

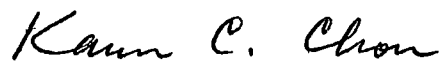
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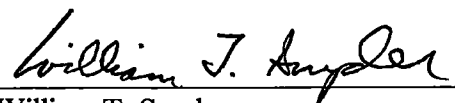
I am submitting herewith a thesis written by Christopher A. Williams entitled "The Development of The *Tension Connection Analyzer* A Computer Aided Teaching Tool for Connection Analysis and Design". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Engineering Science.



Christopher D. Pionke, Major Professor

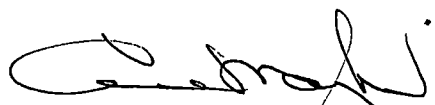
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Interim Vice Provost and Dean of The
Graduate School

**The Development of The *Tension Connection Analyzer*
A Computer Aided Teaching Tool for Connection
Analysis and Design**

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Christopher A. Williams
December 2000

Abstract

The purpose of this thesis is to develop a multimedia simulation tool that allows for the investigation of tensile member connection analysis and design. The motivation behind the creation of this software is to meet the needs of students and their different learning styles for the education of tensile member connections. It is the intent of the program to enhance the student's ability to visualize the failure modes that exist in tension member connected systems. The overall objective of the program is to produce an aide to improve the classroom experience, while at the same time allow students to develop a feel for tensile member design outside of the classroom.

Current in-class methods allow for students to see the before and after of connection failures through the use of static models. However, these methods fall short in their ability to exemplify the dynamic propagation of the failure through the material. Computer simulation serves as a means by which the gap between static examples and real-time dynamic modeling can be bridged. Simulation allows for an animated time-result comparison that, combined with proper instructional interface, can result in a computer aided tutorial program.

The title of the developed computer aided teaching tool is the *Tension Connection Analyzer*. The *Tension Connection Analyzer* is an educational tool that serves both the instructor and the student as a supplemental device for the topic of tensile member design. With minimal in-class demonstration time, the instructor can send students home with an easy-to-use Windows based program that will help the students visualize the topic of tensile member design. Since the program has its own on-line help, the

instructor can feel confident that the students will be able to quickly learn how to use the program, in order to get the most out of the program.

The *Tension Connection Analyzer* consists of two modes of function, analysis and demonstration. The analysis mode serves as a tool for the students with a better feel for the methodology to investigate “what if” scenarios for connection patterns. While the demonstration mode, being more visually oriented allows the students to view numerous failure paths and the corresponding failure loads, in order to more quickly get a feel as to what the “most likely” failure paths might be for different connection patterns. This ability to predict the controlling failure paths will allow the students to become more productive outside the classroom as well as on examinations.

Through all of the aspects contained in the *Tension Connection Analyzer*, it can be seen that the need for an educational media in the area of tensile member design has been met. The *Tension Connection Analyzer* affords an instructor the comfort of sending students home with a tool that not only gives numerous samples, but also allows students to check their hand calculations. In short, instructors gain flexibility in their approach to the topic, and students of all learning styles are given the opportunity to gain competency in the topic of tensile members.

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Chapter 1

Introduction

The purpose of this thesis is to develop a multimedia simulation tool that allows for the investigation of tensile member connection analysis and design. The motivation behind the creation of this software is that of enhancing the student's ability to visualize the failure modes that exist in tension member connected systems. Current in-class methods allow for students to see the before and after of connection failures through the use of static models. However, these methods fall short in their ability to exemplify the dynamic propagation of the failure through the material. Computer simulation serves as a means by which the gap between static examples and real-time dynamic modeling can be bridged. Simulation allows for an animated time-result comparison that, combined with proper instructional interface, can result in a computer aided tutorial program. This type of tutorial program is the primary goal of this thesis. The objective of this program is to produce an aide to enhance the classroom experience, while at the same time allow students to develop a feel for connection design outside of the classroom.

Background

From elementary schools to universities, teachers are looking for the best methods that will allow their students to learn more efficiently while at the same time maintaining topic interest. As students get older they begin to develop their own individual learning styles. As they reach the college level, professors find themselves with a classroom filled with a variety of learning styles. These learning styles range from theoretical to those who prefer hands-on methods. The students with the theoretical learning styles are those

who are satisfied with the theory behind a particular procedure and do not require a practical application in order to fully grasp the topic [1]. While on the opposite end of the spectrum, the students that are of a sensing nature want specific examples that give real-world applications. With such a wide range of learning styles, the instructor finds it difficult to meet the needs of all of the students. The instructor must decide how a compromise can be reached between abstract theory and real-world visualization.

This compromise is particularly important when teaching tensile member connection design. The instructor is burdened with the need to combine the complex theory and methodology behind the engineering codes with ample visualization through real-world examples. The specifications for tensile member connections, found in the American Institute of Steel Construction's (AISC) Load and Resistance Factored Design (LRFD) manual [2], require a knowledge of the grades of steel, beam cross sections, bolts, etc. in order to investigate the functionality of a particular connection. With all of these parameters in mind, it becomes apparent that actual hands-on examples can become very costly. Therefore, budget constraints are another factor that inhibit teachers.

These constraints have led to one current method used in teaching this topic. This method includes the use of small-scale models of the before and after versions of tensile member systems. Each model only shows the failure mode due to a specific loading condition. While an example of this nature does allow students to see how a particular system reacts to a given load, it does not allow for any variation of the parameters. For example, the students cannot physically view the various paths of crack propagation that exist in block shear studies. The inability to change different parameters of the system places the advantage back on the intuitive student and the disadvantage on the sensing

student. This is caused by the resurgence of the theoretical nature of the topic and the reliance on the student to visualize alternative failure modes.

Another area that yields a disadvantage for the sensing student is the time restraint aspect of the class. In courses where the subject of tensile member connection design is covered, this topic is not the only area of emphasis. Therefore, only a portion of the semester can be designated to this topic. The compression of topic discussion forces students to grasp certain concepts such as block shear at an elevated pace. This elevated pace often forces some students to pick-up the details of the topic outside of the classroom. Often times several shear failure paths may exist for a certain system, and the student must perform several iterations of analysis in order to determine the controlling path. This fact not only requires that a student accept the phenomena without being able to visualize the process, but it also requires the student to spend extra time doing several iterations of the hand calculations involved in solving tensile systems. Combining the aspects of budget and time restraints it can be seen that, for this particular area of structural design, students with poor visualization skills are placed at a disadvantage.

Use of Simulation

A particular field of study has been developed in order to deal with the inability to model certain phenomena due to lack of funding and shortages of time. This field is known as simulation. Simulation allows for real-time evaluations to be performed on given systems through the use of computer-aided design. In the area of education, simulation has the ability to enhance topic comprehension without causing an increase in necessary lecture time. Yet, while the positive aspects of simulation and computer aided design (CAD) are recognized by educators, topic specific educational software packages

remain small in number. However, through the efforts of some universities, educational simulators are on the rise.

The Department of Civil and Mechanical Engineering at the United States Military Academy at West Point, NY, has been very active in the creation of educational software for use in undergraduate engineering programs. This department has produced such applications as the: CME-Stacker, CME-Truss, CME-Frame, Visual Stress Transformer, Trebuchet for Windows, and West Point Bridge Designer [3]. The CME Stacker educates students in the Direct Stiffness Method of structural frame analysis through the assistance in the creation of local stiffness matrices for given truss and frame members. The knowledge of the Direct Stiffness Method is then put to use through the CME-Truss and the CME-Frame applications. These two applications are two-dimensional truss and frame analysis programs, respectively, for windows. These applications allow the user to select AISC shapes as members, and then the program utilizes the Direct Stiffness Method to solve for problem solutions.

The Virtual Stress Transformer is a program aimed to aid in the comprehension of two-dimensional stress transformation and the use of Mohr's Circle [4]. This program keeps the sensing student in mind, in that it helps the student visualize the variation of the normal and shear stresses with changing orientation. The program allows the student to simultaneously view the rotating stress block and an animated Mohr's Circle so that the relationship between the plotted points on the circle and the stresses in the material can be seen. This animation gives the sensing student the specific example that is often necessary for full comprehension.

The Trebuchet also aids the sensing student in that the solution to a two-degree of freedom dynamic system is set in motion. This program adds a little fun to the process of understanding dynamic systems for all learning types. The Trebuchet program simulates the motion of medieval catapults and plots the results of the formulated solutions to the governing differential equations of motion. This gives all styles of students the ability to combine some playfulness with differential equations, a combination that is rarely found.

The West Point Bridge Designer is the most popular of all the West Point programs. This program introduces the engineering design process as it guides the student through the two dimensional design of a bridge. This program focuses on the needs of the sensing student in that it provides hands-on design experiences. These experiences include realistic specifications, constraints, and performance criteria. The Bridge Designer also allows the student to visualize the structural behavior of a user designed bridge by demonstrating failure modes and visually identifying the stress levels in various members. The program gives the user the capability to:

- Develop a structural model
- Select material and cross-section
- Run simulated load tests
- Optimize design to minimize cost

With these features, the West Point Bridge Designer takes the user through all of the steps of the engineering design process. The combination of design and simulation allows students to learn while also attaining experience with a computer aided design software package similar to what can be seen in industry.

Other simulation software for civil engineering applications has been developed, such as The Deflect Program and CIVCAL [5, 6]. While applications such as The Deflect Program and CIVCAL serve to promote computer aided learning in general, the West Point applications of computer aided design and simulation in civil engineering have helped to set the standard for the use of computer software in education. By achieving this standard set by West Point, it is the goal of this thesis to continue the success of computer aided design software and its use in education for the purpose of enhancing a student's comprehension of tensile connection design.

Specific Objective

The *Tension Connection Analyzer* is designed to link together abstract theory with real-world visualization in the teaching of tensile member connection design. The program will allow professors to span the range of individual needs between the intuitive and sensing students. The program will permit the intuitive students, who are satisfied with theory, to quickly work through example problems and check their hand written work. While on the other hand the program will permit the sensing students to view an animated model of the tensile member system and its resulting modes of failure. Also, the students who learn best through numerous examples will not be held back by time restraints. The program will allow them to quickly perform numerous examples with different beam cross-sections and bolt types. For each example the student will not only see the calculated result, but also will be able to view a dynamic simulation of all possible failure modes. By fulfilling these classroom needs, a professor can use the methods that he or she feels comfortable with in teaching the topic in class and know that the students have this program as supplemental instruction outside the classroom.

In order to fulfill the aforementioned educational needs, the following characteristics were used in the multimedia simulation tool:

- The program is a Microsoft Windows95/98/NT application with full graphical user interface.
- To accomplish this goal, the program was written using Microsoft Visual Basic 6.0.
- The program is capable of operating in two separate modes, either in “analysis mode” or “demo mode”.

In analysis mode, the program:

- allows the user to determine the load capacities of specific failure paths,
- permits the user to input all the variables necessary to define a particular fracture and block shear path,
- shows the calculations performed in determining the design strength of the connection.

In demonstration mode, the program:

- gives the user the ability to select a failure demonstration from a choice of six different connection patterns,
- takes the user to a screen showing the governing equations along with a “VCR” that presents the user with a series of failure animations from which to choose.

While each mode has its own distinctions, they both have the following characteristics in their graphical user interface:

- a choice between A36 and A572 grades of steel for sections
- a choice of standard W-shape, angle, and channel sections
- a choice between A325 and A490 grades of steel for bolts
- a choice of bolt head type: hex or square
- a choice of bolt diameter
- a choice of square or staggered connection patterns
- a choice of number of bolts in a connection

The program also contains a comprehensive help utility. The help utility directs the user on how to manipulate through the software with a step-by-step tutorial. The help also gives a background to the topic of tensile connections and defines all variables used in the calculations.

The *Tensile Connection Analyzer* is an educational tool that supplies students with the capability to comprehend the topic of tensile connections no matter what their learning style. For instance, the program allows the intuitive student to receive instant feedback on realistic failure paths, as well as paths created in “what if” scenarios. The program gives the sensing style student the capability of sifting through animated failure paths in order to visualize the characteristics of controlling failure paths. While each learning style will gain understanding from the program in different ways, both will be capable of recording their designs as hard-copy printed output.

Chapter 2

Explanation of Tensile Connections

The overall strength of a structural system is limited by the strength of the individual components of the system. The testing of a tensile member and its connection determines the axial loading capacity that a member can resist without failure. Figure 2.1 exemplifies the application of axial load used in testing of tensile members. This testing encompasses failure due to either the yielding of its gross cross-sectional area, the fracture (separation) of the member through the bolt holes, or a combination of fracture and yielding at the connected area. These three forms of failure are classified as:

- tensile yield
- tensile fracture
- block shear rupture.

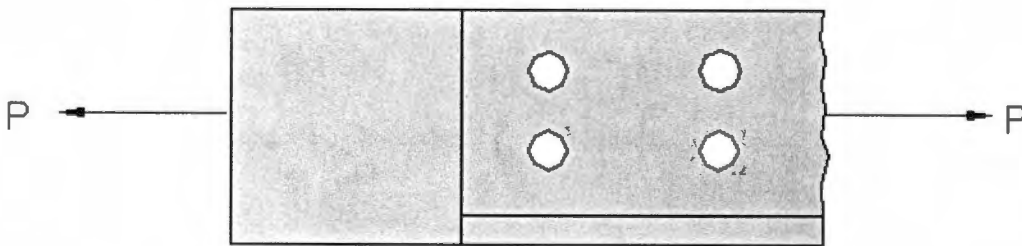


Figure 2.1 Tensile Load

First, a general explanation and the governing equations for all three failure modes will be presented. This will be followed by a detailed example showing all required calculations.

Tensile Yield

Tensile yield occurs when the load placed on a cross-section reaches the yield strength of the material. Failure of this manner occurs away from the connection, as can be seen in Figure 2.2.

Tensile Fracture

Tensile fracture is the separation of a member under an axial force. Tensile fracture occurs at the path that has the least resistance. Hence, a path through the bolt holes would be more likely to fail than one through a section away from the connection. Figure 2.3 shows one of the possible fracture paths under axial force P .

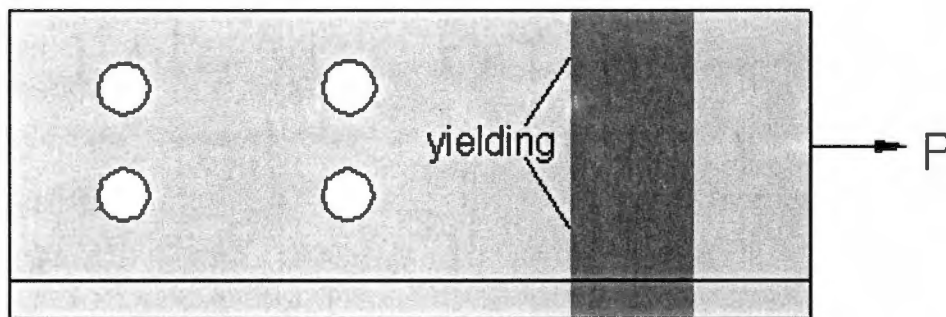


Figure 2.2 Example of Tensile Yield

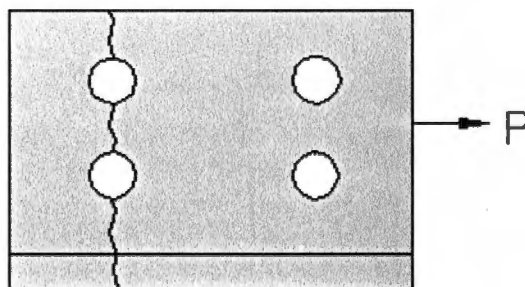


Figure 2.3 Example of Tensile Fracture Path

Block Shear

Block shear is a combination of yielding and fracture. It is a limiting state that is determined by the sum of the shear strength and tensile strength along a particular failure path. An example of block shear can be seen in Figure 2.4. For all designs, all three failure modes must be studied in order to determine the limiting design strength for a given tensile member.

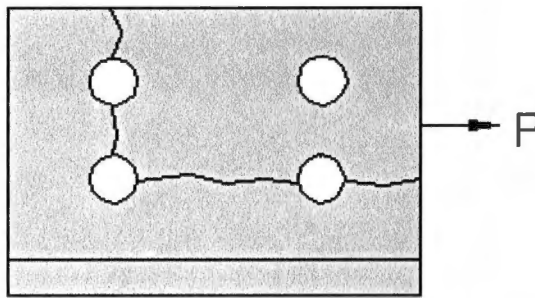


Figure 2.4 Example of Block Shear Path

Design Strength

For any design, the design strength of tension members, T , shall be the lowest value obtained according to the limit states of yielding in the gross cross-section, fracture in the effective net section, and the shear rupture (block shear).

Yielding

For yielding in the gross cross-section, the tensile yield design strength, T_t , is the product of the tensile reduction factor, ϕ_t , and the nominal strength of the cross-section, P_{nt} [2, Section D].

$$T_t = \phi_t P_{nt} \quad (1)$$

$$\phi_t = 0.90$$

$$P_{nt} = A_{gt} F_y \quad (2)$$

A_{gt} = gross cross-sectional area of member

F_y = yield stress

The gross area of a member at any point is the sum of the products of the thickness and the gross width of each element measured normal to the axis of the member [2, Section B].

Fracture

For fracture in the effective net section, the tensile fracture design strength, T_f , is the product of the fracture reduction factor, ϕ_f , and the nominal axial strength, P_{nf} [2, Section D].

$$T_f = \phi_f P_{nf} \quad (3)$$

$$\phi_f = 0.75$$

$$P_{nf} = A_e F_u \quad (4)$$

A_e = effective net cross-sectional area

F_u = ultimate tensile strength

$$A_e = U A_n \quad (5)$$

U = shear lag reduction factor (explained below)

A_n = net cross-sectional area

$$A_n = A_g - n_h \left(d_b + \frac{1}{8} \right) t \quad (6)$$

n_h = number of holes in fracture path

d_b = diameter of bolts.

t = thickness of web

In equation (6) above, the value 1/8 is measured in inches. Using U.S. Customary units, the size of a hole must be 1/8" larger than the diameter of the bolt, (1/16" larger than the bolt for tolerance and 1/16" for damage.)

Staggered hole patterns occur whenever there are holes that are not aligned transverse to the loading direction, as seen in Figure 2.5.

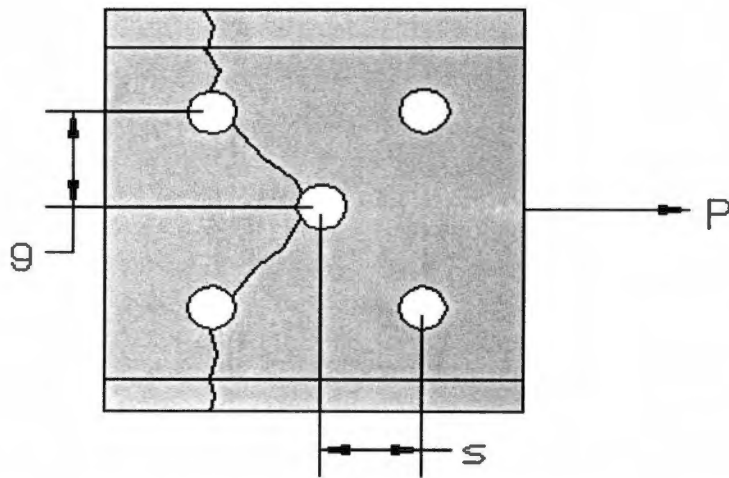


Figure 2.5 Example of Staggered Hole Pattern

When this situation arises, the shortest fracture path may not be in a straight line between the top and bottom of a cross-section. The controlling failure path is the one consisting of the minimum net area. The amendment added to the previous equation for the net area can be seen in equation (7). This addition accounts for the “additional” path length. Equation (6) is modified to become:

$$A_n = A_g - n_h \left(d_b + \frac{1}{8} \right) t + n_d \left(\frac{s^2}{4g} \right) t \quad (7)$$

s = the spacing between two diagonal holes,
parallel to the loading direction

g = the gauge distance between two holes
transverse to the loading

n_d = the number of diagonal paths in
the failure path

Equation (7) assumes the bolts in the connection
are regularly spaced

Shear lag is defined as the non-uniform stress in wide plates or plate elements of rolled sections when a tensile load is applied non-uniformly [2, Section B]. This type of stress can occur when a load is applied eccentrically. The shear lag reduction factor, U , can be computed by equation (8):

$$U = \min \left(1 - \frac{\bar{x}}{L}, 0.90 \right) \quad (8)$$

$\bar{x}$ = the centroid of a cross-section (see Figures 2.6, 2.7, 2.8)

[LRFD, Commentary - Section B]

L = the length of connection in the direction of loading

Also, average values of U exist for certain bolted connections. These values are based on two categories of connections: those with two connections in a row in the direction of the applied load, and those with three or more connections per line. The following conditions govern the values for the reduction factor: [2, Commentary - Section B]

- W, M, or S shapes with flange widths not less than two-thirds the depth, and structural tees cut from these shapes, provided the connection is to the flanges and had no fewer than three fasteners per line in the direction of stress, $U = 0.90$
- For all other shapes (including built-up shapes) with at least three fasteners per line, $U = 0.85$
- All members having only two fasteners per line in the direction of stress, $U = 0.75$.

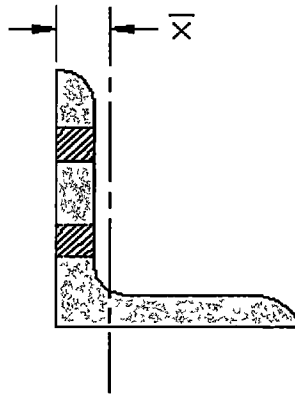


Figure 2.6 Centroid for Angle Section

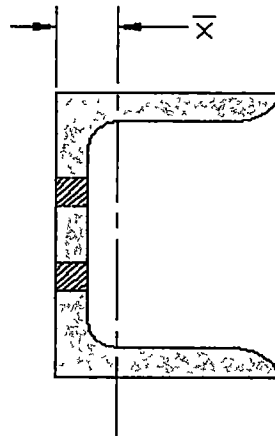


Figure 2.7 Centroid for Channel Section

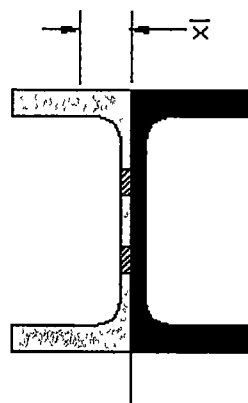


Figure 2.8 Centroid for W Section

Block Shear

Block shear is a limit state in which the resistance is determined by the sum of the shear strength on a failure path(s) and the tensile strength on a perpendicular segment. The design strength for block shear rupture, T_b , can be determined as follows in equations (9,10a,b)[2, Section J]:

$$T_b = \phi_b P_{nb} \quad (9)$$

ϕ_b = block shear resistance factor = 0.75

P_{nb} = nominal block shear load

where,

$$P_{nb} = 0.6F_y A_{gv} + F_u A_{nt} \quad (10a)$$

if $F_u A_{nt} \geq 0.6F_u A_{nv}$

or,

$$P_{nb} = 0.6F_u A_{nv} + F_y A_{gt} \quad (10b)$$

if $0.6F_u A_{nv} > F_u A_{nt}$

A_{gv} = gross area subject to shear (total shear length)

A_{nv} = net area subject to shear (total shear length minus
area of holes and damage)

A_{gt} = gross area subject to tension

A_{nt} = net area subject to tension

Limiting Design Strength

Based on the three possible failure modes, tensile yield, tensile fracture, and block shear rupture, the design strength for a given pin connected tension member can be determined. The design strength, T , for the member is the minimum value of the computed design strengths:

$$T = \min(T_t, T_f, T_b) \quad (11)$$

A sample design strength calculation is presented below.

Sample Calculations

For Angle: 5 x 3 x 1/4 LLV angle section, calculate the design strength for the pattern in Figure 2.9. Consider A572 steel, with 3/4 in. diameter bolts.

From LRFD manual 2nd edition,

$$\begin{array}{llll}
 A_g = 1.94 \text{ in}^2 & t = 1/4 \text{ in} & \bar{x} = 0.657 \text{ in} & L_{e'} = 1 \text{ in} \quad L_e = 1 1/4 \text{ in} \\
 F_y = 50 \text{ ksi} & F_u = 65 \text{ ksi} & d_b = 3/4 \text{ in} & g = 1.75 \text{ in} \quad s = 2.25 \text{ in}
 \end{array}$$

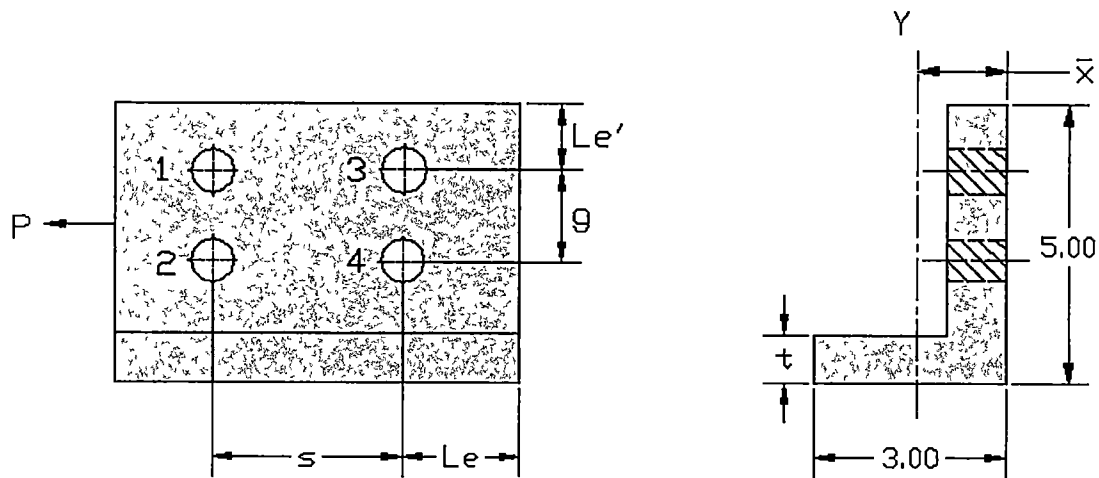


Figure 2.9 Angle with Connection Pattern 1-2-3-4 (all dimensions are in inches)

Tensile Yield:

$$T_t = \phi_t P_{nt}$$

$$\phi_t = 0.90$$

$$P_{nt} = A_g F_y = (1.94)(50) = 97.00 \text{ kips}$$

$$T_t = \phi_t P_{nt} = (0.90)(97.00) = 87.3 \text{ kips}$$

Fracture:

Due to the number of bolts and the given pattern, three different failure paths for fracture must be examined. In addition to the equations presented earlier, the number of holes in the failure has to be considered.

Path # 1: 1-2, %P = 0.50* (See Figure 2.10)

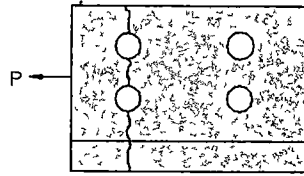


Figure 2.10 Fracture Path 1-2

* Note: Only two of the four holes are involved in the fracture path, therefore only half of the load is associated with fracture path 1-2, whereby, %P = 0.50.

$$T_f = \phi_f P_{nf}$$

$$\phi_f = 0.75$$

$$P'_{nf} = A_e F_u$$

$$A_e = U A_n$$

$$U = \min\left(1 - \left(\frac{\bar{x}}{L}\right), 0.90\right) = \min\left(1 - \left(\frac{.657}{2.25}\right), 0.90\right) = .708$$

$$A_n = A_g - n_h\left(d_b + \frac{1}{8}\right)t = 1.94 - 2\left(\frac{3}{4} + \frac{1}{8}\right)\frac{1}{4} = 1.503 \text{ in}^2$$

$$A_e = UA_n = (0.708)(1.503) = 1.064 \text{ in}^2$$

$$P'_{nf} = A_e F_u = (1.064)(65) = 69.16 \text{ kips}$$

$$P_{nf} = \frac{P'_{nf}}{\%P} = \frac{69.16}{.50} = 138.32 \text{ kips}$$

Therefore, the design load for fracture path 1 - 2 is,

$$T_{f1} = \phi_f P_{nf} = (0.75)(138.32) = 103.74 \text{ kips}$$

Path # 2: 3-4 %P = 1.00* (See Figure 2.11)

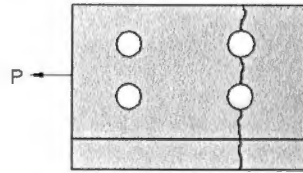


Figure 2.11 Fracture Path 3-4

Note: Path #2 is identical to Path #1, except that %P = 1.00 because all of the holes are included in this path, whereby the entire load is accounted for. Since the effective area of Path #2 is identical to Path #1, P'_{nf} is the same for both paths.

$$P'_{nf} = 69.16 \text{ kips}$$

$$P_{nf} = \frac{P'_{nf}}{\%P} = \frac{69.16}{1.00} = 69.16 \text{ kips}$$

Therefore, the design load for fracture path 3 - 4 is,

$$T_{f2} = \phi_f P_{nf} = (0.75)(69.16) = 51.87 \text{ kips}$$

Path # 3: 3-2 %P = 0.75* (See Figure 2.12)

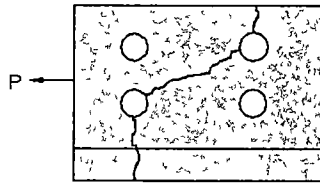


Figure 2.12 Fracture Path 3-2

*Note: Three of the four holes are involved in the fracture path, therefore only three-fourths of the load is associated with fracture path 3-2, whereby, %P = 0.75.

$$T_f = \phi_f P_{nf}$$

$$\phi_f = 0.75$$

$$P'_{nf} = A_e F_u$$

$$A_e = U A_n$$

due to the diagonal path between bolt 3 & 2,

$$A_n = A_g - n_h \left(d_b + \frac{1}{8} \right) t + n_d \left(\frac{s^2}{4g} \right) t$$

$$A_n = 1.94 - 2 \left(\frac{3}{4} + \frac{1}{8} \right) \frac{1}{4} + \left(\frac{2.25^2}{4(1.75)} \right) \frac{1}{4} = 1.68 \text{ in}^2$$

$$A_e = U A_n = (0.708)(1.68) = 1.19 \text{ in}^2$$

$$P'_{nf} = (1.19)(65) = 77.35 \text{ kips}$$

$$P_{nf} = \frac{P'_{nf}}{\%P} = \frac{77.35}{.75} = 103.13 \text{ kips}$$

Therefore, the design load for fracture path 3 - 2 is,

$$T_{f3} = \phi_f P_{nf} = (0.75)(103.13) = 77.35 \text{ kips}$$

The governing fracture load comes from the path with the lowest design load:

$$T_f = \min[T_{f1}, T_{f2}, T_{f3}] = \min[103.74 \text{ kips}, 51.87 \text{ kips}, 77.35 \text{ kips}] \\ = 51.87 \text{ kips}$$

Therefore, the governing load in fracture is 52 kips and the controlling failure path is path #2.

Block Shear:

*Note: l_v is the shear length in the failure path, parallel to the load

l_t is the tensile length in the failure path, perpendicular to the load.

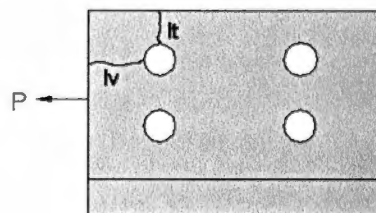


Figure 2.13 Block Shear Path 1-1-L

Path #1: 1-L, %P = 0.25* (See Figure 2.13)

***Note:** Only one of the four holes are involved in the block shear path, therefore only one-fourth of the load is associated with fracture path 1-L, whereby, %P = 0.25.

$$A_{gv} = l_v t = (1.25)(.25) = .313 \text{ in}^2$$

$$A_{nv} = A_{gv} - n_h \left(d_b + \frac{1}{8} \right) t = .313 - .5 \left(\frac{3}{4} + \frac{1}{8} \right) \frac{1}{4} = .203 \text{ in}^2$$

$$A_{gt} = l_t t = (1.00)(.25) = 0.25 \text{ in}^2$$

$$A_{nt} = A_{gt} - n_h \left(d_b + \frac{1}{8} \right) t = A_{gt} - 0.5 \left(\frac{3}{4} + \frac{1}{8} \right) \frac{1}{4} = .141 \text{ in}^2$$

$$\begin{array}{ll} \text{If} & F_u A_{nt} \geq 0.6 F_u A_{nv} \\ \text{then} & P_{nb}' = 0.6 F_y A_{gv} + F_u A_{nt} \\ \text{else} & P_{nb}' = 0.6 F_u A_{nv} + F_y A_{gt} \end{array}$$

$$F_u A_{nt} = (65)(.141) = 9.14 \text{ kips}$$

$$0.6 F_u A_{nv} = 0.6 (65)(.203) = 7.92 \text{ kips}$$

$\therefore$

$$F_u A_{nt} \geq 0.6 F_u A_{nv}$$

$$P_{nb}' = 0.6 F_y A_{gv} + F_u A_{nt} = (0.6)(50)(.313) + (65)(.141) = 18.54 \text{ kips}$$

$$P_{nb} = \frac{P_{nb}'}{\%P} = \frac{18.54}{.25} = 74.16 \text{ kips}$$

Therefore, the design load for block shear path 1 - L is,

$$T_{b1} = \phi_b P_{nb} = (0.75)(74.16) = 55.62 \text{ kips}$$

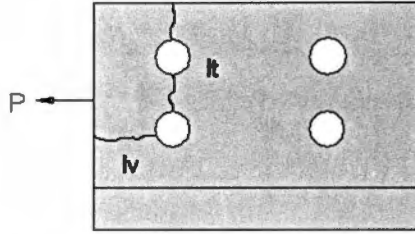


Figure 2.14 Block Shear Path 2-1-L

Path #2: 2-1-L, %P = 0.50* (See Figure 2.14)

*Note: Two of the four holes are involved in the block shear path, therefore only half of the load is associated with fracture path 2-1-L, whereby, %P = 0.50.

$$A_{gv} = l_v t = (1.25)(.25) = .313 \text{ in}^2$$

$$A_{nv} = A_{gv} - n_h \left(d_b + \frac{1}{8} \right) t = .313 - .5 \left(\frac{3}{4} + \frac{1}{8} \right) \frac{1}{4} = .203 \text{ in}^2$$

$$A_{gt} = l_t t = (2.75)(.25) = .688 \text{ in}^2$$

$$A_{nt} = A_{gt} - n_h \left(d_b + \frac{1}{8} \right) t = .688 - 1.5 \left(\frac{3}{4} + \frac{1}{8} \right) \frac{1}{4} = .360 \text{ in}^2$$

$$\begin{array}{ll} \text{If} & F_u A_{nt} \geq 0.6 F_u A_{nv} \\ \text{then} & P'_{nb} = 0.6 F_y A_{gv} + F_u A_{nt} \\ \text{else} & P'_{nb} = 0.6 F_u A_{nv} + F_y A_{gt} \end{array}$$

$$F_u A_{nt} = (65)(.360) = 23.40 \text{ kips}$$

$$0.6 F_u A_{nv} = (0.6)(65)(.203) = 7.92 \text{ kips}$$

∴

$$F_u A_{nt} \geq 0.6 F_u A_{nv}$$

$$P'_{nb} = 0.6F_y A_{gv} + F_u A_{nt} = (0.6)(50)(.313) + (65)(.360) = 32.77 \text{ kips}$$

$$P_{nb} = \frac{P'_{nb}}{\%P} = \frac{32.77}{.50} = 65.54 \text{ kips}$$

Therefore, the design load for block shear path 2 - 1 - L is,

$$T_{b2} = \phi_f P_{nb} = (0.75)(65.54) = 49.15 \text{ kips}$$

Path #3: 1-3-L, %P = 0.50* (See Figure 2.15)

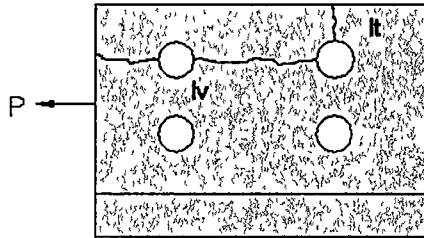


Figure 2.15 Block Shear Path 1-3-L

*Note: Two of the four holes are involved in the block shear path, therefore only half of the load is associated with fracture path 1-3-L, whereby, %P = 0.50.

$$A_{gv} = l_v t = (3.50)(.25) = .875 \text{ in}^2$$

$$A_{nv} = A_{gv} - n_h \left(d_b + \frac{1}{8} \right) t = .875 - 1.5 \left(\frac{3}{4} + \frac{1}{8} \right) \frac{1}{4} = .547 \text{ in}^2$$

$$A_{gt} = l_t t = (1.00)(.25) = .250 \text{ in}^2$$

$$A_{nt} = A_{gt} - n_h \left(d_b + \frac{1}{8} \right) t = .250 - 0.5 \left(\frac{3}{4} + \frac{1}{8} \right) \frac{1}{4} = .141 \text{ in}^2$$

If $F_u A_{nt} \geq 0.6 F_u A_{nv}$
 then $P'_{nb} = 0.6 F_y A_{gv} + F_u A_{nt}$
 else $P'_{nb} = 0.6 F_u A_{nv} + F_y A_{gt}$

$$F_u A_{nt} = (65)(.141) = 9.17 \text{ kips}$$

$$0.6 F_u A_{nv} = (0.6)(65)(.547) = 21.33 \text{ kips}$$

$\therefore$

$$0.6 F_u A_{nv} > F_u A_{nt}$$

$$P'_{nb} = 0.6 F_u A_{nv} + F_y A_{gt} = (0.6)(65)(.547) + (50)(.250) = 33.83 \text{ kips}$$

$$P_{nb} = \frac{P'_{nb}}{\%P} = \frac{33.83}{.50} = 67.66 \text{ kips}$$

Therefore, the design strength for block shear path 1 - 3 - L is,

$$T_{b3} = \phi_b P_{nb} = (0.75)(67.66) = 50.75 \text{ kips}$$

Path #4: 2-4-3-L, %P = 1.00* (See Figure 2.16)

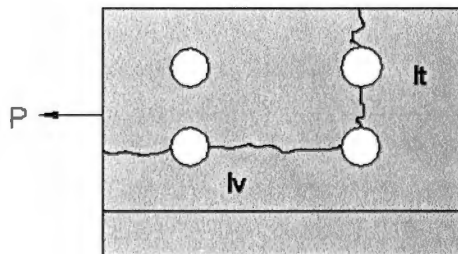


Figure 2.16 Block Shear Path 2-4-3-L

*Note: All four holes are involved in the block shear path,
therefore the entire load is associated with
fracture path 2-4-3-L, whereby, %P = 1.00.

$$A_{gv} = l_v t = (3.50)(.25) = .875 \text{ in}^2$$

$$A_{nv} = A_{gv} - n_h \left(d_b + \frac{1}{8} \right) t = .875 - 1.5 \left(\frac{3}{4} + \frac{1}{8} \right) \frac{1}{4} = .547 \text{ in}^2$$

$$A_{gt} = l_t t = (2.75)(.25) = .688 \text{ in}^2$$

$$A_{nt} = A_{gt} - n_h \left(d_b + \frac{1}{8} \right) t = .688 - 1.5 \left(\frac{3}{4} + \frac{1}{8} \right) \frac{1}{4} = .360 \text{ in}^2$$

If $F_u A_{nt} \geq 0.6 F_u A_{nv}$
then $P'_{nb} = 0.6 F_y A_{gv} + F_u A_{nt}$
else $P'_{nb} = 0.6 F_u A_{nv} + F_y A_{gt}$

$$F_u A_{nt} = (65)(.360) = 23.40 \text{ kips}$$

$$0.6 F_u A_{nv} = (0.6)(65)(.547) = 21.33 \text{ kips}$$

$\therefore$

$$F_u A_{nt} \geq 0.6 F_u A_{nv}$$

$$P'_{nb} = 0.6 F_y A_{gv} + F_u A_{nt} = (0.6)(50)(.875) + (65)(.360) = 49.65 \text{ kips}$$

$$P_{nb} = \frac{P'_{nb}}{\%P} = \frac{49.65}{1.00} = 49.65 \text{ kips}$$

Therefore, the design strength for block shear path 2 - 4 - 3 - L is,

$$T_{b4} = \phi_b P_{nb} = (0.75)(49.65) = 37.23 \text{ kips}$$

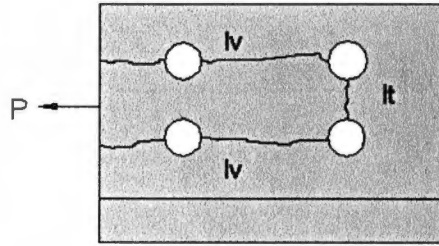


Figure 2.17 Block Shear Path 2-4-3-1-U

Path #5: 2-4-3-1-U, %P = 1.00* (See Figure 2.17)

*Note: All four holes are involved in the block shear path,

therefore the entire load is associated with

fracture path 2-4-3-1-U, whereby, %P = 1.00.

$$A_{gv} = l_v t = (7.00)(.25) = 1.75 \text{ in}^2$$

$$A_{nv} = A_{gv} - n_h \left(d_b + \frac{1}{8} \right) t = 1.75 - 3.0 \left(\frac{3}{4} + \frac{1}{8} \right) \frac{1}{4} = 1.09 \text{ in}^2$$

$$A_{gt} = l_t t = (1.75)(.25) = .438 \text{ in}^2$$

$$A_{nt} = A_{gt} - n_h \left(d_b + \frac{1}{8} \right) t = .438 - 1.0 \left(\frac{3}{4} + \frac{1}{8} \right) \frac{1}{4} = .219 \text{ in}^2$$

If $F_u A_{nt} \geq 0.6 F_u A_{nv}$

then $P_{nb}' = 0.6 F_y A_{gv} + F_u A_{nt}$

else $P_{nb}' = 0.6 F_u A_{nv} + F_y A_{gt}$

$$F_u A_{nt} = (65)(.219) = 14.24 \text{ kips}$$

$$0.6 F_u A_{nv} = (0.6)(65)(1.09) = 42.51 \text{ kips}$$

∴

$$0.6 F_u A_{nv} > F_u A_{nt}$$

$$P_{nb}' = 0.6 F_u A_{nv} + F_y A_{gt} = (0.6)(65)(1.09) + (50)(.438) = 64.41 \text{ kips}$$

$$P_{nb} = \frac{P'_{nb}}{\%P} = \frac{64.41}{1.00} = 64.41 \text{ kips}$$

Therefore, the design load for block shear path 2 - 4 - 3 - 1 - U is,

$$T_{nb} = \phi_b P_{nb} = (0.75)(64.41) = 48.31 \text{ kips}$$

Path #6: 2-1-U, %P = .50* (See Figure 2.18)

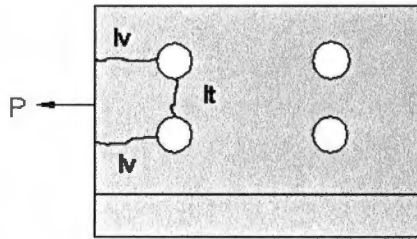


Figure 2.18 Block Shear Path 2-1-U

*Note: Two of the four holes are involved in the block shear path, therefore only half of the load is associated with fracture path 2-1-U, whereby, %P = 0.50.

$$A_{gv} = l_v t = (2.50)(.25) = .625 \text{ in}^2$$

$$A_{nv} = A_{gv} - n_h \left(d_b + \frac{1}{8} \right) t = .625 - 1.0 \left(\frac{3}{4} + \frac{1}{8} \right) \frac{1}{4} = .406 \text{ in}^2$$

$$A_{gt} = l_t t = (1.75)(.25) = .438 \text{ in}^2$$

$$A_{nt} = A_{gt} - n_h \left(d_b + \frac{1}{8} \right) t = .438 - 1.0 \left(\frac{3}{4} + \frac{1}{8} \right) \frac{1}{4} = .219 \text{ in}^2$$

$$\begin{array}{ll} \text{If} & F_u A_{nt} \geq 0.6 F_u A_{nv} \\ \text{then} & P_{nb}' = 0.6 F_y A_{gv} + F_u A_{nt} \end{array}$$

$$\text{else } P'_{nb} = 0.6F_u A_{nv} + F_y A_{gt}$$

$$F_u A_{nt} = (65)(.219) = 14.24 \text{ kips}$$

$$0.6F_u A_{nv} = (0.6)(65)(.406) = 15.83 \text{ kips}$$

$\therefore$

$$0.6F_u A_{nv} > F_u A_{nt}$$

$$P'_{nb} = 0.6F_u A_{nv} + F_y A_{gt} = (0.6)(65)(.406) + (50)(.438) = 37.73 \text{ kips}$$

$$P_{nb} = \frac{P'_{nb}}{\%P} = \frac{37.73}{.50} = 75.46 \text{ kips}$$

Therefore, the design load for block shear path 2 - 1 - U is,

$$T_{b6} = \phi_b P_{nb} = (0.75)(75.46) = 56.59 \text{ kips}$$

The governing block shear load comes from the path with the lowest design load:

$$Final T_b = \min[T_{b1}, T_{b2}, T_{b3}, T_{b4}, T_{b5}, T_{b6}]$$

$$= \min[55.62, 49.15, 50.75, 37.23, 48.31, 56.59] \text{ kips}$$

$$T_b = 37.23 \text{ kips}$$

Therefore, the governing load in fracture is 37 kips and the controlling block shear path is path #4.

Design Strength

The design strength, T , for the tensile member connection is the lowest design load obtained from the limit states of tensile yield(T_t), fracture(T_f), and block shear(T_b), .

$$T = \min[T_t, T_f, T_b]$$

$$= \min[87, 52, 37] \text{ kips}$$

$$= 37 \text{ kips}$$

From this it can be seen that the maximum allowable design load for the tensile member connection is 37 kips. The method of failure resulting from this design load is block shear. The controlling failure path associated with the block shear failure is Path #4 as seen in Figure 2.19.

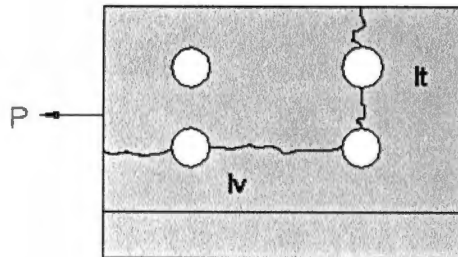


Figure 2.19 Controlling Failure Path - Block Shear Path #4

Chapter 3

Introducing *The Tension Connection Analyzer*

Welcome to the *Tension Connection Analyzer*. It is the intent of this program to enhance student's understanding on the response of tensile members with pinned connections through the use of computer-aided simulation. Whether the user is relatively new to the analysis of tensile members or has a working knowledge of the analytical process, the *Tension Connection Analyzer* can help improve comprehension of this topic. The program has a Windows based environment complete with toolbars, dropdown menus, and a comprehensive help file, which guides the user through a sample session. In short, the *Tension Connection Analyzer* is designed with the student in mind, and consequently contains the tools necessary to create an effective learning environment.

Since the program is intended to help students comprehend the topic of tensile member analysis, it is designed for use both inside and outside the classroom. The *Tension Connection Analyzer* has both a demonstration and an analysis mode.

Demonstration mode is intended more for the overall presentation of tensile member design strength analysis as it gives both a mathematical and an animated graphical representation of the primary failure modes. This mode allows the instructor to exhibit various bolt patterns and their animated failures rapidly and thoroughly. The animation portion of the demonstration mode shows propagation of mode failures through the connection, allowing the students to view dynamic real-time examples versus the static before and after models of the failures.

Also, the demonstration mode allows for a cost-effective method of meeting the needs of the sensing students. Previous in-class examples would have to consist of fabricated, small-scale connection systems. These systems generally can only exhibit a single failure path, thereby making it very costly to generate several examples. The *Tension Connection Analyzer* allows the instructor to show up to ten different failure paths for both fracture and block shear, for up to six different bolt patterns, for angles, channels, or W-shapes. The visualization of the failure modes and their paths is made possible through the use of the “VCR” controls.

The VCR allows for the top ten controlling failure paths for fracture and block shear to be viewed by the user. It displays the failure paths along with their corresponding failure loads. The VCR is intended to help the user get a feel for how the failure loads for different failure paths compare to one another. The user can scroll through the different paths and view the failure simulation by selecting the play button. The calculations screen accompanies the VCR. Each individual failure path on the VCR will have its own failure load. However, the calculation screen only consists of the computations for the controlling fracture and block shear paths for the chosen bolt pattern. The combination of visualization and computation was created for the sensing style student as a means of providing a concrete example. With all of the mentioned features of this mode, it can be seen that the intention of the demonstration mode is to enhance the experience of the sensing student. The focus of the analysis mode, on the other hand, is to allow all students the ability to put their understanding of the behavior of tensile members to work.

The analysis mode of the *Tension Connection Analyzer* allows for direct study of specific failure paths. This study is performed through user input of all the necessary, path-specific variables. Whereas the demonstration mode consists of both graphical and mathematical representation of the failure paths, the analysis mode only displays the computations since the user has already chosen a path. This mode presents a means by which those students with an established background in tensile member analysis can test specific paths for failure.

At first, some may view this mode of the program as a “cheat” tool for students to complete their homework. However, upon further review it can be seen that the students must have a working knowledge of all of the variables necessary to define a specific failure path. This understanding of all necessary variables is the actual focus of the topic of tensile member strength. The number crunching is strictly a formality of the analysis. Also, the analysis mode does not tell the student whether or not the chosen path controls the design, but rather only computes and displays the design strength based on the individual pathway chosen by the student. The student must then generate alternate variable values to describe various other possible failure paths in order to produce a satisfactory, realistic, and complete analysis of the system. Solutions of this type include design parameters such as: lightest cross-section, number of rows of fasteners, number of fasteners per row, and size of fasteners used in the connection. These parameters have been taken into consideration in order to complete the design experience of the *Tension Connection Analyzer*.

The *Tension Connection Analyzer* not only serves as a means to visualize and solve for tensile member behavior, but also encompasses the process of engineering

design. This process includes design based on realistic specifications, restraints, and performance criteria. The specifications include all sizes of cross-sections found in the second edition of the LRFD manual [2] for angles, channels, and W-shapes. They include a choice between A36 and A572 steel for the cross-sections, and A325 and A490 steel for the bolts. Also, there is a choice of bolt diameters ranging from $\frac{1}{2}$ in. to $1\frac{1}{4}$ in., in $\frac{1}{8}$ in. increments, using U.S. Customary units. These parameters allow the *Tension Connection Analyzer* to act as a design tool and not just a solver. By allowing the user to choose the attributes of the connection, they must keep in mind such factors as:

- “Am I using the lightest cross-section possible to minimize cost?”
- “Should I increase the cross-sectional area or change to a stronger steel?”
- “Would adding another row of bolts be realistic or beneficial?”

All of these questions are considerations in tensile member design. Consequently, they are all included in the *Tension Connection Analyzer*. For example, as the user goes through the program he or she has the ability to choose between factors such as material strength, cross-section, and bolt size. Once the design strength for the input criteria is produced, the user can then go back through and change any desired parameters and then compare the results. For example, if a smaller cross-section were used in order to cut down on the cost of the material, would it sacrifice too much strength and become unsafe? The ability to print out any screen in the program allows for load comparisons to

be made as the user changes different design parameters. For questions on how the *Tension Connection Analyzer* works there is a comprehensive on-line help file.

The help file exists not only to assist users through the program step-by-step; it also helps in communicating the language of tensile connections through definitions and explanations. The help file consists of a short summary on the foundation of tensile connections, as well as some of the ideology behind each of the modes, demonstration and analysis. It then takes the user through a sample session of the program showing screen shots for each of the interfaces that the user will be shown. The *Tension Connection Analyzer* is self-guided in that if certain parameters are not selected, the program prompts the user for the necessary details. However, if the user does not understand why a particular parameter is necessary to continue, the help file contains detailed descriptions of the requirements of each screen. Also, the help file contains a complete listing of all the variables used in the calculations, as well as their units of measure.

* The sections to follow have been taken directly from the program's on-line help file.

How The Program Works

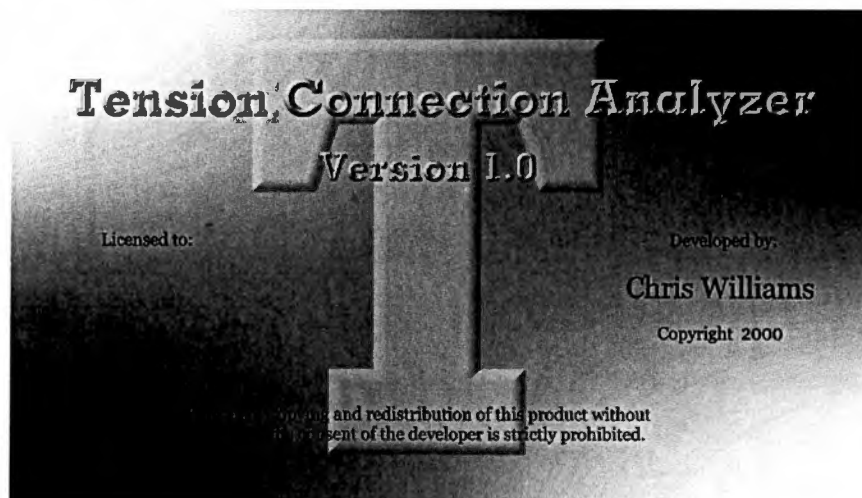


Figure 3.1 Splash Screen Showing Title and Copyright Information

About The Program

Figure 3.1 above shows the splash screen presented to the user as the program loads. This program serves as an educational tool for both the analysis and demonstration of tensile member performance. Tensile members can fail in three possible modes: tensile yield, fracture and block shear. Tensile yield maintains that the design strength of a given cross-section of material is lower than the limit states of the given cross-section. Failure of this manner occurs away from the connection. Tensile fracture forces the design strength of a connection to be less than the ultimate strength of the material coupled with the effective net area of the cross-section. Fracture failure occurs through the holes of a given connection. Block shear is a combination of yielding and fracture. It is a limiting state that is determined by the sum of the shear strength and tensile strength along a particular failure path. For each individual tensile connection one of these three limiting factors controls what is known as the design strength of the

connection. This program is designed to give the user the ability to determine what the design strength is for specific connections.

The program can be run in two different modes, demonstration and analysis. Demonstration mode is intended more for the overall presentation of tensile connections as it gives both a mathematical and graphical representation of the main failure modes. The mathematical representation of the design characteristics allows the user to view the equations and subsequent values for the variables based on the decisions made while stepping through the program. The graphical representation consists of animations that allow the user to view the propagation of different failure paths for both fracture and block shear. This mode is intended to help those students who learn best from seeing numerous examples.

Analysis mode allows for direct study of specific failure paths for specifically designed connections. This mode gives the user the opportunity to input all of the variables for a desired path. Since the user knows what their path looks like, this mode only consists of a mathematical representation of the calculations.

Getting Started

When the program first begins the screen shown in Figure 3.2 is what appears to the user. The user must click the start button in order to begin moving through the program. The user has a choice between two different modes, analysis and demonstration. Figure 3.3 shows the screen presented to the user that allows for the selection of the desired mode. As seen, the analysis mode is selected and then the user would hit the start button in order to move to the next screen.

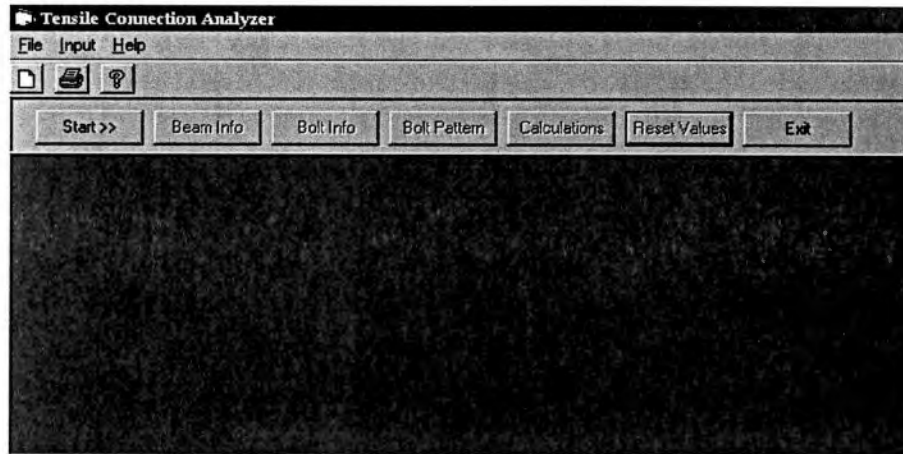


Figure 3.2 Opening Screen Presented to the User

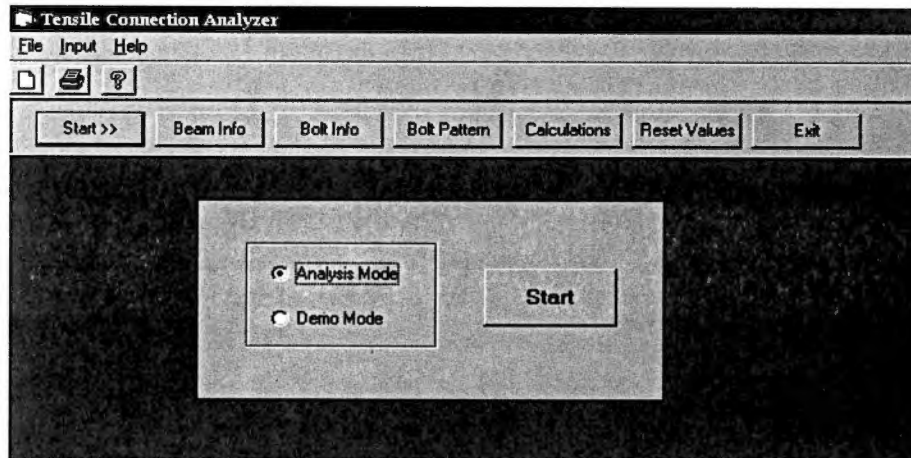


Figure 3.3 Screen Allowing the User to Choose a Mode

Material

This screen allows the user to decide upon two main factors for the member, the grade of steel and the type of cross-section. As shown in Figure 3.4, the user has the choice between A36 and A572 steel. A36 has a yield strength of 36 ksi and an ultimate strength of 58 ksi. A572 has a yield strength of 50 ksi and an ultimate strength of 70 ksi. After selecting the grade, the choice can be made among W-shape, Channel, and Angle sections.

One choice out of each box must be selected, as shown in Figure 3.5, before the user is allowed to continue. Once the material and shape have been selected, the user must then click the available command button in order to move to the next screen and view the properties for the chosen cross-section.

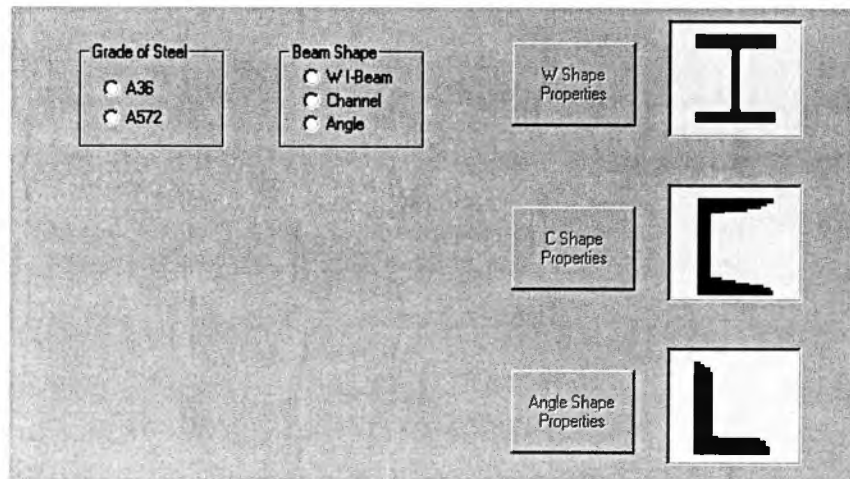


Figure 3.4 Beam Properties Screen

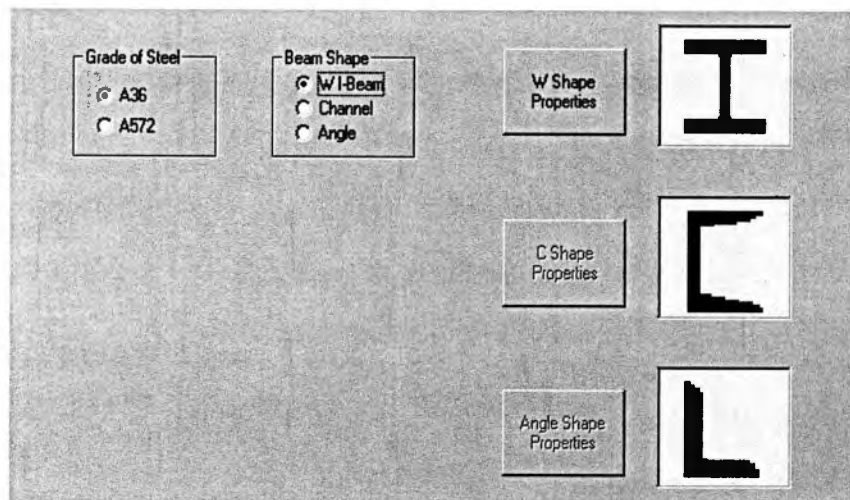


Figure 3.5 Grade and Shape Must Be Selected Before Continuing

Types of Cross Sections

The properties for a given cross-section are the standards from the American Institute of Steel Construction (AISC) as found in the Load and Resistance Factor Design Volume I [2]. Once the desired cross-section has been chosen, the screen in Figure 3.6 is displayed to the user.

W Shapes Dimensions

Shape and Size:

(A) area	88.3	(in ²)	(bf) flange width	16.655	(in)
(d) depth	36.72	(in)	(tw) web thickness	0.945	(in)
(T) distance	33.72	(in)	(tf) flange thickness	1.68	(in)

Diagram: A cross-section of a W-shape with dimensions labeled: Y (vertical axis), X (horizontal axis), d (depth), T (flange thickness), bf (flange width), tw (web thickness), and tf (flange thickness).

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Figure 3.6 W Shape Properties Screen

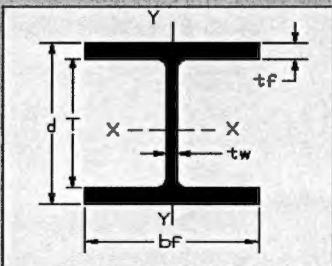
This example demonstrates the W Shape properties screen. Similar screens are included if the user chooses an angle and channel section. The screen allows the user to view the numeric values of the given properties as well as the graphical display of the properties. The shape and size properties for each of the cross-sections consist of a dropdown list that allows the user to choose a specific size for analysis. Figure 3.7 shows the geometric properties of a W36x300 section. By selecting the down arrow to the right of the “Shape and Size” property box, the user can access the corresponding database. The user can then scroll down through the database and highlight the desired size. The user must then continue through the program by selecting the next button, or return to the previous screen by using the back button. Also, at anytime the user can jump

W Shapes Dimensions

	Shape and Size	W36x300		
		W36x280		
		W36x260		
		W36x240		
		W36x230		
		W36x300		
		W36x182		
		W36x170		

(A) area	88.3	(in ²)	18.655	(in)
(d) depth	36.72	(in)	0.945	(in)
(T) distance	33.72	(in)	1.68	(in)

(t) flange thickness



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Figure 3.7 Example of Dropdown List

directly to a specific screen by using the dropdown menus or by selecting the corresponding command button, as previously shown in the Getting Started section.

Bolt Information

This section of the program allows the user to select the size of the bolts that are to be used in the connection. Figure 3.8 shows an example of the bolt properties screen. This screen allows the user to choose the grade of the bolts, the shape of the bolt head, and the diameter of the bolts. The properties displayed on this screen are shown on the right in Figure 3.8 except for the edge distances Le' and Le . The variable Le' refers to the vertical edge distance between the centerline of the exterior row of bolts and the edge of the member. Le refers to the horizontal edge distance between the centerline of the bolts closest to the edge and the end of the member. The edge distances are given as defaulted values in the demo mode. A grade of steel must first be selected before the head style option can be accessed. Also, there is a dropdown list for bolt diameters that allows the user to select a diameter from a database. Again, both property options must be selected before the user is allowed to continue to the next step as shown in Figure 3.9.

Grade of Steel

☐ A325

☐ A490

Style of Head

☐ Square

☐ Hex

Hexagonal Head

Bolt Diameter (in)

0.5

Bolt Properties

	Square	Hex
F	0.75 (in)	0.75 (in)
C	1.0625 (in)	0.875 (in)
H	0.3125 (in)	0.375 (in)
Le	0.875 (in)	
Le'	0.75 (in)	

Square Head

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Figure 3.8 Bolt Properties Screen

Grade of Steel

☐ A325

☐ A490

Style of Head

☐ Square

☐ Hex

Hexagonal Head

Bolt Diameter (in)

0.5
0.625
0.75
0.875
1
1.125
1.25

Bolt Properties

	Square	Hex
F	0.75 (in)	0.75 (in)
C	1.0625 (in)	0.875 (in)
H	0.3125 (in)	0.375 (in)
Le	0.875 (in)	
Le'	0.75 (in)	

Square Head

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Figure 3.9 Bolt Properties Screen

Bolt Pattern Information (Analysis Mode Only)

The pattern makeup screen appears to the user only if analysis mode was selected at the beginning of the session. This screen, shown in Figure 3.10, allows the user to select the number of rows of bolts in the connection and whether the connection is square or staggered in design. Once both properties have been selected, the user can click the enabled button to go on to the next screen. An example of this is shown in Figure 3.11.

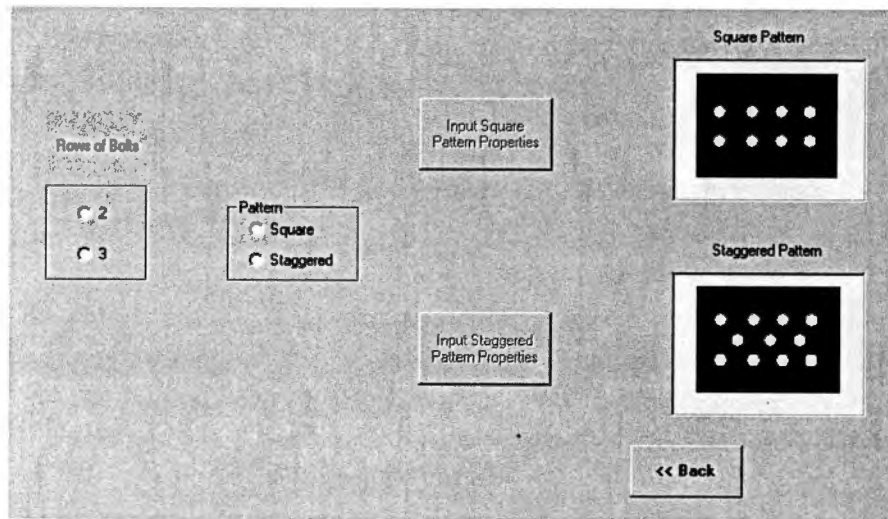


Figure 3.10 Pattern Makeup Screen

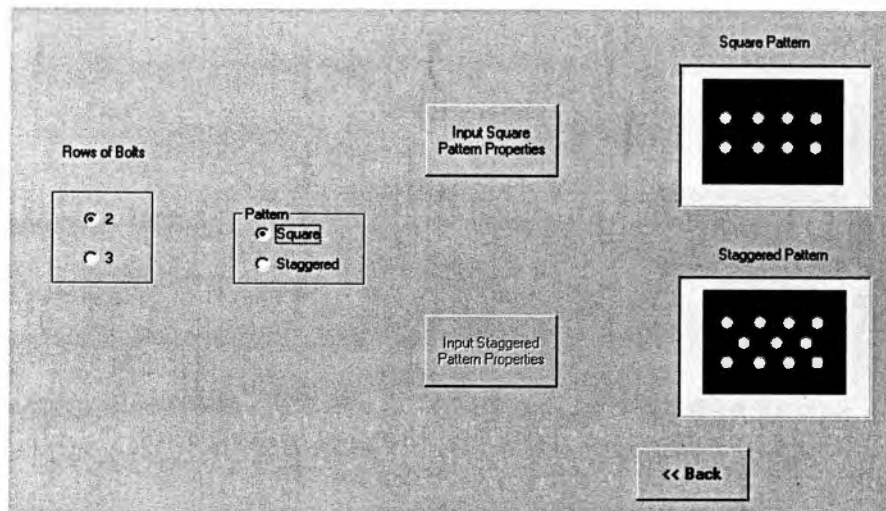
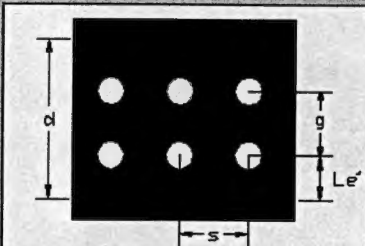


Figure 3.11 Square Pattern Selected

Enter the necessary values for the following variables:

Length of tensile surface in web (ltw)	(in)	Number of diagonal paths fracture (ndf)	
Length of shear surface in web (lv)	(in)	Number of diagonal paths block shear (ndv)	
Number of holes in tension (nt)		Number of Holes in fracture path (nbf)	
Number of holes in shear (ns)		Percent of Load Carried by Fracture Path (%F)	%
Vertical Spacing of bolts (g)	(in)	Percent of Load Carried by Block Shear Path (%P)	%
Horizontal Spacing of bolts (s)	(in)	Total horizontal spacing from left end bolt to right end bolt (L)	(in)



Does the path involve a flange?

☐ Yes ☐ No

Figure 3.12 Blank Square Pattern Variable Screen

The square pattern screen allows the user to input all of the variables necessary to complete the analysis of a user specific square connection pattern. The variables, shown in Figure 3.12, give the user the ability to design and test a specific fracture and block failure paths. The input variables allow for the user to test both a fracture and a block shear failure path. A description of the variables can be seen below.

Square Pattern Variables:

Tensile Load - A load that pulls on an object in a direction perpendicular to the cross-sectional area.

Shear Load - A load that acts on an object in a direction parallel to the applied load.

Length of tensile surface in the web (ltw) - The total length, in the web of a channel or W-section member, that supports a tensile load (for angle sections, ltw is the total length of the tensile surface).

Length of shear surface in the web (lv) - The total length that supports a shear load.

Number of holes in tension (nt) - The number of holes in the studied failure path that support a tensile load.

Number of holes in shear (ns) - The number of holes in the studied failure path the support a shear load.

Vertical spacing of bolts (g) - The vertical distance between any two adjacent rows of bolts.

Horizontal spacing of bolts (s) - The horizontal distance between any two adjacent lines of bolts.

Number of diagonal paths in fracture (ndf) - The number of different diagonal segments of a given fracture path.

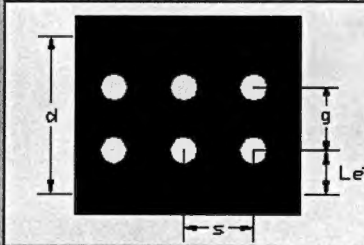
Number of diagonal path in block shear (ndv) - The number of different diagonal segments of a given block shear path.

Percent load carried by fracture (%F) and block shear (%P) - The percentage of the load is determined by the number of holes in the free body diagram of the specified path versus the total number of holes in the connection.

Total horizontal spacing of bolts (L) - The total distance between end bolts of a connection.

Does the path contain a flange? This tells the program to include the area of the flange in the calculations for the net cross-sectional area. The response for an angle section is always no.

Enter the necessary values for the following variables:

Length of tensile surface in web (ltw) 3.25 (in)	Number of diagonal paths fracture (ndf) 1	
Length of shear surface in web (lv) 2.50 (in)	Number of diagonal paths block shear (ndv) 0	
Number of holes in tension (nt) 1.5	Number of Holes in fracture path (nhf) 2	
Number of holes in shear (ns) 1.5	Percent of Load Carried by Fracture Path (%F) 75 %	
Vertical Spacing of bolts (g) 2.00 (in)	Percent of Load Carried by Block Shear Path (%P) 100 %	
Horizontal Spacing of bolts(s) 1.5 (in)	Total horizontal spacing from left end bolt to right end bolt (L) 1.5 (in)	

Does the path involve a flange?
☒ Yes
☐ No

Figure 3.13 Filled Out Square Pattern Variable Screen

Figure 3.13 shows an example of a completed pattern variable screen. All of the variables must be completed before the program will allow the user to proceed. At any time the user can press the reset variables button in order to zero all values and start again. The staggered pattern screen contains the same variables as that of the square pattern, and is filled out in the same manner. For any questions concerning the staggered pattern screen see the square pattern section.

Bolt Pattern Information (Demo Mode Only)

In demo mode, this screen only allows the user to control one factor of the connection design, the gauge length. The gauge length is the vertical spacing between two adjacent rows of bolts. The user is then given the opportunity to choose the connection pattern to be analyzed. Figure 3.14 below shows the interface presented to the user.

The user is required to enter a gauge length between one and three inches into the text box. Any value not within this range will produce an error. Likewise, if the depth of the chosen cross-section cannot support the entered gauge length, an error is given. The

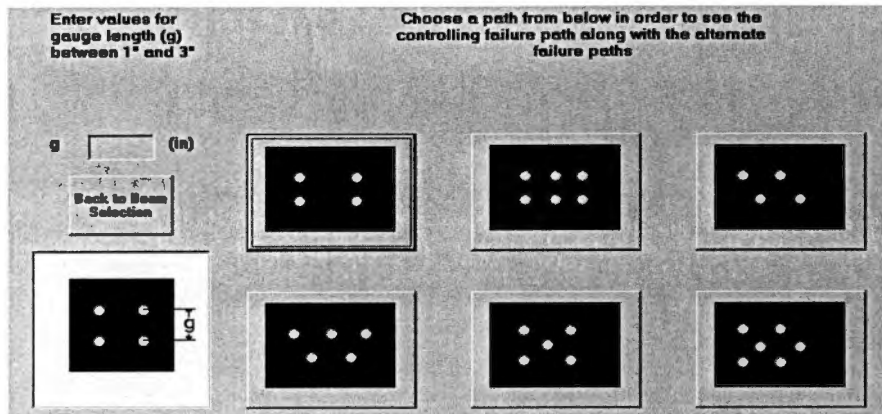


Figure 3.14 Blank Demo Mode Bolt Pattern Screen

user must then either change the gauge length or go back to the cross-section selection screen and select a section with a larger depth. Pressing the “back to beam” selection button accesses the cross-section selection screen.

Once the required gauge length has been entered, the user can select one of the six bolt patterns. By selecting one of the given patterns, the calculations for that pattern are performed based on the chosen design attributes. These calculations along with the animated failure paths are then viewed on the next screen.

Calculations

The calculations screen is comprised of four main areas: tensile yield, fracture on effective area, block shear, and design strength. The purpose of this screen is to give the user the ability to view the calculations associated with the parameters selected while stepping through the program. In demo mode, the VCR screen accompanies the calculations.

In Figure 3.15, the top portion of the calculations screen is shown. This part of the screen consists of the yield and fracture calculations. Yield and fracture are discussed in the About the Program section. The chosen design characteristics also appear on this

part of the screen. The characteristics are shown as a reminder to the user of what cross-section, grades of steel and bolt sizes were used in producing the calculations. All of the values that appear in the text boxes are values that are controlled by the user. Each of the values was produced by a design choice made by the user at some point in the program. Below is a list of the variables that appear in this section of the calculations.

- Pnt** - Nominal tensile Strength
- Ag** - Gross area of cross-section
- Fy** - Yield strength of chosen grade of steel
- Pnf** - Nominal fracture strength
- U** - Shear lag factor
- An** - Net area
- Fu** - Ultimate tensile strength of structural steel
- sg** - Adjustment for diagonal paths
- s** - Horizontal spacing between lines of bolts
- g** - Vertical spacing between rows of bolts
- nh** - Number of bolts involved in fracture path
- dia** - Diameter of bolts
- tw** - Thickness of the web of the given cross-section
- nd** - Number of diagonal paths in the given fracture path

The calculations for block shear are also shown as part of the calculated results. A brief discussion on block shear can be found in the About the Program section. Below is a list of new variables that appear in the block shear calculations.

Calculated Results

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Tensile Yield

$$P_{nt} = A_g \cdot F_y$$

$$= 88.3 \cdot 36$$

$$= 3178.8 \text{ kips}$$

Fracture of Effective Area

$$P_{nt} = U \cdot A_n \cdot F_u$$

$$= U \cdot A_n \cdot 58$$

$$sg = (s^2) / (4 \cdot g)$$

$$= (2.25^2) / (4 \cdot 2)$$

$$A_n = A_g - nh \cdot (dia + (1/8)) \cdot tw + nd \cdot (sg) \cdot (tw)$$

$$= 88.3 - 2 \cdot (0.75 + (1/8)) \cdot 0.945 + 0 \cdot 0.632 \cdot 0.945$$

$$U = 0.75$$

$$A_n = 86.646 \text{ in}^2$$

$$P_{nt} = 3769.11 \text{ kips}$$

Chosen Design Characteristics

Beam: W36x300

Grade: A36

Bolt Size: 0.75 in

Grade: A325

Figure 3.15 Top of Calculations Screen

- Agv** - Gross area in shear
- lv** - Shear length of failure path
- Anv** - Net area in shear
- ns** - Number of holes acting in shear
- Agt** - Gross area in tension
- ltw** - Length of tensile surface in web
- lfl** - Length of tensile surface in flange
- tf** - Thickness of flange for given cross section
- Ant** - Net area in tension
- nt** - Number of holes acting in tension

Block Shear

$A_{gv} = l_v \cdot t_w$
 $= 2 \cdot 0.945$
 $= 1.89 \text{ in}^2$

$A_{nv} = A_{gv} - n_s \cdot (d_{sa} + (1/8)) \cdot t_w$
 $= 1.89 - 1 \cdot 0.875 \cdot 0.945$
<<Back
 $= 1.0631 \text{ in}^2$

$A_{gt} = l_{tw} \cdot t_w + l_f \cdot t_f$
 $= l_{tw} \cdot 0.945 + 0 \cdot 0$
 $= 1.89 \text{ in}^2$

$A_{nt} = A_{gt} - n_t \cdot (d_{sa} + (1/8)) \cdot t_w + n_d \cdot$
 $= 1.89 - 1 \cdot 0.875 \cdot 0.945 + 0 \cdot 0.632 \cdot 0.945$
 $= 1.0631 \text{ in}^2$

If: $F_u \cdot A_{nt} \geq 0.6 \cdot F_u \cdot A_{nv}$ $P_{nb} = (0.6 \cdot F_y \cdot A_{gv} + F_u \cdot A_{nt}) / (\%P)$ $= 61.661 \text{ kips}$	If: $0.6 \cdot F_u \cdot A_{nv} > F_u \cdot A_{nt}$ $P_{nb} = (0.6 \cdot F_u \cdot A_{nv} + F_y \cdot A_{gt}) / (\%P)$ $= 36.996 \text{ kips}$
---	---

Figure 3.16 Block Shear Calculations

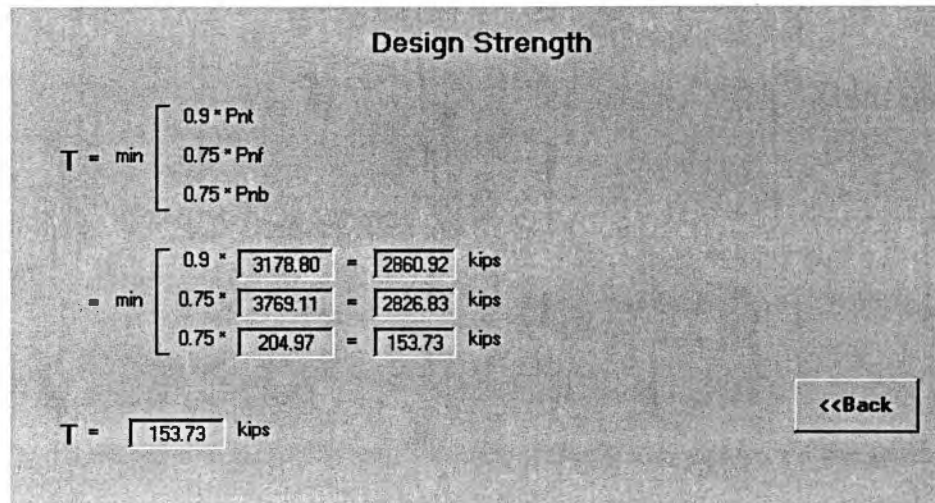


Figure 3.17 Design Strength Calculations

The final component of the calculated results is the design strength. The design strength is the minimum of the calculated values for yield, fracture, and block shear multiplied by a resistance factor. For tensile yield the resistance factor is 0.9. For fracture and block shear the reduction factor is 0.75. A sample of these calculations can be seen in Figure 3.17.

In the demo mode, the fracture and block shear calculations are for the controlling failure paths for each mode of failure. In analysis mode, the calculations are for the specific paths prescribed by the user.

VCR (Demo Mode Only)

This screen allows the user to view animations of the failure paths for fracture and block shear. This screen accompanies the calculation screen and is intended to help the user get a feel for how the different failure paths compare to one another. Figure 3.18 only shows the top half of this screen. The lower portion of the screen shows additional alternate failure paths. The maximum number of viewable failure paths is limited to ten.

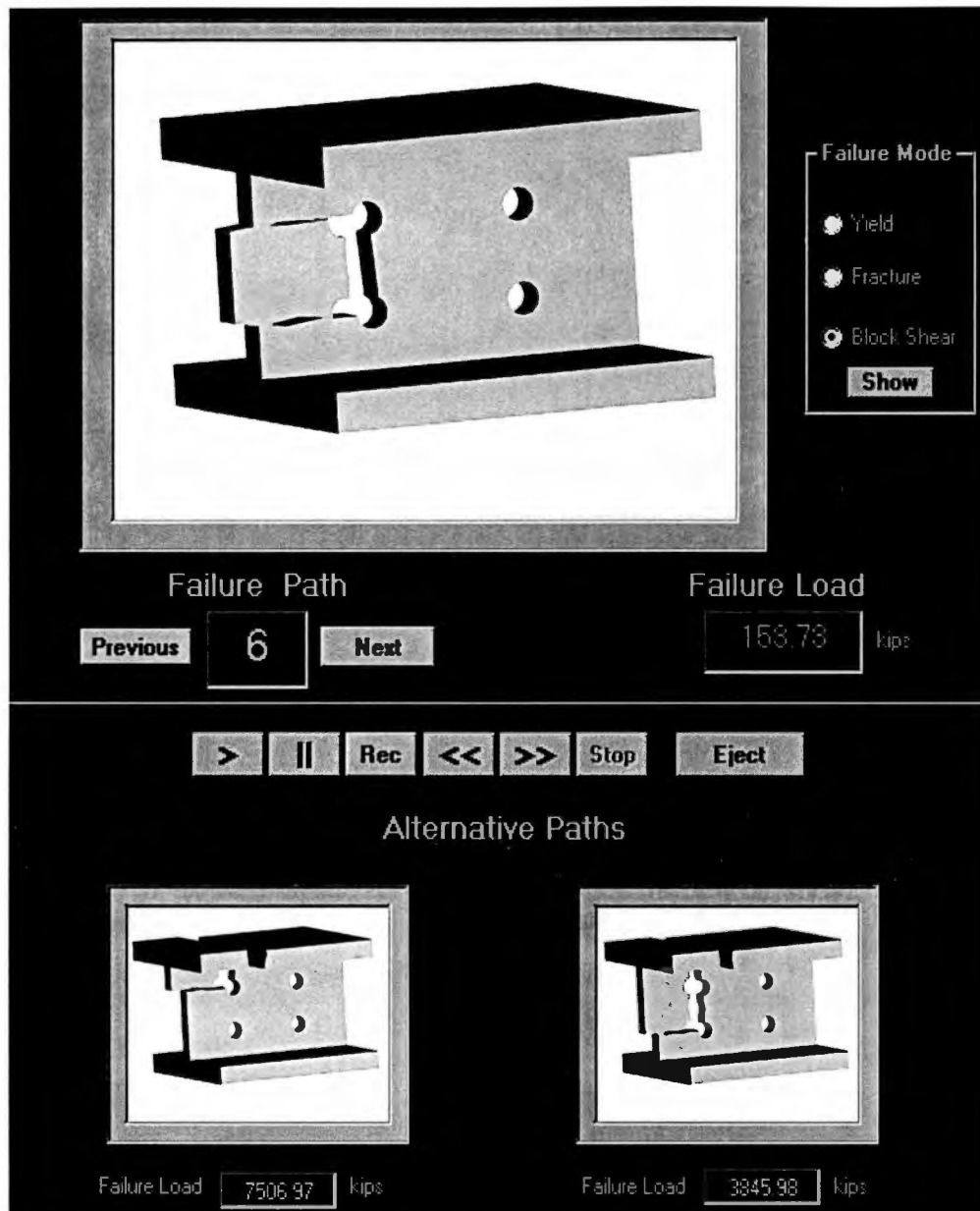


Figure 3.18 VCR Sample

The controlling failure path for the controlling failure mode is what first appears in the large display screen. The mode of failure can be seen to the right of the screen, and the load can be viewed in the failure load box. The displayed path is highlighted in blue in the alternative paths portion of the screen. In order to view the animation of the failure propagation, the user must click the play button (>). The user can click the next or

previous buttons to view alternative failure paths. Also, the user can select a different mode of failure, click show, and then have the failure paths for that mode displayed.

When the failure due to tensile yield is displayed, the user should notice that no alternative paths are shown. This is due to the fact that the yielding of the material occurs away from the connections and the stress is uniform throughout the length of the member. Therefore, the displayed animation is intended to exude that complete yielding of the cross-section occurs at the shown failure load.

It should be understood that for some of the more complicated bolt patterns more failure paths exist than are shown. However, for patterns with more possible failure paths than can be shown, the ten smallest failure loads are displayed.

Printing

To further aid the user in the understanding of the topic of tensile strength, all of the screens in the program can be printed. Printing of the screens can be done by one of two methods. One is through the use of the print option from the file menu as shown in Figure 3.19. The other method for printing utilizes the print icon on the main screen as shown in Figure 3.20. Both of these options produce the same result. The result is a printed output of the current screen on the monitor. Note that a total of four pages will be printed from the Calculated Results and VCR screen in the demo mode.

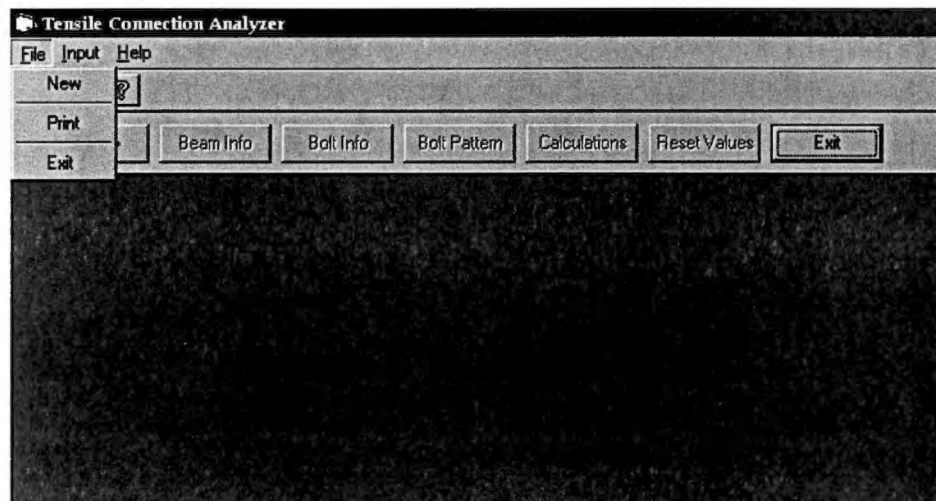


Figure 3.19 Printing Using the File Menu

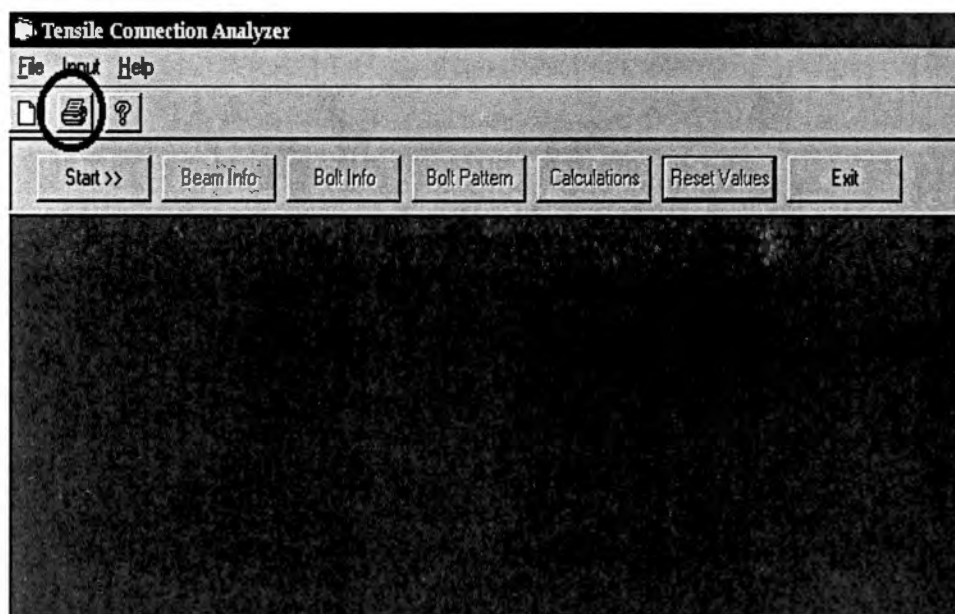


Figure 3.20 Printing Using the Print Icon

Program Example

The following series of figures displays a step-by-step progression through the program using the same example that was used previously in the sample calculations. Figure 3.21 shows the first screen that the user is presented with as the program starts. The user then selects the start button to proceed. The option is then presented as to which mode the user wants to use. In this example, demo mode is selected, Figure 3.22. By clicking the start command button, the user is taken to the screen shown in Figure 3.23. It should be noted that from this point on, the sample screens in the figures will only display portions of the actual screen. The user however should keep in mind that at all times the menus, icons, and command buttons shown in Figure 3.24 are visible.

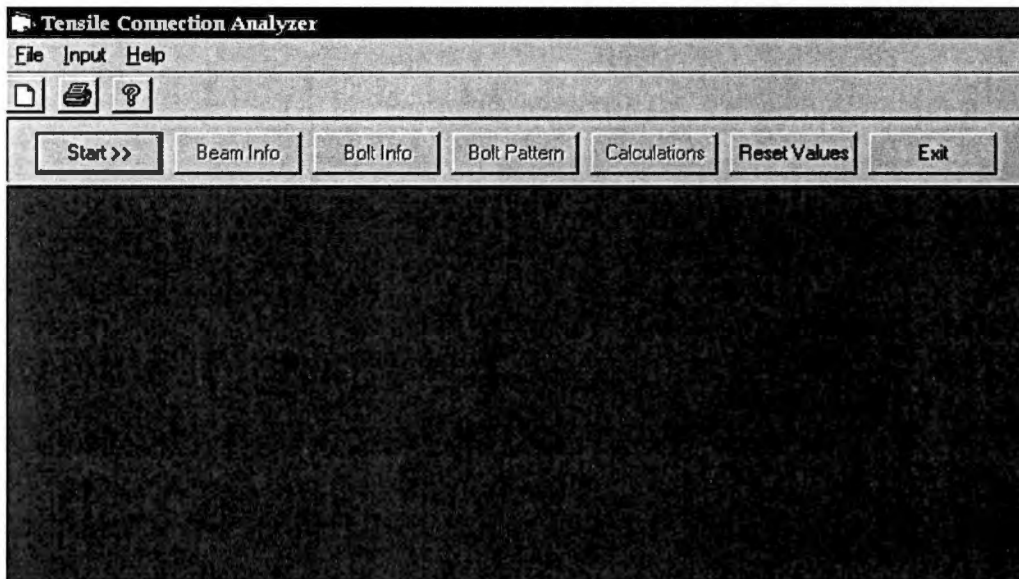


Figure 3.21 First Screen Presented

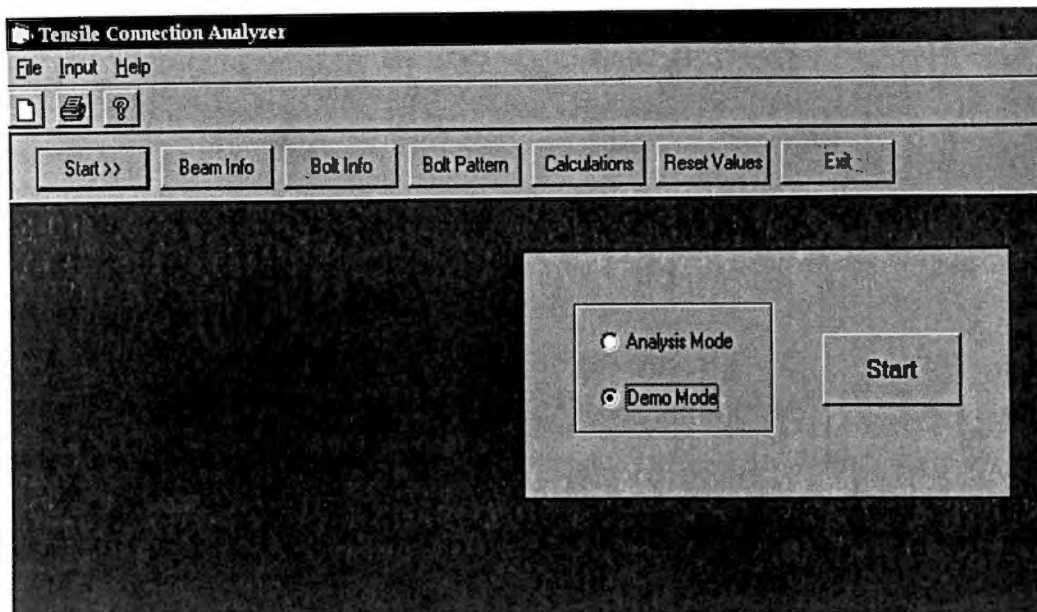


Figure 3.22 Mode Selection

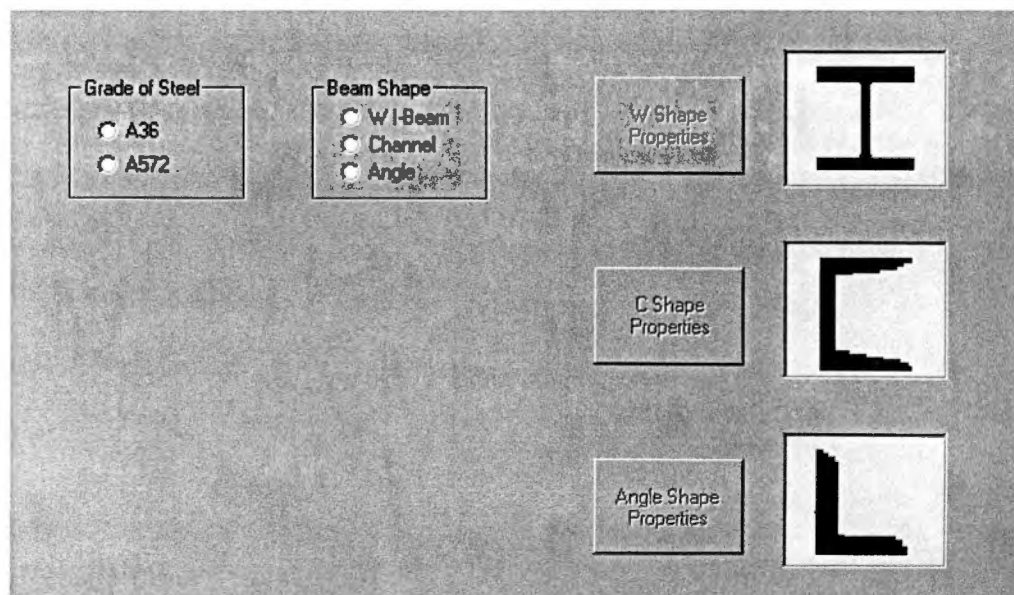


Figure 3.23 Material and Cross-Section Screen

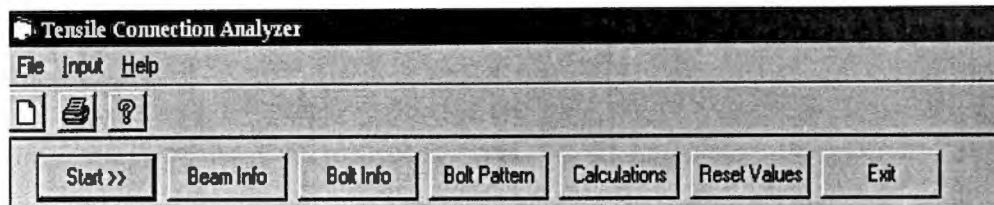


Figure 3.24 Parent Controls

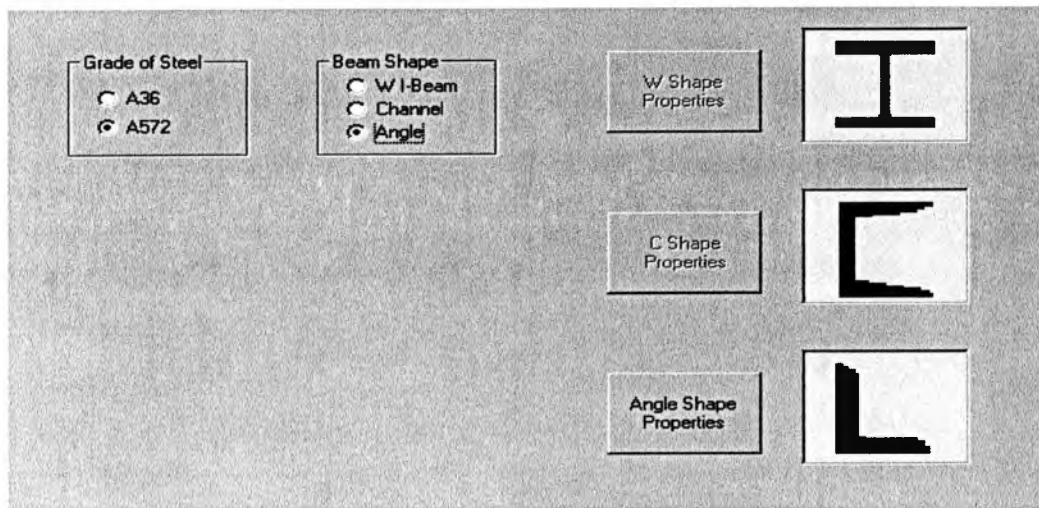
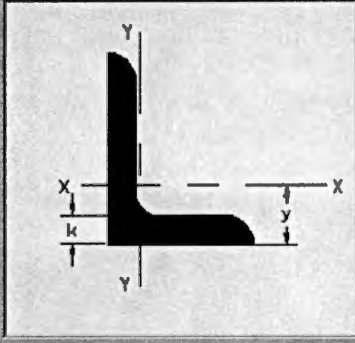


Figure 3.25 Material and Cross-Section Chosen

A572 steel is the material chosen for the angle cross-section shown in Figure 3.25. From the dropdown menu in Figure 3.26, 5 x 3 x ¼ LLV cross-section is selected. The properties for this cross-section are now displayed in the text boxes. Clicking the “Next” button moves the user to the next step. The Bolt Properties screen is the next to be presented. In Figure 3.27, it can be seen that a diameter of ¾ in. has been selected along with arbitrary selections for grade of steel and style of head. The next screen shown in Figure 3.28 allows user input for gauge length. In this case, a value of 1 ¾ in. is used. Then the choice for demonstration path is given, the one with four connectors has been selected. The series of figures (3.29, 3.30, 3.31) display the calculations presented in the program.

Angles Equal and Unequal Legs

Shape and Size 8x8x1.125 5x3.5x.25 5x3x.5 5x3x.4375 5x3x.375 5x3x.3125 5x3x.25 4x4x.75 4x4x.625	(t) leg thickness 1.125 (in)	
Weight per Foot (lb)	Depth of Angle 8 (in)	
(A) area (in ²)	zbar 2.41 (in)	

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Figure 3.26 Selecting Cross-Sectional Properties

Grade of Steel

☒ A325

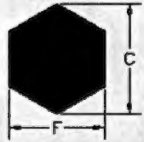
☐ A490

Style of Head

☒ Square

☐ Hex

Hexagonal Head



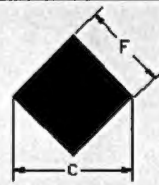
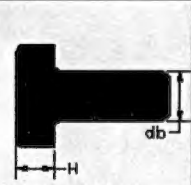

Bolt Diameter (in)

0.75
0.5
0.625
0.75
0.875
1
1.125
1.25

Bolt Properties

	Square	Hex
F	1.125 (in)	1.125 (in)
C	1.5625 (in)	1.3125 (in)
H	0.5 (in)	0.5 (in)
Le	1.25 (in)	
Le'	1 (in)	

Square Head

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Next >>

Figure 3.27 Selection of Bolt Properties

Enter values for gauge length (g) between 1" and 3"

Choose a path from below in order to see the controlling failure path along with the alternate failure paths

g (in)

[Back to Beam Selection](#)

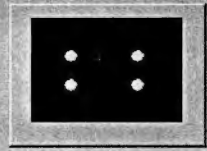
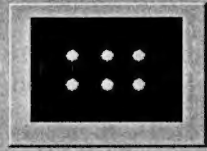
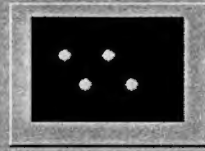
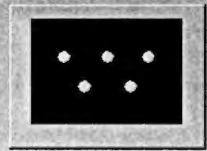
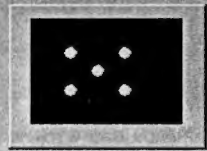
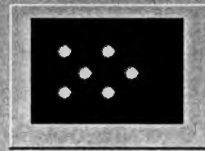








Figure 3.28 Gauge Length and Pattern Selection

Calculated Results

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Tensile Yield

$$P_{nt} = A_g \cdot F_y$$

$$= \boxed{1.94} \cdot \boxed{50}$$

$$= \boxed{97.00} \text{ kips}$$

Fracture of Effective Area

$$P_{nf} = (U \cdot A_n \cdot F_u) / \%P$$

$$= (U \cdot A_n \cdot \boxed{65}) / \%P$$

$$s_g = (s^2) / (4 \cdot g)$$

$$= (\boxed{2.25}^2) / (4 \cdot \boxed{1.75})$$

$$A_n = A_g - n \cdot h \cdot (d_{ia} + (1/8)) \cdot t_w + n \cdot d \cdot (s_g) \cdot (t_w)$$

$$= \boxed{1.94} - \boxed{2} \cdot (\boxed{0.75} + (1/8)) \cdot \boxed{0.25} + \boxed{0} \cdot \boxed{0.723} \cdot \boxed{0.25}$$

$$U = \boxed{.71}$$

$$A_n = \boxed{1.503} \text{ in}^2$$

$$\%P = \boxed{100}$$

$$P_{nf} = \boxed{69.15} \text{ kips}$$

Chosen Design Characteristics

Beam

Grade

Bolt Size in

Grade

Figure 3.29 Tensile Yield and Fracture Calculations

Block Shear

$$A_{gv} = l_v \cdot t_w$$

$$= 3.5 \cdot 0.25$$

$$= 0.875 \text{ in}^2$$

$$A_{nv} = A_{gv} - n_s \cdot (d_{hs} + (1/8)) \cdot t_w$$

$$= 0.875 - 1.5 \cdot 0.875 \cdot 0.25$$

$$= 0.5468 \text{ in}^2$$

<<Back

$$A_{gt} = l_w \cdot t_w + l_f \cdot t_f$$

$$= 2.75 \cdot 0.25 + 0 \cdot 0$$

$$= 0.6875 \text{ in}^2$$

$$A_{nt} = A_{gt} - n_t \cdot (d_{hs} + (1/8)) \cdot t_w + n_d \cdot s_g \cdot t_w$$

$$= 0.6875 - 1.5 \cdot 0.875 \cdot 0.25 + 0 \cdot 0.723 \cdot 0.25$$

$$= 0.3593 \text{ in}^2$$

If:

$$F_u \cdot A_{nt} > 0.6 \cdot F_u \cdot A_{nv}$$

$$P_{nb} = (0.6 \cdot F_y \cdot A_{gv} + F_u \cdot A_{nt}) / (\%P)$$

$$\%P = 100$$

$$= 49.609 \text{ kips}$$

If:

$$0.6 \cdot F_u \cdot A_{nv} > F_u \cdot A_{nt}$$

$$P_{nb} = (0.6 \cdot F_u \cdot A_{nv} + F_y \cdot A_{gt}) / (\%P)$$

$$\%P =$$

$$= \text{ kips}$$

Figure 3.30 Block Shear Calculations

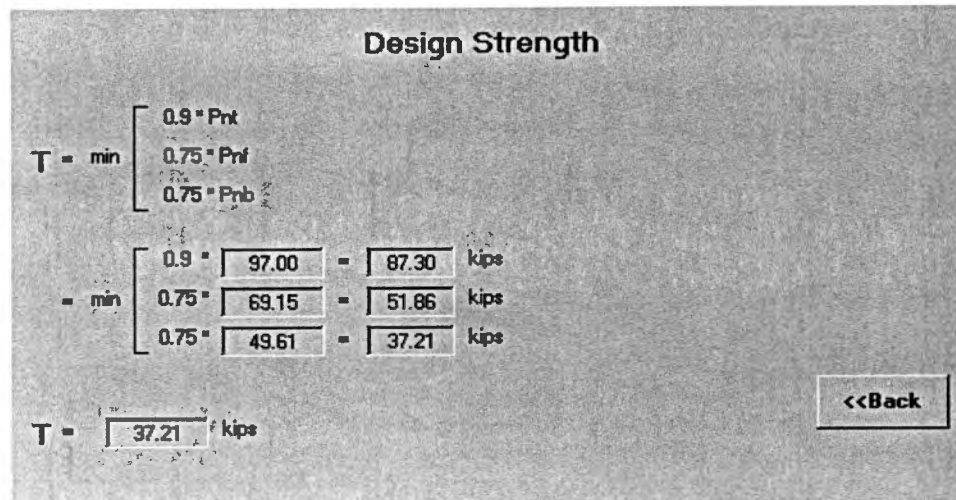


Figure 3.31 Design Strength Determination

It should be noticed that the values produced by the program match the values generated by the hand calculations in the sample calculations. However, the screen only presents the user with the controlling load for each mode of failure. In the figures to follow, it can be seen that the VCR allows the user to view all the alternate paths and their subsequent failure loads. Since block shear is the controlling mode of failure, block shear is displayed on the VCR, in Figures 3.32 and 3.33. Figures 3.34, 3.35, and 3.36 show the VCR display for fracture and yield failure modes.

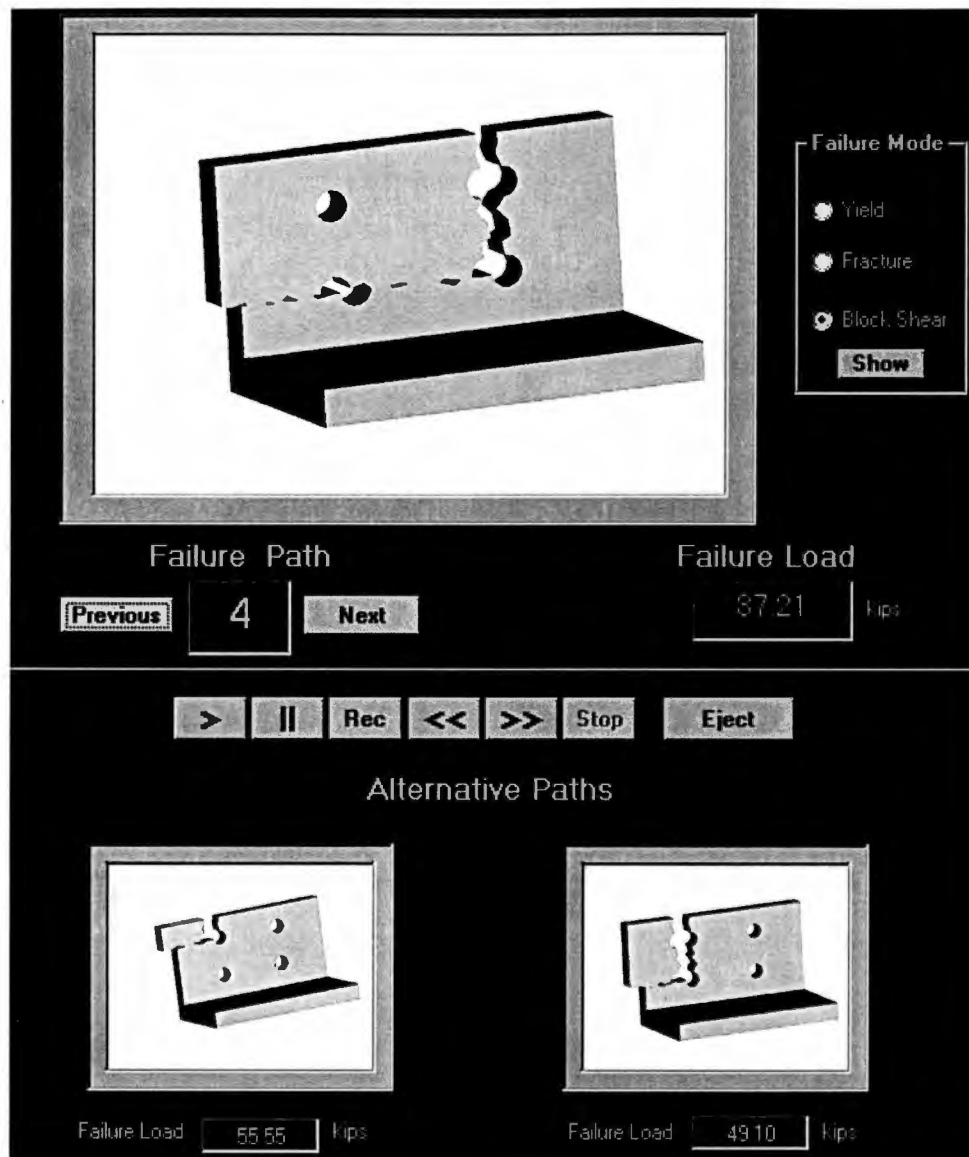


Figure 3.32 Top Half of VCR

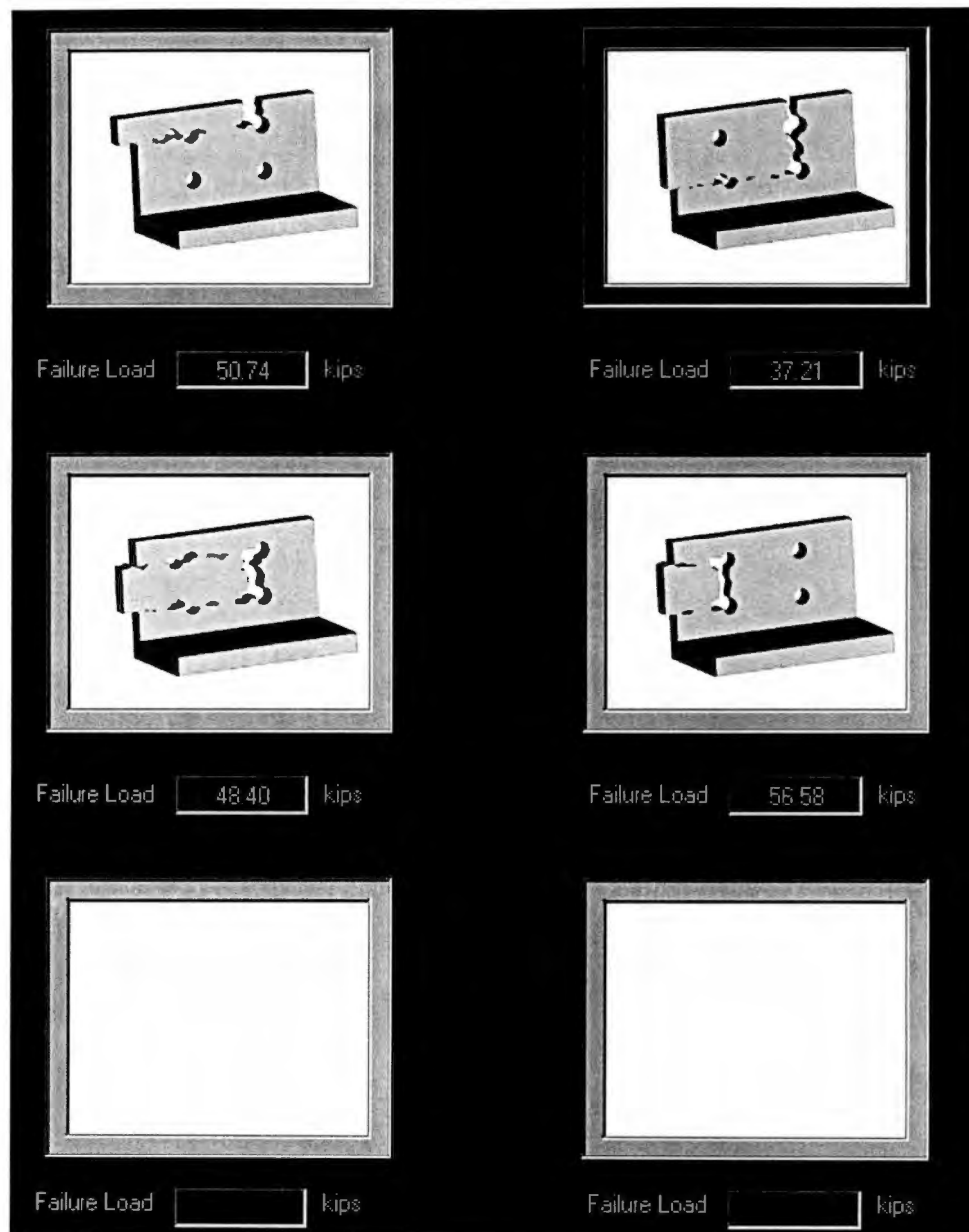


Figure 3.33 Lower Portion of VCR

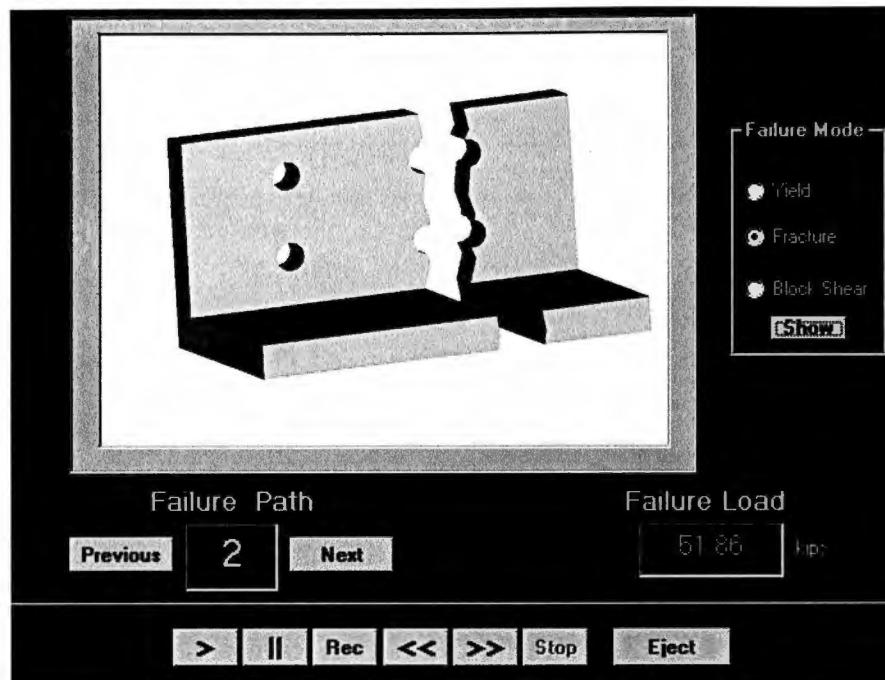


Figure 3.34 VCR Showing Fracture Failure Display

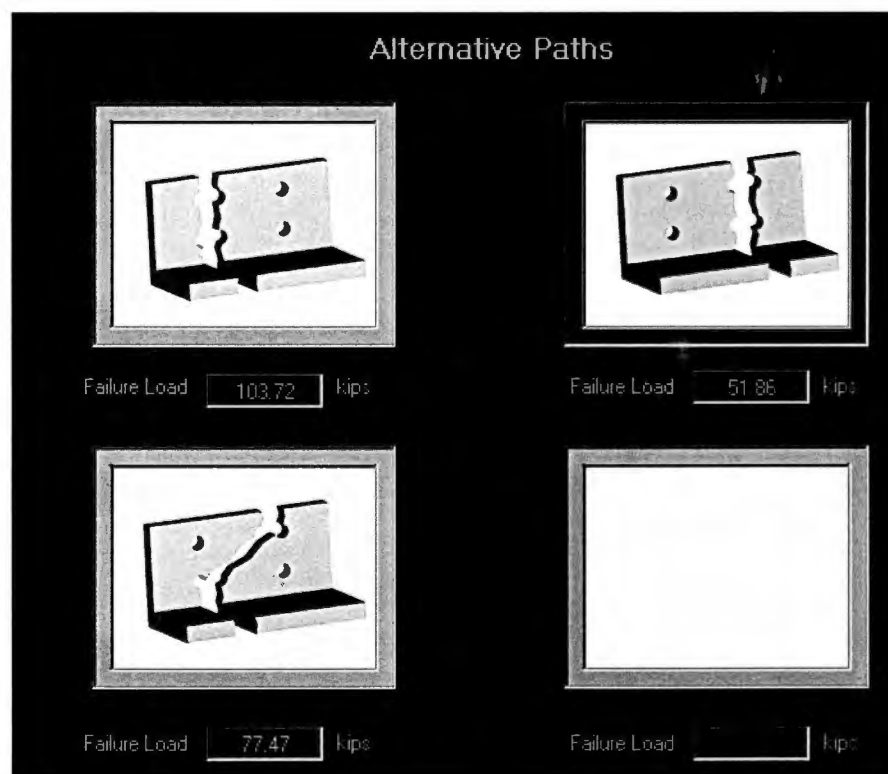


Figure 3.35 VCR Showing Alternate Fracture Paths

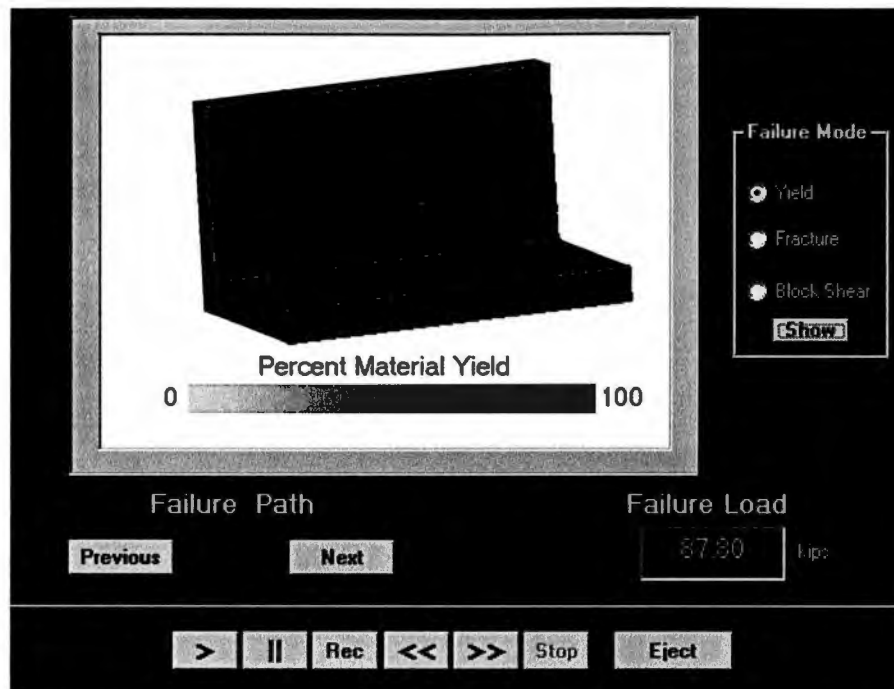


Figure 3.36 VCR Showing Yield Failure Display

Chapter 4

Conclusions

The *Tension Connection Analyzer* is an educational tool that serves both the instructor and the student as a supplemental device for the topic of tensile member design. With minimal in-class demonstration time, the instructor can send students home with an easy-to-use Windows based program that will help the students visualize the topic of tensile member design. Since the program has its own on-line help, the instructor can feel confident that the students will be able to quickly learn how to use the program, in order to get the most out of the program. The analysis mode of the program is intended to help the instructor save class time as it allows students the opportunity to analyze their own “what if” scenarios. Also, the animated visualizations of the *Tension Connection Analyzer* keep the instructor from having to carry around bulky demonstration models to and from class.

As for the students, they will have a program that enhances their knowledge of tensile member design without the burden of lengthy hand calculations. However, as the students become comfortable with the methodology of the tensile member design, the program can then serve as a means of checking their hand calculations. Also, with the *Tension Connection Analyzer* being so visually oriented, the students can view numerous failure paths and the corresponding failure loads, in order to more quickly get a feel as to what the “most likely” failure paths might be for different connection patterns. This ability to predict the controlling failure paths will allow the students to become more productive outside the classroom as well as on examinations.

Through all of the aspects contained in the *Tension Connection Analyzer*, it can be seen that the need for an educational media in the area of tensile connection design has been met. The *Tension Connection Analyzer* affords an instructor the comfort of sending students home with a tool that not only gives numerous samples, but also allows students to check their hand calculations. In short, instructors gain flexibility in their approach to the topic, and students of all learning styles are given the opportunity to gain competency in the topic of tensile connections.

However, with all of the offered features of the *Tension Connection Analyzer*, the groundwork exists within the program for the additions planned for version 2.0. While the *Tension Connection Analyzer* is currently designed to analyze failure of the member, version 2.0 of the program will include the analysis of the behavior of the bolts used in the connection. The *Tension Connection Analyzer* currently has the user select a bolt material, head shape, and diameter. By adding another calculation screen the user will also be able to view the ensuing reactions of the bolts in the user prescribed connection. Also, version 2.0 will have more connection patterns, in the demonstration mode from which the user may choose. Finally, it is the intent of version 2.0 to become a web-based program. This will allow more students the ability to gain access to and knowledge from this educational tool. As the number of students increasing their knowledge of tensile member design increases, the *Tension Connection Analyzer* will draw closer to its goal of becoming a successful supplemental educational device for the topic of tensile member design.

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<http://civcal.media.hku.hk/>

Vita

Chris Williams was born in Nashville, Tennessee on April 29, 1973. He attended Sumner Academy until the eighth grade when he transferred into the public school system in Gallatin, Tennessee. In 1991 he graduated from Gallatin Senior High School. In 1994 he transferred to the University of Tennessee, Knoxville into the College of Engineering. In May of 1997 he attained his Bachelors of Science degree in the field of Engineering Science from the University of Tennessee. That summer he enrolled into the Masters of Science program at the University of Tennessee under an assistantship sponsored by major professor Dr. Christopher D. Pionke. He attained his Masters of Science degree in the field of Engineering Science in the fall of 2000.

On a more personal level Chris has three main loves in his life, God, his family and friends, and sports. As for his salvation, he became a Christian in 1987. As for his family, his immediate family consists of his father (Wayne), his mother (Sharon), his brother (Tommy), and his sister (Michelle). As for his friends, well, they know who they are, and to his family and friends he wants to say thanks for all their support. Then, there were sports.....

Sports, he loves them all. He grew up playing soccer; from age 5 till knee surgery number three (he loved soccer, but often it did not love him back.) He loves to win, hates to lose, and really loves to tell you just how bad he beat you. As far as watching sports, he loves collegiate sports and dislikes the money hungry professionals. He loves watching people who love the game and are driven towards excellence like; Michael,

Walter, and a certain coach named Pat. He is certain that he can coach the Vols better than a man named Phil and, if you don't want to know what he thinking, don't ask him.

In closing, he wants to say; to those who have helped him, thanks, to those who are close to him, he loves you, to those who have rivaled him, thanks for the competition, and to those who have had enough of him he says, lookout, there is more to come.