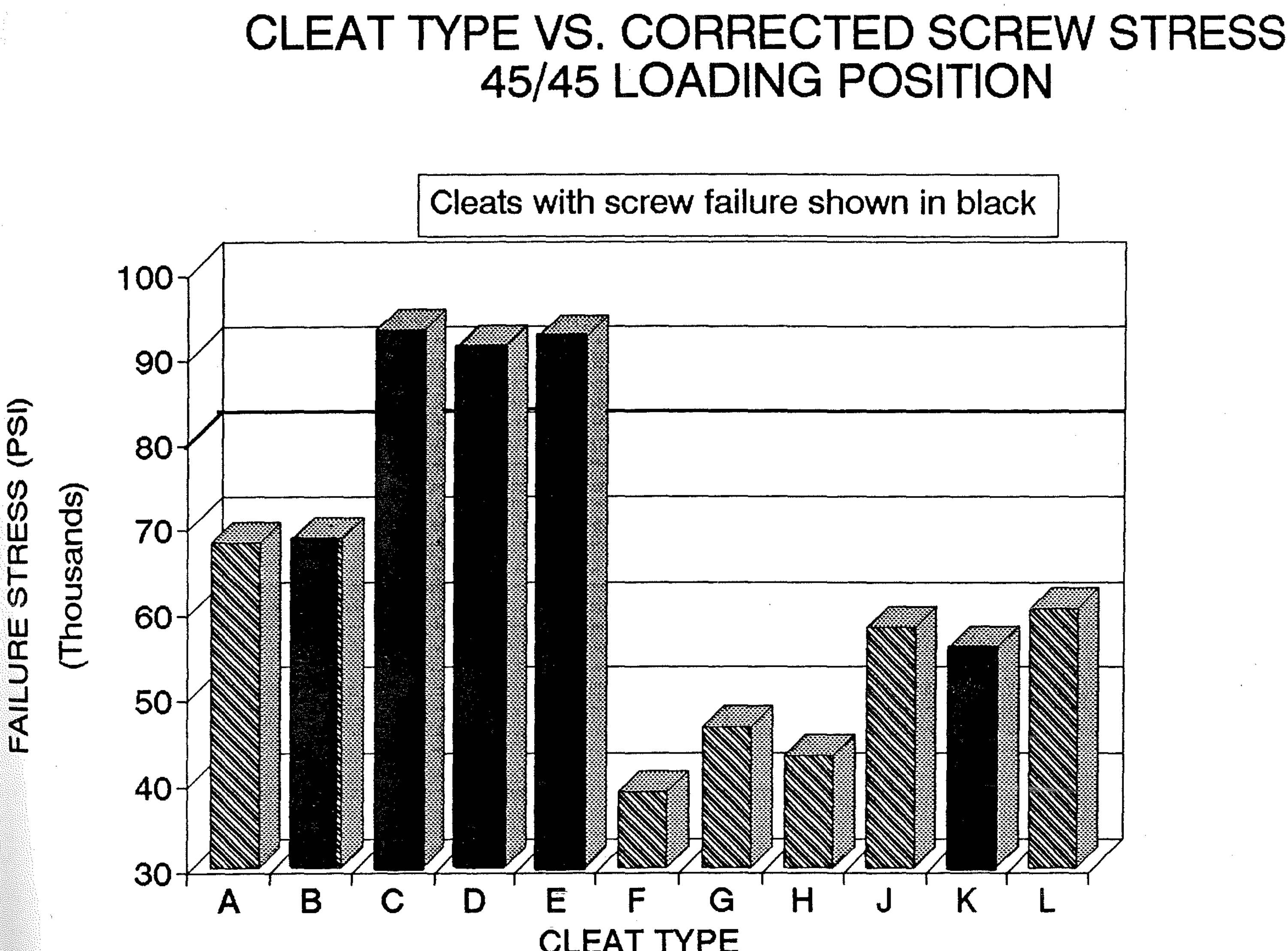

CLEAT TYPE VS. CORRECTED SCREW STRESS
45/45 LOADING POSITION
Cleats with screw failure shown in black
FAILURE STRESS (PSI)
(Thousands)
100
90
80
70
60
50
40
30
A
B
C
D
E
F
G
H
J
K
L
CLEAT TYPE

Figure 4.5

CHAPTER 5

CONCLUSIONS

CHAPTER 5: CONCLUSIONS

Only broad statements can be made about the strength of different types of cleats because of the large number of uncontrollable variables and unknown factors.

5.1 Summary

The goal of this project was to help boat owners make educated choices when purchasing boat cleats. A series of tests were performed to determine the strength of several types of cleats, and two analyses were performed based on the test data. The analyses attempted to find a correlation between loading direction, cleat and screw dimensions, and material strength.

5.1.1 The Simple Analysis

The simple analysis strived to find broad correlations within the data without the use of complex equations and terms. This was a worthy endeavor which would easily lend itself to the average boat owner. However, this analysis provided almost no useful information. The assumptions that were made neglected the important principles of combined shear and tensile loads, directional loading, and unequally distributed forces. Unfortunately, a complex analysis which did not neglect these principles was required to provide a better assessment of the test results.

5.1.2 The Complex Analysis

The complex analysis, as opposed to the simple analysis, analyzed each testing method individually and was based on cleat dimensions and force directions. Although this analysis was lengthy and complex, correlations could be made which matched the data more accurately. The validity of the derived equations was checked by calculating screw stresses at the cleat failure load. The calculated stresses in the screws that failed were compared to the tensile strength of the screw material, (stainless steel = 80,000 psi) and considering the uncertainties involved, the correlation between actual and theoretical cleat/screw performance was quite apparent.

The complex analysis *did* have shortcomings. Although the average of the calculated stresses of failed cleat screws was indeed close to the tensile strength of the screws, there was a large amount of variance. Also, no correlations could be determined between the actual and theoretical behavior of cleat foot breakage.

5.1.3 General Test Variance

Finally, the multiple 90° loading tests of cleat L indicated a large percentage of variance in the testing process as a whole. Even with all possible attempts at maintaining consistency, a spread of nearly 1000 lbs was observed in the data.

5.2 Interpretation

The results of the complex analysis were definitely far superior to the outcome of the simple analysis, and these results can be used to draw *general* conclusions about boat cleat performance and strength. With so much variance noticed in the consistent environment of the laboratory, real-world uncertainty is expected to be even greater. Therefore, only broad statements could be made about the characteristics of strong and flimsy cleat designs.

The screw stress analysis that was performed based on the derived equations indicated the validity and relative accuracy of the complex analysis. These equations were particularly accurate for the two screw cleats A - E (see Figures 4.1 - 4.5) because foot failure is virtually impossible in these cleats. The screws are located in the center of the solid leg of the cleat, and the cord is wrapped around the leg, thereby containing the leg and preventing failure. In most instances, the screws are the only part of the two-screw cleats that can break, and for the most part, the complex analysis predicted this behavior.

The derived equations also predicted which screws on the cleat would be most susceptible to failure. With a quick glance at the equations, one can predict the screws with the highest stresses based on the relative sizes of the cleat dimensions. These predictions were consistently supported by the tests for the cleats which suffered from screw failure. The lowest screws on the assembly generally failed first, as predicted by the analysis.

The preceding observations helped validate the analysis, however, the large amount of data irregularity caused by inconsistencies and unknowns was the most apparent in the foot failure investigation. Nevertheless, the complexity required for an accurate analysis would not be well receive by the audience the results were designed for.

5.2.3 Useful Conclusions for Boat Owners

If the data from this project is to be useful to boat owners, it must be easily interpreted, and more importantly, it must be fail safe. Each cleat was tested with four loading directions that are common in real-world applications. However, because a cleat is subjected to all directions of loading on a boat, only the lowest failure load among the four directions should be reported. The cleats that were chosen by the Boat U.S. Foundation represent a large variation of cleat designs, so cleats that are identical in form to one of the tested cleats could probably be inferred to have the same strength characteristics.

In addition to the data recorded from this project, a number of observations were made that could be useful to a boat owner who is purchasing cleats. These are as follows:

1. Choose cleats with large feet and large screw holes. Large cleats can be severely limited by small feet. The most common failure mode was screw and foot breakage. Common sense applies: "the larger, the stronger."

2. In general cleats made from stainless steel and bronze are superior. Do not be mislead by the chrome plating.

3. Use the largest and strongest screws possible for mounting. Stainless steel is an excellent choice due to high strength and corrosion resistance.

4. Be sure to mount the cleat on the most solid foundation possible, and make sure the screws are reasonably tight.

If the pertinent dimensions of the cleats were cataloged in charts, consumers could use the derived equations to compare probable failure loads. Yet, this is quite unrealistic. Ideally, the equations could be used by cleat manufacturers to estimate failure loads. The calculated values would probably be used as an approximation before a similar strength test was performed.

This project clearly displayed the differences between real-world and text-book engineering problems. What was thought to be a simple system, quickly became very complex, and empirical data was found to be worth more than theoretical postulates and equations.

5.3 Recommendations

Further investigation of this subject would provide a better statistical base of data, but the same variance would be apparent. To increase the accuracy of the study, a finite element computer analysis could be performed on the cleats, but to do so would be overkill of the subject. Finite element analysis is used primarily for design, and because cleats are not components worthy of design optimization, empirical results are more practical. The consistency of the experiment could be improved slightly, but the difference in the variation of results would render such efforts futile.

BIBLIOGRAPHY

The only sources used in this thesis were material property characteristics, and basic Engineering principles discussed in most common engineering textbooks. This information can be regarded as common knowledge in the Engineering field. The equations used were self-derived based on such common information and principles. The Attwood tests referred to in this report were sent to the University of Virginia from the Boat U.S. Foundation without any further referencing information. There is *no* other known published data concerning boat cleat testing.

APPENDIX A

TORQUE CALCULATIONS

MICHAEL C. DREW

$T = KDP$

T = TORQUE
K = LUBRICATION CONSTANT (0.15)
D = NOMINAL OUTSIDE DIAMETER OF THREADS
P = CLAMPING LOAD.

* MAXIMUM CLAMPING LOAD USUALLY 0.75 TIMES THE PROOF LOAD.

PROOF STRENGTH OF BOLTS IS TYPICALLY 90-95% OF YIELD STRENGTH.

YIELD STRENGTH OF STAINLESS STEEL 316 S31600 IS: 30 ksi

∴ PROOF STRENGTH IS: $0.90(30) = \underline{27\ \text{ksi}}$

A_t FOR ¼-20 BOLTS IS: $\underline{0.0318\ \text{in}^2}$

CLAMPING LOAD $P = A_t\,(\text{PROOF STRENGTH})(0.75)$

$P = (0.0318\ \text{in}^2)(27\ \text{ksi})(0.75)$

$\boxed{P = 644\ \text{lb}_f}$

$T = KDP$ $K = 0.15$
$D = 0.250\ \text{in}$
$P = 644\ \text{lb}_f$

$T = 0.2(0.250)(644\ \text{lb}_f)$

$\underline{T = 32.2\ \text{lb}_f \cdot \text{in}}$

APPENDIX B

SIMPLE ANALYSIS DATA

0° loading,		Failure load to tensile load ratio	foot failure?
cleat	H	0.49	yes
	F	0.37	yes
	G	0.34	no
	J	0.34	no
	K	0.37	no
	L	0.14	no

45° loading,		Failure load to tensile load ratio	foot failure?
cleat	H	0.42	yes
	F	0.11	yes
	G	0.33	no
	J	0.30	yes
	K	0.38	no
	L	0.18	no

90° loading,		Failure load to tensile load ratio	foot failure?
cleat	H	0.34	yes
	F	0.16	yes
	G	0.32	no
	J	0.31	yes
	K	0.42	no
	L	0.18	no

45/45 loading,		Failure load to tensile load ratio	foot failure?
cleat	H	0.46	no
	F	0.42	yes
	G	0.20	no
	J	0.43	yes
	K	0.37	no
	L	0.21	no

Cleat ID:	A
Material:	ABS plastic(I think)
Tensile strength:	10,000 psi
No. of legs:	2
Screw size:	#10-32
No. screws = No. feet:	2
Screw cross section:	0.0199
Screw tensile strength:	60,000 psi*
Tensile load per screw:	1195 lb
Tensile load, all screws:	2390 lb
Minimum foot area:	0.15 in^2
Tensile load per foot:	1500 lb
Tensile load, all feet:	3000 lb
Minimum leg area:	0.25 in^2
Tensile load per leg:	2500 lb
Tensile load, all legs:	5000 lb
Body area:	0.43 in^2
Body tensile load:	4300 lb

0°	Failure load:	2780 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	1.16
	Failure load/tensile load, all feet:	0.93
	Failure load/tensile load per leg:	1.11

45°	Failure load:	1390 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.58
	Failure load/tensile load, all feet:	0.46
	Failure load/tensile load, all legs:	0.56

90°	Failure load:	1590 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.66
	Failure load/tensile load, all feet:	0.53
	Failure load/tensile load, all legs:	0.32

45/45	Failure load:	2380 lb
	Item that failed:	body **
	Failure load/tensile load, all screws:	0.99
	Failure load/tensile load, all feet:	0.79
	Failure load/tensile load, all legs:	0.48
	Failure load/body tensile load:	0.55

---

* We did not have stainless steel screws long enough to go through this cleat so we had to use plain steel. But we tested the plain steel screws in tension to get their tensile strength accurately.

I am not sure that this is ABS plastic but it seems the most logical kind to use. The tensile strength of plastics is not very well documented. This seems like a reasonable value.

** We calculated the minimum body area as that at the base of the arm sticking out similar to the method determine by section A-A of the sketch of cleat H. This cleat failed in the main body through the screw hole where the area is less, about 0.31 in^2 making the ratio 0.77 based on the area where it failed instead of 0.55

Cleat ID:	B
Material:	Cast aluminum
Tensile strength:	40,000 psi
No. of legs:	2
Screw size:	¼-20
No. screws = No. feet:	2
Screw cross section:	0.0317 in^2
Screw tensile strength:	80,000 psi
Tensile load per screw:	2535 lb
Tensile load, all screws:	5070 lb
Minimum foot area:	0.15 in^2
Tensile load per foot:	6000 lb
Tensile load, all feet:	12000 lb
Minimum leg area:	0.71 in^2
Tensile load per leg:	28400 lb
Tensile load, all legs:	56800 lb
Body area:	0.44 in^2
Body tensile load:	17600 lb

0°	Failure load:	3780 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.74
	Failure load/tensile load, all feet:	0.32
	Failure load/tensile load per leg:	0.13

45°	Failure load:	3860 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.76
	Failure load/tensile load, all feet:	0.32
	Failure load/tensile load, all legs:	0.07

90°	Failure load:	3800 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.75
	Failure load/tensile load, all feet:	0.32
	Failure load/tensile load, all legs:	0.07

45/45	Failure load:	4000 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.79
	Failure load/tensile load, all feet:	0.33
	Failure load/tensile load, all legs:	0.07
	Failure load/body tensile load:	0.23

Cleat ID:	C
Material:	Cast aluminum
Tensile strength:	40,000 psi
No. of legs:	2
Screw size:	¼-20
No. screws = No. feet:	2
Screw cross section:	0.0317 in^2
Screw tensile strength:	80,000 psi
Tensile load per screw:	2535 lb
Tensile load, all screws:	5070 lb
Minimum foot area:	0.13 in^2
Tensile load per foot:	5200 lb
Tensile load, all feet:	10400 lb
Minimum leg area:	0.26 in^2
Tensile load per leg:	10400 lb
Tensile load, all legs:	20800 lb
Body area:	0.39 in^2
Body tensile load:	15600 lb

0°	Failure load:	2500 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.49
	Failure load/tensile load, all feet:	0.24
	Failure load/tensile load per leg:	0.24

45°	Failure load:	3890 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.77
	Failure load/tensile load, all feet:	0.37
	Failure load/tensile load, all legs:	0.19

90°	Failure load:	3700 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.73
	Failure load/tensile load, all feet:	0.36
	Failure load/tensile load, all legs:	0.18

45/45	Failure load:	4770 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.94
	Failure load/tensile load, all feet:	0.46
	Failure load/tensile load, all legs:	0.23
	Failure load/body tensile load:	0.30

Cleat ID:	D
Material:	Die cast zinc
Tensile strength:	40,000 psi
No. of legs:	2
Screw size:	¼-20
No. screws = No. feet:	2
Screw cross section:	0.0317 in^2
Screw tensile strength:	80,000 psi
Tensile load per screw:	2535 lb
Tensile load, all screws:	5070 lb
Minimum foot area:	0.10 in^2
Tensile load per foot:	4000 lb
Tensile load, all feet:	8000 lb
Minimum leg area:	0.16 in^2
Tensile load per leg:	6400 lb
Tensile load, all legs:	12800 lb
Body area:	0.18 in^2
Body tensile load:	7200 lb

0°	Failure load:	3580 lb
	Item that failed:	screws/body*
	Failure load/tensile load, all screws:	0.71
	Failure load/tensile load, all feet:	0.45
	Failure load/tensile load per leg:	0.56
45°	Failure load:	3380 lb
	Item that failed:	screws/body*
	Failure load/tensile load, all screws:	0.67
	Failure load/tensile load, all feet:	0.42
	Failure load/tensile load, all legs:	0.26
90°	Failure load:	3970 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.78
	Failure load/tensile load, all feet:	0.50
	Failure load/tensile load, all legs:	0.31
45/45	Failure load:	4760 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.94
	Failure load/tensile load, all feet:	0.59
	Failure load/tensile load, all legs:	0.37
	Failure load/body tensile load:	0.66

* The screws broke first, then the body bent and broke before we could stop the machine.

Cleat ID:	E
Material:	Cast aluminum
Tensile strength:	40,000 psi
No. of legs:	1
Screw size:	¼-20
No. screws = No. feet:	2
Screw cross section:	0.0317 in²
Screw tensile strength:	80,000 psi
Tensile load per screw:	2325 lb
Tensile load, all screws:	5070 lb
Minimum foot area:	0.10 in²
Tensile load per foot:	4000 lb
Tensile load, all feet:	8000 lb
Minimum leg area:	1.4 in²
Tensile load per leg:	56000 lb
Tensile load, all legs:	56000 lb
Body area:	0.38 in²
Body tensile load:	15200 lb

0°	Failure load:	4970 lb
	Item that failed:	screws/feet*
	Failure load/tensile load, all screws:	0.98
	Failure load/tensile load, all feet:	0.62
	Failure load/tensile load per leg:	0.09
45°	Failure load:	3780 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.74
	Failure load/tensile load, all feet:	0.47
	Failure load/tensile load, all legs:	0.07
90°	Failure load:	4170 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.82
	Failure load/tensile load, all feet:	0.52
	Failure load/tensile load, all legs:	0.07
45/45	Failure load:	5360
	Item that failed:	screws
	Failure load/tensile load, all screws:	1.06
	Failure load/tensile load, all feet:	0.52
	Failure load/tensile load, all legs:	0.096
	Failure load/body tensile load:	0.35

Cleat ID:	F
Material:	Cast aluminum
Tensile strength:	40,000 psi
No. of legs:	4
Screw size:	¼-20
No. screws = No. feet:	4
Screw cross section:	0.0317 in^2
Screw tensile strength:	80,000 psi
Tensile load per screw:	2535 lb
Tensile load, all screws:	10140 lb
Minimum foot area:	0.07 in^2
Tensile load per foot:	2800 lb
Tensile load, all feet:	11200 lb
Minimum leg area:	0.29 in^2
Tensile load per leg:	11600 lb
Tensile load, all legs:	23200 lb
Body area:	0.4 in^2
Body tensile load:	16000 lb

0°	Failure load:	4170
	Item that failed:	feet/body*
	Failure load/tensile load, all screws:	0.41
	Failure load/tensile load, all feet:	0.37
	Failure load/tensile load per leg:	0.36
45°	Failure load:	1190 lb
	Item that failed:	feet
	Failure load/tensile load, all screws:	0.12
	Failure load/tensile load, all feet:	0.11
	Failure load/tensile load, all legs:	0.05
90°	Failure load:	1790 lb
	Item that failed:	feet
	Failure load/tensile load, all screws:	0.18
	Failure load/tensile load, all feet:	0.16
	Failure load/tensile load, all legs:	0.08
45/45	Failure load:	4770
	Item that failed:	feet
	Failure load/tensile load, all screws:	0.47
	Failure load/tensile load, all feet:	0.42
	Failure load/tensile load, all legs:	0.21
	Failure load/body tensile load:	0.30

* The feet failed. Then the cleat pulled away on one end and the resulting forces broke the body before we could stop the machine.

Cleat ID:	G
Material:	Cast aluminum*
Tensile strength:	40,000 psi
No. of legs:	4
Screw size:	¼-20
No. screws = No. feet:	4
Screw cross section:	0.0317 in^2
Screw tensile strength:	80,000 psi
Tensile load per screw:	2535 lb
Tensile load, all screws:	10140 lb
Minimum foot area:	0.13 in^2
Tensile load per foot:	5200 lb
Tensile load, all feet:	20800 lb
Minimum leg area:	0.34 in^2
Tensile load per leg:	13600 lb
Tensile load, all legs:	27200 lb
Body area:	0.42
Body tensile load:	16800 lb

0°	Failure load:	7160 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.71
	Failure load/tensile load, all feet:	0.34
	Failure load/tensile load per leg:	0.53

45°	Failure load:	6760 lb
	Item that failed:	leg
	Failure load/tensile load, all screws:	0.67
	Failure load/tensile load, all feet:	0.33
	Failure load/tensile load, all legs:	0.25

90°	Failure load:	6720 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.66
	Failure load/tensile load, all feet:	0.32
	Failure load/tensile load, all legs:	0.25

45/45	Failure load:	5370 lb
	Item that failed:	leg/body**
	Failure load/tensile load, all screws:	0.53
	Failure load/tensile load, all feet:	0.26
	Failure load/tensile load, all legs:	0.20
	Failure load/body tensile load:	0.32

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* This cleat is hollow inside

** The leg broke and the forces then broke the body before we could stop the machine.

Cleat ID:	H
Material:	Die cast zinc
Tensile strength:	40,000 psi
No. of legs:	2
Screw size:	#10-32
No. screws = No. feet:	4
Screw cross section:	0.0199 in^2
Screw tensile strength:	80,000 psi
Tensile load per screw:	1590 lb
Tensile load, all screws:	6360 lb
Minimum foot area:	0.043 in^2
Tensile load per foot:	1720 lb
Tensile load, all feet:	6880 lb
Minimum leg area:	0.2 in^2
Tensile load per leg:	8000 lb
Tensile load, all legs:	16,000 lb
Body area:	0.18 in^2
Body tensile load:	7200 lb

0°	Failure load:	3380 lb
	Item that failed:	feet
	Failure load/tensile load, all screws:	0.53
	Failure load/tensile load, all feet:	0.49
	Failure load/tensile load per leg:	0.42
45°	Failure load:	2920 lb
	Item that failed:	feet
	Failure load/tensile load, all screws:	0.46
	Failure load/tensile load, all feet:	0.42
	Failure load/tensile load, all legs:	0.18
90°	Failure load:	2380 lb
	Item that failed:	feet
	Failure load/tensile load, all screws:	0.37
	Failure load/tensile load, all feet:	0.34
	Failure load/tensile load, all legs:	0.15
45/45	Failure load:	3180 lb
	Item that failed:	body
	Failure load/tensile load, all screws:	0.50
	Failure load/tensile load, all feet:	0.46
	Failure load/tensile load, all legs:	0.20
	Failure load/body tensile load:	0.44

Cleat ID:	J
Material:	Die case zinc
Tensile strength:	40,000 psi
No. of legs:	2
Screw size:	#10-32
No. screws = No. feet:	4
Screw cross section:	0.0199 in^2
Screw tensile strength:	80,000 psi
Tensile load per screw:	1590 lb
Tensile load, all screws:	6360 lb
Minimum foot area:	0.058 in^2
Tensile load per foot:	2320 lb
Tensile load, all feet:	9280 lb
Minimum leg area:	0.17 in^2
Tensile load per leg:	6800 lb
Tensile load, all legs:	13600 lb
Body area:	0.21 in^2
Body tensile load:	8400 lb

0°	Failure load:	3180 lb
	Item that failed:	leg
	Failure load/tensile load, all screws:	0.50
	Failure load/tensile load, all feet:	0.34
	Failure load/tensile load per leg:	0.47
45°	Failure load:	2780 lb
	Item that failed:	feet
	Failure load/tensile load, all screws:	0.44
	Failure load/tensile load, all feet:	0.30
	Failure load/tensile load, all legs:	0.20
90°	Failure load:	2880 lb
	Item that failed:	feet
	Failure load/tensile load, all screws:	0.45
	Failure load/tensile load, all feet:	0.31
	Failure load/tensile load, all legs:	0.21
45/45	Failure load:	3970 lb
	Item that failed:	feet
	Failure load/tensile load, all screws:	0.62
	Failure load/tensile load, all feet:	0.43
	Failure load/tensile load, all legs:	0.29
	Failure load/body tensile load:	0.47

Cleat ID:	K
Material:	Stainless steel
Tensile strength:	80,000 psi*
No. of legs:	2
Screw size:	¼-20
No. screws = No. feet:	4
Screw cross section:	0.0317 in^2
Screw tensile strength:	80,000 psi
Tensile load per screw:	2535 lb
Tensile load, all screws:	5070 lb
Minimum foot area:	0.056 in^2
Tensile load per foot:	4480 lb
Tensile load, all feet:	17920 lb
Minimum leg area:	0.16 in^2
Tensile load per leg:	12800 lb
Tensile load, all legs:	25600 lb
Body area:	0.18 in^2
Body tensile load:	14400 lb

0°	Failure load:	6600 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	1.3
	Failure load/tensile load, all feet:	0.37
	Failure load/tensile load per leg:	0.52
45°	Failure load:	6800 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	1.34
	Failure load/tensile load, all feet:	0.38
	Failure load/tensile load, all legs:	0.26
90°	Failure load:	7550 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	1.49
	Failure load/tensile load, all feet:	0.42
	Failure load/tensile load, all legs:	0.29
45/45	Failure load:	6560 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	1.3
	Failure load/tensile load, all feet:	0.37
	Failure load/tensile load, all legs:	0.26
	Failure load/body tensile load:	0.45

Cleat ID:	L
Material:	Bronze
Tensile strength:	55,000 psi
No. of legs:	2
Screw size:	#10-32
No. screws = No. feet:	4
Screw cross section:	0.0199 in^2
Screw tensile strength:	80,000 psi
Tensile load per screw:	1590 lb
Tensile load, all screws:	6360 lb
Minimum foot area:	0.10 in^2
Tensile load per foot:	5500 lb
Tensile load, all feet:	22000 lb
Minimum leg area:	0.16 in^2
Tensile load per leg:	8800 lb
Tensile load, all legs:	17600 lb
Body area:	0.23 in^2
Body tensile load:	12650 lb

0°	Failure load:	3180 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.50
	Failure load/tensile load, all feet:	0.14
	Failure load/tensile load per leg:	0.36

45°	Failure load:	3990 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.63
	Failure load/tensile load, all feet:	0.18
	Failure load/tensile load, all legs:	0.23

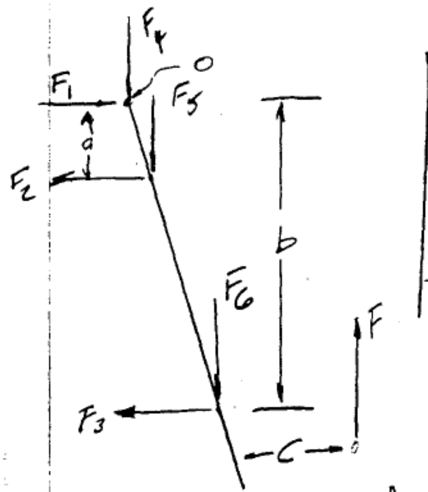
90°	Failure load:	3970 lb
	Item that failed:	screws
	Failure load/tensile load, all screws:	0.62
	Failure load/tensile load, all feet:	0.18
	Failure load/tensile load, all legs:	0.22

45/45	Failure load:	4570 lb
	Item that failed:	leg
	Failure load/tensile load, all screws:	0.72
	Failure load/tensile load, all feet:	0.21
	Failure load/tensile load, all legs:	0.26
	Failure load/body tensile load:	0.20

APPENDIX C

COMPLEX CALCULATIONS FOR THE 0° LOADING DIRECTION

MARCH 7, 1993 0° LOADING ANALYSIS M.C. DREW

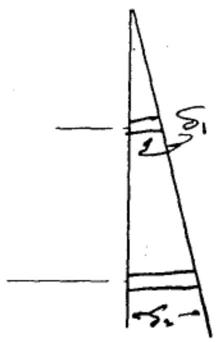


FORCE EQUILIBRIUM

NOTE: FOR FOUR SCREW CLEAT, SIMPLY DIVIDE F BY 2

$$\boxed{\begin{aligned} \Sigma F_x &= F_1 - F_2 - F_3 = 0 \\ \Sigma F_y &= F_4 + F_5 + F_6 - F = 0 \\ \Sigma M_0 &= F_2 a + F_3 b - Fc = 0 \end{aligned}}$$

* ASSUME CLEAT IS RIGID AND SCREWS STRETCHING.



$$\delta_1 = \frac{F_2 L_0}{AE}$$

A = SCREW CROSS SECTION

$$\delta_2 = \frac{F_3 L_0}{AE}$$

FOR RIGID CLEAT: $\frac{\delta_1}{a} = \frac{\delta_2}{b}$

THUS, $\frac{F_2 L_0}{AE a} = \frac{F_3 L_0}{AE b}$

$$\therefore \boxed{\frac{F_2}{a} = \frac{F_3}{b}}$$

I. NOW, 1ST WE SAY $F_5 = F_6$ AND BECAUSE F_4 IS DUE TO FRICTION, $F_4 = \mu F_1$ SO:

$$F_1 = F_2 + F_3 \qquad F_4 = \mu F_1$$
$$F = 2F_5 + \mu F_1 \qquad F_5 = F_6$$
$$Fc = F_2 a + F_3 b$$
$$F_2/a = F_3/b$$

SHEAR FORCE: NEED F_5

$$F_2 a + F_3 b = Fc \qquad F_2 = {}^a\!/_b F_3$$

$$a^2/b\, F_3 + F_3 b = Fc \qquad F_3 = \frac{Fc}{\frac{a^2}{b} + b}$$

$$F = F_4 + F_5 + F_6 \qquad F_5 = F_6 \quad F_4 = \mu F_1$$
$$F_1 = F_2 + F_3$$

$$F = \mu(F_2 + F_3) + 2F_5 \qquad F = \mu\left(\frac{a}{b}F_3 + F_3\right) + 2F_5$$

$$F = F_3 \mu\left(\frac{a}{b} + 1\right) + 2F_5$$

$$F_5 = \left[F - F_3 \mu\left(\frac{a}{b} + 1\right)\right]/2$$

$$F_5 = \left[F - \mu\left(\frac{a}{b} + 1\right)\left(\frac{Fc}{\frac{a^2}{b} + b}\right)\right]/2$$

$$F_5 = \frac{F}{2}\left[1 - \mu c \frac{(a+b)}{(a^2+b^2)}\right]$$

$$\therefore \boxed{\tau = \frac{F}{2A}\left[1 - \mu c \frac{(a+b)}{(a^2+b^2)}\right]}$$

0° LOADING ANALYSIS   M.C. DREW

- TENSILE STRENGTH IN TOP SCREW: (NEED F_2)

DIVIDE F BY 2 FOR FOUR SCREW CLEATS

$$F_2 a + F_3 b = F_c \qquad F_3 = \frac{b}{a} F_2$$

$$F_2 a + \left(\frac{b}{a}\right) F_2 b = F_c \qquad F_2 = \frac{F_c}{a + b^2/a}$$

$$\boxed{\sigma_2 = \frac{1}{A} \cdot \frac{F_c}{a + b^2/a}}$$

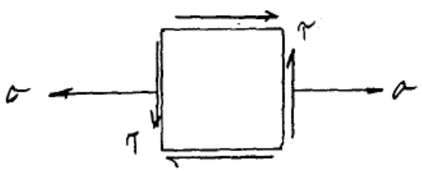
- TENSILE STRENGTH IN BOTTOM SCREW: (NEED F_3)

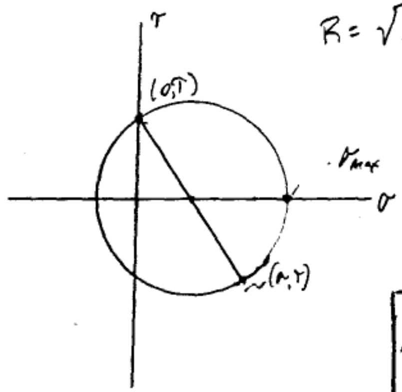
FROM PAGE 1: $F_3 = \dfrac{F_c}{\frac{a^2}{b} + b}$

$$\boxed{\sigma_3 = \frac{1}{A} \cdot \frac{F_c}{\frac{a^2}{b} + b}}$$

- MAXIMUM PRINCIPLE STRESSES (MOHR'S CIRCLE ANALYSIS)

$$R = \sqrt{(\sigma/2)^2 + \tau^2}$$





$$\boxed{\sigma_{max} = \sigma/2 + R}$$

$$\boxed{\begin{aligned} \sigma_{max} &= \sigma/2 + \sqrt{(\sigma/2)^2 + \tau^2} \\ \tau_{max} &= R = \sqrt{(\sigma/2)^2 + \tau^2} \end{aligned}}$$

II. NEXT, WE CONSIDER NO FRICTION $F_4 = 0$

$$F = F_5 + F_6 \qquad F_5 = F_6 \qquad \therefore \quad F_5 = F/2$$

$$\boxed{\tau = \frac{F}{2A}}$$

$$\boxed{\sigma_2 = \frac{1}{A} \cdot \frac{F_c}{a + b^2/a}}$$

$$\boxed{\sigma_3 = \frac{1}{A} \cdot \frac{F_c}{a^2/b + a}}$$

III. LET US COMPARE THE TWO APPROXIMATIONS:

- THE ADDITION OF FRICTION EFFECTS SHEAR STRESS τ ONLY.

ADDING FRICTION REDUCES THE SHEAR STRESS ON EACH BOLT.

$$\tau_{w/o} - \tau_{w/} = \frac{F}{2A}\left[\cancel{1} - \cancel{1} + \frac{\mu c(a+b)}{(a^2+b^2)}\right]$$

$$\boxed{\tau_{w/o} - \tau_{w/} = \frac{F}{2A} \cdot \frac{\mu c(a+b)}{(a^2+b^2)}}$$

OR!

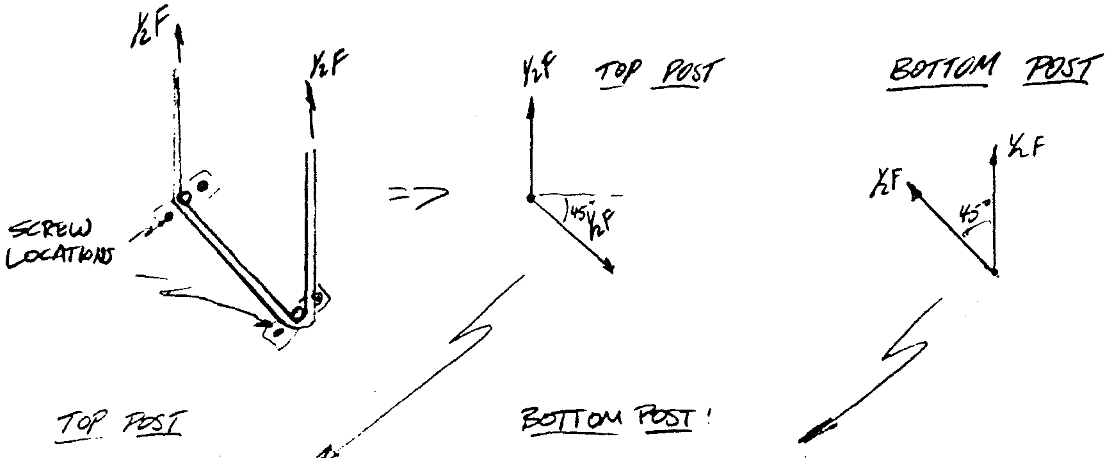
$$\boxed{\frac{\tau_{w/}}{\tau_{w/o}} = 1 - \frac{\mu c(a+b)}{(a^2+b^2)}}$$

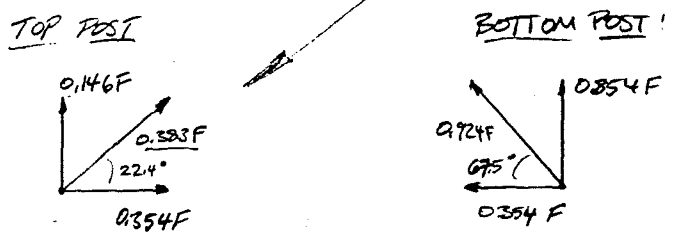
$\therefore$ THE AMOUNT WHICH FRICTION EFFECTS THE SHEAR STRESS IS DEPENDENT ON THE COEFFICIENT OF FRICTION μ, AND THE DIMENSIONS OF THE CLEAT.

APPENDIX D

COMPLEX CALCULATIONS FOR THE 45° LOADING DIRECTION

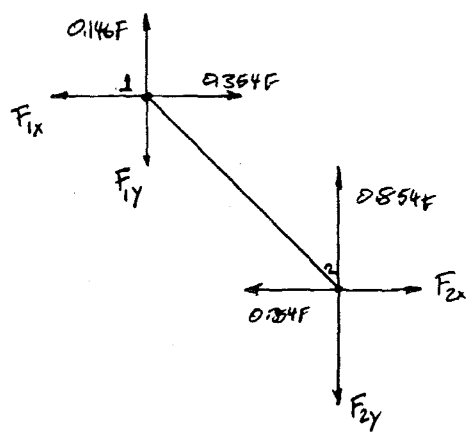
SHEAR FORCE ANALYSIS:





* FOR SIMPLICITY, WE CONSIDER THE SCREWS LOCATED DIRECTLY UNDER THE CLEAT POSTS.

HENCE, THE F.B.D. OF THE CLEAT IS:



OBVIOUSLY, FOR EQUILIBRIUM OF THE POSTS:

$F_{1x} = \underline{0.354F}$ $\quad F_{2x} = \underline{0.354F}$

$F_{1y} = \underline{0.146 F}$ $\quad 2_{2y} = \underline{0.854F}$

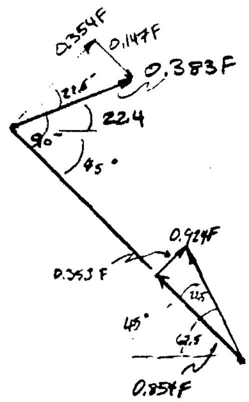
∴ THE TOTAL FORCE IN EACH SCREW (w/o FRICTION) IS:

$$\boxed{F_{S1} = 0.383F}$$

$$\boxed{F_{S2} = 0.924F}$$

MARCH 9, 1993

- NOW, WE WILL ANALYZE THE SCREW FORCES LIKE WE DID W/ THE 0° LOADING, ONLY NOW, WE NEED TO DIVIDE THE ANALYSIS INTO TWO PARTS: PERPINDICULAR AND PARALLEL TO THE CLEAT.



PERPINDICULAR ANALYSIS: TOTAL PERPINDICULAR FORCE IS: $(0.354 + 0.353)F$

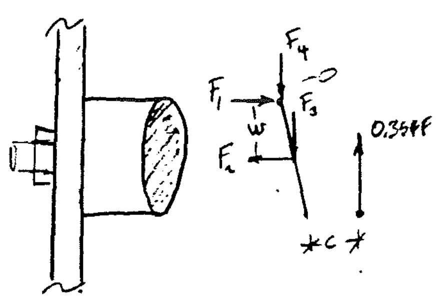
* BUT SINCE WE WILL ONLY LOOK AT ½ OF THE CLEATS SCREWS AT A TIME, WE DIVIDE THE FORCE BY 2.

$$F_{TOTAL} = \frac{1}{2}(0.354 + 0.353)F$$

$$F_{TOTAL} = \underline{0.354F}$$

WE LOOK AT TWO CASES:

NO. 1: 2 SCREW CLEAT



$\Sigma F_x = 0; \quad F_1 = F_2$ $\quad\quad F_4 = 4F_1$

$\Sigma F_y = 0; \quad 0.354F = F_4 + F_3$

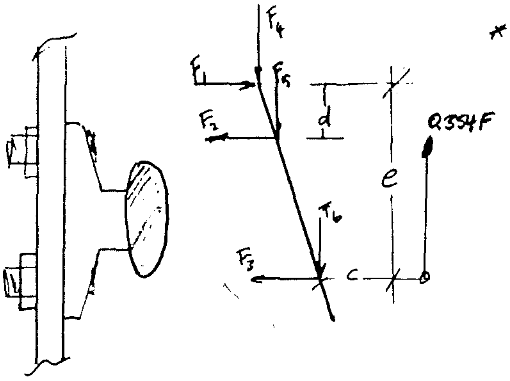
$\Sigma M_o = 0; \quad F_2 w = (0.354F)c$

SHEAR FORCE: $\boxed{F_{3y} = 0.354F\left[1 - 4\left(\frac{c}{w}\right)\right]}$

TENSILE FORCE: $\boxed{F_{2y} = \frac{c}{w}(0.354F)}$ BOTH TOP & BOTTOM SCREWS

$= 0.2(.25)$ in

CASE NO. 2 (4 SCREW CLEAT)



* THIS ANALYSIS IS EXACTLY EQUIVALENT TO THE 0° ANALYSIS.

∴ SHEAR FORCE

$$\boxed{F_{5y'} = F_{6y'} = \frac{0.354F}{2}\left[1 - \mu c\,\frac{(d+e)}{(d^2+e^2)}\right]}$$

TENSILE FORCE:

$$\boxed{F_{2y'z'} = \frac{0.354\,F\,c}{d + e^2/d}}$$ TOP SCREWS

$$\boxed{F_{3y'z'} = \frac{0.354\,F\,c}{\frac{d^2}{e} + e}}$$ BOTTOM SCREWS

PARALLEL ANALYSIS:

* WE ASSUME THAT THE CLEAT IS RIGID, SO THAT THE TOTAL PARALLEL FORCE IS $(0.854 - 0.147)F = \boxed{0.707F}$

*NOTE: FOR THE FOUR SCREW CLEAT, THIS FORCE SHOULD BE DIVIDED BY 2

- THIS ANALYSIS IS AGAIN EQUIVALENT TO THE 0° ANALYSIS:

SHEAR FORCE:

$$\boxed{F_{5x'} = \frac{0.707F}{2}\left[1 - \mu c\,\frac{(a+b)}{(a^2+b^2)}\right]}$$

TENSILE FORCE:

$$\boxed{F_{2x'z'} = \frac{0.707\,F_c}{a + b^2/a}}$$ TOP SCREW

$$\boxed{F_{3x'z'} = \frac{0.707\,F_c}{a^2/b + b}}$$ BOTTOM SCREW

CONCLUSIONS: FINAL COMBINATION OF FORCES

1) 2 SCREW CLEAT:

SHEAR STRESS:

$$\boxed{\tau = \frac{1}{A}\sqrt{\left(0.354F\left[1-\mu\left(\frac{c}{w}\right)\right]\right)^2 + \left(0.354F\left[1-\mu c\frac{(a+b)}{(a^2+b^2)}\right]\right)^2}}$$

(WE ADD THE SHEAR FORCES BY COMBINING F_x & F_y)

TENSILE STRESS: (WE ADD THE TENSILE FORCES)

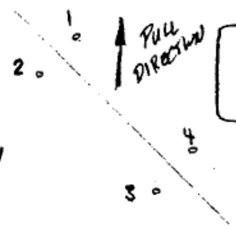
TOP SCREW:

$$\boxed{\sigma_{TOP} = \frac{F_c}{A}\cdot\left[\frac{0.354}{w} + \frac{0.707}{a + b^2/a}\right]}$$

BOTTOM SCREW:

$$\boxed{\sigma_{BOTTOM} = \frac{F_c}{A}\cdot\left[\frac{0.354}{w} + \frac{0.707}{a^2/b + b}\right]}$$

2) 4 SCREW CLEAT



CLEAT ORIENTATION

$$\boxed{\tau_1 = \frac{1}{A}\cdot\sqrt{\left(\frac{0.354F}{2}\left[1-\mu c\frac{(d+e)}{(d^2+e^2)}\right]\right)^2 + \left(\frac{0.354F}{2}\left[1-\mu c\frac{(a+b)}{(a^2+b^2)}\right]\right)^2}}$$

$$\boxed{\sigma_1 = \frac{0.354F_c}{A}\cdot\left[\frac{1}{d + e^2/d} + \frac{1}{a + b^2/a}\right]}$$

SCREW #2

$$\boxed{\tau_2 = \tau_1} \quad \boxed{\sigma_2 = \frac{0.354F_c}{A}\left[\frac{1}{d^2/e + e} + \frac{1}{a + b^2/a}\right]}$$

SCREW #3

$$\boxed{\tau_3 = \tau_1} \quad \boxed{\sigma_3 = \frac{0.354F_c}{A}\cdot\left[\frac{1}{d^2/e + e} + \frac{1}{a^2/b + b}\right]}$$

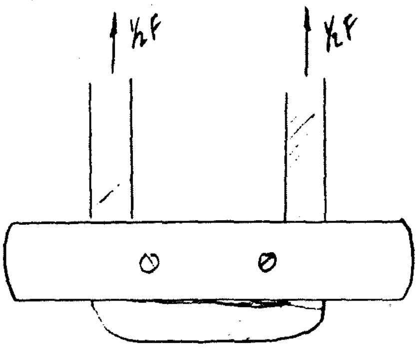
SCREW #4

$$\boxed{\tau_4 = \tau_1} \quad \boxed{\sigma_4 = \frac{0.354F_c}{A}\left[\frac{1}{d + e^2/d} + \frac{1}{a^2/b + b}\right]}$$

APPENDIX E

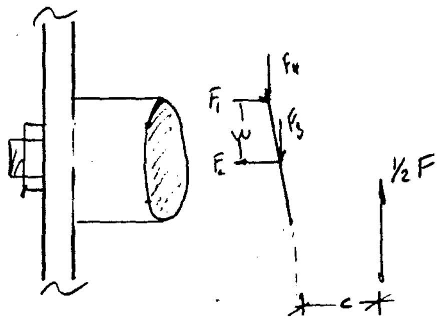
COMPLEX CALCULATIONS FOR THE 90° LOADING DIRECTION

MARCH 20, 1993   90° LOADING   M.C. DREW



- WE CAN USE THE SAME ANALYSIS USED IN THE PERPENDICULAR ANALYSIS SECTION OF THE 45° LOADING ANALYSIS. WE ANALYZE ½ OF THE CLEAT, AND ANALYZE BOTH 2-SCREW AND 4-SCREW CLEATS.

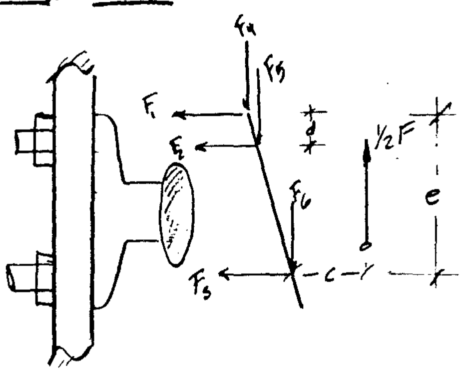
<u>2 SCREW CLEAT:</u>



$$F_3 = \tfrac{1}{2}F\left[1-\mu\left(\tfrac{c}{w}\right)\right] \quad \therefore \quad \boxed{\tau = \frac{F}{2A}\left[1-\mu\left(\frac{c}{w}\right)\right]}$$

$$F_2 = \tfrac{1}{2}F\left(\tfrac{c}{w}\right) \qquad \boxed{\tau = \frac{Fc}{2Aw}}$$

<u>4 SCREW CLEAT:</u>



$$F_5 = F_6 = \frac{F}{4}\left[1-\mu c\,\frac{(d+e)}{(d^2+e^2)}\right]$$

$$\boxed{\tau = \frac{F}{4A}\left[1-\mu c\,\frac{(d+e)}{(d^2+e^2)}\right]}$$

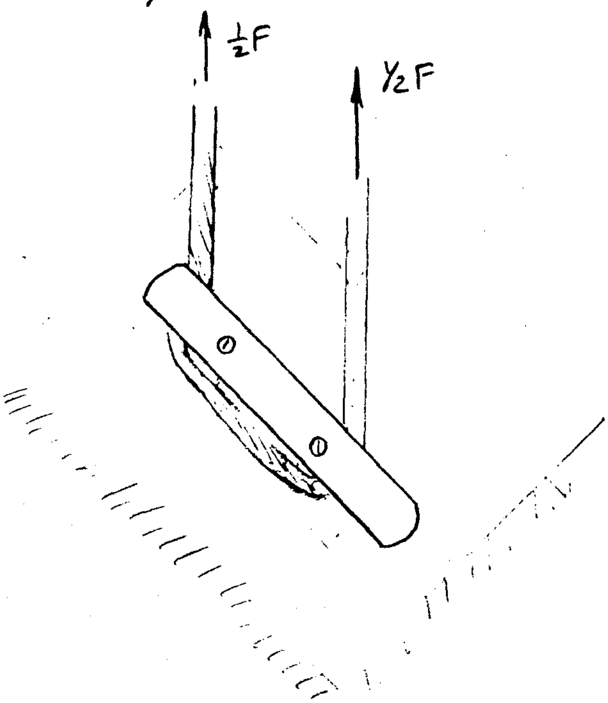
$$F_2 = \frac{\tfrac{1}{2}Fc}{d+e^2/d} \qquad F_3 = \frac{\tfrac{1}{2}Fc}{d^2/e+e}$$

$$\boxed{\tau_{top} = \frac{Fc}{2A}\cdot\frac{1}{d+e^2/d}} \qquad \boxed{\tau_{bottom} = \frac{Fc}{2A}\cdot\frac{1}{d^2/e+e}}$$

APPENDIX F

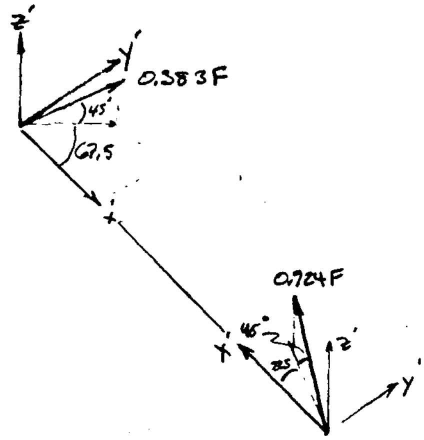
COMPLEX CALCULATIONS FOR THE 45°/45° LOADING DIRECTION

MARCH 11, 1993 45°/45° LOADING M.C. DREW

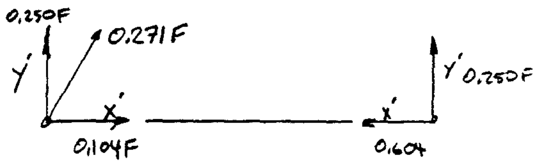


THIS IS EQUIVALENT TO THE 45° LOADING ORIENTATION, BUT THE FORCE VECTORS ARE ROTATED 45° NORMAL TO THE PAGE

SO, FROM THE 45° ANALYSIS, THE FORCES ON THE CLEAT ARE SHOWN AS:



THE x' AND y' FORCES THEN BECOME:



∴ WE CAN SEE THAT THE FORCES WILL BE EQUAL (SEE WORK FROM MARCH 8-9) TO THE FORCES FROM THE 45° ANALYSIS × COS45° = (0.707)

SO, FOLLOWING THIS ANALYSIS:

- PERPINDICULAR ANALYSIS: (y') (2 SCREW CLEAT)

  SHEAR: $\boxed{F_{5y'} = 0.250F\left[1-\mu\left(\frac{c}{w}\right)\right]}$ TENSILE: $\boxed{F_{2y'z'} = \frac{c}{w}(0.250F)}$

- (4 SCREW CLEAT)

  SHEAR: $\boxed{F_{5y'} = F_{6y'} = \frac{0.250F}{2}\left[1-\mu c\frac{(d+e)}{(d^2+e^2)}\right]}$ TENSILE: $\boxed{F_{2y'z'} = \frac{0.250Fc}{d+e^2/d}}$ TOP FROM SIDE VIEW

  $\boxed{F_{3y'z'} = \frac{0.250Fc}{d^2/e+e}}$ BOTTOM FROM SIDE VIEW

PARALLEL ANALYSIS:

*NOTE: THE FORCES IN THIS SECTION SHOULD BE DIVIDED BY 2 FOR THE FOUR-SCREW CLEATS.

SHEAR: $\boxed{F_{5x'} = \frac{F}{4}\left[1 - \mu c \frac{(a+b)}{(a^2+b^2)}\right]}$

TENSILE FORCE: $\boxed{F_{2z'} = \frac{1}{2} \cdot \frac{F_c}{a + b^2/a}}$ TOP SCREW

$\boxed{F_{3xz'} = \frac{1}{2} \frac{F_c}{a^2/b + b}}$ BOTTOM SCREW

- VERTICAL (z') COMPONENT FORCES:

THIS COMPONENT OF FORCE CAUSES TENSILE FORCE ONLY

FORCE AT TOP OF CLEAT: $0.383F(\sin 45) = \underline{0.271F}$

FORCE AT BOTTOM OF CLEAT: $0.924F(\sin 45°) = \underline{0.653F}$

- SO, FOR 2 SCREW CLEAT:

$\boxed{F_{TOP} = 0.271F}$ $\boxed{F_{BOTTOM} = 0.653F}$

- FOR 4 SCREW CLEAT: (ASSUMING THE TENSILE FORCE IS DISTRIBUTED EQUALY AMONG BOTH TOP AND BOTTOM SCREWS)

$\boxed{F_{TOP} = 0.136F}$ $\boxed{F_{BOTTOM} = 0.327F}$

- **CONCLUSIONS:** (ADDING THE FORCES)

- **2 SCREW CLEAT:**

SHEAR STRESS:

$$\boxed{\tau_{ALL} = \frac{1}{A}\cdot\sqrt{\left(0.250F\left[1-\mu\left(\frac{c}{w}\right)\right]\right)^2 + \left(0.250F\left[1-\mu c\frac{(a+b)}{(a^2+b^2)}\right]\right)^2}}$$

TENSILE STRESS:

TOP SCREW:

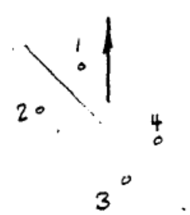
$$\boxed{\sigma_{TOP} = \frac{F_c}{A}\left[\frac{0.250}{w} + \frac{1}{2}\cdot\frac{1}{a+b^2/a} + \frac{0.271}{c}\right]}$$

BOTTOM SCREW:

$$\boxed{\sigma_{BOTTOM} = \frac{F_c}{A}\left[\frac{0.250}{w} + \frac{1}{2}\cdot\frac{1}{a^2/b+b} + \frac{0.653}{c}\right]}$$

- **4 SCREW CLEAT:**

CLEAT ORIENTATION:



SCREW #1

$$\boxed{\tau_1 = \frac{1}{A}\cdot\sqrt{\left(\frac{F}{8}\left[1-\mu c\frac{(d+e)}{(d^2+e^2)}\right]\right)^2 + \left(\frac{F}{8}\cdot\left[1-\mu c\frac{a+b}{(a^2+b^2)}\right]\right)^2}}$$

$$\boxed{\sigma_1 = \frac{F_c}{A}\cdot\left[\frac{0.250}{d+e^2/d} + \frac{0.250}{a+b^2/a} + \frac{0.136}{c}\right]}$$,544

SCREW #2 $\boxed{\tau_2 = \tau_1}$

$$\boxed{\sigma_2 = \frac{F_c}{A}\cdot\left[\frac{0.250}{d^2/e+e} + \frac{1}{4}\cdot\frac{1}{a+b^2/a} + \frac{0.136}{c}\right]}$$

SCREW #3 $\boxed{\tau_3 = \tau_1}$

$$\boxed{\sigma_3 = \frac{F_c}{A}\cdot\left[\frac{0.250}{d^2/e+e} + \frac{1}{4}\cdot\frac{1}{a^2/b+b} + \frac{0.327}{c}\right]}$$ 1.308

SCREW #4 $\boxed{\tau_4 = \tau_1}$

$$\boxed{\sigma_4 = \frac{F_c}{A}\cdot\left[\frac{0.250}{d+e^2/d} + \frac{1}{4}\cdot\frac{1}{a^2/b+b} + \frac{0.327}{c}\right]}$$

APPENDIX G

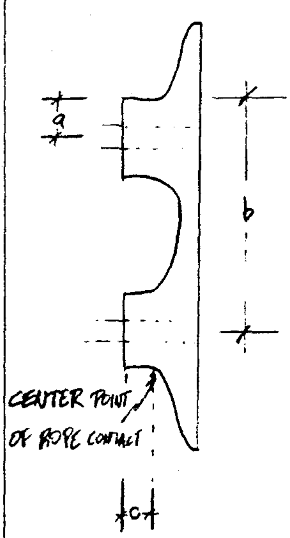
CLEAT DIMENSIONS

M.C. DREW

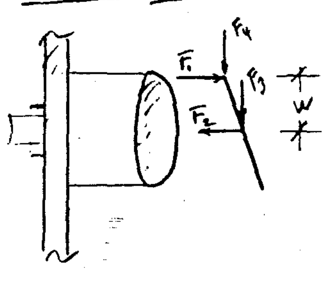
CLEAT DATA:

CLEAT	a	b	c	d	e	w	2 OR 4 SCREW
A	0.62	2.29	0.45			0.44	
B	0.46	2.04	0.39			0.5	2
C	0.40	1.90	0.56			0.45	2
D	0.47	2.42	0.62			0.51	2
E	0.38	2.09	0.36			0.43	2
F	0.37	1.85	0.43	0.26	1.96		4
G	0.40	1.79	0.59	0.36	2.10		4
H	0.25	2.344	0.55	0.223	1.745		4
J	0.29	2.48	0.70	0.26	1.48		4
K	0.30	2.29	0.48	0.29	1.39		4
L	0.27	2.93	0.48	0.27	1.47		4

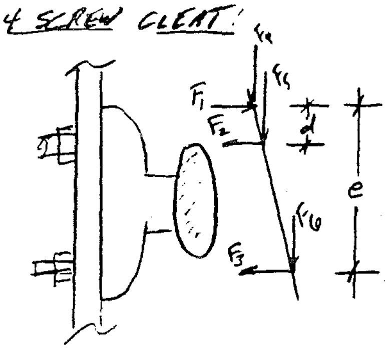
ALL DIMENSIONS IN INCHES



2 SCREW CLEAT:



4 SCREW CLEAT:



APPENDIX H

COMPLEX FOOT ANALYSIS

Two Screw Cleats: 45 Degree Loading

CLEAT	MAX SHEAR FORCE	MAX TENSILE STRESS ON FEET	PERCENTAGE TEN. STRESS OF CLEAT	DID FOOT BREAK?
A	610	4070	41	NO
B	1741	11604	29	NO
C	1647	12666	32	NO
D	1444	14437	36	NO
E	1700	16996	42	NO

Two Screw Cleats: 45/45 Degree Loading

CLEAT	MAX SHEAR FORCE	MAX TENSILE STRESS ON FEET	PERCENTAGE TEN. STRESS OF CLEAT	DID FOOT BREAK?
A	739	10555	26	NO
B	1275	9806	25	NO
C	1427	33189	83	NO
D	1437	24777	62	NO
E	1703	30417	38	NO

Four Screw Cleat: 45 Degree Loading

CLEAT	MAX SHEAR FORCE	MAX TENSILE STRESS ON FEET	PERCENTAGE TEN. STRESS OF CLEAT	DID FOOT BREAK?
F	283	4037	10	YES
G	1573	12101	30	NO
H	687	15970	40	YES
J	637	10981	27	YES
K	1595	28476	36	NO
L	944	9439	17	NO

Four Screw Cleat: 45/45 Degree Loading

CLEAT	MAX SHEAR FORCE	MAX TENSILE STRESS ON FEET	PERCENTAGE TEN. STRESS OF CLEAT	DID FOOT BREAK?
F	800	11429	29	YES
G	883	6788	17	NO
H	528	12282	31	NO
J	642	11074	28	YES
K	1086	19400	24	NO
L	763	7635	14	NO

APPENDIX I

GLOSSARY OF TERMS

APPENDIX I: GLOSSARY OF TERMS

MOHR'S CIRCLE - Mathematical and graphical technique of determining maximum shear and tensile stresses in a system of combined shear and tensile loads.

SHEAR STRESS - Stress caused by a force parallel to the cross section of the element on which it acts. The force perpendicular to the axis of a screw (shear force) causes shear stress across the screw's cross-sectional area.

STRESS - Stress is equal to force divided by the cross-sectional area over which the force acts. It usually has the units pounds per square inch (psi).

TENSILE STRESS - Stress caused by a force perpendicular to the cross section of the element on which it acts. The force parallel to the axis of a screw (tensile force) causes tensile stress on the screw's cross-sectional area.

¼-20 SCREWS - Screws with a quarter-inch nominal diameter and 20 threads per inch.

#10-32 SCREWS - Screws with a No. 10 gauge diameter and 32 threads per inch.

APPENDIX J

AUTOBIOGRAPHICAL SKETCH

AUTOBIOGRAPHICAL SKETCH OF THE STUDENT

This thesis requires a thorough knowledge of many mechanical engineering concepts. Many design principles must be understood including the effects internal moments and forces, bending and shear stress, and stress concentration factors. Some material concepts like ductile and brittle behavior must also be understood.

As a fourth-year mechanical engineering student, I feel that I am definitely qualified for this project. I have performed very well in many classes and labs where I have acquired a superb understanding of the principles mentioned above. I also have extensive hands-on experience with tools and mechanical items from years of tinkering with automobiles and machines. This experience will be of great value in the laboratory where I will perform my tests.

APPENDIX K

TECHNOLOGY IMPACT STATEMENT

UNDERGRADUATE THESIS IMPACT STATEMENT

by
Michael C. Drew

February 4, 1993
H402 Soudek

used to secure a boat at dock when the vessel is not in use. Many boat owners must always store their boats at dock, and therefore, they depend on the strength of the ropes and the cleats for the security of their investment.

The forces exerted on a typical cleat are usually very small, but during severe weather conditions, a single cleat may be required to withstand extreme forces and shocks. High winds jostle the boat from above the surface, and more importantly, powerful waves attack the boat from below. If the securing system does not do its job, the boat can be severely damaged or destroyed within a matter of seconds. Therefore, it is absolutely crucial that the ropes and cleats are rugged enough to withstand these high forces.

In nearly all cases of securing failure, it is not the cleats, but the ropes which fail most often. However, the U.S.F.B.S wants the cleats to be tested for another reason. Cleats can cost anywhere from three to thirty dollars, and a customer may not need a thirty dollar cleat if a three dollar one will suffice. Since the strength of cleats varies greatly because of basic shape and material differences, it is important that the customer choose the right cleat for the application. The U.S.F.B.S. wants a compilation of strength data so that a boat owner can wisely select a cleat that is strong, yet economical.

CONSUMER IMPACTS:

POSITIVE IMPACTS:

The impact that this project will have is quite narrow and specific. Cleats are definitely important to all boat owners alike, and this project will help those owners choose the proper cleats for their boats. There is very little information available about the strength and qualities of different cleats. Even the cleats themselves are not rated by strength, or performance capabilities, and it is very likely that customers make their purchases based on the appearance of the cleat (which, as I have learned can be quite deceiving!) instead of the capabilities of the cleat. My work will allow customers to make informed purchases when buying cleats.

NEGATIVE IMPACTS:

In all probability, this project will have only positive impacts on the boating community. Nevertheless, I have thought about one unlikely negative consequence. It is possible that I could incorrectly measure a cleat as stronger than it really is. A boat owner might then use this cleat in a manner that seemed to be safe according to my results. This cleat could then theoretically break during a storm causing severe property damage. This scenario is very unlikely. As stated above, most failures occur with the rope. The next likely point of failure is the mount which holds the cleat. The method used in my project to determine breaking strength is quite accurate, and every effort has been made to err on the conservative side.

MANUFACTURING IMPACTS:

If taken seriously enough, my results could encourage some cleat manufacturers to include strength capability indications with their products, and instructions on how to mount the cleats safely. Although this is a good idea, I do not think manufactures will start including such information unless people start suing the manufacturers for not doing so!

CONCLUSION:

The impact of this project is really only significant for boat and yacht owners and is very isolated from the rest of society. Yet, within this range of significance, this project should have nothing but positive results. Those who subscribe to the U.S.F.B.S.'s monthly magazine will for once be informed about a product they will definitely need for their boats. Any possible negative impacts should be negligible. I am assured of this project's importance and positive impacts because of the U.S.F.B.S's initiation of the project and their constant involvement with it.

Bibliography?

This is well written + informative!

Good Job!

95

APPENDIX L

APPROVED PROPOSAL

PROPOSAL APPROVAL FORM

***STUDENT**, PLEASE COMPLETE ITEMS I-IV (PRINT OR TYPE)*

I. Student's Name MICHAEL C. DREW

II. Working Title of Project STRENGTH TESTING OF BOAT CLEATS

III. Humanities Advisor Mr. GIANNINY
H401, Section ____________

IV. Technical Advisor T.C. SCOTT
Title/Position M.E. PROFESSOR
Department M.E. DEPT.

***TECHNICAL ADVISOR,** PLEASE COMPLETE ITEM V, SIGN AND RETURN TO STUDENT*

V. Comments: Please circle numbers of the appropriate items.

1. I have read this proposal and agree to be the technical advisor for the project, with the understanding that the student will confer with me regularly during the course of the project.
2. I would agree to be the advisor if the student satisfactorily addresses points indicated below in the proposal.
3. I believe this project, as described, is unacceptable and would not challenge the student's abilities.
4. I believe this project is beyond the scope of the student's abilities and should not be attempted.
5. This project requires materials, equipment, or facilities not available to the student.

Further Comments: ____________

Technical Advisor's Signature T. C. Scott
Date: 11/30/92

Please check if Technical Advisor wishes to confer with Humanities Advisor ____ and/or student ____.

STUDENT ATTACHES THIS PAGE TO PROPOSAL.

OAG
12/7/92

UNDERGRADUATE THESIS PROPOSAL:

(REWRITE)

STRENGTH TESTING OF BOAT CLEATS

by,
Michael C. Drew

H401, Professor O.A. Gianniny
December 4, 1992

This qualifies as a minimal project, with little to show engineering judgment (as distinguished from lab technician's. No background given so we can only assume it is a text book problem

C

OAG
12/14/92

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The purpose of this project is to determine the strength capabilities of boat cleats and/or their mounting systems. The characteristics of good cleat designs will be determined, and the most effective way of installing cleats ~~shall~~ will be identified. An assortment of cleats will be tested with four different loading methods common in real-world applications using a hydraulic press. A cleat will be mounted on the bottom of the press in one of the four orientations and a cable, simulating a rope, will be wrapped around the cleat and fixed to the moving part of the press. The press will then be activated to pull on the cleat until the cleat fails. The force at this point will be recorded as the failure force. These tests will identify how cleats fail as a function of the magnitude and direction of the load. I will explain why certain failures occur by performing a stress analysis on the cleats, based on shape and direction of the load. This will allow me to determine the factor of safety of various designs and the probability of failure. I will also be able to identify features of good and bad cleat designs. In some instances, the screws may break or pull out before the cleat actually breaks. The stress analysis will allow me to determine the required screw sizes that should be used for cleat installation. After I have tested all the cleats in the four loading methods, I will perform a statistical analysis on the failure of one type of cleat from one loading method to determine the probability of a manufacturing inconsistency which can result

not directive

?

gr.

def?

in a weak cleat. This will be accomplished by testing the same cleat with the same method many times. The data can then be analyzed to determine the failure probability. ? Process not clear

RATIONAL AND OBJECTIVES

Boat owners everywhere constantly depend on cleats for the safety and security of their vessels. Even when a boat is not in use, cleats are crucial for securing boats tied at dock. The failure of a cleat during a violent storm could cause extensive and very costly damage to a boat or yacht. ?

Although cleats have been around for many years, according to the U. S. Foundation for Boating Safety, very little has been done to test and analyze the strength capabilities of most cleats. Consumers has no way of knowing for sure what type of cleat they should buy for a certain application, how they should use the cleat most effectively, or what types of screws or bolts they should use in mounting the cleat. Most cleat manufacturers are small, and do not have the facilities to determine or publish this type of information. In fact, many cleats are sold loose without any packaging or description of the product. It would be helpful for consumers to have a general knowledge of strength capabilities for different sizes and shapes of cleats so they could purchase the best cleat for their needs. Source?

My experiment and analysis will provide useful information regarding the strength and effectiveness of many types of cleats.

The following is a list of the objectives of my project:

1. Identify how cleats fail as a function of the magnitude and direction of the load. gr.

2. Identify the features of good and bad cleat designs.

3. Determine the required screw size for mounting.

4. Explain why different failures occur based on stress analysis, given the cleat shape and the direction of the load.

5. Determine failure probability from a statistical analysis.

The stress analysis is the most important part of the project, because it will explain why failure occurs at certain locations on the cleat. From this analysis, I will obtain a good understanding for how the cleats behave under different loaded conditions, and I can determine a factor of safety for different designs and loads. In general, I will be able to differentiate between good and bad cleat designs.

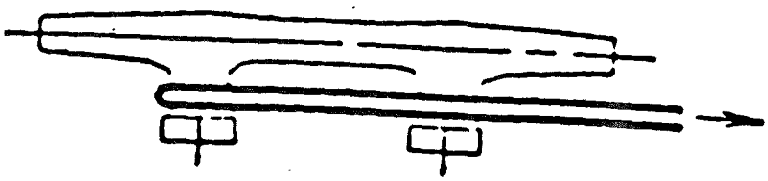
Can you not do all this by computer analysis?

The statistical analysis is useful because it will determine the likelihood of unexpected cleat failure due to manufacturing inconsistencies. This analysis will also check the validity of my previous experimental data because it analyzes the congruency of data from the same type of cleat loaded and broken in the same method many times.

In order to determine how to most effectively mount and load Gr. a cleat, the cleat must be strength tested using different def ? loading methods. The experiment must simulate real-world loads on the cleat, so the U.S. Foundation for Boating Safety has suggested four loading methods which are shown below. I must design mounts to secure the cleats to the base of the hydraulic press so ~~that~~ they can be loaded from a cable (which can only be pulled in an upward vertical direction from the moving part of the press) in the directions and configurations shown.

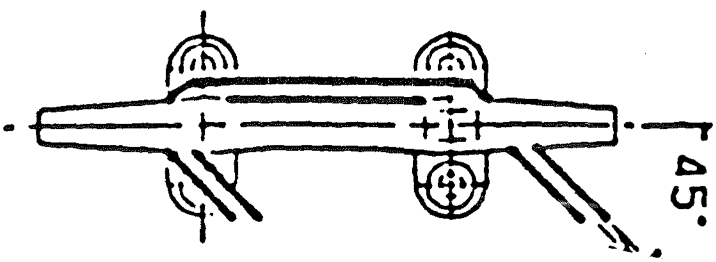
Pull 1:

Straight and Level.



Pull 2:

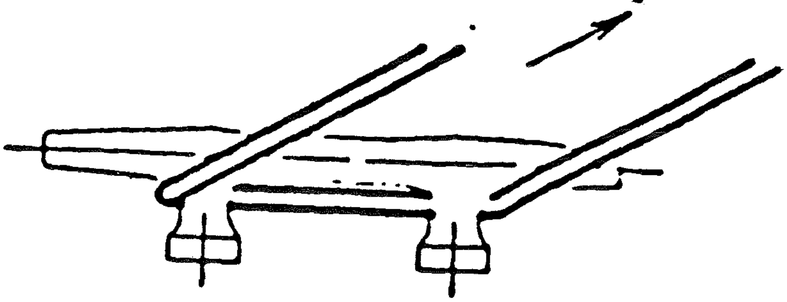
45° and Level.



Pull 3:

45° To the Side, and

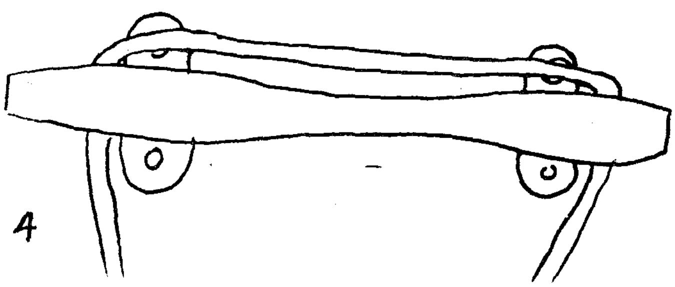
45° Up.



Pull 4:

90° To the Side and

Level.



The University of Virginia has been asked by the U. S. Foundation for Boating Safety to perform these cleat tests, and I have selected this project for my thesis. My results and analysis will be published in the U.S.F.B.S. newsletter so that many boat owners can benefit from my findings.

The literature search for this topic is very limited. The U.S.F.B.S. only knew of only one other strength test that was performed on boat cleats, but the documentation is lacking in vital information, and very little is known about the experiment. However, I do know that the previous experiment incorporated a hydraulic press to perform tensile tests on the cleats. This is a typical, common sense engineering approach for the cleat experiment, and these tests will be emulated in my project. As far as anyone involved with this project knows, there is no other useful information about boat cleats. This is precisely why the U.S.F.B.S. wants the university to run this experiment.

STATEMENT OF PROJECT ACTIVITIES

ACTIVITIES

Before I can begin the experimental process, I must first obtain a collection of cleats that I wish to test. The U.S.F.B.S. has already supplied a box of assorted cleats labeled according different shapes and sizes. The next step is designing an appropriate mount to attach the cleats to the base of the press.

The mount must be able to accommodate the different types of cleats, and must allow testing in the four loading methods. The mount will be subjected to high stresses while testing the cleats, and must be able to withstand these stresses. I need to make sure that the cleat or screws will break before my mount does. The mount can easily be created by the machine shop in the basement of the mechanical engineering building from inexpensive materials. ?

Once the mounts for each type of cleat and loading method have been created, I must obtain a suitable cable to break the cleats with. Fr. Since the cable will be thinner than a typical rope, a piece of plastic tubing will be slipped around the cable to simulate the diameter of a rope. This creates a force distribution on the cleat similar to that of a rope. The cable can then easily be connected to the moving part of the press. Assumption Not Tested

At this point, I can begin testing the cleats. Every cleat must be tested in all four loading methods. When failure occurs (indicated either by cleat or screw breakage) I must record the hydraulic pressure indicated by a meter on the press. This can easily be translated into a force from a simple equation. The remains of the cleats will be labeled with the force of failure and the corresponding loading method, and will be set aside for a stress analysis. Suppose they bend rather than failure

The stress analysis will be the most lengthy part of the project, because every cleat must be analyzed according to the force magnitude and direction that caused failure. The stress on

? not parallel concept

the screws, the safety factors, and possibly the stress concentrations must also be calculated. This is the most critical part of the project which will give me the greatest knowledge of cleat strength and the most useful information for cleat users. Run-on sentence

After reviewing the data from my experiment, I will choose a suitable type of cleat out of the group already tested for use in a statistical analysis. Run-on sentence I will need to obtain about ten to twenty cleats of this type and test them using an identical loading method. I will determine the possibility of unexpected failure due to manufacturing inconsistencies by statistically analyzing the results of this series of tests. This will allow me to make a statement about the quality of the cleat which could be useful knowledge for a boat owner.

The final step of the project is to gather and organize all my data and analyses so that I can form conclusions about the behavior of loaded cleats. I will be able to make specific statements about the characteristics of good and bad cleats as well as some statements about cleats in general. I should, at this point, have reached the goals of the project as stated above.

SCHEDULE

The U.S.F.B.S. would like results from this project as soon as possible, so I hope to have most of the testing and stress analysis completed by the end of November. If anything goes wrong, however, I should have plenty of time at the end of this semester or the beginning of the following semester to correct the problem. The machine shop and the press are located in the Mechanical Engineering building, so if I need anything made in a hurry to aid in mounting or loading the cleats, the parts can be manufactured almost immediately. The following is a proposed schedule for my thesis:

November 8 - 14: Complete designs for mounts and have them made in the machine shop.

November - January 25: Begin and complete nearly all loading tests on all the cleats and begin stress analysis.

January 25 - March 1: Have stress analysis completed, and begin statistical analysis.

March 1 - March 15: Complete statistical analysis and statistical analysis calculations.

March 15 - Due date: Establish final conclusions and prepare final report.

PERSONNEL

The people involved in this project are myself, my technical advisor, Professor T.C. Scott, my humanities advisor, Professor O.A. Gianniny, and the correspondents from the U.S.F.B.S. The project was presented to me by Professor Scott who helped me layout the tasks I need to accomplish and pointed me in the right direction towards completing this project. He will continue to advise me on the technical aspects of the project when necessary.

Professor Gianniny has helped me narrow the focus of the project and has challenged me to understand the social implications and significance of my work.

The U.S.F.B.S. has aided in supplying the cleats for completing the project and will continue to provide cleats if I need more for the statistical analysis or for any experimental errors that may occur. They have also specified the types of tests they want performed on the cleats, and will be available to answer any questions concerning real-world applications of cleats.

The machine shop technicians also play a vital role in my project by creating the mounts which I must design for the cleats.

I am obviously the critical element in this list of personnel. All responsibility for designing the mounts, performing the tests and doing the analyses is mine, but I will not be alone if I run into any problems.

RESOURCES

This project requires very few resources. The material required to fabricate the cleat mounts is typical steel supplied from the mech. building. The hydraulic press will be available during normal business hours and possibly in the evenings when the lab is open. Cleats will be supplied by the U.S.F.B.S. and any other materials I need can probably be found or made in the mech. building.

EXPECTED OUTCOMES

At the completion of my project, I hope to have made some significant discoveries about boat cleats. I expect all the cleats or their mounting screws to fail when loaded on the press. I also expect these results will allow me to make some definite stress calculations on the cleats and screws that will aid in determining the characteristics of good (strong) and bad (weak) cleats. I should expect to see failures at known stress concentrations and on thin sections of the cleats. My knowledge of structural stress behavior will allow me to make specific statements about the cleats such as safety factors and required screw sizes for mounting. This type of data has previously not been available to cleat customers.

I expect that the statistical analysis will be successful and will allow me to make some estimates about manufacturing quality of the cleats. I do not expect to find a wide variation in a single cleat's performance, but if I do, this information could turn out to be very important. Such variations are not safe, and customer's should be made aware of this if cleats do in fact have a lot of manufactured inconsistencies.

If I can draw such specific conclusions that will benefit customers, and receive valid data from my tests, I will consider my thesis a success. I believe that this type of success is well within my grasp as I work with both my technical and humanities advisors. I am certain that my work will indeed be valuable to any boat owners who take an interest in the safety and security of their vessels.

APPENDICES

A. BUDGET AND EQUIPMENT CHECKLIST

The following is a list of the equipment and material I will need for the completion of my thesis:

1. 10,000 lb Hydraulic Press: Located in the Mech. Building.

2. Approximately 40 - 50 Boat Cleats: Supplied from the U.S.F.B.S.

3. Steel Cleat Mounts For the Press: Fabricated in the Mech. Building.

4. Mounting Screws: Inexpensive. Can be bought anywhere.

5. 1.4" D. Steel Cable: Supplied from the Mech. Building.

6. Plastic Tubing: Supplied from the Mech. Building.

B. ANNOTATED BIBLIOGRAPHY

The only reference that is available to me a copy of some cleat test results from an unnamed organization. This article was supplied to me by the U.S.F.B.S., but absolutely no reference is given and all other information is very limited.

C. BIOGRAPHICAL SKETCH OF THE STUDENT

This thesis requires a thorough knowledge of many mechanical engineering concepts. Many design principles must be understood including the effects internal moments and forces, bending and shear stress, and stress concentration factors. Some material concepts like ductile and brittle behavior must also be understood.

As a fourth-year mechanical engineering student, I feel that I am definitely qualified for this project. I have performed very well in many classes and labs where I have acquired a superb understanding of the principles mentioned above. I also have extensive hands-on experience with tools and mechanical items from years of tinkering with automobiles and machines. This experience will be of great value in the laboratory where I will perform my tests.

D. PRELIMINARY OUTLINE OF THE TECHNICAL REPORT

TITLE: Strength Testing of Boat Cleats

I. Design of Cleat Mounts

Explanation and sketches of the designs

II. Testing Process

Testing procedures and methodology

Summary of results

III. Data

Failure loads and orientation

IV. Explanation of Data

Stress analysis calculations

V. Conclusions Drawn From Stress Analysis

Qualities of good and bad cleat design

Screw sizes

Factor of safeties

VI. Statistical Analysis Testing Procedure

VII. Statistical Analysis Data

VII. Explanation of Data

Statistical analysis calculations

VIII. Conclusions Drawn From Statistical Analysis

Manufacturing inconsistencies

Likelihood of unexpected failure

IX. General Conclusions

Benefit to customers

APPENDIX M

PRE-PROPOSAL

The particulars are spelled out — the rationale + level of sophistication is being developed - still needs work to avoid oversimple approach -

Strength Testing of Cleats
Thesis Pre-Proposal
by Michael C. Drew (Revised)

B

The forecasting of a major storm is a serious threat for people who own boats kept at dock. A boat must be prepared to sustain heavy winds from above and powerful waves from beneath. Even then, serious and costly property damage may occur.

Probably the most important safety measure taken by boat owners is securing the vessel tightly to the dock with some sort of heavy rope or cord. The cord is usually tied or looped around one of the boat's many cleats. Cleats are usually two-pronged pieces of highly polished or chromed steel securely fastened to the boat. They come in many sizes and shapes according to brand and application, but no matter what cleat is used, the owner would like to be certain the cleat can sustain the stresses applied to it during a serious storm without breaking. Boating terminology

The U.S. Foundation for Boating Safety has asked the university to run some strength experiments on boat cleats. Cleats have been strength tested before, and the U.S.F.B.S. has sent the university some test procedures and results from an unnamed organization. However, there is very little background information on the experiment and the testing procedures, and the validity of the experiment is somewhat in doubt. Therefor, the U.S.F.B.S. is in search of some clear and reliable cleat strength data and has asked the University of Virginia for assistance.

I plan to use this project for my thesis. I will use the information given to me as a basis for my own testing procedures, and I will test the strength of several types of cleats loaded in a variety of orientations. The orientations tested by the other organization seem to represent typical real world applications of the cleats. Nevertheless, I may wish to limit or expand the number of loading orientations according to what I think is possible and necessary to investigate. After all the cleats are tested, I will have determined the direction and magnitude of the smallest force required to break each type of cleat.

Before I proceed with the experimental process, there are some things about this project that I must consider. At this point, there a few things I am unsure about. It does not seem likely to me that a cleat should fail before it rips out of its mount, or before the rope breaks. Yet, in certain extreme cases, the security of a vessel may well be entirely dependent on the strength of the cleat. If the U.S.F.B.S. is interested in testing cleats, I assume it is a worthwhile investigation. I must research this topic more thoroughly before I can comment further on the implications of this project.

More discussion? that informs reader expect? What level confidence?

I will also need to do some research into the material composition and structural design of the cleats after I have done some of the lab experimentation. From the laboratory experience, I should learn more than just the direction of the smallest force required to break a cleat. There may be different modes of failure other than ordinary fracture. A cleat probably breaks easiest from a sudden hit, or shock. Unfortunately this type of failure is apparently too difficult to test. Also, under the steady load that I will apply in my experiment, the cleat may bend before it breaks. I may determine that a case of extreme

to more general?
define failure?

bending renders the cleat useless so I would have to treat this condition as a failure. Such conditions and complications may well exist, and I must decide how to handle them. Observations made in the lab will increase my knowledge of the cleat's characteristics, and may possibly suggest a better cleat design. After the testing procedure is complete, I will know which cleats are the strongest for steady loads, but most importantly, I will know which loading methods are the safest and most dependable, and I will have a knowledge of a cleat's design and structure.

what will client know?

In order to conduct this experiment, I have been given permission to use the University's hydraulic press. Before I can begin, however, I must design a platform mount for the cleats. The mount will secure a cleat to the base of the press and allow an assortment of orientations so that each cleat can be tested with a variety of loading methods. Since the press can deliver up to 10,000 lb force, I must design the mount to be accordingly strong and durable.

With the cleat securely mounted to the base of the press, I will attach a piece of steel cable to the mobile part of the press above, and wrap it around the cleat according to one of the loading orientations. The press can then be operated to pull on the cable thereby applying a load to the cleat. I am using steel wire cable instead of typical boat rope to apply the loads because typical rope might break before the cleat does. This would cause an unexpected variable in my experiment. The cable will be able to withstand any amount of force required to break a cleat and should eliminate any unexpected results.

The cost of this project should be very low. The cleats are cheap and will probably be provided by the U.S.F.B.S., or by the university. The mount will be crafted in the metal shop in the basement of the Mec. Building from materials supplied within.

The data and information gathered from this project will be valuable for consumers who own boats and purchase cleats. The results should lead to safer and more reliable usage of cleats by informing the consumer on how to them in a more effective manner. In fact, the U.S. Foundation for Boating Safety has expressed a desire to publish the test results and implications upon completion of the project.

This project was presented to me by Professor T.C. Scott who has worked on other projects for the U.S. Foundation for Boating Safety. I feel that I have the necessary background and skills to work on this project and with the tutelage of Professor Scott, I believe I can complete it successfully.