BEHAVIOR AND DISTRIBUTION OF FORCES IN MULTIPLE FASTENERS OF A STEEL-CONCRETE CONNECTION

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BEHAVIOR AND DISTRIBUTION OF FORCES IN MULTIPLE FASTENERS OF A STEEL-CONCRETE CONNECTION

by

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THESIS

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A *Dios* que me ilumino en todo momento;
a mi esposa *Sylvia*, que con su amor y
amistad me apoyo siempre; y a mi hijo
Bernardo J. por alegrar mi vida.

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Bernardo Sauter
Austin, Texas
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ABSTRACT

BEHAVIOR AND DISTRIBUTION OF FORCES IN MULTIPLE FASTENERS OF A STEEL-CONCRETE CONNECTION

by

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To transfer lateral loads from an existing reinforced concrete structure to a new steel lateral force-resisting system, an understanding of the behavior and distribution of loads to bolts in a steel-concrete connection is needed. The behavior and distribution of forces to bolts in a multiple fastener connection was studied analytically. A computer program was written based on models (load-deformation response) of the measured behavior of 3/4" diameter single bolt connections tested under a variety of conditions. Connections loaded monotonically and cyclically in pure shear were analyzed. The ultimate strength was controlled by the strength of the steel plate or the anchor bolt. Parameters affecting the design and construction of connections included clamping force in the bolts, hole clearance between the steel plate and the bolt, material used to fill the void between the bolt and the steel plate (non-shrink grout and structural epoxy), distance between bolts, and bolt position in the connection. Results of the analyses are used to develop design recommendations.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

CHAPTER 1

INTRODUCTION

1.1 Statement of the problem

In repairing and rehabilitating concrete structures using steel elements attached to existing concrete elements, connections play an important role in the transfer of lateral loads from the existing structure to the new lateral force-resisting system. If the connection between these two systems does not have the capability of transferring the design load or if it fails under the imposed load, the rehabilitation of the structure may not achieve its objective, namely, to change the response of the damaged structure or to improve the response of an undamaged structure by increasing the lateral strength, stiffness, or ductility. Therefore, an understanding of the behavior of the steel-concrete connection is needed.

In practice, a common approach in the design of connections is to compute the number of bolts required by dividing the total shear force transferred at the connection by the shear capacity of a single bolt. However, it is obvious that all bolts do not carry the same load due to the influence of various characteristics of the connection, such as distance between bolts, area and strength of the steel element, the void between bolt and the steel plate, the material filling that void, and the material filling the gap between the steel plate and the concrete element. Figure 1.1 shows the characteristics that influence the behavior of a connection. A study of the effect of the variables shown in Fig. 1.1 on the behavior of the connection and on the distribution of load to bolts in a steel-concrete connections will provide the designer with the necessary analytical tools and understanding needed to improve the design of the rehabilitation scheme.

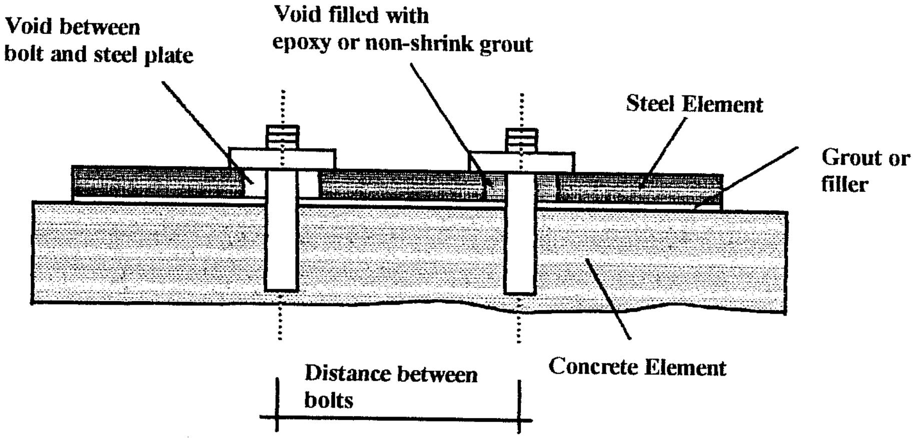


Figure 1.1. Characteristics of a steel-concrete connection.

1.2 Objective

The main objective of this study is to understand the behavior of the connection and the distribution of loads to bolts in a steel element connected to concrete with multiple-fasteners. Experimental results from single bolt tests carried out by Jimenez (5) are used to analyze multi-fastener connections..

The scope of the study is limited to an analysis of the behavior of multiple bolts in a steel-concrete connection using adhesive anchors loaded in shear. The ultimate strength is controlled by the strength of the steel plate or the anchor bolt. It is assumed that the bolts are not near the edge of the plate so splitting is not a problem.

A computer program based on models of the behavior of a single bolt was written for estimating the response of multiple bolt installations. In the computer program, different parameters affecting the design and construction of connections were analyzed. The parameters considered were (1) amount of clamping force in bolts, (2) hole clearance between the steel plate and bolt, (3) material used to fill the void between the bolt and steel plate (non-shrink grout and structural epoxy), (4) distance between bolts, and (5) bolt position in the connection.

Results of the calculated behavior of bolts in steel-concrete connections were used to propose design recommendations in order to give to the designer some guidance for better control of performance of repaired and rehabilitated concrete structures.

CHAPTER 2

BASIC CONCEPTS OF STEEL-CONCRETE CONNECTIONS

2.1 General Review

Repair and strengthening techniques for reinforced concrete structures consist of adding new structural elements to the existing lateral force-resisting system of a structure to increase its strength and stiffness and to improve behavior during an earthquake. The most common elements used in rehabilitation of structures are:

- shear walls
- reinforced concrete jacketing
- internal or external steel bracing or jacketing
- wing walls

To transfer the lateral inertia forces from the horizontal diaphragms to these new structural elements a connection is needed. Connection, according to Webster's Dictionary, means "to bind or fasten together", "to establish communication between two parts". From the engineering point of view, every structure is the union of individual parts, members or elements that must be fastened together, using various techniques or procedures.

Steel elements, such as steel bracing, are often used in strengthening existing reinforced concrete structures for the following reasons:

- easy installation from exterior of the building, and minimizing interference with the operation of the building;
- minimal weight added to the structure;
- reasonable cost of fabrication and installation;
- better distribution of shear forces throughout the structure due to the flexibility of arranging the steel bracing in the structure thereby avoiding the need for foundation strengthening (5).

To join the steel bracing elements to the existing concrete structure, a steel-concrete connection is used. In a typical steel-concrete connection, the new steel structural element is attached to an existing concrete element with anchor bolts which transfer forces from the steel plate to the concrete element (2). Figure 2.1 shows a typical steel-concrete connection.

The success of a strengthening technique for a structure strongly depends on the connection. According to experimental investigations conducted by Sugano and Fujimura using steel bracing elements, "the steel bracing were unable to fully develop their capacities due to failure of the joints. The steel strengthening members should be designed to undergo ductile failures before anchor bolts or connections fail in a brittle manner" (8). Therefore, careful attention must be given to connection details, not only in the design process, but also in the construction process. Connections need to be designed to ensure that the desired strength of the steel bracing members is fully developed before the connection fails (4).

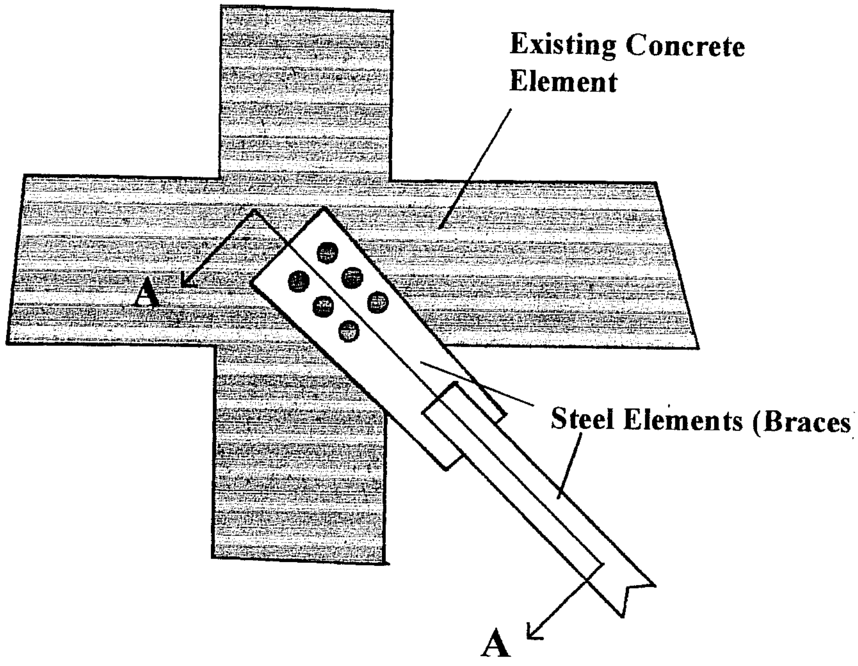
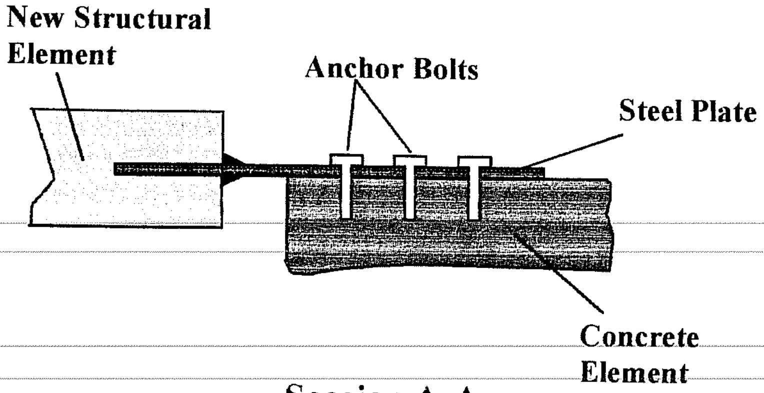


Figure 2.1 Typical steel - concrete connection



Seccion A-A

2.2 Failure Modes of Steel-Concrete Connections

The capacity of a connection will be governed by the strength of either the steel or concrete. Therefore, the steel-concrete connection can be divided into two groups: those whose strength is controlled by the strength of the concrete element and those whose strength is controlled by the anchor bolts or steel elements (2).

For the first group of connections whose strength is controlled by the strength of the concrete element, the connection will exhibit non ductile behavior if tension or bearing failures occur in the concrete. Two factors define the limits between the two groups of failures: the embedded length of the anchor bolt and tensile strength of the concrete.

If the anchor bolt is embedded properly, ultimate strength is controlled by the strength of the steel elements, steel plate or anchor bolts, and the connection will have ductile behavior.

Ductile behavior is defined as the ability of a structural component to undergo significant inelastic deformation at predictable loads without significant loss of strength. A ductile connection fails by yielding and large displacements of the anchor bolts or steel plate.

2.3 Connection Installation Concern

Installation of a steel-concrete connection in the field is one of the most difficult steps in the retrofitting process. It is nearly impossible to construct the connection exactly as specified in plans provided by the engineer. The exact position of longitudinal and transverse reinforcement in the existing concrete element is unknown, poor fabrication and construction of the steel elements, and poor quality labor introduce conditions that make it difficult to construct connections precisely as designed. In a typical case, longitudinal or transverse reinforcement interferes with the position of the bolts, causing the specified distance between bolts to change and the hole in the steel element to be oversized to accommodate these problems. Therefore, the behavior of the specified connection may be different than assumed initially.

2.4 Types of Anchor Bolts

The anchor used in connections can be of two types, cast-in-place or post-installed (installed in hardened concrete). A cast-in-place anchor is installed in position before the concrete is placed and it is usually used for new construction. A post-installed anchor is installed after the concrete has hardened and it is commonly used for strengthening of structures. There are four types of post-installed anchors: undercut, adhesive, grouted, or expansion. Figure 2.2 shows different types of anchors. These types of bolts are used to attach new steel elements, such as steel bracing and moment resisting frames, to existing concrete structures (2).

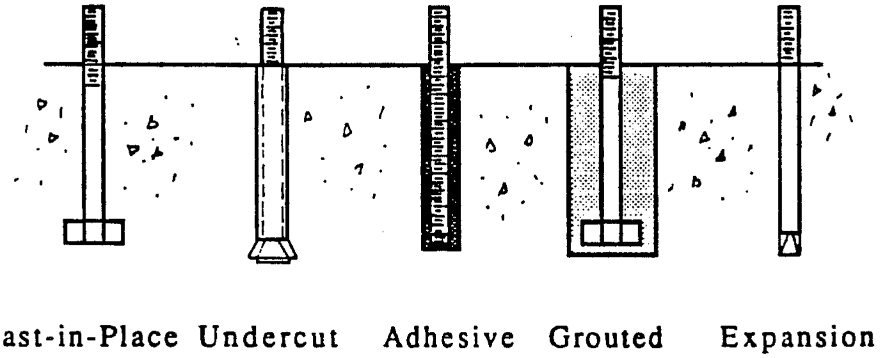


Figure 2.2 Types of anchor bolts (2)

2.5 Failure of a Single Anchor Bolt Connection

A single anchor bolt can fail under any of the following load conditions:

a) tension
b) shear
c) tension and shear

For a single anchor bolt connection loaded in direct tension, the failure mechanism will be triggered by yielding and fracture in the threaded portion of the anchor. Figure 2.3 shows a yielding anchor bolt subjected to tension.

For a connection loaded in shear the failure mechanism is due to yielding and fracture of the anchor bolt at the shear plane due to kinking and bending. Anchors transfer shear by bearing of the plate against the anchor, and by bearing of the anchor against the concrete. Local crushing of concrete can occur but this should not limit the strength of the anchor. Figure 2.4 shows the failure mechanism of a bolt loaded in shear. Welded studs and threaded anchors behave differently in shear due to the fixity between the stud and baseplate provided by the weld.

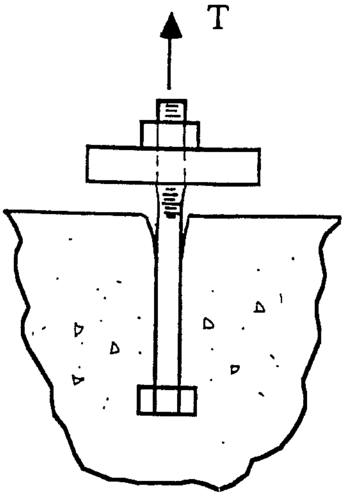


Figure 2.3 Yielded anchor bolt subjected to tension (2).

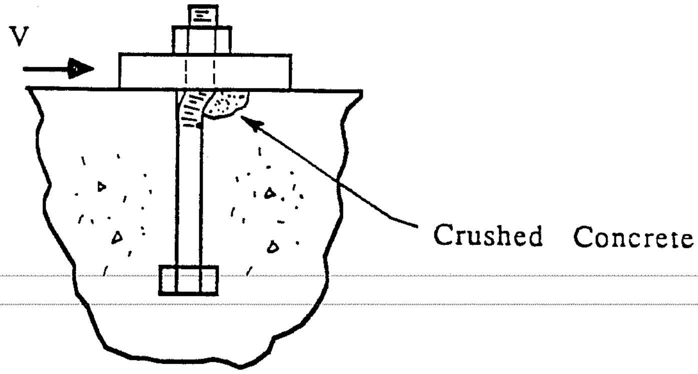


Figure 2.4 Failure mechanism of a bolt loaded in shear (2).

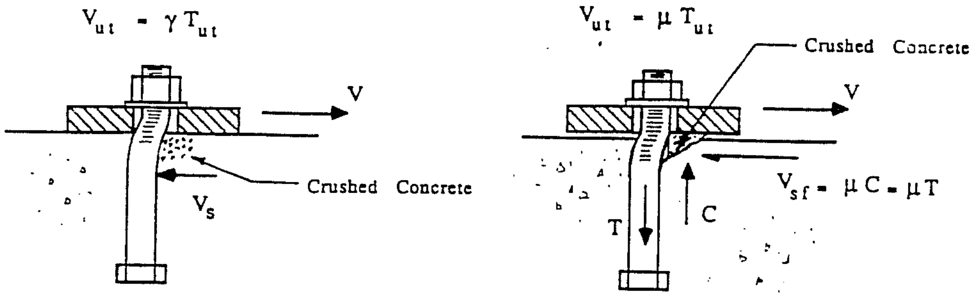
Two design approaches exist for shear transfer (Fig. 2.5):

a) Shear transfer by bearing on the anchor

b) Shear transfer by shear friction

The first approach is based on the assumption that shear is transferred directly by bearing on the anchor, and the second, by a frictional force which develops between the steel plate and concrete surface.

For a connection loaded in tension and shear, the failure mechanism is characterized by yielding and fracture of the anchor due to tension, kinking, and bending. Figure 2.6 shows a connection which has failed by combined tension and shear.



SHEAR TRANSFER BY BEARING ON THE ANCHOR

SHEAR TRANSFER BY SHEAR FRICTION

Figure 2.5 Shear transfer in steel-concrete connections (2).

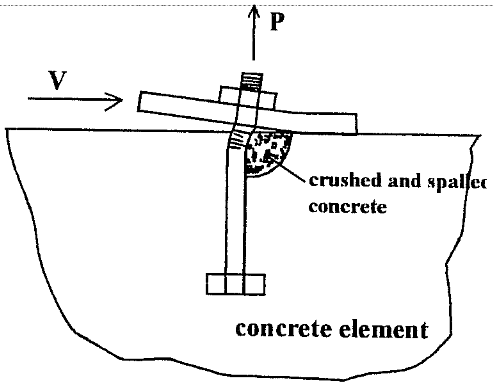


Figure 2.6 Connection failed by combined tension and shear (2).

CHAPTER 3

COMPUTER PROGRAM

3.1 Introduction

A computer program was written to analyze the behavior of a steel-concrete connection consisting of multiple-fasteners. Description of the computer program and the chosen analytical models for single bolts to analyze the behavior of the connection are presented in this chapter.

3.2 Computer Program Description

The computer program BOLTS was developed to analyze the behavior of a steel-concrete connection in a multiple fastener installation. It was written in Fortran Language using a simple algorithm incorporating two important objectives: (1) it should be understandable by anyone with a basic background in Fortran Language, and (2) can be easily modified to reflect developments in the understanding of connection behavior.

The BOLTS program is composed of three sections: the main program and two major subroutines. The first major subroutine executes the algorithm for a steel-concrete connection loaded monotonically. The second is for a connection loaded cyclically. Each major subroutine is composed of several subroutines. A listing of the computer program is presented in Appendix A.

3.2.1 Main Program. The main program executes the following instructions:

- initializes the program,

- opens the output file which stores the input data information and results of the analysis,

- asks for general information concerning the area (in^2) and yield point (ksi) of the steel element, number of bolts and bolt spacing (in.),

- asks the user to choose the load history:

a) Monotonic load
b) Cyclic load

For monotonic loading, the Main Menu has the following options included in the program (see Fig. 3.1):

(1) Plain Connection
(2) Grouted Connection
(3) Epoxy Connection
(4) Other Type
(5) Help

And for cycGlic load, the Main Menu has the following options included in the program (see Fig. 3.1):

(1) Epoxy Connection

(2) Help

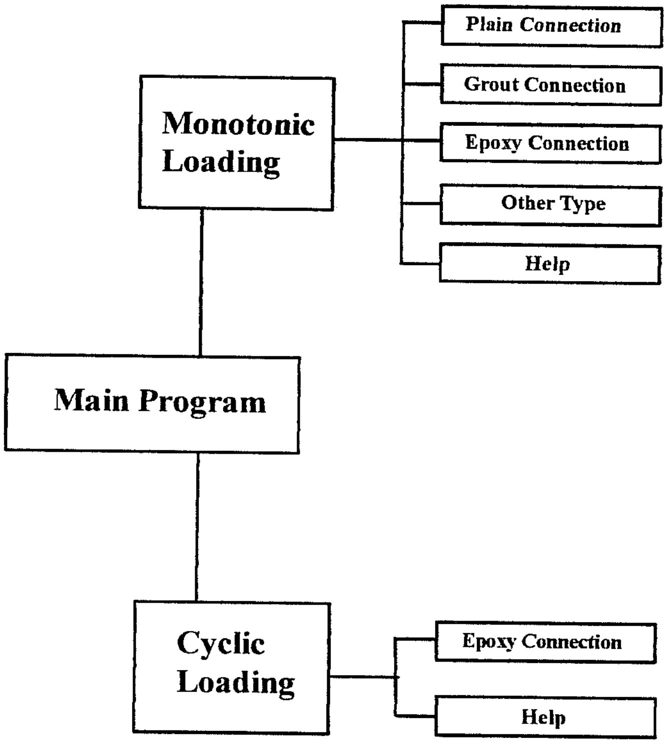


Figure 3.1 Main menu flow chart

The plain connection option is for a connection in which neither the gap between the anchor bolt and steel element nor the interface between the concrete and steel element are filled with any structural material. The grouted connection option is for a connection in which both the gap between the anchor bolt and steel element, and the interface between the concrete and steel element are filled with non-shrink grout. In epoxy connections, epoxy is used to fill the gap between the anchor bolt and steel plate.

The option called "Other Type" is a subroutine which allows the use of models not included in the Main Menu. The purpose of this option is to give freedom to the user to analyze other options and to generalize the use of the program to any type of connection. Details for the use of this option are explained in Appendix C, Section C.1, Use of the program. If the user continually introduces new models, the Main Menu can be amended by following the steps described in Appendix C, Section C.2, How to include a new model. A model is included in the Main Menu to reduce input data time and to provide an opportunity to use the model for different construction details. Option "Help" gives a brief explanation of how use the program.

Depending on the type of connection, the program asks for additional information such as type of surface treatment, interface thickness, clamping force applied to bolts in terms of friction force, and hole size in the steel plate.

3.2.2 Analytical Procedure. After the User has chosen the option type, the program resolves several sets of mathematical equations to compute the shear forces and displacements in the bolts. Three sets of equations are needed for determining the distribution of shear forces in the bolts:

1- To obtain a solution, the system must satisfy equilibrium of forces; the total shear force applied to the system has to be the same as the sum of the shear force of the bolts.

$$\mathbf{V_T = V_{b1} + V_{b2} + V_{b3} + \ldots\ldots} \qquad \mathbf{(1)}$$

or

$$\mathbf{V_T - \Sigma\, V_{bi} = 0}$$

where V_T is the total shear force applied to the system (See Fig. 3.2)

V_{b1}, V_{b2}, V_{b3}, ..., is the shear force acting in bolt 1,2,3, ...

When the difference between the shear load applied to the system and sum of the shears carried by the bolts is less than 0.01 kips, equilibrium is assumed to be satisfied in the calculations.

2- Conditions of compatibility of deformations have to be satisfied at all points throughout the connection. Therefore, the deformation of any bolt will be equal to the deformation at the prior bolt (the adjacent bolt closest to the point of load application) minus the deformation of the steel plate between them.

$$db_{(i+1)} = db_i - d_{plate} \tag{2}$$

where $db_{(i+1)}$ = deformation of bolt in question

db_i = deformation of the prior bolt

d_{plate} = elongation of the steel plate

Figure 3.2 is a typical steel-concrete connection showing the deformation and distribution of shear loads to bolts.

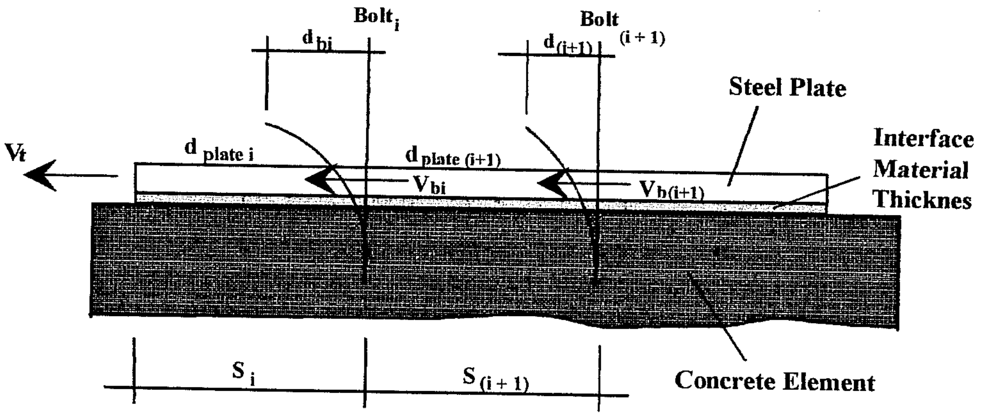


Figure 3.2 Typical steel-concrete connection showing the deformation and distribution of loads to bolts.

3- In addition, the constitutive equation for the force-displacement response of an individual bolt in the group is obtained from the load-deformation response of a single bolt tested in the laboratory.

The approach for solving the problem is outlined below:

- an initial displacement is assigned to the first bolt.

- with the initial displacement, the respective force of the first bolt is computed using the load deformation response of a single anchor bolt obtained from experimental tests. The load-deformation response of a single anchor bolt for different types of connections is defined in Section 3.3.

- the force applied to the steel plate between the first and second bolt is obtained by subtracting the force carried by the first bolt from the total force applied to the system.

- knowing the force applied to the steel element between the first and second bolt, the elongation of the plate is computed.

Steel Element Elongation = Force * S / (E * A)

where E = modulus of elasticity of the steel plate.
A= steel plate area
S = distance between bolts
Force = force applied to the steel plate

- the deformation of the second bolt is obtained subtracting the deformation of the first bolt and the elongation of the steel plate between these two bolts, according to equation (2).

- knowing the deformation of the second bolt, the force of the second bolt is calculated using the load deformation response of a single bolt obtained from experimental tests.

- the same process is repeated for the remainder of bolts in the system.

After computing the force in each bolt, the sum of all the bolt forces must be equal to the total applied force, according to equation (1).

The total deformation of the system is equal to the deformation of the first bolt plus the deformation of the steel plate:

$$\mathbf{D_t = d_{b1} + d_{plate1}} \qquad \textbf{(3)}$$

where D_t = total deformation of the system,

d_{b1} = deformation of bolt #1,

$d_{plate\ 1}$ = deformation of steel plate #1.

If the sum of bolt forces is greater than the total force, the new initial displacement value for the first bolt will be less than the initial displacement value used to start the solution. Otherwise, a new displacement value greater than that assumed initially must be imposed. The process is repeated until equilibrium is reached. For this study, equilibrium is considered to be achieved if the difference between the load applied to the system and the sum of bolt forces is less than 1% of the load applied to the system. Each time equilibrium is reached, the forces and displacements of the system are printed in the output file specified by user at the beginning of the input data. The total force applied to the connection is increased by an increment specified by the user. When any of the bolts reach their maximum load capacity, that bolt is assumed to have failed and is omitted in subsequent computations. The load capacity of bolts is already specified and stored in the program. The program stops when all bolts in the system fail. Thus, if the properties of the steel plate and the load-deformation response of a single bolt are known, the behavior of the connection and the distribution of shear forces among bolts in a multiple-fastener connection can be determined. An example of the analytical procedure is shown in Appendix B.

3.3 Analytical Models

3.3.1 Analytical Model for the Anchor Bolt. The analytical models used to model the behavior of the bolts in a multiple fastener were based on the load-deformation response of a single bolt obtained in an experimental study carried out by Jimenez (5). The computer program uses the single bolt model to generalize the behavior of a multiple bolt installation.

The computer program includes the following three cases:

1- Plain connection
2- Grouted connection
3- Epoxy Grouted connection

A plain connection is defined as a connection in which neither the gap between the anchor bolt and the steel element nor the gap at the interface between the existing concrete element and the steel plate were filled with any structural material. In a grouted connection, both the gap between the anchor bolt and the steel element and the gap at the interface between the existing concrete element and the steel plate were filled with non-shrink grout. In an epoxy grouted connection, epoxy was applied to the base of the anchor bolt and in the gap between the anchor bolt and the steel plate.

For each case, the influence of the following variables in the behavior of a multiple fastener connection was studied:

a) bearing clearance is defined as the clear distance between the anchor bolt and the steel element on the side of the bolt opposite the applied force. Figure 3.3 illustrates the definition of bearing clearance.

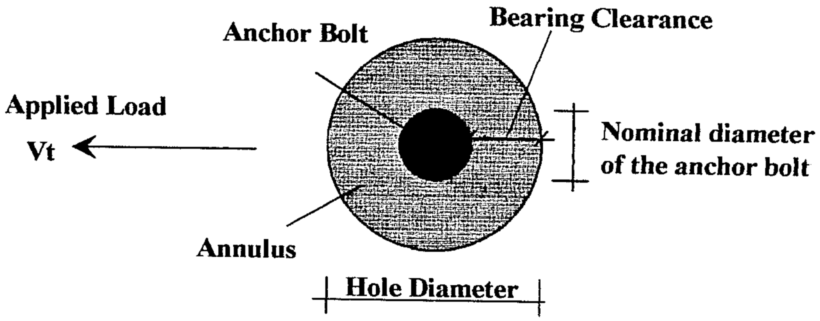
b) amount of clamping force applied to the bolts to produce friction between the steel plate and the existing concrete surface. Figure 3.4 shows the friction force due to tension (tightening) of the bolts.

Figure 3.5 illustrates qualitatively the effect of hole oversize and friction force on load-deformation response.

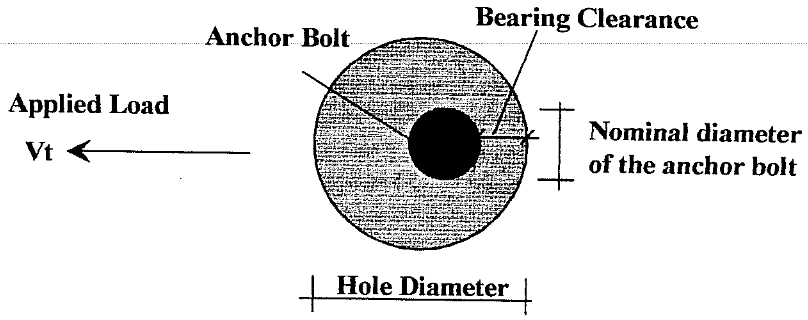
c) number of bolts in a row. Figure 3.6 shows the number of bolts per row in a steel-concrete connection.

d) spacing between bolts. Figure 3.6 clarifies the definition of spacing between bolts.

e) effect of interface thickness. See Fig. 3.2



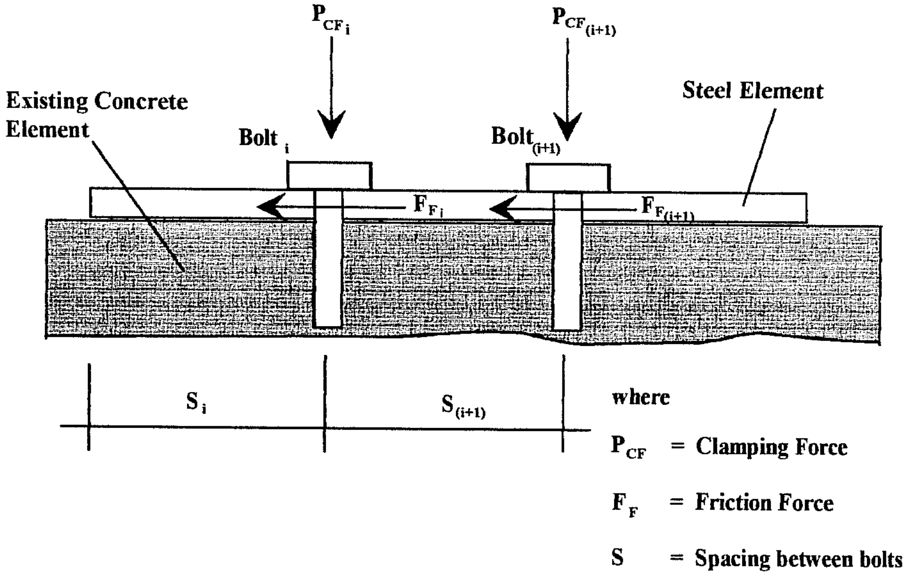
a) Bolt placed in the middle of the hole



Hole clearance = Difference in hole diameter of the steel plate and nominal diameter of the anchor bolt.

Bearing clearance = clear distance, measure on the opposite bolt edge of the applied force, between the anchor bolt and the steel plate.

Figure 3.3 Definition of bearing clearance, hole clearance, and annulus



where

P_{CF} = Clamping Force

F_F = Friction Force

S = Spacing between bolts

Figure 3.4 Clamping force applied to bolts

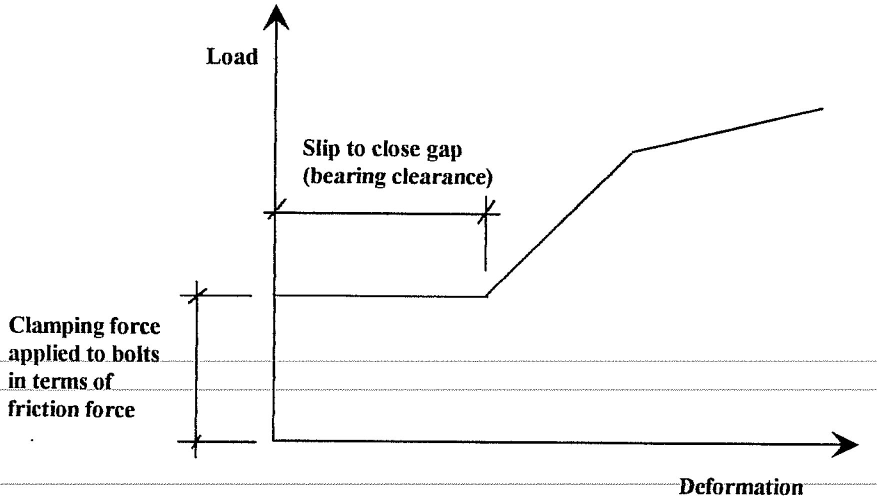


Figure 3.5 Typical load-deformation response graph

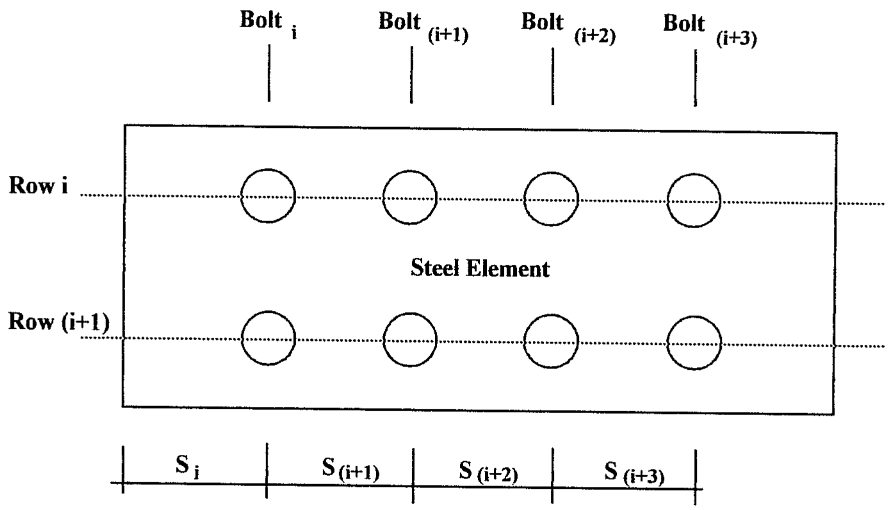


Figure 3.6 Definition of number of bolts and spacing between bolts in a steel-concrete connection.

Monotonic Loading Models. The behavior of a plain connection for a single bolt obtained in the experimental research is presented in Fig. 3.7. The analytical model chosen to represent the curve in Fig. 3.7 is presented in Fig. 3.8.

For a grouted connection two types of surface roughness were considered in the experimental research:

a) acetone-cleaned steel
b) sandblasted steel

For the acetone-cleaned steel, the results are presented in Fig. 3.9. Figure 3.10 shows the comparison of results between the response of a connection with

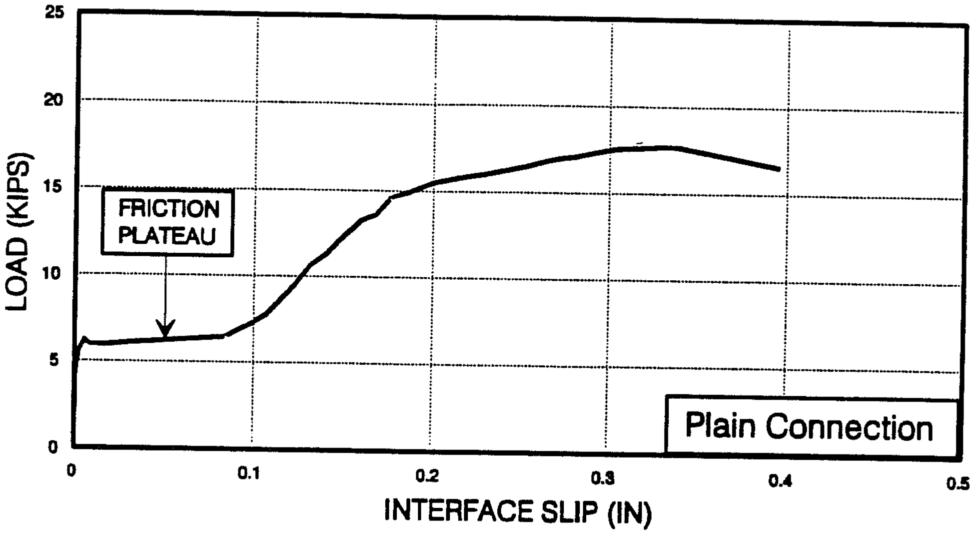


Figure 3.7 Plain connection behavior of a single bolt obtained from experimental test (5).

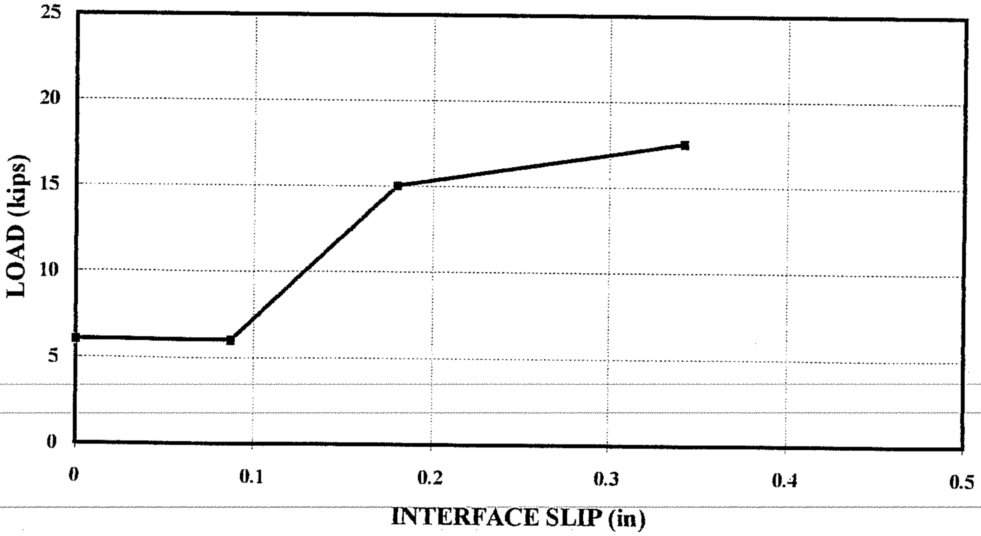


Figure 3.8 Analytical model of the behavior of a plain connection

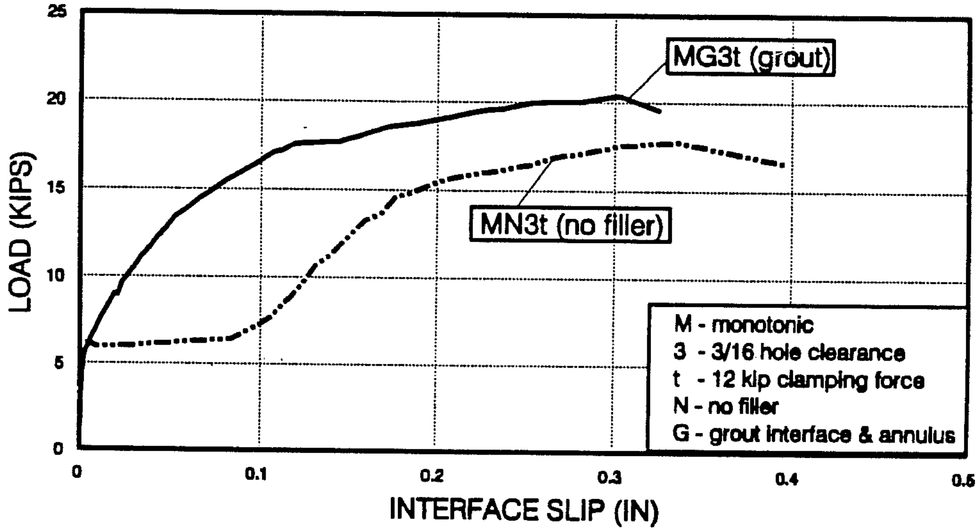


Figure 3.9 Behavior of a single bolt grouted connection with acetone-cleaned steel plate (MG3t) obtained from experimental test (5).

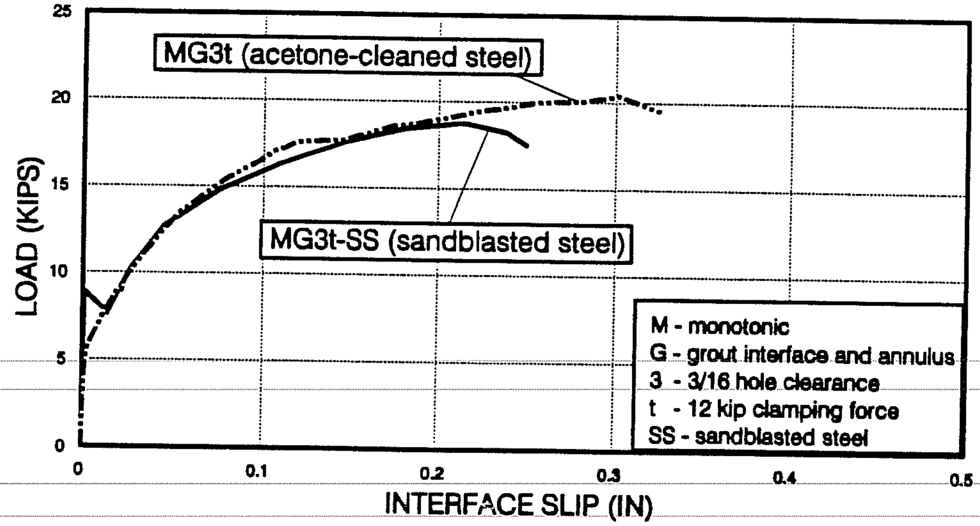


Figure 3.10 Effect of surface roughening in a grouted connection.

acetone-cleaned steel and sandblasted surface treatment. The results show that the behavior of a grouted connection with acetone-cleaned surface treatment is similar to the behavior of a grouted connection utilizing light sandblasting. Therefore, the same analytical model will be used for a grouted connection with acetone-cleaned steel surface and a sandblasted surface.

For the sandblasted steel surface, two hole clearances were considered in the experimental research:

a) 3/16 in.
b) 7/16 in.

Figure 3.11 shows the results of the effect of hole clearance obtained from the experimental research. Figure 3.12 shows the analytical models for these cases.

The effect of two grout thickness was tested using:

a) 1/4 in. thick
b) 1/2 in. thick

The experimental results showing the influence of 1/2" grout thickness are illustrated in Fig. 3.13, and the analytical model is shown in Fig. 3.14.

For the epoxy grouted connection, two hole clearances were tested:

a) 3/16 in.
b) 7/16 in.

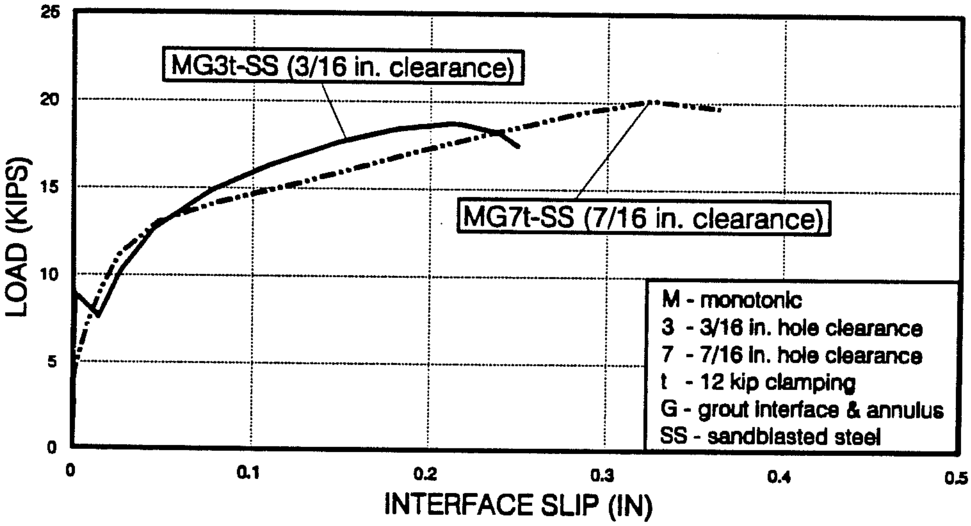


Figure 3.11 Effect of hole clearance with grout in annulus and interface of a single bolt grouted connection obtained from experimental test (5).

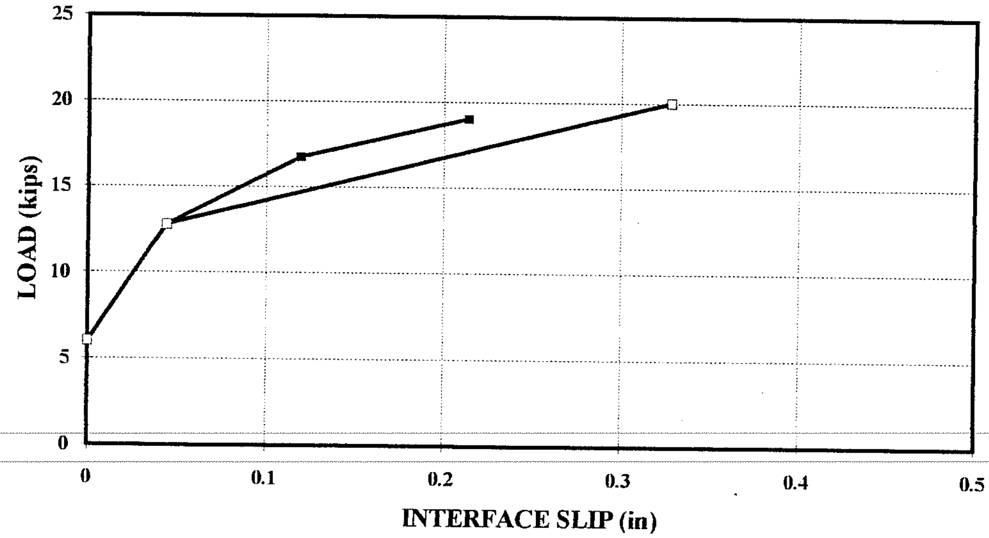


Figure 3.12 Analytical model of the effect of hole clearance with grout in annulus and interface of a grouted connection.

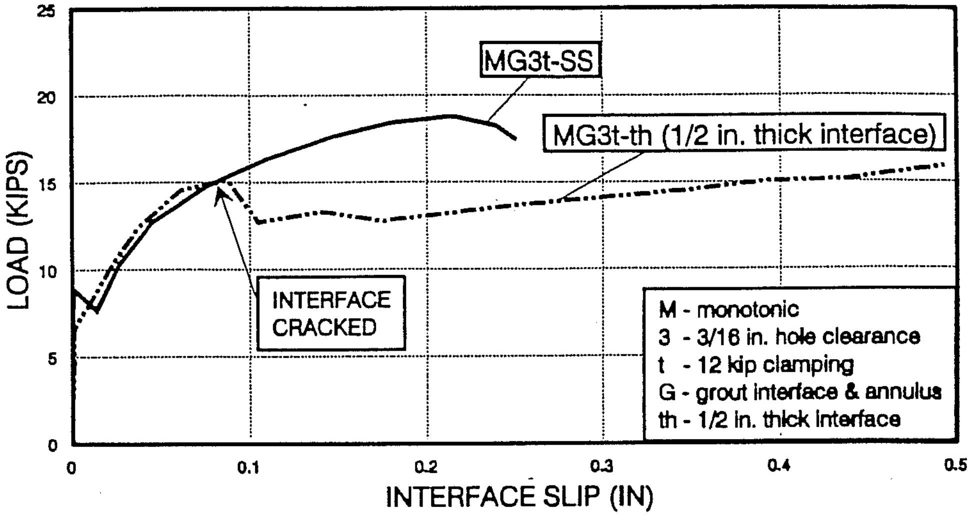


Figure 3.13 Effect of interface thickness with grout in annulus and interface of a single bolt grouted connection obtained from experimental test (5).

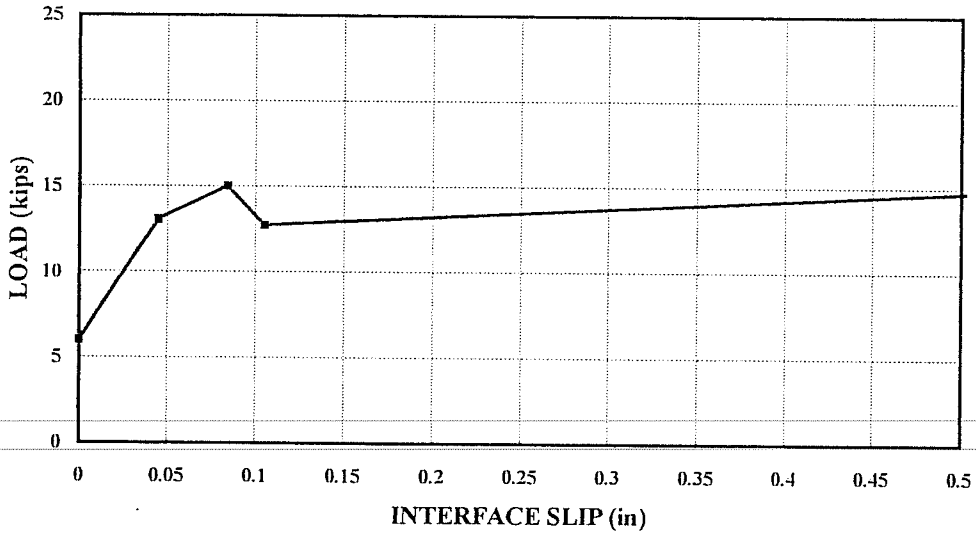


Figure 3.14 Analytical model of the effect of interface thickness (MG3t-th) with grout in the annulus and interface of a single grouted connection.

For each hole oversize, the influence of clamping force was analyzed. The results of the influence of clamping force, for a hole clearance of 3/16 in., is shown in Fig. 3.15 (hand tightened connection) and 3.17 (for a 12 kip clamping force). Analytical models for these cases are shown in Fig. 3.16 and 3.18, respectively.

For a hole clearance of 7/16 in., the influence of clamping force is shown in Fig. 3.19 and its analytical model in Fig. 3.20.

Cyclic Loading Models. Although several single bolt specimens were tested (5), the epoxy grouted test with 3/16 in. hole clearance and a clamping force of 12 kips was chosen as an example. Figure 3.21 shows the results of this test and Fig. 3.22 the analytical model for this case.

3.3.2 Analytical Model of the Steel Element. The analytical model of the steel element was based on the ideal elastic-plastic stress-strain relationship shown in Fig. 3.23. This model neglects strain hardening which increases the yield point of the element and strain aging which increases the yield point.

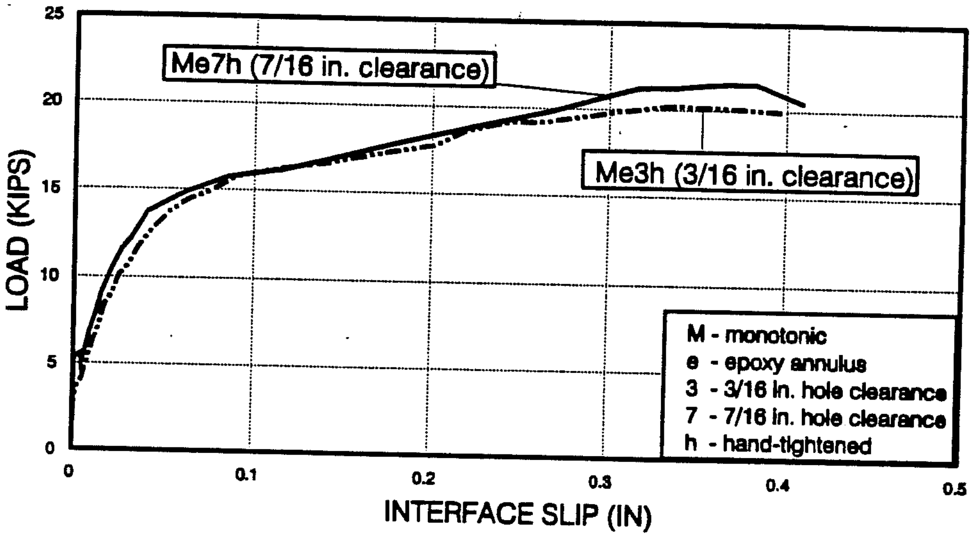


Figure 3.15 Effect of hole clearance with hand-tightened and epoxy filled annulus of a single bolt epoxy connection obtained from experimental test (5).

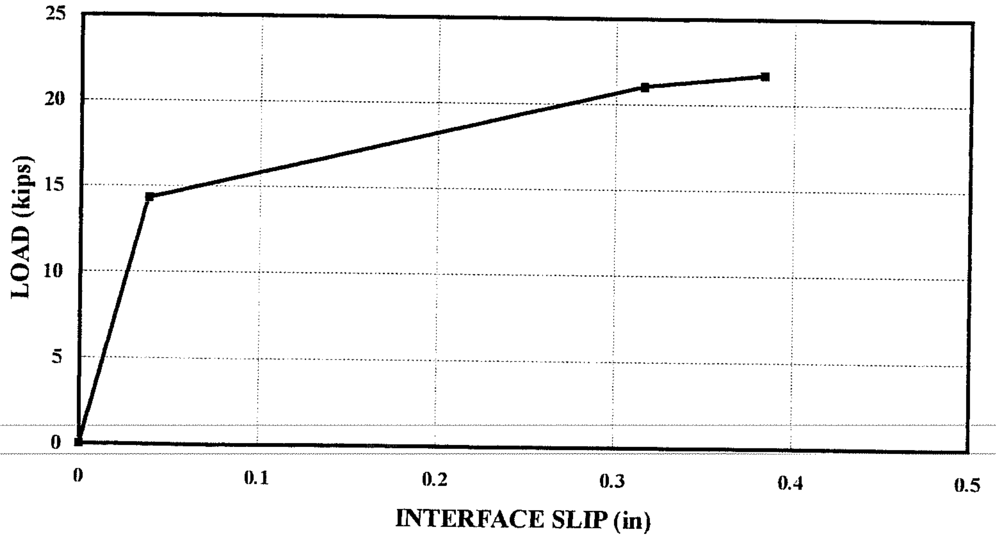


Figure 3.16 Analytical model of the effect of hole clearance with hand-tightened of a epoxy connection (Me7h).

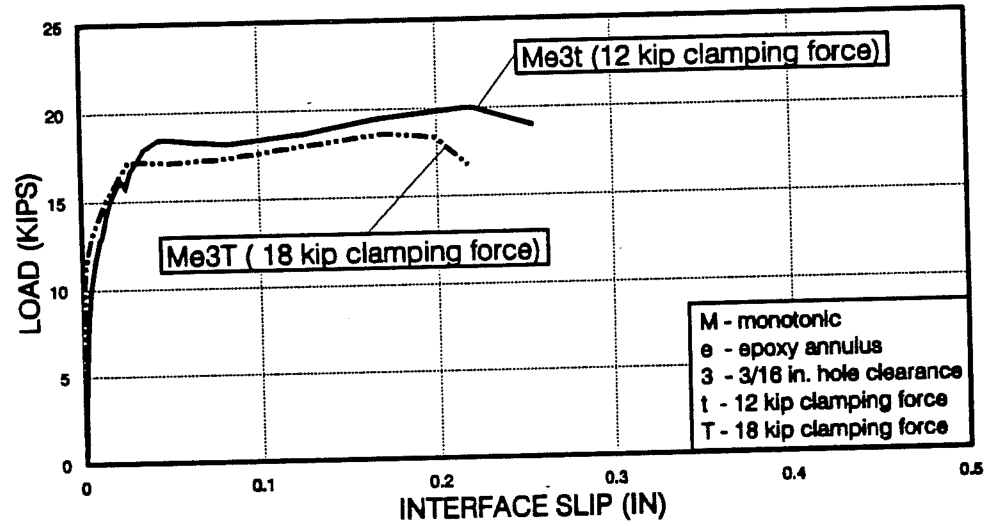


Figure 3.17 Response of single bolt epoxy grouted connection with 3/16 in. hole clearance and clamping force obtained from experimental test (5).

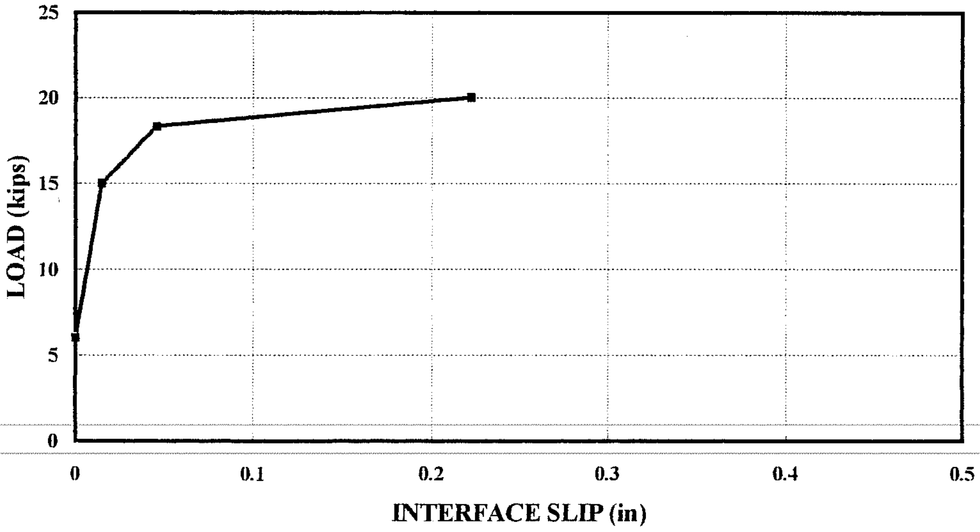


Figure 3.18 Analytical model for single bolt epoxy grouted connection with 3/16 in. hole clearance and clamping force.

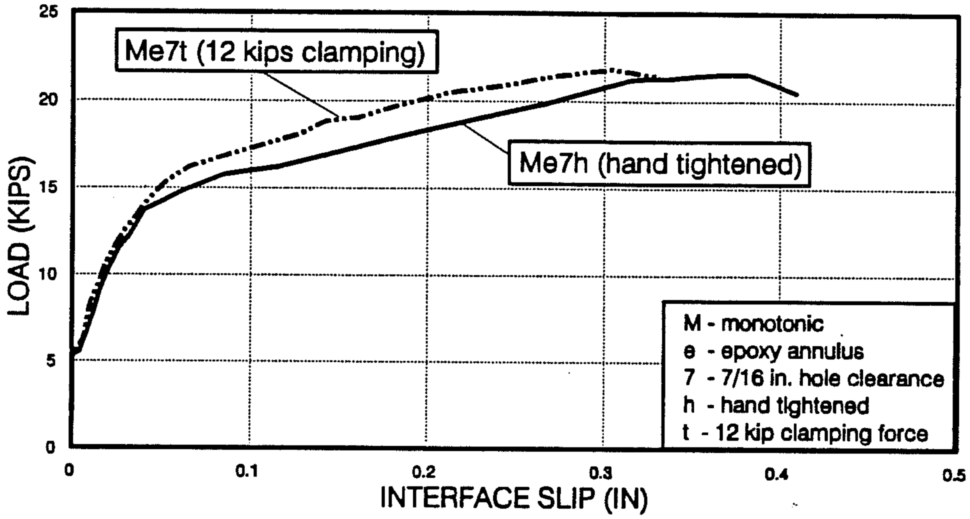


Figure 3.19 Effect of clamping force with 7/16 in. hole clearance of a single bolt epoxy grouted connection obtained from experimental test (5).

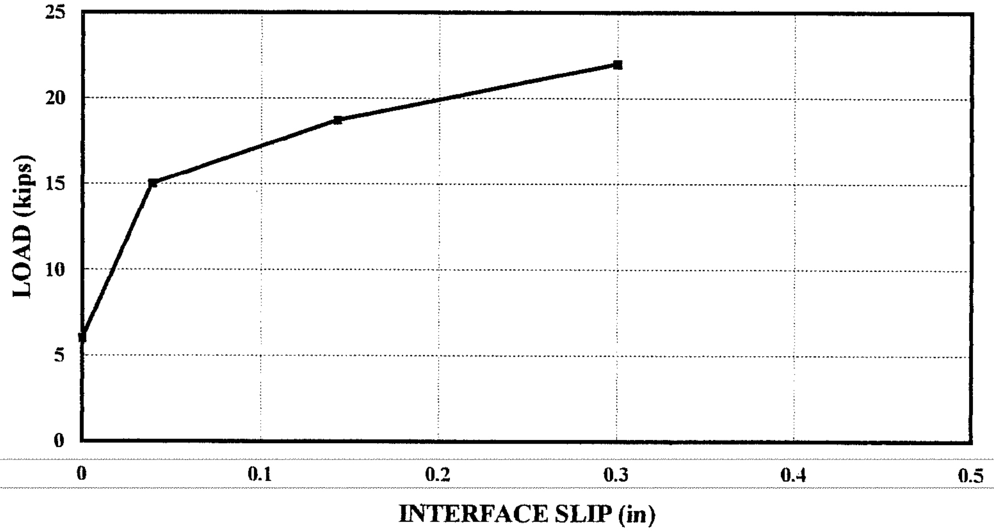


Figure 3.20 Analytical model for single bolt epoxy grouted connection with 7/16 in. hole clearance and clamping force.

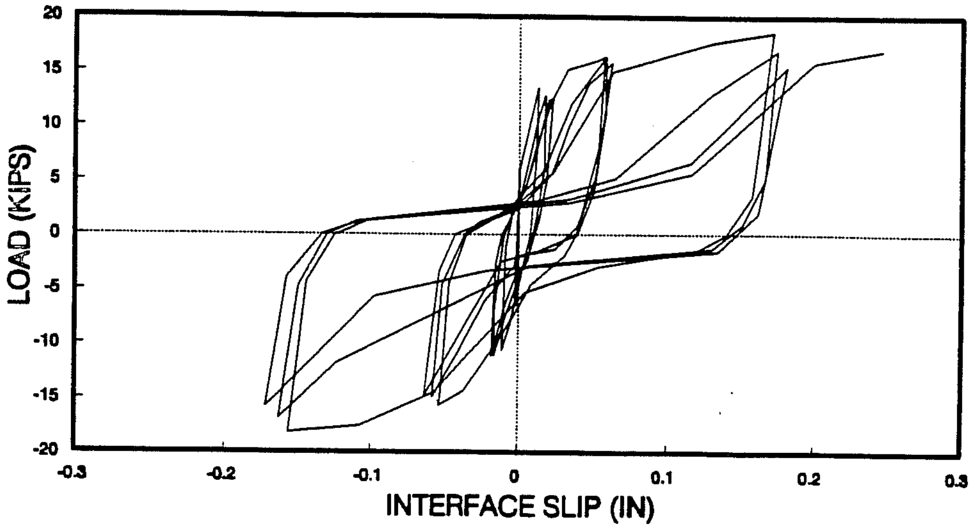


Figure 3.21 Epoxy grouted connection behavior of a single bolt with 3/16 in. hole clearance and 12 kips of clamping force loaded cyclically obtained from experimental test (5).

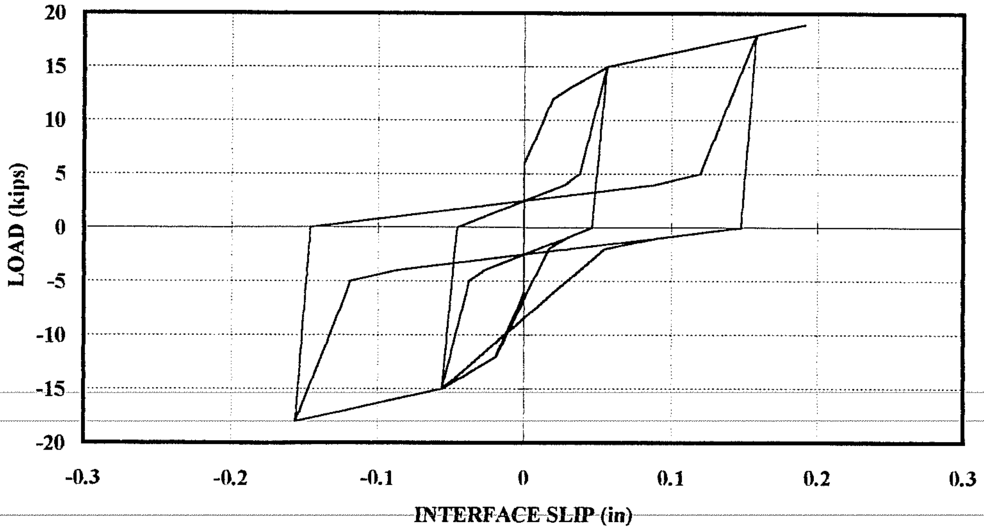


Figure 3.22 Analytical model of the behavior of a epoxy grouted connection loaded cyclically.

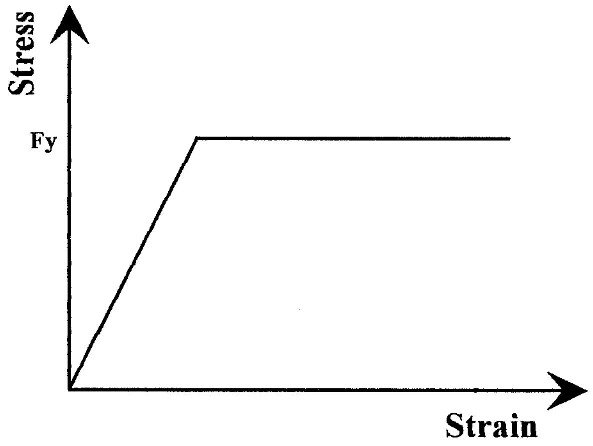


Figure 3.23 Stress-Strain relationship for the steel plate

CHAPTER 4

PRESENTATION OF RESULTS

4.1 Introduction

The computer program BOLTS was used for computing the behavior of plain, grouted, and epoxy grouted connections, under monotonic loading, and for epoxy grouted connections under cyclic loading. The influence of hole clearance, amount of clamping force applied to bolts, number of bolts in a row, spacing between bolts, and effect of interface thickness was investigated.

4.2 Monotonic Loading

4.2.1 Plain Connection. A plain connection is defined as one in which neither the gap between the anchor bolt and the steel element nor the gap at the interface between the existing concrete element and steel plate is filled with any structural material.

Load-deformation responses for this type of connection are plotted in Fig. 4.1 through 4.16. A connection with the following characteristics was studied:

Number of bolts (N) = 4
Spacing between bolts (S) = 10 in.
Clamping force per bolt (CF) = 8 kips
Steel plate area (SPA) = 1.5 in^2
Bearing clearance (BC) = All bolts were placed with the same bearing clearance.

Hole Clearance. The effect of hole clearances from 0 to 1/4 in. is presented in Fig. 4.1. The figure shows that the hole oversize did not have any influence on the ultimate strength or stiffness of the connection once slip occurred. It shows that the greater the hole clearance, the greater the slip of the steel plate before it transferred load to the bolts. When the steel plate slipped enough to bear against an anchor bolt, load was transferred directly to the bolts and stiffness of the connection increased. For a connection in a retrofitting system, the flexibility increased with each incremental increase in hole clearance. After failure of the first bolt, the capacity of the connection dropped rapidly as additional bolts failed with little increase in deformation.

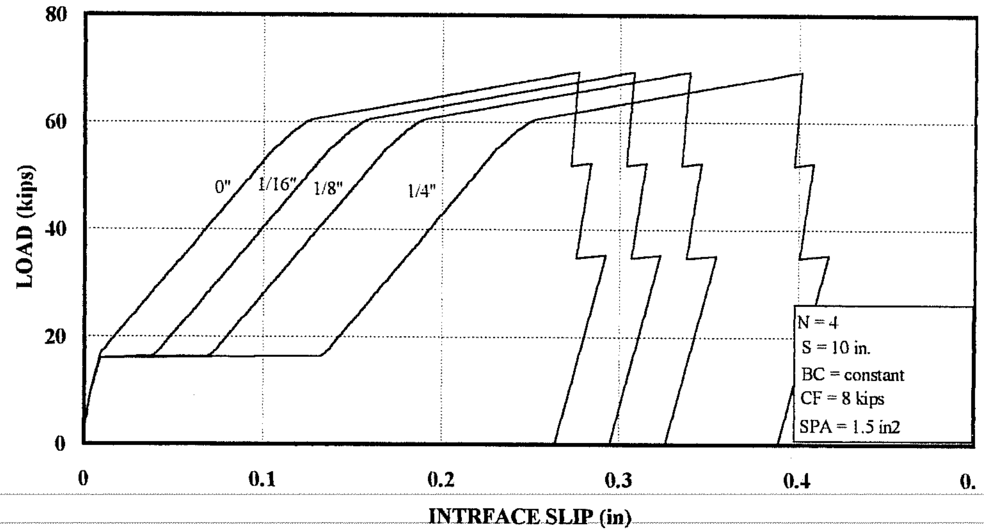
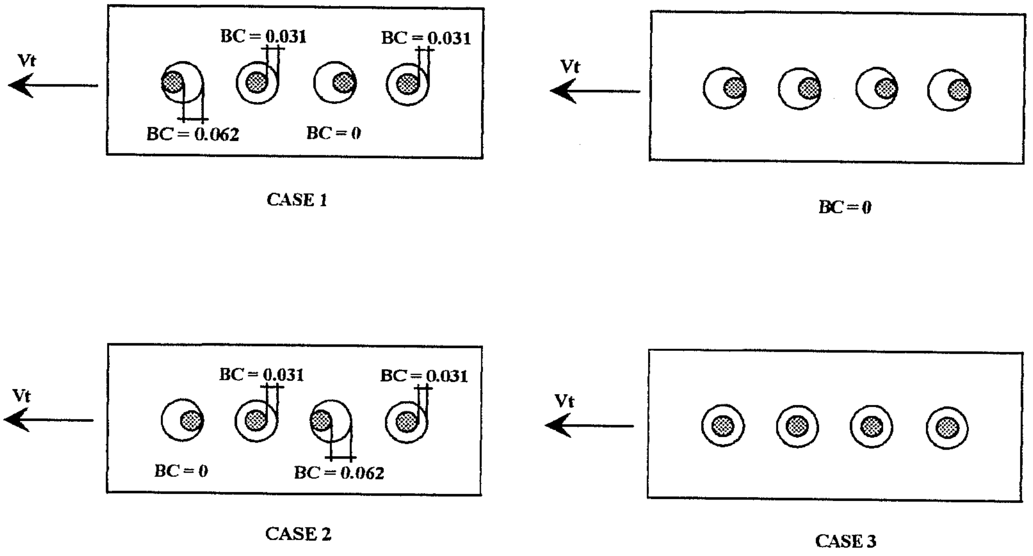


Figure 4.1 Effect of hole clearance on the behavior of a plain steel-concrete connection.

The Load & Resistance Factor Design Specifications (LRFD) allow a hole 1/16 in. greater than the bolt diameter for standard round holes. The behavior of four connections with 1/16 in. hole clearance and bolts placed with different bearing clearance (see Fig. 4.2) is compared in Fig. 4.3.



CASE 1

BC=0

CASE 2

CASE 3

Figure 4.2 Bolt position of connections analyzed in Fig. 4.3

The results show that the influence of bearing clearance, for small hole diameters, on the response of the connection in terms of capacity, stiffness, and deformation was quite small.

Figure 4.4 shows the influence of hole clearance for a connection where all bolts, except bolt 1 (BC=0), are placed with the same bearing clearance, as shown in Fig. 4.5.

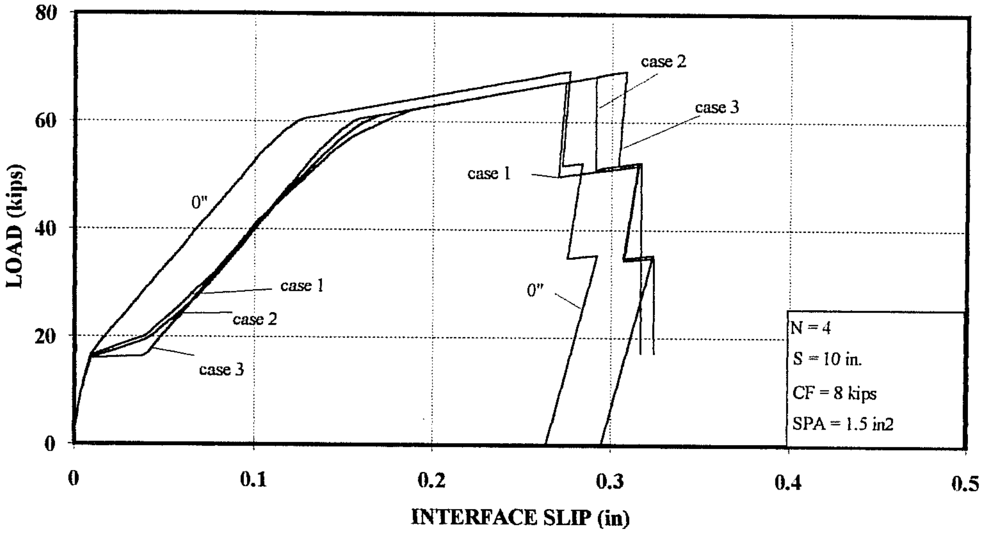


Figure 4.3 Effect of different bearing clearance for each bolt on the behavior of a 1/16 in. hole clearance plain steel-concrete connection.

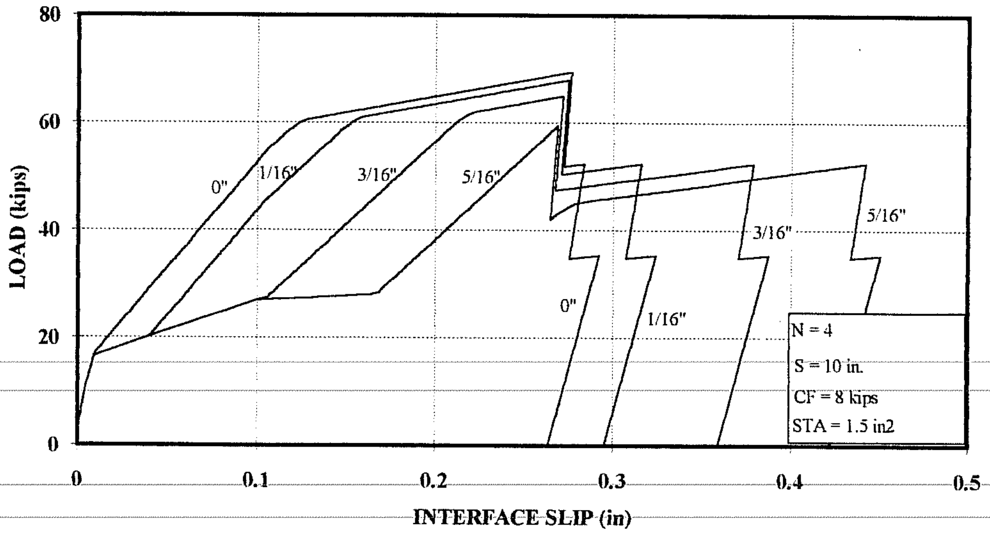


Figure 4.4 Effect of hole clearance on the behavior of a plain steel-concrete connection with all bolts having the same bearing clearance except bolt 1 (BC=0).

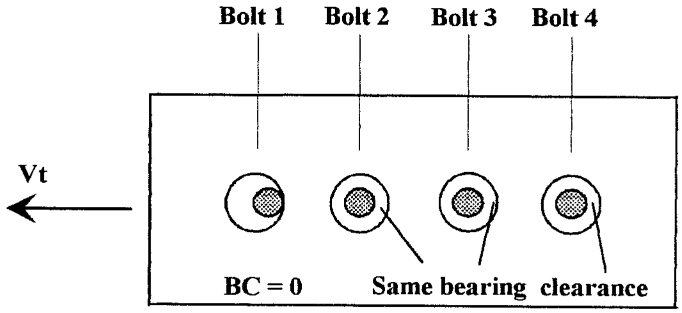


Figure 4.5 Bolt position of the connection analyzed in Fig. 4.4

Figure 4.4 shows that by increasing the hole clearance, the maximum capacity and the plastic deformation of the connection decreased. The first bolt failed before the rest of the bolts reached their maximum elastic deformation capacity. After the failure of the lead bolt, remaining bolts did not develop their strength and allowed additional deformation of the connection. Figure 4.6 shows that the effect of the position along the connection of the bolt with bearing clearance equal to zero does not modify the response of the connection. The deformation capacity of the bolt located at the end of the connection has very little influence on response.

Figure 4.7 shows the distribution of loads for a connection where all bolts have the same hole clearance (1/16 in.) and the same bearing clearance, as shown in Case 3, Fig. 4.2. The lead bolt carries the highest load. In the elastic range, applied load is not divided equally among all bolts. However, when the bolts reach the non-linear range, the distribution of load becomes more uniform. If in the connection analyzed above, the first bolt had a bearing clearance equal to zero (see Fig. 4.5) the percentage of load resisted by the first bolt increases when the hole clearance increases, as shown in Fig. 4.8 and 4.9. If the bolt with zero bearing

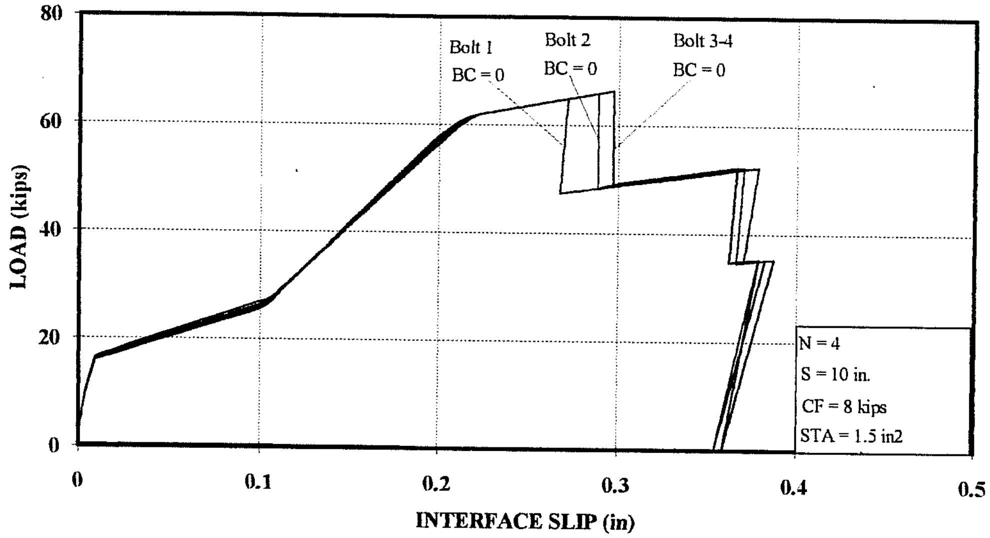


Figure 4.6 Effect of bearing clearance on the behavior of a plain steel-concrete connection with all but one bolt having the same bearing clearance.

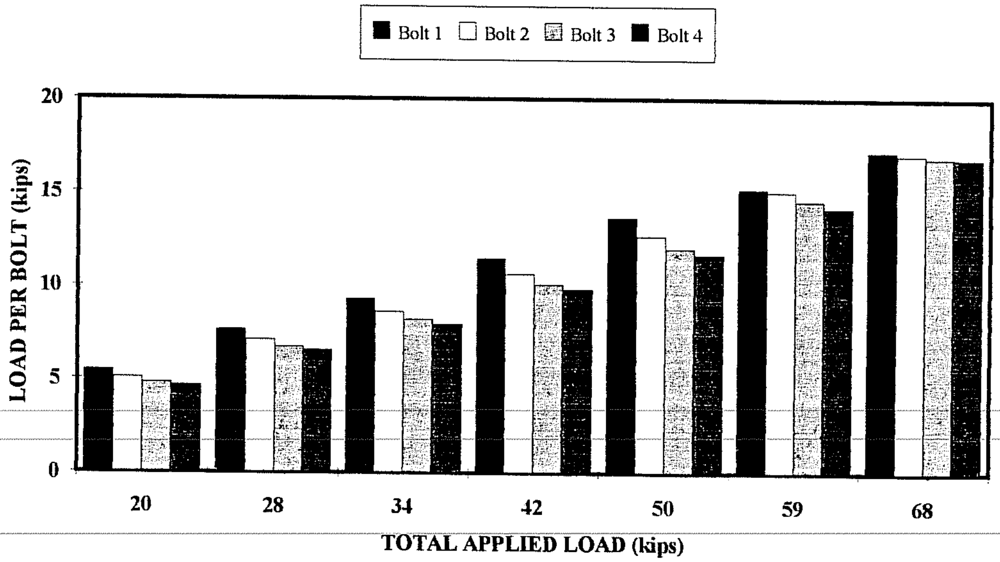


Figure 4.7 Bolt load distribution in a plain connection with 1/16 in. hole clearance.

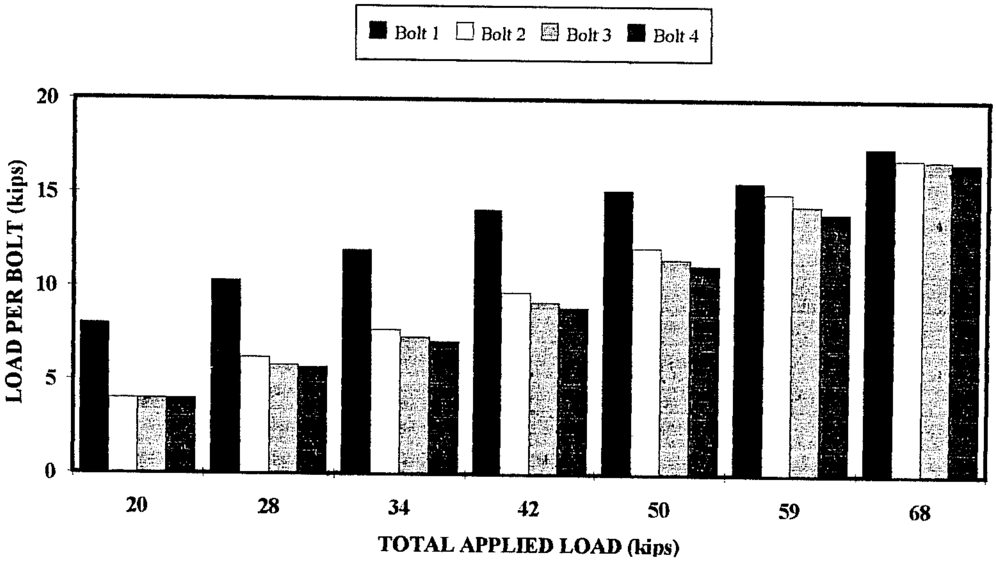


Figure 4.8 Effect of hole clearance in the distribution of loads to bolts in a plain steel-concrete connection with all bolts having the same hole clearance (1/16 in.) and bearing clearance except bolt 1 (BC=0).

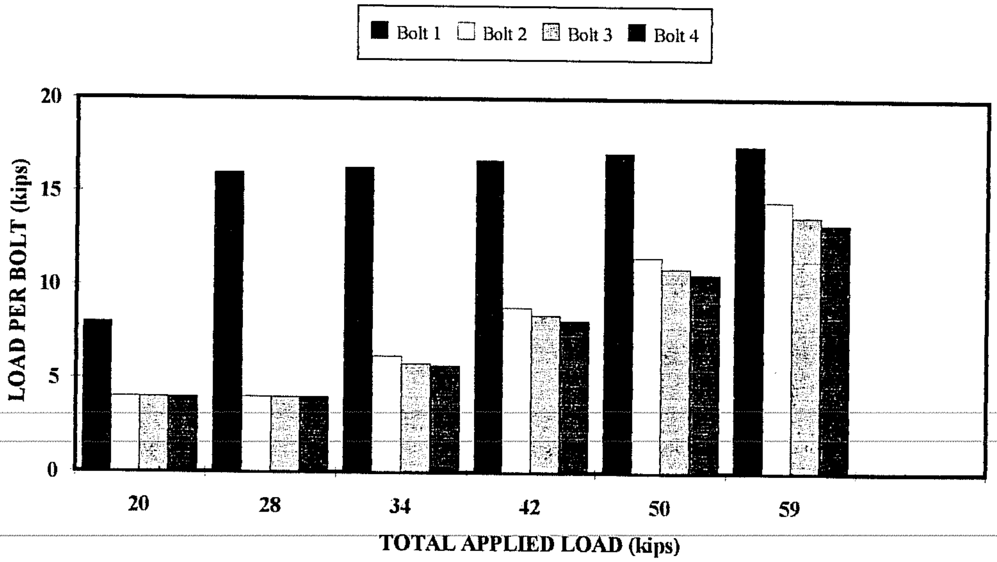


Figure 4.9 Effect of hole clearance in the distribution of loads to bolts in a plain steel-concrete connection with all bolts having the same hole clearance (5/16 in.) and bearing clearance except bolt 1 (BC=0).

clearance is located near the end of the connection, a better load distribution is obtained as shown in Fig. 4.10.

Clamping force. The effect of a clamping force from 0 to 18 kips applied to bolts was analyzed and the results are presented in Fig. 4.11. Before first slip, stiffness of the system increased when the clamping force increased. After reaching the plastic deformation range, clamping force had no influence. Unequal clamping force in bolts may result from imprecise preloading or poor inspection during the installation process. Examples of this are shown in Fig. 4.12. The effect of these variations are shown in Fig. 4.13. It illustrates that variations in clamping force do not have an important influence on the response of connections.

Number of Bolts per Row. Four connections with the same number of bolts placed in different rows, as shown in Fig. 4.14 were analyzed. Figure 4.15 shows the effect of increasing the number of bolts per row. An increase in number of bolts per row resulted in a decrease in stiffness and plastic deformation of the connection; although, the maximum capacity of the system was not significantly changed. An increase in distance between bolts had a similar effect as shown in Fig. 4.16.

4.2.2 Grouted Connection. The grouted connection is defined as a connection in which both the gap between the anchor bolt and the steel element and the gap at the interface between the existing concrete element and the steel plate were filled with non-shrink grout.

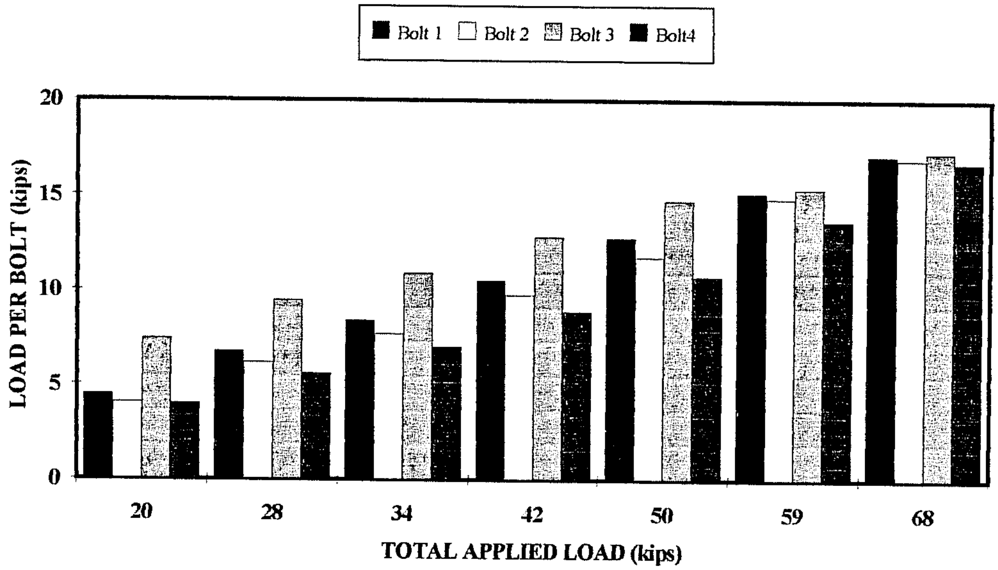


Figure 4.10 Effect of hole clearance on the distribution of loads to bolts in a plain steel-concrete connection with all bolts having the same hole clearance (1/16 in.) and bearing clearance except bolt 3 (BC=0)

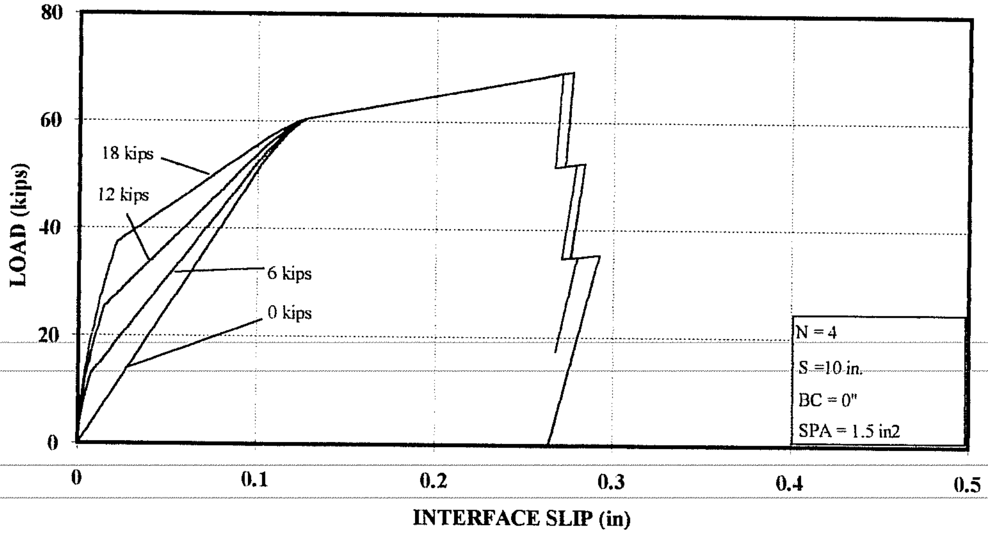
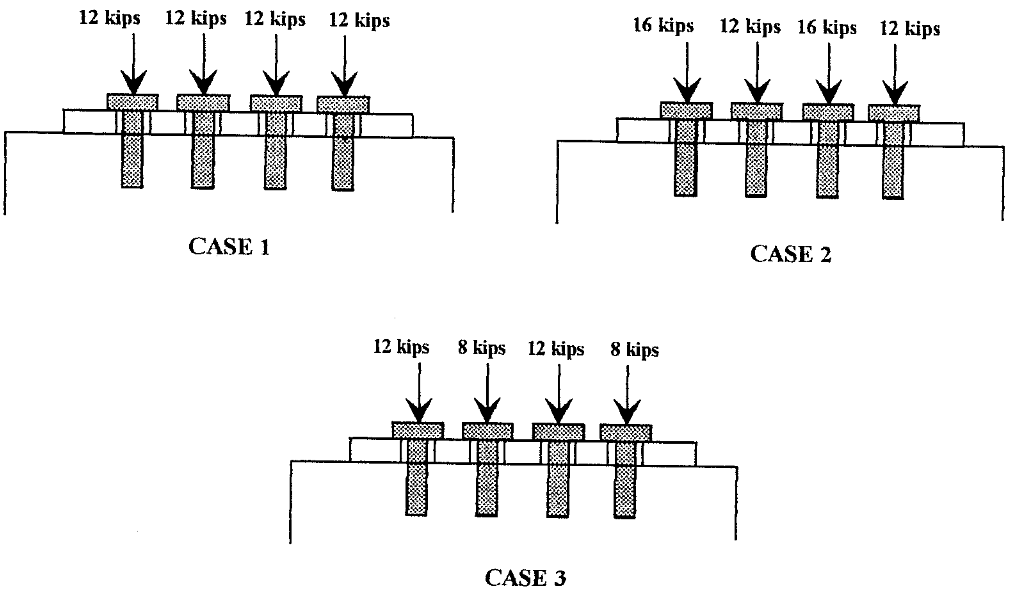


Figure 4.11 Effect of equal clamping force on all bolts on the behavior of a plain steel-concrete connection.



CASE 1

CASE 2

CASE 3

Figure 4.12 Variation in clamping force applied to bolts.

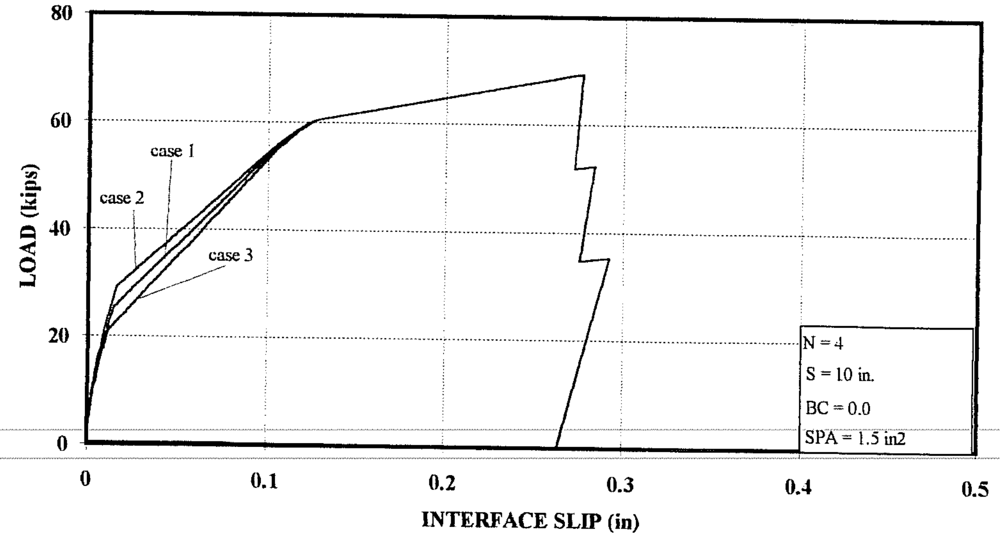


Figure 4.13 Effect of varying clamping force on the behavior of a plain steel-connection with half the bolts 50% overtightened or 50% no tightened sufficiently.

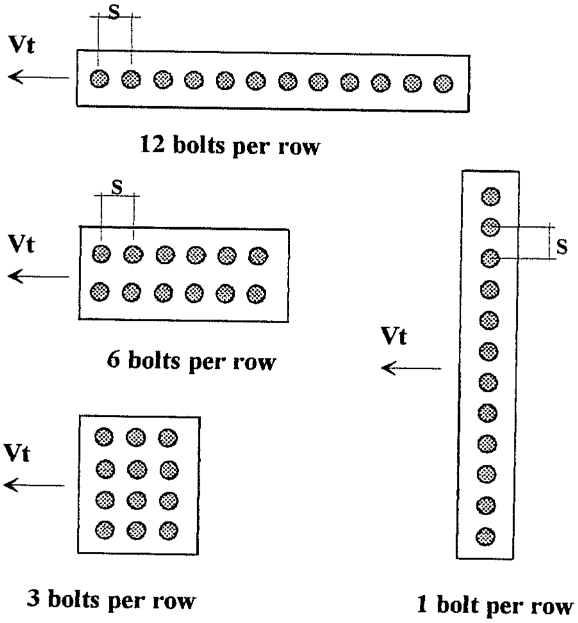


Figure 4.14 Comparison of connections with he same number of bolts placed in different number of rows.

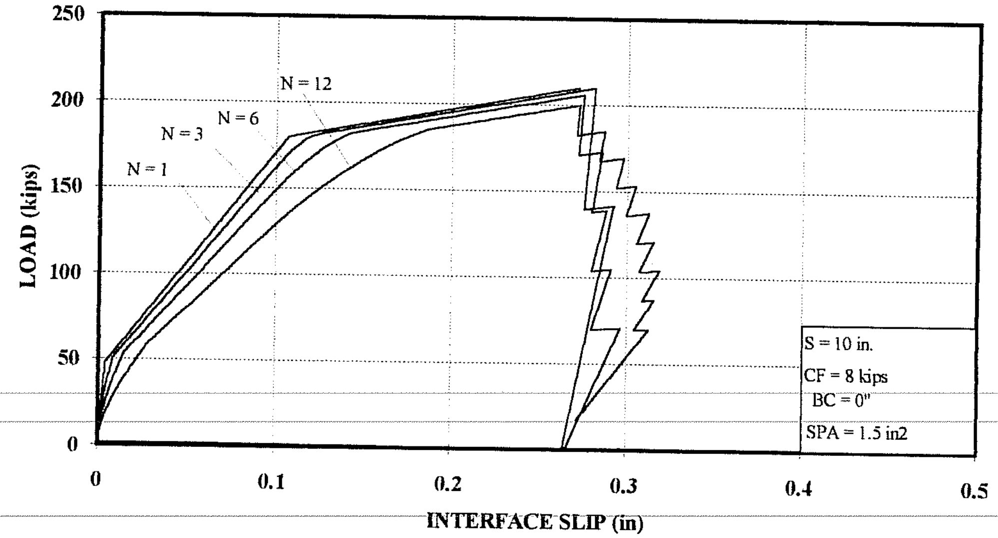


Figure 4.15 Effect of number of bolts per row in a plain steel-concrete connection.

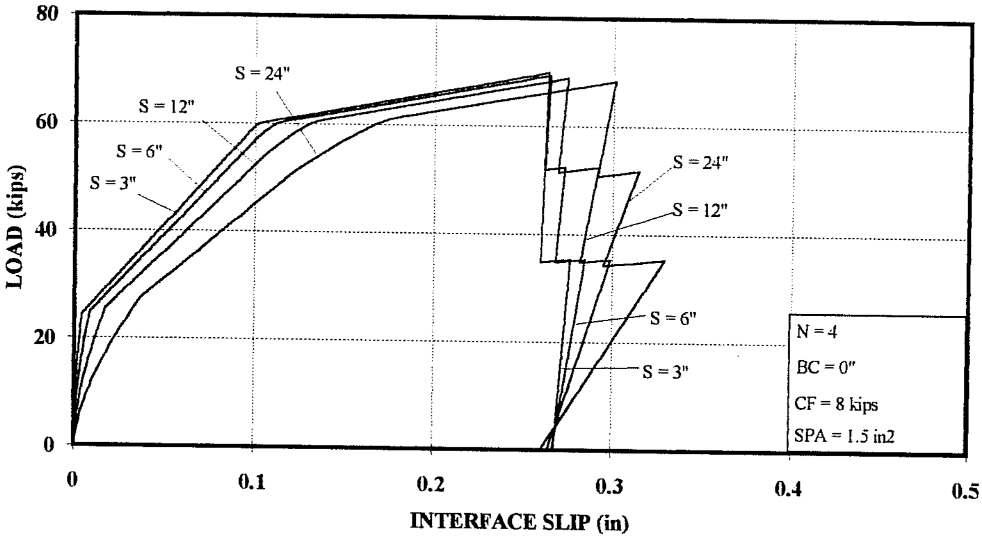


Figure 4.16 Effect of distance between adjacent bolts in a plain steel-concrete connection.

The results for this type of connection are plotted in Fig 4.17 through 4.26. A connection with the following characteristics was studied:

Number of bolts (N) = 4
Spacing between bolts (S) = 10 in.
Clamping force (CF) = 8 kips
Steel plate area (SPA) = 1.5 in^2
Hole clearance (HC) = All bolts were placed with the same hole clearance.

Hole Clearance. The effect of the hole clearance (3/16 in. to 7/16 in.) on the response of a connection is shown in Fig. 4.17. In the elastic range, calculated response was similar in terms of stiffness and deformation . In the inelastic range, some important differences were apparent: the smaller the hole clearance, the greater the stiffness, and the larger the hole clearance, the greater was the deformation capacity of the connection. Connections having all bolts, except bolt 1, with the same hole clearance (see Fig. 4.5) demonstrated that hole clearance did not have a significant influence on the behavior of the connection, as shown in Fig. 4.18.

Clamping force. Figure 4.19 shows the effect of clamping force applied to bolts. Connections with higher clamping force demonstrated greater stiffness before first slip. The first slip capacity increased proportionally with the increase in clamping force. Beyond that, clamping force did not affect the connection behavior.

Number of Bolts per Row. The effect of number of bolts in a row (see Fig. 4.14) and distance between adjacent bolts changed the stiffness of the connection with little effect on the strength and deformation capacity, as shown in Fig. 4.20 and 4.21 respectively.

The distribution of loads among bolts was not affected by the hole clearance as shown in Fig. 4.22 and 4.23. The connection analyzed was similar to Case 3, Fig. 4.2, where all bolts had the same hole and bearing clearance. The lead bolt resisted more load than the remainder of the bolts; however, when the connection reached the non-linear range the distribution became more uniform. Similar behavior was observed for connections with a different number of bolts per row, as shown in Fig. 4.24 and 4.25.

Thickness of Interface. The effect of interface material thickness is shown in Fig. 4.26. The connection analyzed was similar to Case 3, Fig. 4.2. After first

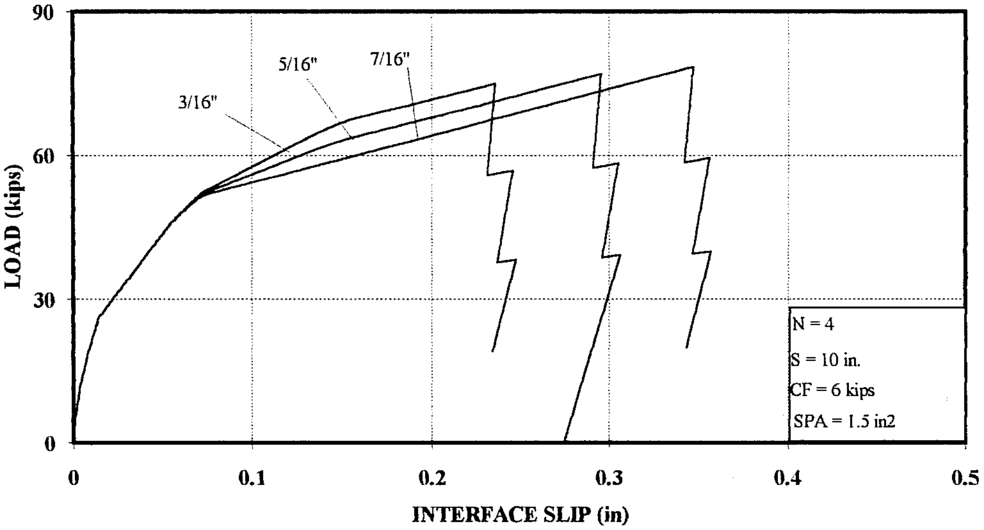


Figure 4.17 Effect of hole clearance on the behavior of a grouted connection.

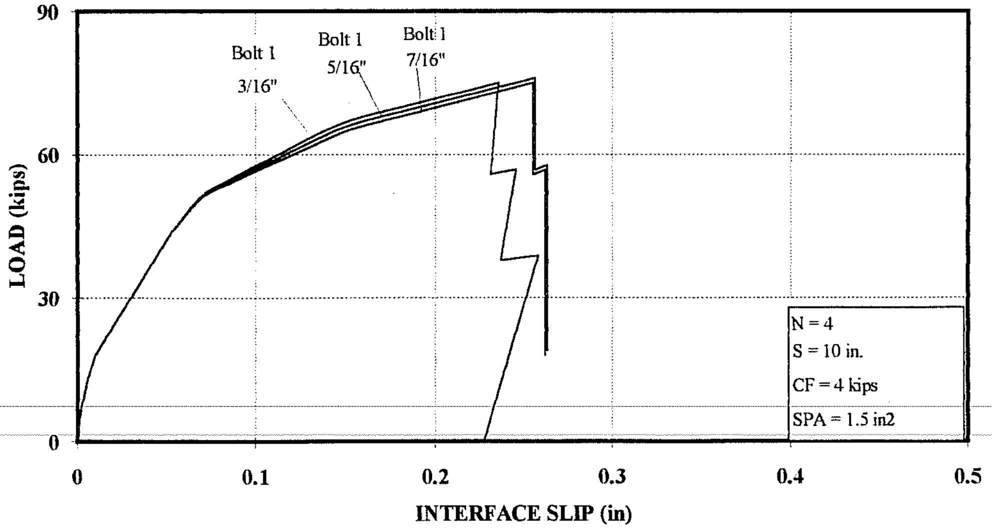


Figure 4.18 Effect of hole clearance on the behavior of a grouted connection with all bolts, except bolt 1, having the same hole clearance (3/16 in.).

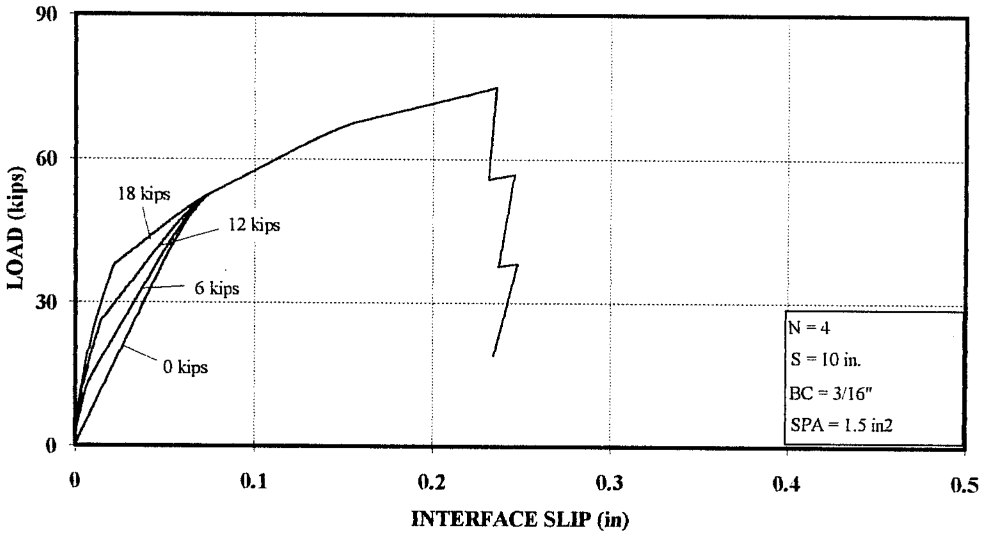


Figure 4.19 Effect of clamping force on the behavior of a grouted connection.

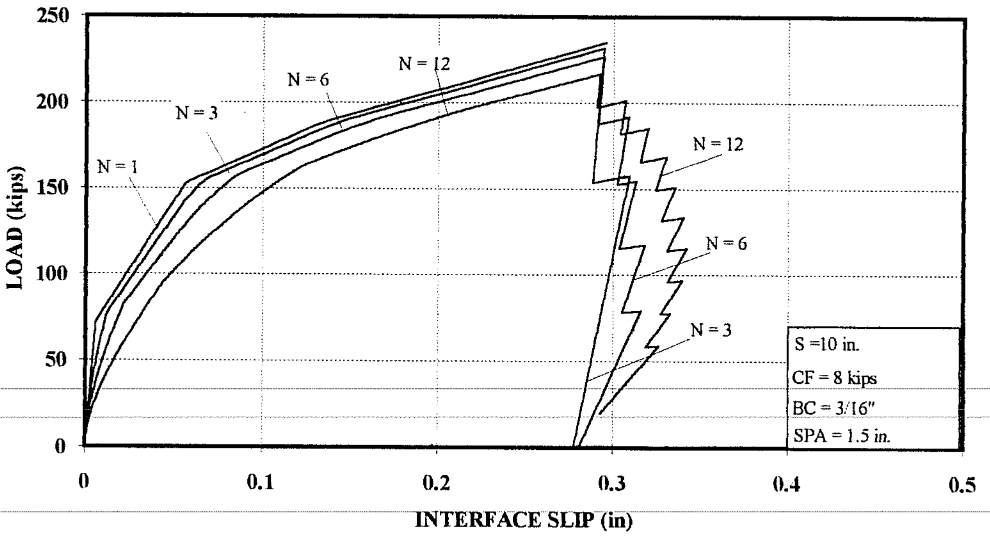


Figure 4.20 Effect of number of bolts per row on the behavior of a grouted connection.

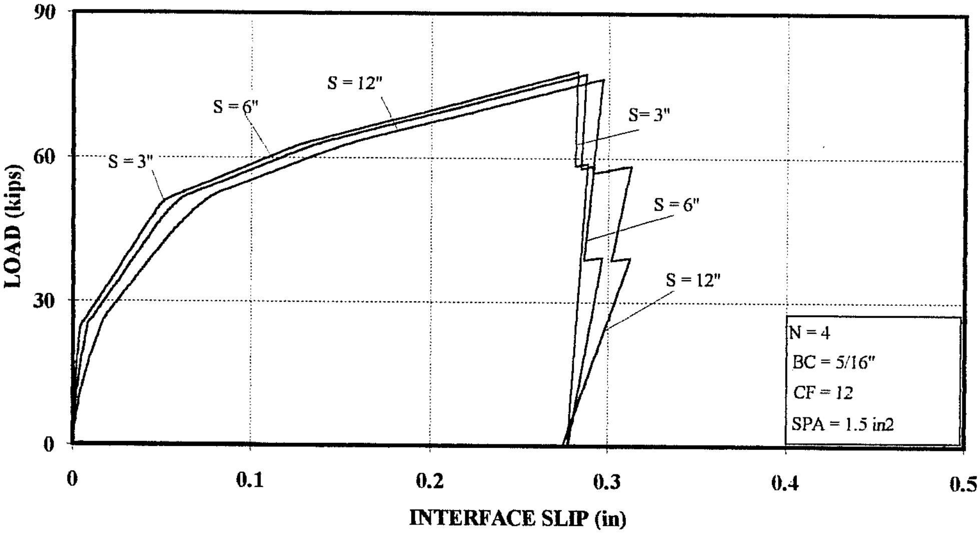


Figure 4.21 Effect of distance between adjacent bolts on the behavior of a grouted connection.

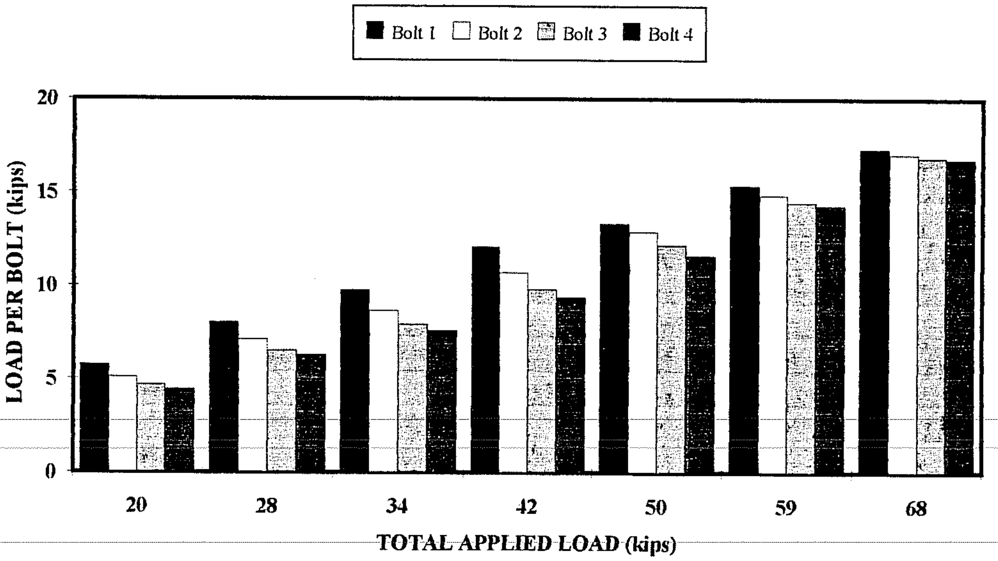


Figure 4.22 Bolt load distribution for a grouted connection with 3/16 in. hole clearance.

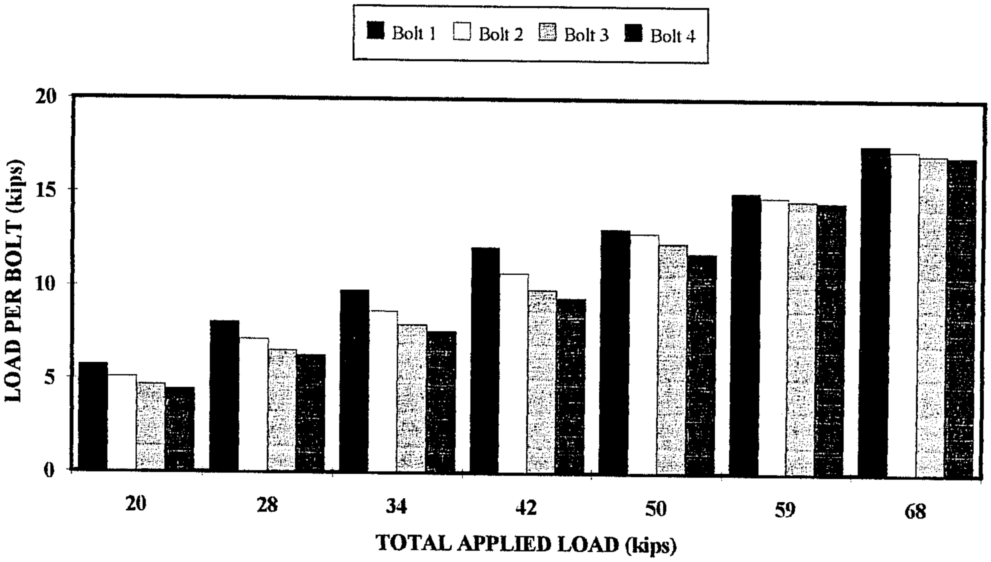


Figure 4.23 Bolt load distribution for a 7/16 in. hole clearance grouted connection.

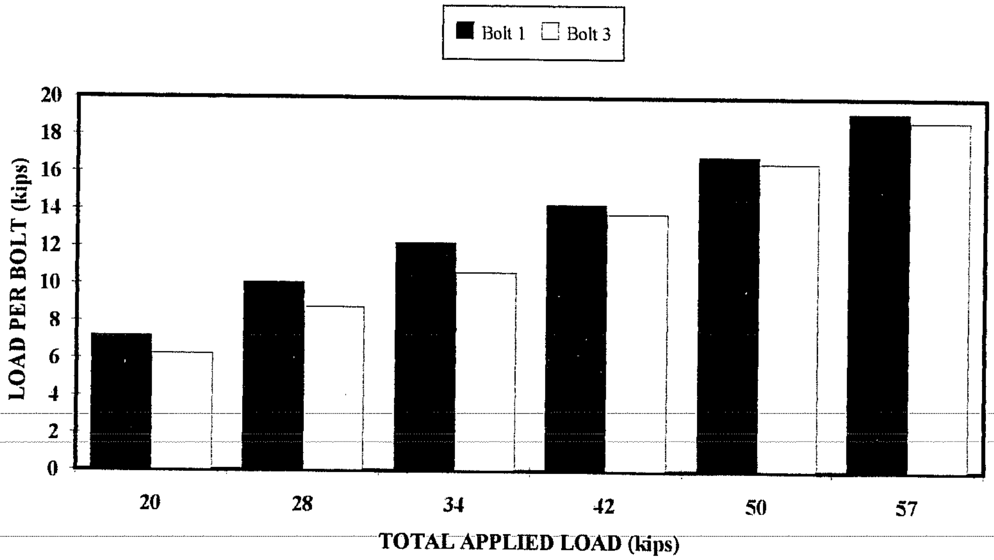


Figure 4.24 Bolt load distribution for a 3 bolts per row grouted connection with 5/16 in. hole clearance.

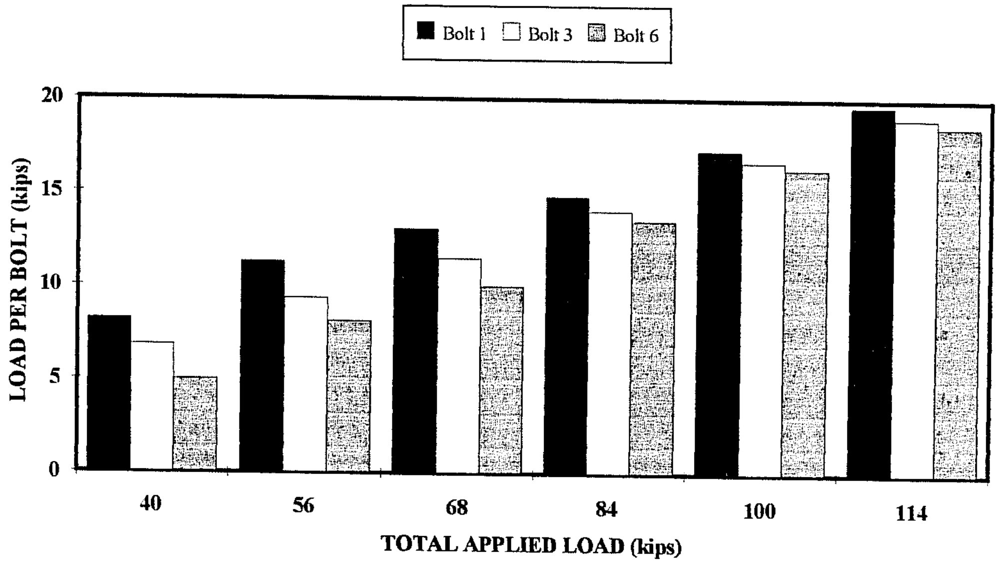


Figure 4.25 Bolt load distribution for a 6 bolts per row grouted connection with 5/16 in. hole clearance.

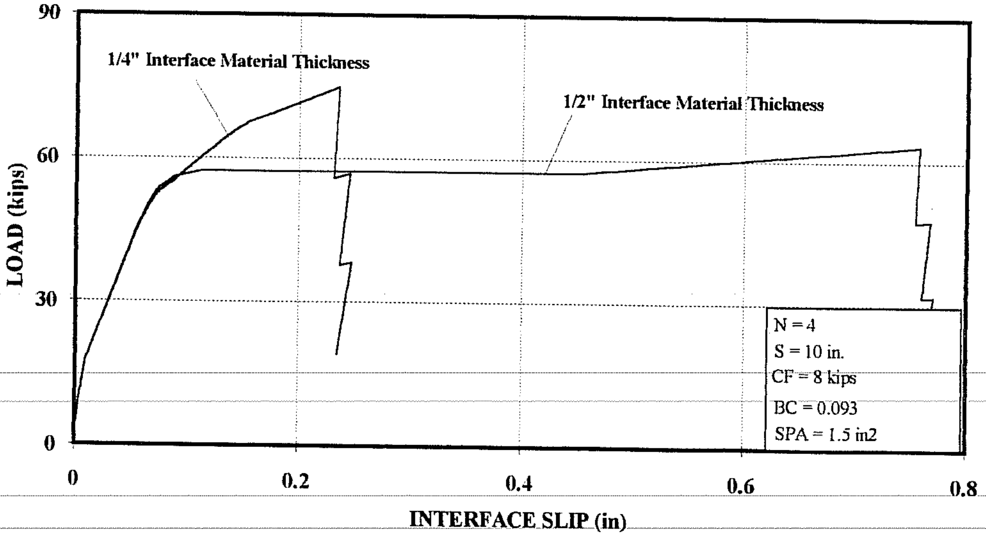


Figure 4.26 Effect of interface material thickness on a 3/16 in. hole clearance grouted connection.

slip, the behavior for both connections was similar up to a displacement of 0.1. After that displacement, the behavior was completely different. The connection with a 1/4 in. interface thickness was stiffer than the connection with a 1/2 in. interface. However, the deformation capacity decreased with a decrease in material thickness.

4.2.3 Epoxy Grouted Connection.

Epoxy was applied to the base of the anchor bolt and in the gap between the anchor bolt and steel plate. Load deformation response for this type of connection are plotted in Fig. 4.27 through 4.32. A connection with the following characteristics was studied:

Number of bolts (N) = 4
Spacing between bolts (S) = 10 in.
Clamping force (CF) = 8 kips
Steel Plate Area (SPA) = 1.5
Hole clearance (HC) = all bolts were placed with the same hole clearance.

Hole Clearance. The effect of hole clearance is shown in Fig. 4.27. Up to first slip, the behavior was similar for all hole clearance sizes. However, after first slip, the maximum strength and deformation capacity increased with an increase in hole clearance. The stiffness of the connection decreased with increase in hole clearance. Connections with small hole clearance reach maximum strength first. The deformation after failure of the first bolt is similar for all hole clearances.

Clamping force. The clamping force affected the stiffness of the connection as shown in Fig. 4.28. Stiffness was greatly improved with an increase in clamping force. For a clamping force exceeding 12 kips, an increase of clamping force did

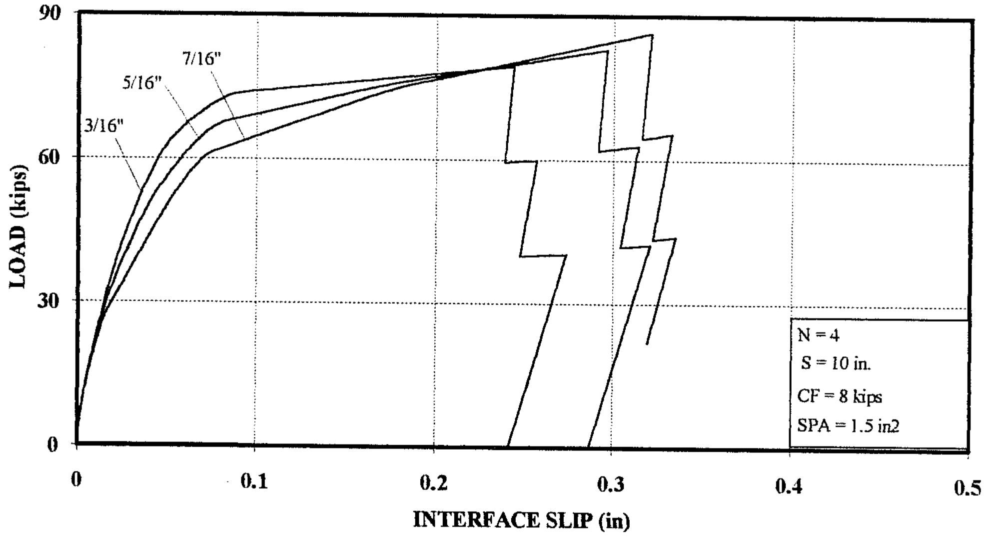


Figure 4.27 Effect of hole clearance on the behavior of an epoxy grouted connection.

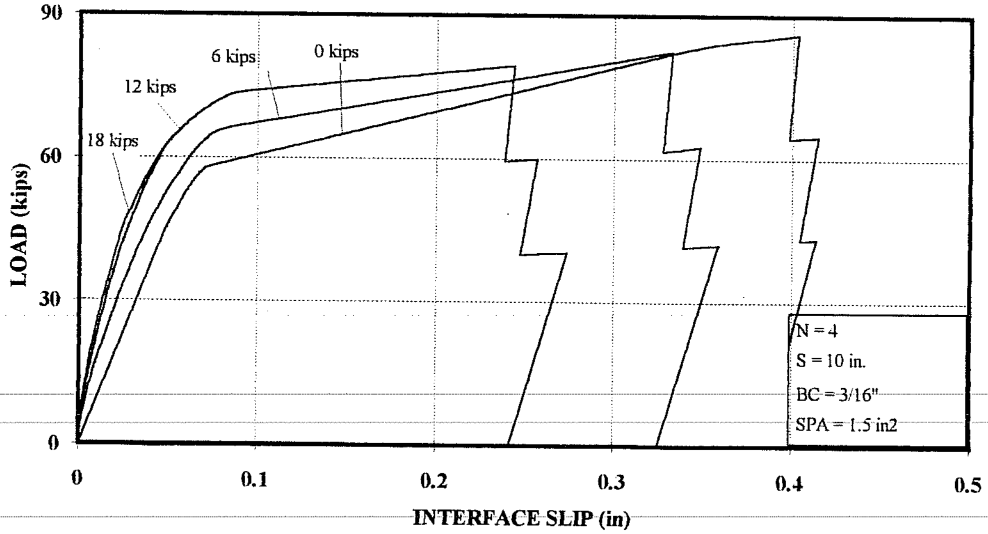


Figure 4.28 Effect of clamping force on the behavior of an epoxy grouted connection.

not improve the behavior of the connection. Although clamping force increased connection stiffness, strength decreased as did inelastic deformation capacity.

Number of Bolts per Row. An increase in the number of bolts in a row (see Fig. 4.14) greatly decreased the stiffness of the connection as presented in Figure 4.29. Strength did not change significantly. Figure 4.30 illustrates the effect of distance between adjacent bolts. Stiffness decreased with increase in distance between bolts, but strength was not affected.

The load distribution among bolts was similar to that for grouted connections (see Fig. 4.31 and 4.32). The connection analyzed was similar to Case 3, Fig. 4.2. The lead bolt resisted more load and the distribution became more uniform as applied load on the connection increased.

4.2.4 Comparison of Cases. Figure 4.33 shows a comparison of the three cases studied: plain, grouted, and epoxy grouted connections. It shows that the epoxy grouted connection is stiffer and stronger than the other two cases. The flexibility of the plain connection is due to slip of the steel plate until it bears against bolts.

4.3 Cyclic Loading

Examples of the behavior of a epoxy connection loaded cyclically is presented in Figs. 4.34 and 4.35. These two figures show the effect of increment of distance between adjacent bolts in a connection with the following characteristics:

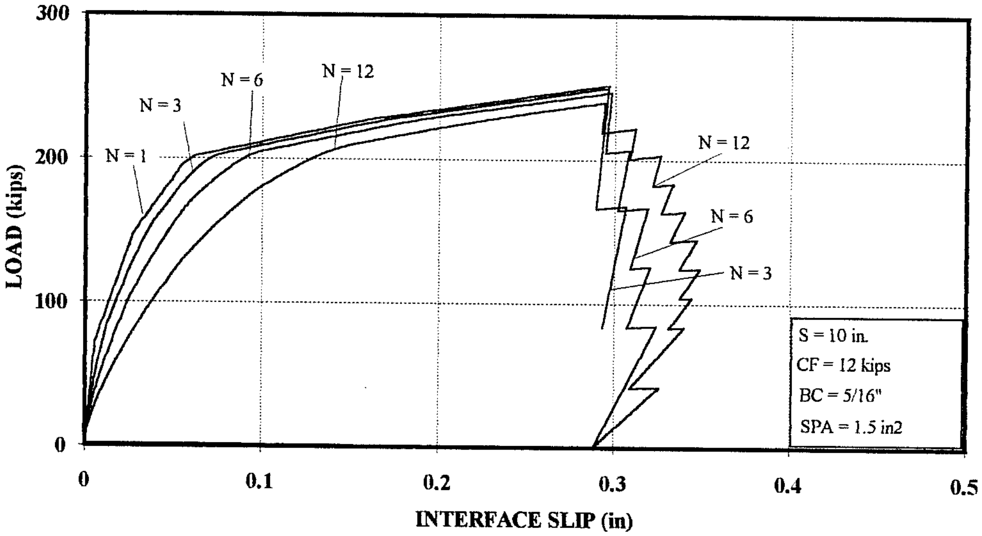


Figure 4.29 Effect of number of bolts per row on the behavior of an epoxy grouted connection.

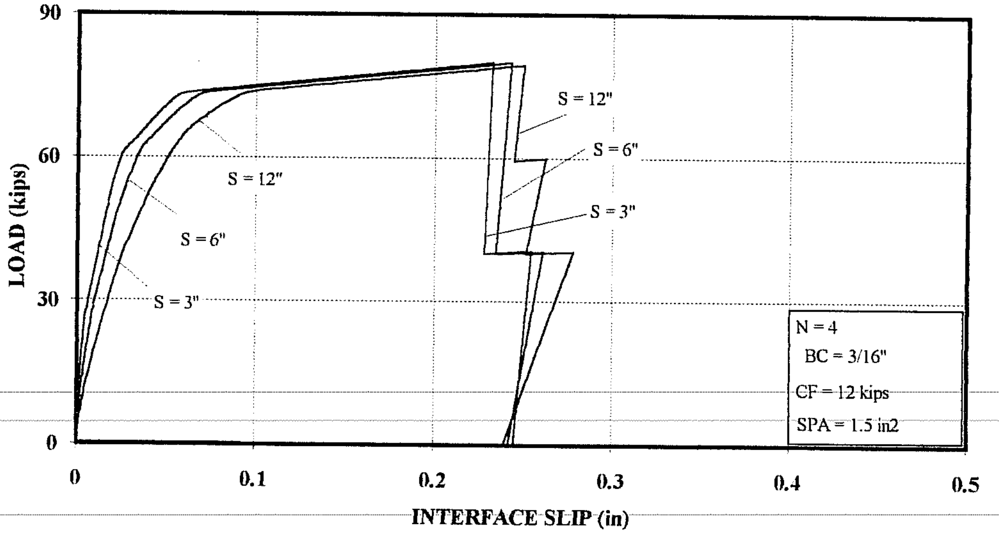


Figure 4.30 Effect of distance between adjacent bolts on the behavior of an epoxy grouted connection.

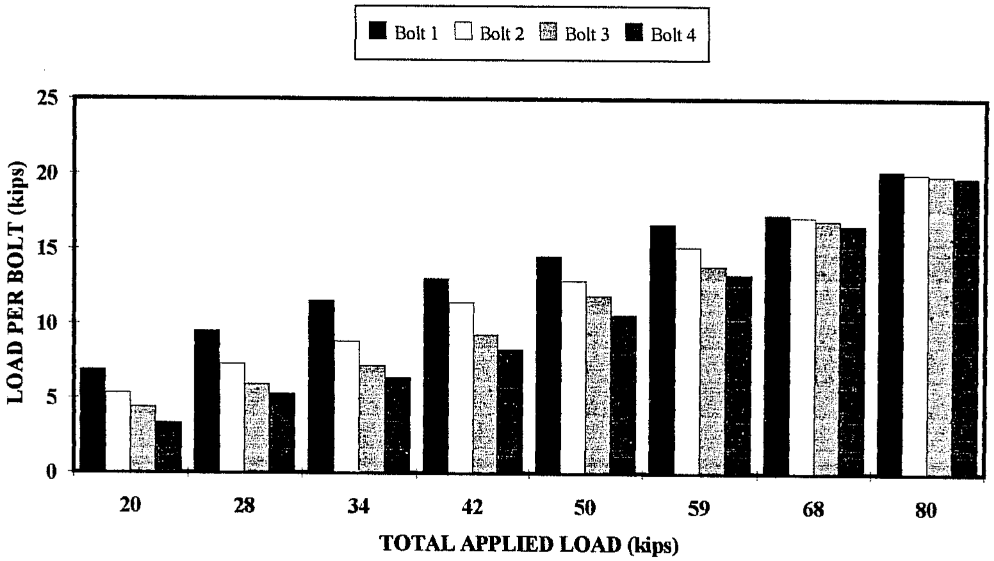


Figure 4.31 Bolt load distribution for a 3/16 in. hole clearance epoxy grouted connection.

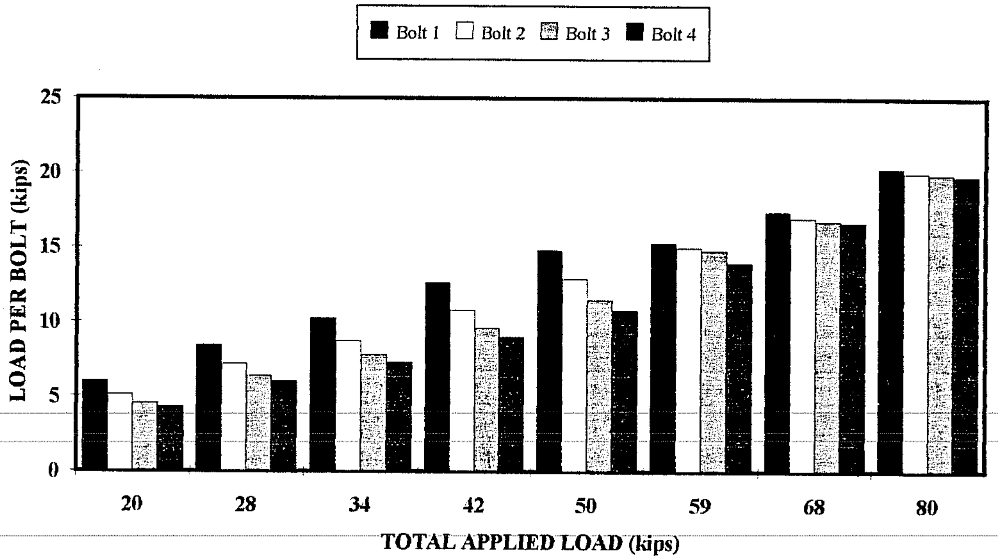


Figure 4.32 Bolt load distribution for a 7/16 in. hole clearance epoxy grouted connection.

Number of bolts (N) = 3
Clamping force (CF) = 6 kips
Steel Plate Area = 1.5
Hole clearance (HC) = 3/16 in.

As it was shown in section 4.2, connections loaded monotonically, an increment of distance between adjacent bolts reduce the stiffness of the connection without affecting the maximum strength of the connection.

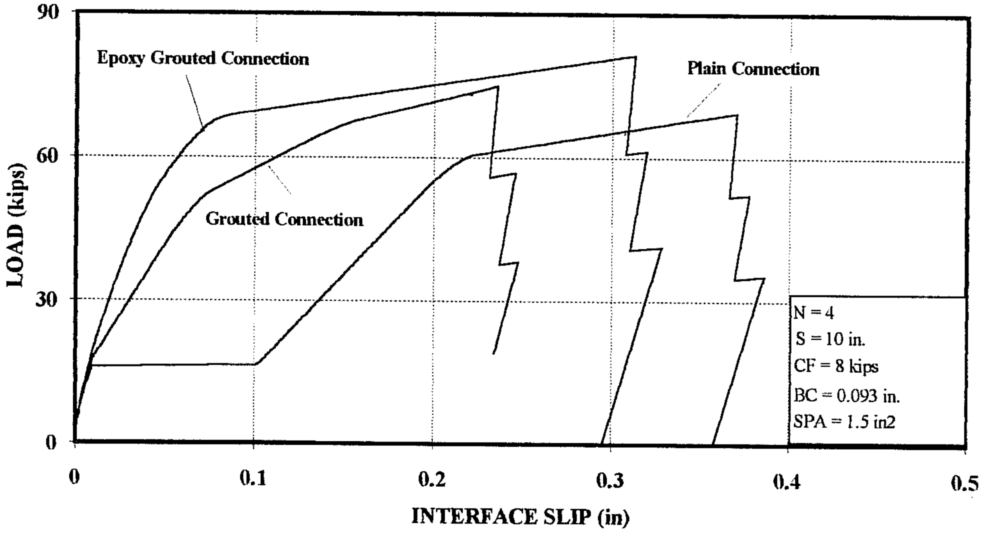


Figure 4.33 Comparison response of a 3/16 in. hole clearance plain, grouted and epoxy grouted connection.

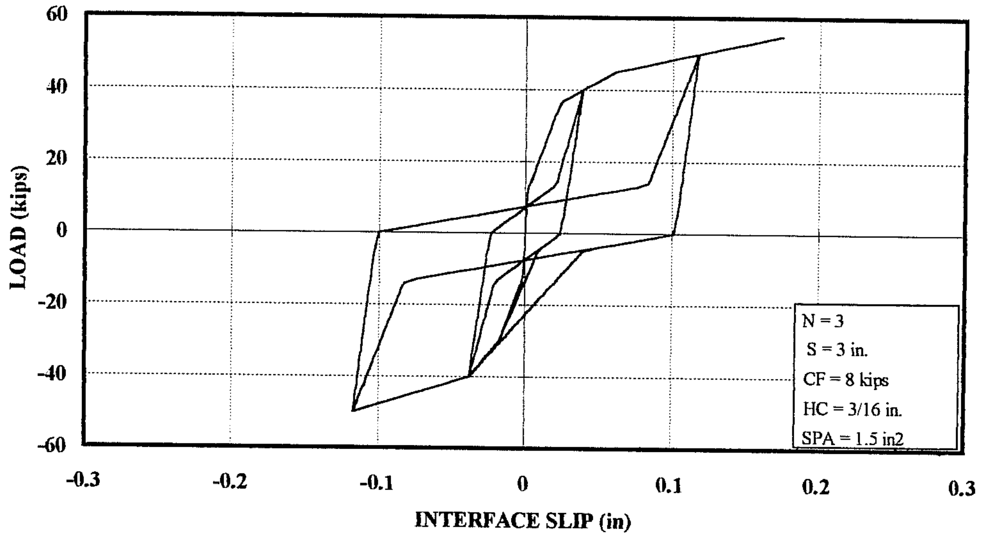


Figure 4.34 Behavior of an epoxy connection loaded cyclically with 3 in. distance between bolts.

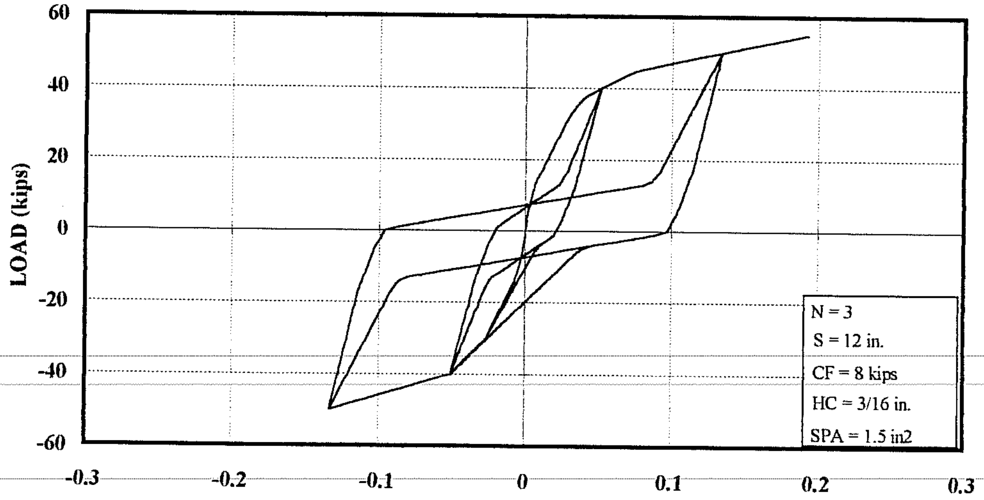


Figure 4.35 Behavior of an epoxy connection loaded cyclically with 12 in. distance between bolts.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of the study

The behavior and distribution of forces in a multiple-fastener steel-concrete connection were studied analytically. A computer program was written for estimating the response and distribution of loads to bolts in a multiple bolt installation. The program was based on load-deformation models developed using the observed behavior of single bolt connections tested in the laboratory.

In the study, only steel-concrete connections using adhesive anchor bolts loaded in pure shear were tested. Connection strength was controlled by the strength of the steel plate or anchor bolt. Splitting failures of the concrete around the anchor bolt were not included.

The analytical study included connections loaded monotonically and cyclically. For monotonic loading, three cases were studied, plain, grouted and epoxy-grouted connections. For each case, the influence of the following variables was explored: hole clearance, amount of clamping force applied to bolts (bolt pre-load), number of bolts in a row, distance between bolts, and interface thickness. For cyclic loading, the behavior of a four bolt connection is presented to illustrate the results of the computer program.

5.2 Conclusions

Results obtained from the analytical study provide information for studying uncertainties in design of multiple-fastener connections. The results lead to following conclusions:

1- The use of plain connections could produce unexpected large deformations of the connections due to variable hole clearance. The greater the hole clearance, the greater the overall deformation of the connection.

2- Plain connections with all bolts having a small hole clearance performed better and had a better bolt load distribution than those with large, varying clearances.

3- Plain connections with bolts having different hole clearance performed poorly and had a non-uniform bolt load distribution at all load stages. The greater the variation in bearing clearance along the connection, the greater the non-uniformity of bolt load distribution.

4- The use of grout or epoxy filler material between the bolt and steel element resulted in better behavior than plain connections (no grout). The load distribution to bolts was also better for connections with grout than connections without any filler material.

5- The use of epoxy and grouted connections resulted in a more even distribution of loads among bolts in the elastic deformation range. Prior to failure, shear forces in each bolt became nearly uniform in the connection. In general, the bolt closest to the applied load resisted more load and failed before the remaining bolts reached their peak strength.

6- Connection flexibility was affected by the material filling the annulus. Epoxy grouted connections were stiffer and developed more inelastic deformation than did grouted connections.

7- For any type of connection, the use of a large number of bolts per row and/or large distance between adjacent bolts decreased the stiffness of the connection.

8- The effect of interface material thickness had a very important role in the behavior of grouted connections. Connection response improved considerably in terms of deformation capacity when the thickness of the interface material was increased.

5.3 Design Recommendations

1- The use of plain connections (no filler) to attach new lateral steel resisting systems to existing structures could result in a response different than that desired by the designer. The designer should be cautious, large deformations of connections can result from excessive hole clearances due to labor errors and/or construction difficulties. Therefore, high quality labor and equipment is required.

2- For a plain connection, flexibility of the retrofitting system increased as hole clearance increased. The overall structural stiffness of the system should be evaluated taking into account the maximum expected hole oversize.

3- The use of plain connections may result in unequal distribution of load to bolts when different bearing clearances are introduced. In such cases, the first bolt carried higher forces and failed before remaining of bolts developed full capacity.

4- The use of connections with filler materials between the bolt and steel plate is recommended. These connections demonstrated better control of deformations and even load distribution among bolts.

5- The use of epoxy grouted connections resulted in small deformations, improved stiffness, and even distribution of forces among bolts.

6- For connections with a large number of bolts per row or large distance between adjacent bolts, overdesigning the steel plate ensured ductile behavior of the bolts, increased the stiffness of the connection, and reduced the non-uniformity of bolt load distribution in the elastic range.

5.4 Recommendations for Further Research

The following aspects require further study:

1- Conduct experimental research using multiple-bolt steel-concrete connections to compare experimental results with the analytical results of this study which were based on single bolt behavior.

2- Resume the experimental research program for a single anchor bolt connection using different bolt diameters and higher strength materials in order to enlarge the design options.

3- Conduct experimental tests of connections with non-uniform hole clearance and without any filler in the gap between the bolt and steel plate.

4 - Enlarge the experimental investigation of the effect of interface material thickness on grouted connection behavior.

5- Modify the BOLTS program to reflect any development in the understanding of connection behavior.

APPENDIX A
COMPUTER PROGRAM PRINTOUT

```
      PROGRAM BOLTS
C
C      MAIN PROGRAM
C      ANALYSIS OF STEEL-CONCRETE CONNECTIONS
C
C      DEVELOPED BY BERNARDO SAUTER
C
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      CHARACTER*15 OUTPUT

      DO 1 I=1,40
1      WRITE(*,*)

      WRITE(*,2)
2      format(15x,'===============================================')
      WRITE(*,3)
3     format(20x,'          BOLTS PROGRAM')
      WRITE(*,*)
      WRITE(*,4)
4     format(20x,'Program to Compute the Distribution')
      WRITE(*,5)
5     format(20x,'          of Forces to Bolts')
      WRITE(*,6)
6     format(20x,' in a Multiple-Fastener Connection')
      WRITE(*,*)
      WRITE(*,7)
7     format(20x,'          developed by')
      WRITE(*,*)
      WRITE(*,8)
8     format(20x,'        BERNARDO A. SAUTER')
      WRITE(*,*)
      WRITE(*,9)
9     format(20x,' as fulfillment of the requirements')
      WRITE(*,10)
10    format(20x,'          for the degree of')
      WRITE(*,11)
11    format(20x,'  Master of Science in Engineering')
      WRITE(*,*)
      WRITE(*,12)
12    format(20x,'THE UNIVERSITY OF TEXAS AT AUSTIN')
      WRITE(*,13)
13    format(15x,'===============================================')
```

```
       DO 15 I=1,3
 15    WRITE(*,*)
       WRITE(*,20)
 20    format(20x,'PRESS <ENTER> TO CONTINUE')

       DO 25 I=1,2
 25    WRITE(*,*)
       PAUSE
       DO 30 I=1,40
 30    WRITE(*,*)

       WRITE(*,35)
 35    format(10x,'ENTER OUTPUT FILE NAME: ')
       READ(*,36) OUTPUT
 36    FORMAT(A15)

       OPEN (UNIT=13, FILE=OUTPUT, STATUS='UNKNOWN')

       WRITE(*,40)
 40    format(10x,'GENERAL INFORMATION')
       WRITE(*,42)
 42    format(10x,'-------------------')
       WRITE(*,*)
       WRITE(*,*)

       WRITE(*,45)
 45    format(10x,'ENTER NUMBER OF BOLTS: ')
       READ(*,*) IBOLT

       WRITE(13,50)
 50    format(10x,'----------------------------------')
       WRITE(13,55)
 55    format(10x,' DISTRIBUTION OF FORCES TO BOLTS')
       WRITE(13,56)
 56    format(10x,'IN A MULTIPLE-FASTENER CONNECTION')
       WRITE(13,*)
       WRITE(13,58)
 58    format(10x,'          OUTPUT FILE')
       WRITE(13,50)
       WRITE(13,*)
       WRITE(13,*)
       WRITE(13,59)
 59    format(10x,'GENERAL INFORMATION')
       WRITE(13,*)
       WRITE(13,60) IBOLT
 60    format(10x,'# OF BOLTS = ',1I3)
```

```
      DO 70 I= 1,IBOLT
      WRITE(*,62) I
62    format(10x,'SPACING (',1I2,')','(in): ')
      READ(*,*) SPAC1(I)
      WRITE(13,65) I, SPAC1(I)
65    format(10x,'SPACING (',1I2,')',' = ',1F5.2,2x,'in.')
70    CONTINUE

      WRITE(*,72)
72    format(10x,'AREA(PLATE) (in2): ')
      READ(*,*) A
      WRITE(*,74)
74    format(10x,'GRADE (ksi): ')
      READ(*,*) FY
      WRITE(13,75) A, FY
75    format(10x,'AREA = ',1F5.2,2x,'in2',5x,'FY = ',1F5.2,2x,'ksi')

      E = 29000
      PPLATE = A * FY

      WRITE(13,76) PPLATE
76    format(10x,'MAXIMUM STRENGTH OF THE PLATE =',1F7.2,2x,'ksi')
      WRITE(13,77) E
77    format(10x,'YOUNGS MODULUS = ',1F8.2,2x,'ksi')

      DO 80 J=1,40
80    WRITE(*,*)
      WRITE(*,85)
85    format(15x,'LOAD HISTORY')
      WRITE(*,90)
90    format(15x,'------------')
      WRITE(*,*)
      WRITE(*,95)
95    format(15x,'MONOTONIC LOAD (1):')
      WRITE(*,96)
96    format(15x,'CYCLIC LOAD    (2):')
      DO 97 J=1,5
97    WRITE(*,*)
      WRITE(*,98)
98    format(15x,'SELECT: ')
      READ(*,*) LOAD
      IF (LOAD.EQ.1) THEN
      CALL MONOT(A,E,PPLATE)
      ELSE
      CALL CYC(A,E,PPLATE)
      ENDIF
      CLOSE (13)
      END
```

```
C ----------------------------------------------------------------
C
C     SUBROUTINES
C
C ----------------------------------------------------------------
      SUBROUTINE MONOT(A,E,PPLATE)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON CLAM(15), OVERS(15)
      COMMON AUMEN, CYCLO, IPRINT
      COMMON X1(15,3), Y1(15,3)
      COMMON ITHICK(15), XMAXN(15), IDIA(15)
      DIMENSION DS(15), DB9(15), FS(15), XMAX(15)

      DO 2 J=1,40
2     WRITE(*,*)

      CALL INP

      XMAX(1) = 17.5
      XMAX(2) = 20.51
      XMAX(3) = 19.1
      XMAX(4) = 20.0
      XMAX(5) = 15.9
      XMAX(6) = 21.7
      XMAX(7) = 20.0
      XMAX(8) = 21.96

      WRITE(13,*)
      WRITE(13,*)
      IF (IPRINT.EQ.1) THEN
      WRITE(13,*) 'DISPLACEMENT - TOTAL FORCE'
      ELSE
      IF (IPRINT.EQ.2) THEN
      WRITE(13,5) (I, I=1,IBOLT)
      ELSE
      WRITE(13,*) 'DISPLACEMENT - TOTAL FORCE'
      WRITE(13,*)
      WRITE(13,5) (I, I=1,IBOLT)
      ENDIF
      ENDIF
      WRITE(13,*)
5     format(15(3x,'DISP/FORCE BOLT #',1I2,8x))

      K2 = 0
      VTA = 0.0
      FORCE = 0.0
```

```
20    FORCE = FORCE + AUMEN

      DO 22 I=1,IBOLT
      V(I) = 0.0
      DB(I) = 0.0
22    FS(I) = 0.0
      K = 0.0

      IF (FORCE.LE.CLAM(1)) THEN
      V(1) = FORCE
      DB(1) = 0.0
      GOTO 45
      ENDIF

      IF (K2.EQ.1) THEN
      DB(1) = DANT
      VANT = DANT1
      ENDIF

      IF (K2.EQ.0) THEN
      IF (ITYPE(1).EQ.1) THEN
      DB(1) = OVERS(1) + 0.01
      VANT = 0.0
      K2 = 1
      ELSE
      DB(1) = 0.01
      VANT = 0.0
      K2 = 1
      ENDIF
      ENDIF

37    CALL PFORCE (1,P)

30    V(1) = P

      DIF = FORCE - V(1)
      DO 83 I=2,IBOLT
      IF (DIF.GT.CLAM(I)) THEN
      DS(I) = DIF * SPAC1(I) / (E * A)
      DB(I) = DB(I-1) - DS(I)

      CALL PFORCE (I,P)

      V(I) = P
      DIF = DIF - V(I)

      ELSE
```

```
      FS(I) = DB(I-1) * E * A / SPAC1(I)
      V(I) = FS(I)
      DB(I) = 0.0

      DO 42 J=(I+1),IBOLT
      V(J) = 0.0
42    DB(J) = 0.0
      GOTO 45
      ENDIF
83    CONTINUE

45    VT = 0
      DO 50 I=1,IBOLT
50    VT = VT + V(I)

      K = K + 1
      IF (K.GT.100) THEN
      GOTO 20
      ENDIF

      IF (ABS(FORCE-VT).LE.(FORCE*0.01)) THEN
      GOTO 91
      ENDIF

      IF (FORCE.GT.VT) THEN
      IF (VTA.LE.VT) THEN
      AV1 = ABS(DB(1) - VANT)
      VANT = DB(1)
      DB(1) = DB(1) + AV1
      VTA = VT
      GOTO 37
      ELSE
      VANT1 = DB(1)
      DB(1) = (DB(1) + VANT) / 2
      VANT = VANT1
      VTA = VT
      GOTO 37
      ENDIF

      ELSE

      IF (VTA.GT.VT) THEN
      AV1 = ABS(VANT - DB(1))
      VANT = DB(1)
      DB(1) = DB(1) - AV1
      VTA = VT
      GOTO 37
      ELSE
```

```
      VANT1 = DB(1)
      DB(1) = (DB(1) + VANT) / 2
      VANT = VANT1
      VTA = VT
      GOTO 37
      ENDIF
      ENDIF

 91   DS1 = VT * SPAC1(1) / (E * A)
      DS2 = DS1 + DB(1)

      CALL OUTPRINT (IPRINT,FORCE,DS2)

      DANT = DB(1)
      DANT1 = DANT/2

      DO 86 I=1,IBOLT
      GOTO (200,210,220,230), ITYPE(I)
 200  XKA = XMAX(1)
      GOTO 85

 210  IF (ITHICK(I).EQ.1) THEN
      XKA = 20 - (20 - 19.1) * (0.21875-OVERS(I)) / 0.125
      ELSE
      XKA = XMAX(5)
      ENDIF
      GOTO 85

 220  IF (CLAM(I).LT.6) THEN
      XKA1 = 21.7 - (21.7 - 20) * CLAM(I) / 6
      XKA2 = 21.7 + (21.96 - 21.7) * CLAM(I) / 6
      IF (XKA1.GT.XKA2) THEN
      XKA = XKA2 + (XKA1-XKA2) * (0.21875-OVERS(I)) / 0.125
      ELSE
      XKA = XKA2 - (XKA2-XKA1) * (0.21875-OVERS(I)) / 0.125
      ENDIF
      GOTO 85
      ELSE
      XKA = 21.96 - (21.96-20) * (0.21875-OVERS(I)) / 0.125
      ENDIF
      GOTO 85

 230  XKA = XMAXN(I)
      GOTO 85

 85   IF (V(I).GE.XKA) THEN
      ITYPE(I) = 8
      V(I) = 0
```

```
      ENDIF
 86   CONTINUE

      DO 170 I=1,IBOLT
      IF (ITYPE(I).EQ.8) THEN
      GOTO 175
      ENDIF
170  CONTINUE
      GOTO 90

175  DIST = 0.0
      DO 150 I=1,IBOLT
      IF (V(I).EQ.0) THEN
      DIST = DIST + SPAC1(I)
      ELSE
      VT = 0.0
      DO 151 J=1,IBOLT
151  VT = VT + V(J)
      DS1 = VT * (DIST + SPAC1(I)) / (E*A)
      DS2 = DB(I) + DS1
      FORCE = VT
      GOTO 164
      ENDIF
150  CONTINUE

164  CALL OUTPRINT (IPRINT,FORCE,DS2)

165  CALL FRAC

      IF (IBOLT.LE.1) THEN
      GOTO 999
      ENDIF

90   IF (VT.GE.PPLATE) THEN
      WRITE(13,*) 'PLATE YIELD'
      GOTO 999
      ENDIF

      GOTO 20

999   DO 1000 J=1,5
1000  WRITE(*,*)

       WRITE(*,1030)
1030   format(10x,'END OF PROCESS')

      RETURN
      END
```

```
C -------------------------------------------------------------------
      SUBROUTINE OUTPRINT (IPRINT,FORCE,DS2)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)

      GOTO (10,20,30), IPRINT

10    WRITE(13,40) DS2, FORCE
      WRITE(*,40) DS2, FORCE
      GOTO 50
20    WRITE(13,40) (DB(I),V(I), I=1,IBOLT)
      WRITE(*,40) (DB(I),V(I), I=1,IBOLT)
      GOTO 50
30    WRITE(13,40) DS2, FORCE
      WRITE(*,40) DS2, FORCE
      WRITE(13,40) (DB(I),V(I), I=1,IBOLT)
      WRITE(*,40) (DB(I),V(I), I=1,IBOLT)

40    FORMAT(15(1F9.5,',',5x))

50    RETURN
      END

C -------------------------------------------------------------------
      SUBROUTINE FRAC
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON CLAM(15), OVERS(15)
      COMMON X1(15,3), Y1(15,3)
      COMMON ITHICK(15), XMAXN(15), IDIA(15)

      J = 1
      M1 = 0

      DO 20 I=1,IBOLT
      IF (ITYPE(I).NE.8) THEN

      ITYPE(J) = ITYPE(I)
      ITHICK(J) = ITHICK(I)
      CLAM(J) = CLAM(I)
      OVERS(J) = OVERS(I)

      IF (ITYPE(I).EQ.7) THEN
      XMAXN(J) = XMAXN(I)
      DO 25 K=1,3
      X1(J,K) = X1(I,K)
```

```
25    Y1(J,K) = Y1(I,K)
       ENDIF

       IF (M1.EQ.0) THEN
       SPAC1(J) = SPAC1(I)
       J = J + 1
       ELSE
       K = I - (J-1)
       ACU = 0
       DO 30 K1=1,K
30    ACU = ACU + SPAC1((J-1)+K1)
       SPAC1(J) = ACU
       J = J + 1
       M1 = 0
       ENDIF

       ELSE

       M1 = 1
       ENDIF
20    CONTINUE

       IBOLT = (J-1)
       RETURN
       END

C -----------------------------------------------------------------
       SUBROUTINE PLAIN1 (A,P,I)
       IMPLICIT REAL*8(A-H,O-Z)
       COMMON IBOLT, V(15), SPAC1(15)
       COMMON ITYPE(15), DB(15)
       COMMON CLAM(15), OVERS(15)

       IF (OVERS(I).GT.0) THEN
       IF (A.LE.OVERS(I)) THEN
       P= CLAM(I)
       GOTO 99
       ENDIF
       ENDIF
       IF (A.LE.(0.0928 + OVERS(I))) THEN
       SLOPE = (15 - CLAM(I)) / ((0.0928 + OVERS(I)) - OVERS(I))
       B = 15 - (SLOPE * (0.0928 + OVERS(I)))
       P = SLOPE * A + B
       ELSE
       SLOPE = (17.5 - 15) / ((0.2549+OVERS(I))-(0.0928+OVERS(I)))
       B = 15 - (SLOPE * (0.0928 + OVERS(I)))
       P = SLOPE * A + B
       ENDIF
```

```
99    RETURN
      END

C ---------------------------------------------------------------
      SUBROUTINE GRO1 (A,P,I)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON CLAM(15), OVERS(15)
      COMMON AUMEN, CYCLO, IPRINT
      COMMON X1(15,3), Y1(15,3)
      COMMON ITHICK(15), XMAXN(15), IDIA(15)

      IF (A.LE.0.0448) THEN
      SLOPE = (13.04 - CLAM(I)) / 0.0448
      B = CLAM(I)
      P = (SLOPE * A) + B
      GOTO 99
      ENDIF

      IF (A.LE.0.0844) THEN
      SLOPE = (15 - 13.04) / (0.0844 - 0.0448)
      B = 15 - (0.0844 * SLOPE)
      P = SLOPE * A + B
      GOTO 99
      ENDIF

      IF (A.LE.0.1051) THEN
      SLOPE = (12.70 - 15) / (0.1051 - 0.0844)
      B = 15 - (0.0844 * SLOPE)
      P = SLOPE * A + B
      ELSE
      SLOPE = (15.9 - 12.70) / (0.74 - 0.1051)
      B = 15.9 - (0.74 * SLOPE)
      P = SLOPE * A + B
      ENDIF

99    RETURN
      END

C ---------------------------------------------------------------
      SUBROUTINE GROUTC31 (A,P,I)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON CLAM(15), OVERS(15)
```

```
      IF (A.LE.0.044) THEN
      SLOPE = (12.76 - CLAM(I)) / 0.044
      B = 12.76 - (SLOPE * 0.044)
      P = SLOPE * A + B
      GOTO 99
      ENDIF

      IF (A.LE.0.119) THEN
      SLOPE = (16.72 - 12.76) / (0.119 - 0.044)
      B = 12.76 - (SLOPE * 0.044)
      P = SLOPE * A + B
      ELSE
      SLOPE = (19 - 16.72) / (0.214 - 0.119)
      B = 16.72 - (SLOPE * 0.119)
      P = SLOPE * A + B
      ENDIF

99    RETURN
      END

C ------------------------------------------------------------------
      SUBROUTINE GROUTC71 (A,P,I)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON CLAM(15), OVERS(15)

      IF (A.LE.0.044) THEN
      SLOPE = (12.76 - CLAM(I)) / 0.044
      B = 12.76 - (SLOPE * 0.044)
      P = SLOPE * A + B
      ELSE
      SLOPE = (20 - 12.76) / (0.328 - 0.044)
      B = 12.76 - (SLOPE * 0.044)
      P = SLOPE * A + B
      ENDIF

99    RETURN
      END

C ------------------------------------------------------------------
      SUBROUTINE EPOXYC1 (A,P,I)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON CLAM(15), OVERS(15)
```

```
      IF (A.LE.0.038) THEN
      SLOPE = 14.30 / 0.038
      B = 14.30 - (SLOPE * 0.038)
      P = SLOPE * A + B
      GOTO 99
      ENDIF

      IF (A.LE.0.316) THEN
      SLOPE = (21 - 14.30) / (0.316 - 0.038)
      B = 14.30 - (SLOPE * 0.038)
      P = SLOPE * A + B
      ELSE
      SLOPE = (21.7 - 21) / (0.383 - 0.316)
      B = 21 - (SLOPE * 0.316)
      P = SLOPE * A + B
      ENDIF

99    RETURN
      END

C -----------------------------------------------------------------
      SUBROUTINE EPOC3C12 (A,P,I)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON CLAM(15), OVERS(15)

      IF (A.LE.0.015) THEN
      SLOPE = (15 - CLAM(I)) / 0.015
      B = 15 - (SLOPE * 0.015)
      P = SLOPE * A + B
      GOTO 99
      ENDIF

      IF (A.LE.0.046) THEN
      SLOPE = (18.33 - 15) / (0.046 - 0.015)
      B = 18.33 - (SLOPE * 0.046)
      P = SLOPE * A + B
      ELSE
      SLOPE = (20 - 18.33) / (0.222 - 0.046)
      B = 20 - (SLOPE * 0.222)
      P = SLOPE * A + B
      ENDIF

99    RETURN
      END
```

```
C -----------------------------------------------------------------
      SUBROUTINE EPOC7C12 (A,P,I)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON CLAM(15), OVERS(15)

      IF (A.LE.0.039) THEN
      SLOPE = (15 - CLAM(I)) / 0.039
      B = 15 - (SLOPE * 0.039)
      P = SLOPE * A + B
      GOTO 99
      ENDIF

      IF (A.LE.0.143) THEN
      SLOPE = (18.7 - 15) / (0.143 - 0.039)
      B = 18.7 - (SLOPE * 0.143)
      P = SLOPE * A + B
      ELSE
      SLOPE = (21.96 - 18.7) / (0.3 - 0.143)
      B = 21.96 - (SLOPE * 0.3)
      P = SLOPE * A + B
      ENDIF

99    RETURN
      END

C -----------------------------------------------------------------
      SUBROUTINE MNEW1 (A,P,I)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON CLAM(15), OVERS(15)
      COMMON AUMEN, CYCLO, IPRINT
      COMMON X1(15,3), Y1(15,3)
      COMMON ITHICK(15), XMAXN(15), IDIA(15)

      IF (OVERS(I).GT.0) THEN
      IF (A.LE.OVERS(I)) THEN
      P= CLAM(I)
      GOTO 99
      ENDIF
      ENDIF

      IF (A.LE.(X1(I,1) + OVERS(I))) THEN
      SLOPE = (Y1(I,1) - CLAM(I)) / ((X1(I,1)+OVERS(I))-OVERS(I))
      B = Y1(I,1) - (SLOPE * (X1(I,1) + OVERS(I)))
      P = SLOPE * A + B
```

```
      GOTO 99
      ENDIF

      IF (A.LE.(X1(I,2) + OVERS(I))) THEN
      SLOPE1 = (Y1(I,2)-Y1(I,1))
      SLOPE = SLOPE1 / ((X1(I,2)+OVERS(I))-(X1(I,1)+OVERS(I)))
      B = Y1(I,1) - (SLOPE * (X1(I,1) + OVERS(I)))
      P = SLOPE * A + B
      ELSE
      SLOPE1 = (Y1(I,3)-Y1(I,2))
      SLOPE = SLOPE1 / ((X1(I,3)+OVERS(I))-(X1(I,2)+OVERS(I)))
      B = Y1(I,2) - (SLOPE * (X1(I,2) + OVERS(I)))
      P = SLOPE * A + B
      ENDIF

99    RETURN
      END

C --------------------------------------------------------------------
      SUBROUTINE INP
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON CLAM(15), OVERS(15)
      COMMON AUMEN, CYCLO, IPRINT
      COMMON X1(15,3), Y1(15,3)
      COMMON ITHICK(15), XMAXN(15), IDIA(15)

      DO 42 I= 1, IBOLT
      ITYPE(I) = 0.0
      IDIA(I) = 0.0
      ITHICK(I) = 0.0
      CLAM(I) = 0.0
42    OVERS(I) = 0.0

      WRITE(*,45)
45    format(10x,'LOAD INCREMENT (Kips): ')
      READ(*,*) AUMEN
      WRITE(*,*)

      DO 5000 I= 1,IBOLT

46    DO 47 J=1,40
47    WRITE(*,*)

      WRITE(*,50)
50    format(15x,'MAIN MENU')
      WRITE(*,52)
```

```
52   format(15x,'---------')
      WRITE(*,54) I
54   format(10x,'TYPE OF CONNECTION OF BOLT #',1x,1I2)
      WRITE(*,*)
      WRITE(*,56)
56   format(10x,'(1) PLAIN CONNECTION: ')
      WRITE(*,58)
58   format(10x,'(2) GROUTED CONNECTION: ')
      WRITE(*,60)
60   format(10x,'(3) EPOXY CONNECTION: ')
      WRITE(*,62)
62   format(10x,'(4) OTHER TYPE: ')
      WRITE(*,64)
64   format(10x,'(5) HELP: ')
      WRITE(*,*)
      DO 66 J=1,5
66   WRITE(*,*)
      WRITE(*,68)
68   format(10x,'SELECT: ')
      READ(*,*) ITYPE(I)

      IF (ITYPE(I).EQ.5) THEN
      GOTO 1500
      ENDIF

      DO 69 J=1,40
69   WRITE(*,*)

70   WRITE(*,71)
71   format(10x,'BOLT DIAMETER: ')
      WRITE(*,*)
      WRITE(*,72)
72   format(18x,'(1)  3/4 MILD STEEL THREADED ROD:')
      WRITE(*,74)
74   format(18x,'(2)  FREE SPACE, future investigation:')
      DO 76 J=1,5
76   WRITE(*,*)
      WRITE(*,78)
78   format(10x,'SELECT: ')
      READ(*,*) IDIA(I)

      WRITE(13,*)
      WRITE(13,80) I
80   format(10x,'BOLT = ',1I3)
      WRITE(13,82)
82   format(10x,'----------')
```

```
      IF (IDIA(I).EQ.1) THEN
      WRITE(13,84)
 84   format(10x,'BOLT DIAMETER = 3/4 MILD STEEL THREADED ROD')
      ELSE
      WRITE(13,86)
 86   format(10x,'FREE SPACE, future investigation, TRY AGAIN')
      GOTO 70
      ENDIF

      WRITE(13,98) ITYPE(I)
 98   format(10x,'TYPE = ',1I3)

      GOTO (1000,2000) IDIA(I)

1000   GOTO (1001,1200,1300,1400,1500), ITYPE(I)

1001   DO 1005 J=1,40
1005   WRITE(*,*)

        WRITE(*,1100)
1100   format(10x,'PLAIN CONNECTION')
        WRITE(*,*)
        WRITE(13,1110)
1110   format(10x,'PLAIN CONNECTION')

        WRITE(*,1120)
1120   format(10x,'BEARING CLEARANCE (in.): ')
        READ(*,*) OVERS(I)

        WRITE(13,1130) OVERS(I)
1130   format(10x,'BEARING CLEARANCE = ',1F5.3,2x,'in.')

1135   WRITE(*,1140)
1140   format(10x,'FRICTION FORCE (Kips): ')
        READ(*,*) CLAM(I)

      IF (CLAM(I).GT.9) THEN
      WRITE(*,*) '--------------------------------------------'
      WRITE(*,*) 'THE CLAMPING FORCE APPLIED IS GREATER THAN THE'
      WRITE(*,*) '90% OF YIELD IN THE ANCHOR BOLT'
      WRITE(*,*) 'MAXIMUM CLAMPING FORCE = 18 kips'
      WRITE(*,*) 'FRICTION FORCE = 9 kips'
      WRITE(*,*) '--------------------------------------------'
      WRITE(*,*)
      GOTO 1135
      ENDIF
```

```
        WRITE(13,1150) CLAM(I)
1150   format(10x,'FRICTION FORCE = ',1F5.2,2x,'Kips')

        GOTO 5000

1200   DO 1205 J=1,40
1205   WRITE(*,*)

        WRITE(*,1210)
1210   format(10x,'GROUTED CONNECTION: ')
        WRITE(*,*)

        WRITE(13,1211)
1211   format(10x,'GROUTED CONNECTION')

        WRITE(*,1255)
1255   format(10x,'INTERFACE THICKNESS')
        WRITE(*,1256)
1256   format(10x,'1/4 in.  (1):')
        WRITE(*,1257)
1257   format(10x,'1/2 in.  (2):')
        DO 1258 J=1,5
1258   WRITE(*,*)
        WRITE(*,1259)
1259   format(10x,'SELECT: ')
        READ(*,*) ITHICK(I)

        IF (ITHICK(I).EQ.1) THEN
        WRITE(13,1260)
1260   format(10x,'INTERFACE THICKNESS = 1/4 ')
        ELSE
        WRITE(13,1261)
1261   format(10x,'INTERFACE THICKNESS = 1/2 ')
        ENDIF

      GOTO (1270,1280), ITHICK(I)

1270   DO 1271 J=1,40
1271   WRITE(*,*)

        WRITE(*,1272)
1272   format(10x,'GROUTED CONNECTION: 1/4 INTERFACE THICKNESS')
1273   WRITE(*,1274)
1274   format(10x,'BEARING CLEARANCE (in.): ')
        READ(*,*) OVERS(I)

      IF (OVERS(I).GT.0.25) THEN
      WRITE(*,*) '----------------------------------------------'
```

```
      WRITE(*,*) 'THE BEARING CLEARANCE DOES NOT FIT IN ANY MODEL'
      WRITE(*,*) 'MAXIMUM BEARING CLEARANCE = 0.25 in.'
      WRITE(*,*) '---------------------------------------------'
      WRITE(*,*)
      GOTO 1273
      ELSE
      IF (OVERS(I).LT.0.0625) THEN
      WRITE(*,*) '---------------------------------------------'
      WRITE(*,*) 'THE BEARING CLEARANCE DOES NOT FIT IN ANY MODEL'
      WRITE(*,*) 'MINIMUM BEARING CLEARANCE = 0.0625 in.'
      WRITE(*,*) '---------------------------------------------'
      WRITE(*,*)
      GOTO 1273
      ENDIF
      ENDIF

        WRITE(13,1275) OVERS(I)
1275   format(10x,'BEARING CLEARANCE = ',1F5.3,2x,'in.')

1277   WRITE(*,1278)
1278   format(10x,'FRICTION FORCE (Kips): ')
        READ(*,*) CLAM(I)

      IF (CLAM(I).GT.9) THEN
      WRITE(*,*) '---------------------------------------------'
      WRITE(*,*) 'THE CLAMPING FORCE APPLIED IS GREATER THAN THE'
      WRITE(*,*) '90% OF YIELD IN THE ANCHOR BOLT'
      WRITE(*,*) 'MAXIMUM CLAMPING FORCE = 18 kips'
      WRITE(*,*) 'FRICTION FORCE = 9 kips'
      WRITE(*,*) '---------------------------------------------'
      WRITE(*,*)
      GOTO 1277
      ENDIF

        WRITE(13,1279) CLAM(I)
1279   format(10x,'FRICTION FORCE = ',1F5.2,2x,'Kips')

      GOTO 5000

1280   DO 1281 J=1,40
1281   WRITE(*,*)

        WRITE(*,1282)
1282   format(10x,'GROUTED CONNECTION: 1/2 INTERFACE THICKNESS')
1283   WRITE(*,1284)
1284   format(10x,'BEARING CLEARANCE (in.): ')
        READ(*,*) OVERS(I)
```

```
        IF (OVERS(I).GT.0.094) THEN
        WRITE(*,*) '---------------------------------------------'
        WRITE(*,*) 'THE BEARING CLEARANCE DOES NOT FIT IN ANY MODEL'
        WRITE(*,*) 'MAXIMUM BEARING CLEARANCE = 0.094 in.'
        WRITE(*,*) '---------------------------------------------'
        WRITE(*,*)
        GOTO 1283
        ELSE
        IF (OVERS(I).LT.0.093) THEN
        WRITE(*,*) '---------------------------------------------'
        WRITE(*,*) 'THE BEARING CLEARANCE DOES NOT FIT IN ANY MODEL'
        WRITE(*,*) 'MINIMUM BEARING CLEARANCE = 0.093 in.'
        WRITE(*,*) '---------------------------------------------'
        WRITE(*,*)
        GOTO 1283
        ENDIF
        ENDIF

          WRITE(13,1285) OVERS(I)
1285     format(10x,'BEARING CLEARANCE = ',1F5.3,2x,'in.')

1287     WRITE(*,1288)
1288     format(10x,'FRICTION FORCE (Kips): ')
          READ(*,*) CLAM(I)

        IF (CLAM(I).GT.9) THEN
        WRITE(*,*) '---------------------------------------------'
        WRITE(*,*) 'THE CLAMPING FORCE APPLIED IS GREATER THAN THE'
        WRITE(*,*) '90% OF YIELD IN THE ANCHOR BOLT'
        WRITE(*,*) 'MAXIMUM CLAMPING FORCE = 18 kips'
        WRITE(*,*) 'FRICTION FORCE = 9 kips'
        WRITE(*,*) '---------------------------------------------'
        WRITE(*,*)
        GOTO 1287
        ENDIF

          WRITE(13,1289) CLAM(I)
1289     format(10x,'FRICTION FORCE = ',1F5.2,2x,'Kips')

          GOTO 5000

1300     DO 1301 J=1,40
1301     WRITE(*,*)

          WRITE(*,1302)
1302     format(10x,'EPOXY CONNECTION')
          WRITE(13,1304)
1304     format(10x,'EPOXY CONNECTION')
```

```
1309   WRITE(*,1310)
1310   format(10x,'BEARING CLEARANCE (in.): ')
        READ(*,*) OVERS(I)

      IF (OVERS(I).GT.0.25) THEN
      WRITE(*,*) '------------------------------------------------'
      WRITE(*,*) 'THE BEARING CLEARANCE DOES NOT FIT IN ANY MODEL'
      WRITE(*,*) 'MAXIMUM BEARING CLEARANCE = 0.25 in.'
      WRITE(*,*) '------------------------------------------------'
      WRITE(*,*)
      GOTO 1309
      ENDIF

      IF (OVERS(I).LT.0.0625) THEN
      WRITE(*,*) '------------------------------------------------'
      WRITE(*,*) 'THE BEARING CLEARANCE DOES NOT FIT IN ANY MODEL'
      WRITE(*,*) 'MINIMUM BEARING CLEARANCE = 0.0625 in.'
      WRITE(*,*) '------------------------------------------------'
      WRITE(*,*)
      GOTO 1309
      ENDIF

        WRITE(13,1315) OVERS(I)
1315  format(10x,'BEARING CLEARANCE = ',1F5.3,2x,'in.')

1320   WRITE(*,1325)
1325   format(10x,'FRICTION FORCE (Kips): ')
        READ(*,*) CLAM(I)

      IF (CLAM(I).GT.9) THEN
      WRITE(*,*) '------------------------------------------------'
      WRITE(*,*) 'THE CLAMPING FORCE APPLIED IS GREATER THAN THE'
      WRITE(*,*) '90% OF YIELD IN THE ANCHOR BOLT'
      WRITE(*,*) 'MAXIMUM CLAMPING FORCE = 18 kips'
      WRITE(*,*) 'FRICTION FORCE = 9 kips'
      WRITE(*,*) '------------------------------------------------'
      WRITE(*,*)
      GOTO 1320
      ENDIF

        WRITE(13,1330) CLAM(I)
1330  format(10x,'FRICTION FORCE = ',1F5.2,2x,'Kips')

        GOTO 5000

1400  DO 1401 J=1,40
1401  WRITE(*,*)
```

```
        WRITE(*,1402)
1402   format(10x,'NEW CURVE')
        WRITE(*,*)

        WRITE(13,1403)
1403   format(10x,'NEW CURVE')

        WRITE(*,1404)
1404   format(10x,'HOLE CLEARANCE (in.): ')
        READ(*,*) OVERS(I)
        WRITE(*,*)

        WRITE(13,1406) OVERS(I)
1406   format(10x,'OVERSIZE = ',1F5.3,2x,'in.')

        WRITE(*,1408)
1408   format(10x,'FRICTION FORCE (Kips): ')
        READ(*,*) CLAM(I)

        WRITE(13,1409) CLAM(I)
1409   format(10x,'FRICTION FORCE = ',1F5.2,2x,'Kips')

        WRITE(*,1410)
1410   format(10x,'MAXIMUM BOLT CAPACITY (Kips): ')
        READ(*,*) XMAXN(I)
       WRITE(*,*)

        WRITE(13,1411) XMAXN(I)
1411   format(10x,'MAXIMUM BOLT CAPACITY = ',1F5.2,2x,'Kips')

        DO 1418 J=1,3
        WRITE(*,1412) J
1412   format(10x,'X-Y COORDINATES(',1I1,'): ')
        READ(*,*) X1(I,J), Y1(I,J)
        WRITE(13,1414) J, X1(I,J), Y1(I,J)
1414   format(10x,'X-Y COORDINATES(',1I1,'): ',1F5.2,3x,1F5.2)

1418   WRITE(*,*)
        WRITE(13,*)

        GOTO 5000

1500   CALL HELP
        GOTO 46

2000   WRITE(*,2010)
2010   format(10x,'FREE SPACE')
```

```
        GOTO 5000

 5000  CONTINUE

        DO 6050 J=1,40
 6050  WRITE(*,*)

        WRITE(*,6100)
 6100  format(10x,'PRINT LOAD-DEFORMATION OF :')
        WRITE(*,*)
        WRITE(*,6110)
 6110  format(18x,'(1)   THE CONNECTION: ')
        WRITE(*,6120)
 6120  format(18x,'(2)   THE BOLTS: ')
        WRITE(*,6130)
 6130  format(18x,'(3)   BOTH: ')
        WRITE(*,*)
        DO 6140 J=1,5
 6140  WRITE(*,*)
        WRITE(*,6145)
 6145  format(10x,'SELECT: ')
        READ(*,*) IPRINT

        RETURN
        END

C
C -----------------------------------------------------------------
C
      SUBROUTINE PFORCE(I,P)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON CLAM(15), OVERS(15)
      COMMON AUMEN, CYCLO, IPRINT
      COMMON X1(15,3), Y1(15,3)
      COMMON ITHICK(15), XMAXN(15), IDIA(15)

      GOTO (1000,2000), IDIA(I)

 1000  GOTO (1100,1200,1300,1400), ITYPE(I)

 1100  CALL PLAIN1 (DB(I),P,I)
        GOTO 5000

 1200  GOTO (1260,1280) ITHICK(I)

 1260  CALL GROUTC31 (DB(I),PP1,I)
```

```
      CALL GROUTC71 (DB(I),PP2,I)

     IF (PP1.GT.PP2) THEN
     P = PP2 + (PP1 - PP2) * (0.21875 - OVERS(I)) / 0.125
     GOTO 5000
     ELSE
     P = PP2 - (PP2 - PP1) * (0.21875 - OVERS(I)) / 0.125
     GOTO 5000
     ENDIF

1280  CALL GRO1 (DB(I),P,I)
        GOTO 5000

1300  CALL EPOXYC1 (DB(I),PP1,I)
        BCLAM = CLAM(I)
        CLAM(I) = 6
        CALL EPOC3C12 (DB(I),PP2,I)
        CALL EPOC7C12 (DB(I),PP3,I)
        CLAM(I) = BCLAM
        CALL EPOC3C12 (DB(I),PP4,I)
        CALL EPOC7C12 (DB(I),PP5,I)

     IF (CLAM(I).LT.6) THEN

     IF (PP1.GT.PP2) THEN
     P1 = PP1 - (PP1 - PP2) * CLAM(I) / 6
     ELSE
     P1 = PP1 + (PP2 - PP1) * CLAM(I) / 6
     ENDIF
     IF (PP1.GT.PP3) THEN
     P2 = PP1 - (PP1 - PP3) * CLAM(I) / 6
     ELSE
     P2 = PP1 + (PP3 - PP1) * CLAM(I) / 6
     ENDIF

     IF (P1.GT.P2) THEN
     P = P2 + (P1 - P2) * (0.21875 - OVERS(I)) / 0.125
     ELSE
     P = P2 - (P2 - P1) * (0.21875 - OVERS(I)) / 0.125
     ENDIF
     GOTO 5000

     ELSE

     IF (PP4.GT.PP5) THEN
     P = PP5 + (PP4 - PP5) * (0.21875 - OVERS(I)) / 0.125
     ELSE
     P = PP5 - (PP5 - PP4) * (0.21875 - OVERS(I)) / 0.125
```

```
      ENDIF
      GOTO 5000
      ENDIF

1400  CALL MNEW1 (DB(I),P,I)
        GOTO 5000

2000  WRITE(*,*) 'FREE SPACE, future investigation'

5000  RETURN
        END

C ---------------------------------------------------------------
      SUBROUTINE HELP
      IMPLICIT REAL*8(A-H,O-Z)

      DO 2 J=1,40
2     WRITE(*,*)

      WRITE(*,5)
5     format(10x,'DEFINITION OF TYPES OF CONNECTIONS')
      WRITE(*,*)
      WRITE(*,*)
      WRITE(*,*)
      WRITE(*,10)
10    format(10x,'PLAIN CONNECTION: connection in which neither')
      WRITE(*,11)
11    format(10x,'the gap between the anchor bolt and the steel')
      WRITE(*,12)
12    format(10x,'element nor the gap at the interface between')
      WRITE(*,13)
13    format(10x,'the existing concrete element and the steel')
      WRITE(*,14)
14    format(10x,'plate were filled with any structural material.')
      WRITE(*,*)
      WRITE(*,*)
      WRITE(*,*)'          TYPE <ENTER> TO CONTINUE'

      DO 15 J=1,3
15    WRITE(*,*)
      PAUSE

      DO 17 J=1,40
17    WRITE(*,*)

      WRITE(*,20)
20    format(10x,'GROUTED CONNECTION: both the gap between the')
      WRITE(*,21)
```

```
21    format(10x,'anchor bolt and the steel element and the gap')
       WRITE(*,22)
22    format(10x,'at the interface between the existing concrete')
       WRITE(*,23)
23    format(10x,'element and the steel plate were filled with')
       WRITE(*,24)
24    format(10x,'non-shrink grout.')
       WRITE(*,*)
       WRITE(*,*)
       WRITE(*,*)'         TYPE <ENTER> TO CONTINUE'

       DO 25 J=1,3
25    WRITE(*,*)
       PAUSE

       DO 27 J=1,40
27    WRITE(*,*)

       WRITE(*,30)
30    format(10x,'EPOXY GROUTED CONNECTION: epoxy was applied to')
       WRITE(*,31)
31    format(10x,'the base of the anchor bolt and in the gap')
       WRITE(*,32)
32    format(10x,'between the anchor bolt and the steel plate.')
       WRITE(*,*)
       WRITE(*,*)
       WRITE(*,*)'         TYPE <ENTER> TO CONTINUE'

       DO 33 J=1,3
33    WRITE(*,*)
       PAUSE

       DO 37 J=1,40
37    WRITE(*,*)

       WRITE(*,40)
40    format(10x,'         STEEL-CONCRETE CONNECTION ')
       WRITE(*,*)
       WRITE(*,*)
       WRITE(*,50)
50    format(10x,'                 BOLT # ')
       WRITE(*,52)
52    format(10x,'               1      2      3 ')
       WRITE(*,54)
54    format(10x,' V  <--  ======|======|======|====== ')
       WRITE(*,56)
56    format(10x,'        S(1)   S(2)   S(3) ')
       WRITE(*,*)
```

```
      WRITE(*,*)
      WRITE(*,*) '          WHERE: '
      WRITE(*,*) '          V = APPLIED LOAD '
      WRITE(*,*) '          S(i) = DISTANCE BETWEEN BOLT (i)-(i+1)'
      WRITE(*,*)
      WRITE(*,*)
      WRITE(*,*)'           TYPE <ENTER> TO CONTINUE'

      DO 58 J=1,3
58    WRITE(*,*)
      PAUSE

      RETURN
      END

C -----------------------------------------------------------------
      SUBROUTINE CYC(A,E,PPLATE)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON ULT(15), VAR, ULTD(15), ICY, CLAM(15)
      COMMON XN(15,3), YN(15,3), BN(15,2), PORCN(15,3)
      COMMON ANT(15), ANTD(15), VAR1, IDIA(15)
      DIMENSION DS(15), XMAX(15), YMAX(15)

      CALL INP1(IPRINT,INTER,INTER1)

      XMAX(1) = 18.33
      YMAX(1) = 12.22

      WRITE(13,*)
      WRITE(13,*)
      IF (IPRINT.EQ.1) THEN
      WRITE(13,*) 'DISPLACEMENT - TOTAL FORCE'
      ELSE
      IF (IPRINT.EQ.2) THEN
      WRITE(13,5) (I, I=1,IBOLT)
      ELSE
      WRITE(13,*) 'DISPLACEMENT - TOTAL FORCE'
      WRITE(13,*)
      WRITE(13,5) (I, I=1,IBOLT)
      ENDIF
      ENDIF
      WRITE(13,*)
5     format(15(3x,'DISP/FORCE BOLT #',1I2,8x))

      DO 19 I = 1,IBOLT
      DS(I) = 0.0
```

```
      ULTD(I) = 0.0
19    ULT(I) = 0.0

      VAR1 = VAR
      FORCE = 0.0
      ICY = 0.0

20    FORCE = FORCE + VAR1

      DO 22 I=1,IBOLT
      V(I) = 0.0
22    DB(I) = 0.0
      K = 0.0
      VTA = 0.0

      IF (ULT(1).LE.YMAX(1)) THEN
      IF (ABS(FORCE).LE.CLAM(1)) THEN
      V(1) = FORCE
      DB(1) = 0.0
      GOTO 91
      ENDIF
      ENDIF

      IF (ULT(1).LE.YMAX(1)) THEN
      V(1) = FORCE / IBOLT
      ELSE
      IF (VAR1.LT.0) THEN
      VANT = VB1
      V(1) = VB1 - ABS(VAR1 / IBOLT)
      VTA = VST
      ELSE
      VANT = VB1
      V(1) = VB1 + ABS(VAR1 / IBOLT)
      VTA = VST
      ENDIF
      GOTO 37
      ENDIF

      IF (FORCE.LT.0) THEN
      V(1) = V(1) - 1
      VANT = V(1) + 2
      ELSE
      V(1) = V(1) + 1
      VANT = V(1) - 2
      ENDIF

      IF (ULT(1).LE.YMAX(1)) THEN
      IF (ABS(V(1)).LE.CLAM(1)) THEN
```

```
       IF (V(1).LT.0) THEN
       V(1) = -CLAM(1) - 0.40
       VANT = -CLAM(1)
       ELSE
       V(1) = CLAM(1) + 0.40
       VANT = CLAM(1)
       ENDIF
       ENDIF
       ENDIF

37     GOTO(11,15), ITYPE(1)

11     CALL EPOXY (DB(1))
        GOTO 30

15     GOTO 30

30     K = K + 1
        IF (K.GT.30) THEN
        GOTO 20
        ENDIF

        VS = V(1)

        DO 10 I = 2,IBOLT
        IF (ULT(I).LE.YMAX(1)) THEN
        IF (ABS(FORCE-VS).LE.CLAM(I)) THEN
        V(I) = DB(I-1) * E * A / SPAC1(I)

        DB(I) = 0.0
        DO 41 J=(I+1),IBOLT
        V(J) = 0.0
41     DB(J) = 0.0
        GOTO 45
        ENDIF
        ENDIF

        DS(I) = (FORCE-VS) * SPAC1(I) / (E*A)
        DB(I) = DB(I-1) - DS(I)

        GOTO (21,25), ITYPE(I)

21     CALL EPOXY1 (DB(I),P,I)
        GOTO 28

25     GOTO 28

28     V(I) = P
```

```
10     VS = VS + V(I)

45     VT = 0
        DO 50 I=1,IBOLT
50     VT = VT + V(I)

        IF (ABS(FORCE-VT).LE.0.01) THEN
        GOTO 91
        ENDIF

        IF (FORCE.GE.0) THEN

        IF (FORCE.GT.VT) THEN
        IF (VTA.LT.VT) THEN
        AV1 = V(1) - VANT
        VANT = V(1)
        V(1) = V(1) + AV1
        VTA = VT
        GOTO 37
        ELSE
        VANT1 = V(1)
        V(1) = (V(1) + VANT) / 2
        VANT = VANT1
        VTA = VT
        GOTO 37
        ENDIF

        ELSE

        IF (VTA.GT.VT) THEN
        AV1 = (VANT - V(1))
        VANT = V(1)
        V(1) = V(1) - AV1
        IF (ULT(1).LE.YMAX(1)) THEN
        IF (V(1).LE.CLAM(1)) THEN
        V(1) = CLAM(1) + 0.001
        ENDIF
        ENDIF
        VTA = VT
        GOTO 37
        ELSE
        VANT1 = V(1)
        V(1) = (V(1) + VANT) / 2
        VANT = VANT1
        IF (ULT(1).LE.YMAX(1)) THEN
        IF (V(1).LE.CLAM(1)) THEN
        V(1) = CLAM(1) + 0.001
        ENDIF
```

```
ENDIF
VTA = VT
GOTO 37
ENDIF
ENDIF

ELSE

IF (FORCE.GT.VT) THEN
IF (VTA.LT.VT) THEN
AV1 = V(1) - VANT
VANT = V(1)
V(1) = V(1) + AV1
VTA = VT
GOTO 37
ELSE
VANT1 = V(1)
V(1) = (V(1) + VANT) / 2
VANT = VANT1
VTA = VT
GOTO 37
ENDIF

ELSE

IF (VTA.GT.VT) THEN
AV1 = (VANT - V(1))
VANT = V(1)
V(1) = V(1) - AV1
IF (ULT(1).LE.YMAX(1)) THEN
IF (ABS(V(1)).LE.CLAM(1)) THEN
V(1) = -CLAM(1) - 0.001
ENDIF
ENDIF
VTA = VT
GOTO 37
ELSE
VANT1 = V(1)
V(1) = (V(1) + VANT) / 2
VANT = VANT1
IF (ULT(1).LE.YMAX(1)) THEN
IF (ABS(V(1)).LE.CLAM(1)) THEN
V(1) = -CLAM(1) - 0.001
ENDIF
ENDIF
VTA = VT
GOTO 37
ENDIF
```

```
      ENDIF

      ENDIF

 91   DB8 = FORCE * SPAC1(1) / (E * A)
      DB9 = DB8 + DB(1)

      CALL OUTPRINT (IPRINT,FORCE,DB9)

      DO 86 I=1,IBOLT
      HKA = XMAX(ITYPE(I))
      IF (V(I).GE.HKA) THEN
      GOTO 999
      ENDIF
 86   CONTINUE

      IF (VT.GE.PPLATE) THEN
      WRITE(13,*) 'PPLATE = ',PPLATE
      WRITE(13,*) 'PLATE YIELD'
      GOTO 999
      ENDIF

      IF (ABS(FORCE).GE.INTER) THEN
      IF (FORCE.GE.0) THEN

      FORCE = INTER
      VAR1 = -VAR
      ICY = ICY + 1

      IF (ICY.EQ.1) THEN
      DO 93 I=1,IBOLT
      ULT(I) = V(I)
 93   ULTD(I) = DB(I)
      ENDIF

      ELSE
      FORCE = -INTER
      VAR1 = VAR
      IF (ICY.GE.2) THEN
      INTER = INTER + INTER1
      ICY = 0

      DO 70 I=1,IBOLT
      ANT(I) = -ULT(I)
 70   ANTD(I) = -ULTD(I)

      ENDIF
      ENDIF
```

```
      ENDIF

      VB1 = V(1)
      VST = VT

      GOTO 20

999   RETURN
      END
C
C -----------------------------------------------------------------
C
      SUBROUTINE INP1(IPRINT,INTER,INTER1)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON ULT(15), VAR, ULTD(15), ICY, CLAM(15)
      COMMON XN(15,3), YN(15,3), BN(15,2), PORCN(15,3)
      COMMON ANT(15), ANTD(15), VAR1, IDIA(15)
      DIMENSION DS(15), XMAX(15), YMAX(15)

      DO 2 I=1,IBOLT
      ITYPE(I) = 0.0
      IDIA(I) = 0.0
2     CLAM(I) = 0.0

      DO 5 J=1,40
5     WRITE(*,*)

      DO 5010 I= 1, IBOLT

3      WRITE(*,52)
52    format(15x,'MAIN MENU')
       WRITE(*,54)
54    format(15x,'---------')
       WRITE(*,56) I
56    format(10x,'TYPE OF CONNECTION OF BOLT #',1x,1I2)
       WRITE(*,*)
       WRITE(*,58)
58    format(10x,'(1) EPOXY ANNULUS: ')
       WRITE(*,62)
62    format(10x,'(2) HELP: ')
       WRITE(*,*)
       DO 65 J=1,5
65    WRITE(*,*)
       WRITE(*,67)
67    format(10x,'SELECT: ')
      READ(*,*) ITYPE(I)
```

```
       IF (ITYPE(I).EQ.2) THEN
       GOTO 1500
       ENDIF

       DO 69 J=1,40
 69    WRITE(*,*)

 70    WRITE(*,71)
 71    format(10x,'BOLT DIAMETER:  ')
       WRITE(*,*)
       WRITE(*,72)
 72    format(18x, '(1)   3/4 MILD STEEL THREADED ROD:  ')
       WRITE(*,74)
 74    format(18x, '(2)   FREE SPACE, future investigation:')
       DO 76 J=1,5
 76    WRITE(*,*)
       WRITE(*,78)
 78    format(10x,'SELECT:  ')
       READ(*,*) IDIA(I)

       WRITE(13,*)
       WRITE(13,80) I
 80    format(10x,'BOLT  = ',1I3)
       WRITE(13,82)
 82    format(10x,'------------')

       WRITE(*,*)
       IF (IDIA(I).EQ.1) THEN
       WRITE(13,84)
 84    format(10x,'BOLT DIAMETER = 3/4 MILD STEEL THREADED ROD')
       ELSE
       WRITE(13,86)
 86    format(10x,'FREE SPACE, future investigation, TRY AGAIN')
       GOTO 70
       ENDIF

       WRITE(13,98) ITYPE(I)
 98    format(10x,'TYPE = ',1I3)

       GOTO (1000,2000) IDIA(I)

 1000   GOTO (1010), ITYPE(I)

 1010   DO 1020 J=1,40
 1020   WRITE(*,*)

          WRITE(*,1025)
 1025   format(10x,'EPOXY CONNECTION')
```

```
        WRITE(13,1030)
1030   format(10x,'EPOXY CONNECTION ')

        WRITE(*,1031)
1031   format(10x,'HOLE CLEARANCE = 3/16 in. ')
        WRITE(*,*)
        WRITE(13,1032)
1032   format(10x,'HOLE CLEARANCE = 3/16 in. ')

1035   WRITE(*,1040)
1040   format(10x,'FRICTION FORCE (Kips):  ')
        READ(*,*) CLAM(I)

      IF (CLAM(I).GT.9) THEN
      WRITE(*,*) '--------------------------------------------'
      WRITE(*,*) 'THE CLAMPING FORCE APPLIED IS GREATER THAN THE'
      WRITE(*,*) '90% OF YIELD IN THE ANCHOR BOLT'
      WRITE(*,*) 'MAXIMUM CLAMPING FORCE = 18 kips'
      WRITE(*,*) 'FRICTION FORCE = 9 kips'
      WRITE(*,*) '--------------------------------------------'
      WRITE(*,*)
      GOTO 1035
      ENDIF

        WRITE(13,1045) CLAM(I)
1045   format(10x,'FRICTION FORCE = ',1F5.3,2x,'Kips')
        GOTO 5000

1500   CALL HELP
        DO 1501 J=1,40
1501   WRITE(*,*)
        GOTO 3

2000   WRITE(*,*) 'FREE SPACE, future investigation'

5000   DO 5001 J=1,40
5001   WRITE(*,*)

5010   CONTINUE

      WRITE(*,*)
      WRITE(*,*)

        WRITE(*,5100)
5100   format(10x,'INITIAL INTERVAL VALUE: ')
        READ(*,*) INTER

        WRITE(*,5110)
```

```
5110    format(10x,'INCREMENT INTERVAL VALUE: ')
          READ(*,*) INTER1

          WRITE(*,5120)
5120    format(10x,'LOAD INCREMENT : ')
          READ(*,*) VAR

          DO 6050 J=1,40
6050    WRITE(*,*)

          WRITE(*,6100)
6100    format(10x,'PRINT LOAD-DEFORMATION OF :')
          WRITE(*,*)
          WRITE(*,6110)
6110    format(18x,'(1)   THE CONNECTION: ')
         WRITE(*,6120)
6120    format(18x,'(2)   THE BOLTS: ')
         WRITE(*,6130)
6130    format(18x,'(3)   BOTH: ')
         WRITE(*,*)
          DO 6140 J=1,5
6140    WRITE(*,*)
          WRITE(*,6145)
6145    format(10x,'SELECT: ')
          READ(*,*) IPRINT

      RETURN
      END
C
C -----------------------------------------------------------------
C
      SUBROUTINE EPOXY (DISP)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON ULT(15), VAR, ULTD(15), ICY, CLAM(15)
      COMMON XN(15,3), YN(15,3), BN(15,2), PORCN(15,3)
      COMMON ANT(15), ANTD(15), VAR1, IDIA(15)

      IF (ABS(V(1)).LE.12.22.AND.ULT(1).LE.12.22) THEN
      SLOPE = (12.22 - CLAM(1)) / 0.02
      B = 12.22 - (SLOPE * 0.02)
      IF (V(1).GE.0) THEN
      DISP = (V(1) - B) / SLOPE
      GOTO 99
      ELSE
      DISP = (V(1) + B) / SLOPE
      GOTO 99
```

```
ENDIF
ENDIF

IF (ABS(V(1)).LE.15.AND.ULT(1).LE.12.22) THEN
SLOPE = (15 - 12.22) / (0.056 - 0.02)
B = 12.22 - (SLOPE * 0.02)
DISP = (V(1) - B) / SLOPE
GOTO 99
ENDIF

IF (ULT(1).GT.15) THEN
GOTO 10
ENDIF

IF (ABS(V(1)).LE.15.AND.ULT(1).GT.12.22) THEN

IF (V(1).GT.ULT(1)) THEN
SLOPE = (15 - 12.22) / (0.056 - 0.02)
B = 12.22 - (SLOPE * 0.02)
DISP = (V(1) - B) / SLOPE
GOTO 99

ELSE

IF (VAR1.EQ.-VAR) THEN

IF (V(1).GE.0) THEN
SLOPE = ULT(1) / 0.01
B = ULT(1) - (SLOPE * ULTD(1))
DISP = (V(1) - B) / SLOPE
GOTO 99

ELSE

IF (ICY.EQ.1) THEN
SLOPE = 2.5 / (ULTD(1)-.01)
B = -2.5
Y = SLOPE * (0.40 * (ULTD(1) - 0.01)) + B

IF (V(1).GE.Y) THEN
DISP = (V(1) - B) / SLOPE
GOTO 99
ELSE
IF (V(1).GE.(ANT(1))) THEN
SLOPE = (Y - ANT(1)) / ((0.40 * (ULTD(1) - 0.01)) - ANTD(1))
B = ANT(1) - (SLOPE * ANTD(1))
DISP = (V(1) - B) / SLOPE
GOTO 99
```

```
ELSE
SLOPE = (ANT(1) + ULT(1)) / (ANTD(1) + ULTD(1))
B = -ULT(1) + (SLOPE * ULTD(1))
DISP = (V(1) - B) / SLOPE
GOTO 99
ENDIF
ENDIF

ELSE

SLOPE = 2.5 / (ULTD(1) - 0.01)
B = -2.5
PORC = -0.80 * (ULTD(1) - 0.01)
Y = SLOPE * PORC + B

IF (V(1).GE.Y) THEN
DISP = (V(1) - B) / SLOPE
GOTO 99
ELSE
SLOPE = (Y + ULT(1)) / (PORC + ULTD(1))
B = Y - (SLOPE * PORC)
DISP = (V(1) - B) / SLOPE
GOTO 99
ENDIF
ENDIF
ENDIF

ELSE

IF (V(1).LE.0) THEN
SLOPE = ULT(1) / 0.01
B = -ULT(1) + (SLOPE * ULTD(1))
DISP = (V(1) - B) / SLOPE
GOTO 99

ELSE

SLOPE = 2.5 / (ULTD(1) - 0.01)
B = 2.5
PORC = 0.8 * (ULTD(1) - 0.01)
Y = SLOPE * PORC + B
IF (V(1).LE.Y) THEN
DISP = (V(1) - B) / SLOPE
GOTO 99
ELSE
SLOPE = (ULT(1) - Y) / (ULTD(1) - PORC)
B = Y - (SLOPE * PORC)
DISP = (V(1) - B) / SLOPE
```

```
      GOTO 99
      ENDIF
      ENDIF
      ENDIF
      ENDIF
      ENDIF

      IF (ABS(V(1)).LE.25.AND.ULT(1).LE.15) THEN
      SLOPE = (18.33 - 15) / (0.168 - 0.056)
      B = 15 - (SLOPE * 0.056)
      DISP = (V(1) - B) / SLOPE
      GOTO 99
      ENDIF

10    IF (ABS(V(1)).LE.25.AND.ULT(1).GT.15) THEN

      IF (V(1).GT.ULT(1)) THEN
      SLOPE = (18.33 - 15) / (0.168 - 0.056)
      B = 15 - (SLOPE * 0.056)
      DISP = (V(1) - B) / SLOPE
      GOTO 99
      ELSE

      IF (VAR1.EQ.-VAR) THEN

      IF (V(1).GE.0) THEN
      SLOPE = ULT(1) / 0.01
      B = ULT(1) - (SLOPE * ULTD(1))
      DISP = (V(1) - B) / SLOPE
      GOTO 99
      ELSE

      IF (ICY.EQ.1) THEN
      SLOPE = 2.5 / (ULTD(1)-.01)
      B = -2.5
      Y = SLOPE * (0.40 * (ULTD(1) - 0.01)) + B

      IF (V(1).GE.Y) THEN
      DISP = (V(1) - B) / SLOPE
      GOTO 99
      ELSE
      IF (V(1).GE.ANT(1)) THEN
      SLOPE = (Y - ANT(1)) / ((0.40 * (ULTD(1) - 0.01)) - ANTD(1))
      B = ANT(1) - (SLOPE * ANTD(1))
      DISP = (V(1) - B) / SLOPE
      GOTO 99
      ELSE
      SLOPE = (ANT(1) + ULT(1)) / (ANTD(1) + ULTD(1))
```

```
B = -ULT(1) + (SLOPE * ULTD(1))
DISP = (V(1) - B) / SLOPE
GOTO 99
ENDIF
ENDIF

ELSE

SLOPE = 2.5 / (ULTD(1) - 0.01)
B = -2.5
PORC = -0.80 * (ULTD(1) - 0.01)
Y = SLOPE * PORC + B

IF (V(1).GE.Y) THEN
DISP = (V(1) - B) / SLOPE
GOTO 99

ELSE

SLOPE = (Y + ULT(1)) / (PORC + ULTD(1))
B = Y - (SLOPE * PORC)
DISP = (V(1) - B) / SLOPE
GOTO 99
ENDIF
ENDIF
ENDIF

ELSE

IF (V(1).LE.0) THEN
SLOPE = ULT(1) / 0.01
B = -ULT(1) + (SLOPE * ULTD(1))
DISP = (V(1) - B) / SLOPE
GOTO 99
ELSE
SLOPE = 2.5 / (ULTD(1) - 0.01)
B = 2.5
PORC = 0.8 * (ULTD(1) - 0.01)
Y = SLOPE * PORC + B
IF (V(1).LE.Y) THEN
DISP = (V(1) - B) / SLOPE
GOTO 99
ELSE
SLOPE = (ULT(1) - Y) / (ULTD(1) - PORC)
B = Y - (SLOPE * PORC)
DISP = (V(1) - B) / SLOPE
GOTO 99
ENDIF
```

```
      ENDIF
      ENDIF
      ENDIF

      ENDIF

 99   RETURN
      END
C
C ------------------------------------------------------------------
C
      SUBROUTINE EPOXY1 (A,P,I)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON IBOLT, V(15), SPAC1(15)
      COMMON ITYPE(15), DB(15)
      COMMON ULT(15), VAR, ULTD(15), ICY, CLAM(15)
      COMMON XN(15,3), YN(15,3), BN(15,2), PORCN(15,3)
      COMMON ANT(15), ANTD(15), VAR1, IDIA(15)

      IF (A.LE.0.02.AND.ULT(I).LE.12.22) THEN
      SLOPE = (12.22 - CLAM(I)) / 0.02
      B = 12.22 - (SLOPE * 0.02)
      IF (A.GE.0) THEN
      P = SLOPE * A + B
      GOTO 99
      ELSE
      P = SLOPE * A - B
      GOTO 99
      ENDIF
      ENDIF

      IF (A.LE.0.056.AND.ULT(I).LE.12.22) THEN
      SLOPE = (15 -12.22) / (0.056 - 0.02)
      B = 12.22 - (SLOPE * 0.02)
      P = (SLOPE * A) + B
      GOTO 99
      ENDIF

      IF (ULT(I).GT.15) THEN
      GOTO 10
      ENDIF

      IF (A.LE.0.056.AND.ULT(I).GT.12.22) THEN

      IF(A.GT.ULTD(I)) THEN
      SLOPE = (15 -12.22) / (0.056 - 0.02)
      B = 12.22 - (SLOPE * 0.02)
      P = SLOPE * A + B
```

```
GOTO 99

ELSE

IF (VAR1.EQ.-VAR) THEN

IF (A.GT.(ULTD(I)-0.01)) THEN
SLOPE = ULT(I) / 0.01
B = ULT(I) - (SLOPE * ULTD(I))
P = SLOPE * A + B
GOTO 99

ELSE

IF (ICY.EQ.1) THEN
SLOPE = 2.5 / (ULTD(I)-.01)
B = -2.5
Y = SLOPE * (0.40 * (ULTD(I) - 0.01)) + B

IF (A.GE.(0.40*(ULTD(I)-0.01))) THEN
P = SLOPE * A + B
GOTO 99
ELSE
IF (A.GE.ANTD(I)) THEN
SLOPE = (Y - ANT(I)) / ((0.40 * (ULTD(I) - 0.01)) - ANTD(I))
B = ANT(I) - (SLOPE * ANTD(I))
P = SLOPE * A + B
GOTO 99
ELSE
SLOPE = (ANT(I) + ULT(I)) / (ANTD(I) + ULTD(I))
B = -ULT(I) + (SLOPE * ULTD(I))
P = SLOPE * A + B
GOTO 99
ENDIF
ENDIF

ELSE

SLOPE = 2.5 / (ULTD(I) - 0.01)
B = -2.5
PORC = -0.80 * (ULTD(I) - 0.01)
Y = SLOPE * PORC + B

IF (A.GT.PORC) THEN
P = SLOPE * A + B
GOTO 99
ELSE
SLOPE = (Y + ULT(I)) / (PORC + ULTD(I))
```

```
B = Y - (SLOPE * PORC)
P = SLOPE * A + B
GOTO 99
ENDIF
ENDIF
ENDIF

ELSE

IF (A.LE.(-ULTD(I)+0.01)) THEN
SLOPE = ULT(I) / 0.01
B = -ULT(I) + (SLOPE * ULTD(I))
P = SLOPE * A + B
GOTO 99

ELSE

SLOPE = 2.5 / (ULTD(I) - 0.01)
B = 2.5
PORC = 0.80 * (ULTD(I) - 0.01)
Y = SLOPE * PORC + B
IF  (A.LE.PORC) THEN
P = SLOPE * A + B
GOTO 99
ELSE
SLOPE = (ULT(I) - Y) / (ULTD(I) - PORC)
B = Y - (SLOPE * PORC)
P = SLOPE * A + B
GOTO 99
ENDIF
ENDIF
ENDIF
ENDIF
ENDIF

IF (ABS(A).LE.0.25.AND.ULT(I).LE.15) THEN
SLOPE = (18.33 - 15) / (0.168 - 0.056)
B = 15 - (SLOPE * 0.056)
P = SLOPE * A + B
GOTO 99
ENDIF

10   IF (ABS(A).LE.0.25.AND.ULT(I).GT.15) THEN

IF(A.GT.ULTD(I)) THEN
SLOPE = (18.33 - 15) / (0.168 - 0.056)
B = 15 - (SLOPE * 0.056)
P = SLOPE * A + B
```

```
GOTO 99

ELSE

IF (VAR1.EQ.-VAR) THEN

IF (A.GT.(ULTD(I)-0.01)) THEN
SLOPE = ULT(I) / 0.01
B = ULT(I) - (SLOPE * ULTD(I))
P = SLOPE * A + B
GOTO 99

ELSE

IF (ICY.EQ.1) THEN
SLOPE = 2.5 / (ULTD(I)-.01)
B = -2.5
Y = SLOPE * (0.40 * (ULTD(I) - 0.01)) + B

IF (A.GE.(0.4*(ULTD(I)-0.01))) THEN
P = SLOPE * A + B
GOTO 99
ELSE
IF (A.GE.ANTD(I)) THEN
SLOPE = (Y - ANT(I)) / ((0.40 * (ULTD(I) - 0.01)) - ANTD(I))
B = ANT(I) - (SLOPE * ANTD(I))
P = SLOPE * A + B
GOTO 99
ELSE
SLOPE = (ANT(I) + ULT(I)) / (ANTD(I) + ULTD(I))
B = -ULT(I) + (SLOPE * ULTD(I))
P = SLOPE * A + B
GOTO 99
ENDIF
ENDIF

ELSE

SLOPE = 2.5 / (ULTD(I) - 0.01)
B = -2.5
PORC = -0.80 * (ULTD(I) - 0.01)
Y = SLOPE * PORC + B

IF (A.GT.PORC) THEN
P = SLOPE * A + B
GOTO 99
ELSE
SLOPE = (Y + ULT(I)) / (PORC + ULTD(I))
```

```
      B = Y - (SLOPE * PORC)
      P = SLOPE * A + B
      GOTO 99
      ENDIF
      ENDIF
      ENDIF

      ELSE

      IF (A.LE.(-ULTD(I)+0.01)) THEN
      SLOPE = ULT(I) / 0.01
      B = -ULT(I) + (SLOPE * ULTD(I))
      P = SLOPE * A + B
      GOTO 99

      ELSE

      SLOPE = 2.5 / (ULTD(I) - 0.01)
      B = 2.5
      PORC = 0.80 * (ULTD(I) - 0.01)
      Y = SLOPE * PORC+ B
      IF  (A.LE.PORC) THEN
      P = SLOPE * A + B
      GOTO 99
      ELSE
      SLOPE = (ULT(I) - Y) / (ULTD(I) - PORC)
      B = Y - (SLOPE * PORC)
      P = SLOPE * A + B
      GOTO 99
      ENDIF
      ENDIF
      ENDIF
      ENDIF
      ENDIF

99    RETURN
      END
```

APPENDIX B

ANALYTICAL PROCEDURE EXAMPLE

An example of the analytical procedure of the BOLTS program (see Section 3.2.2, Chapter 3) explaining the sequence of basic steps to obtain equilibrium in both deformations and forces is explained in this section.

The characteristics of the connection used in this example were the following:

Type of connection: Grouted connection
Number of bolts: 3
Spacing between bolts: 5 in.
Clamping force applied per bolt: 12 kips
Hole clearance: 3/16 in.
Interface thickness material: 1/4 in.
Steel plate area: 1.5 in.^{2}
Steel plate grade: 60
Load analyzed: 26 kips

Figure B.1 shows the characteristics of the connection used in this example. The analytical model used for this connection was the 3/16 in. hole clearance load-deformation response curve presented in Fig. 3.12.

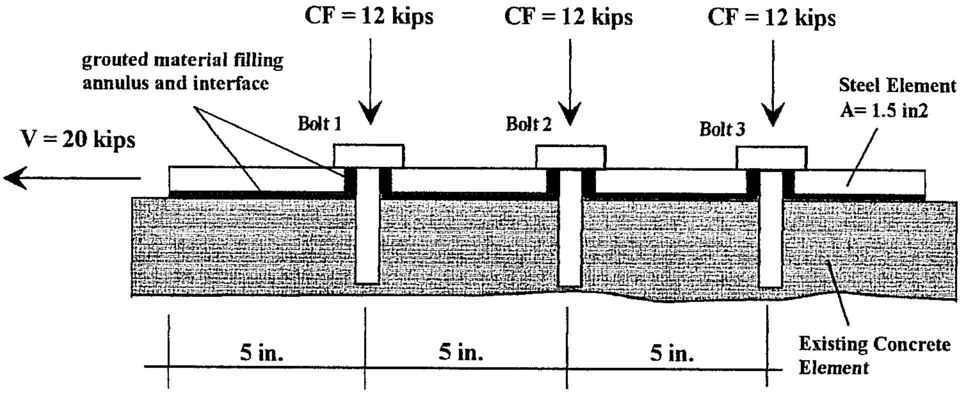


Figure B.1 Characteristics of the grouted connection used in the example.

For a given initial deformation of bolt (1) equal to 0.01711, the program performs the following steps:

a- compute the force in bolt (1) using the load-deformation response curve of Fig. 3.12 and the given deformation of bolt (1), V(1) = 8.62 kips;

b- compute the elongation of the steel plate between bolt (1) and (2),

$$\text{Elongation}_{(1\text{-}2)} = (\text{Force} * \text{Dist}) / (E * A)$$

where:

Force = force carries by the steel plate
Dist = distance between bolt (1) and (2)
E = Young's Modulus
A = steel plate area

$$\text{Elongation}_{(1\text{-}2)} = (26 - 8.62) * 5 / (29000*1.5) = 0.00199 \text{ in.};$$

c- compute the deformation of the second bolt, from equation 2, Chapter 3:

Deformation $_{(\text{bolt 2})}$ = Deformation $_{(\text{bolt 1})}$ - Elongation $_{(1\text{-}2)}$ of the steel plate

Deformation $_{(\text{bolt 2})}$ = 0.01711 - 0.00199 = 0.01511 in.;

d- compute the force in bolt (2) using the load deformation response curve of Fig. 3.12, and the calculated deformation of bolt (2), V(2) = 8.32 kips;

e- compute the elongation of the steel plate between bolt (2) and (3),

Elongation $_{(2\text{-}3)}$ = (Force * Dist) / (E * A)

Elongation $_{(2\text{-}3)}$ = (26 - 8.62 - 8.32) * 5 / (29000 * 1.5) = 0.00104 in.;

f- compute the deformation of bolt (3),

Deformation $_{(\text{bolt 3})}$ = Deformation $_{(\text{bolt 2})}$ - Elongation $_{(2\text{-}3)}$ of the steel plate

Deformation $_{(\text{bolt 3})}$ = 0.01511 - 0.00104 = 0.01407 in.;

g- compute the force of bolt (3) using the load-deformation response curve of Fig. 3.12, and the calculated deformation of bolt (3), V(3) = 8.16 kips;

h- compute the total force carries by bolts, from equation (1), Chapter 3

$V_{(\text{total force})} = \Sigma V(i)$

$V_{(\text{total force})} = 8.62 + 8.32 + 8.16 = 25.11$ kips;

i- subtract the total load applied to the connection and the obtained total force,

$$\Delta = \text{ABS}\{ 26 - 25.11 \} = 0.89 \text{ kips} > (26 * 0.01 = 0.26 \text{ kips})$$

As the difference between these two values is greater than the 1% of the applied load, the program chooses a new deformation value for bolt (1) and repeats the procedure explained above until equilibrium is achieved. The new deformation value is chosen depending on the calculated total force. If the calculated total force is less than the total load applied to the connection, the new deformation value for bolt (1) will be greater than the previous deformation value; otherwise, it will be less than the previous deformation value. Table B.1 shows the force per bolt (V(i)) and its deformation (Def(i)) for each iteration until equilibrium of forces is obtained.

Table B.1 Load and deformation per bolt for each computed iteration.

Iteration No.	Force (kips)	Def (1) (in.)	V(1) (kips)	Def (2) (in.)	V(2) (kips)	Def (3) (in.)	V(3) (kips)
1	25.11	0.01711	8.62	0.01511	8.32	0.01407	8.16
2	29.15	0.02564	9.94	0.02381	9.66	0.02308	9.54
3	27.13	0.02138	9.28	0.01946	8.99	0.01858	8.85
4	25.11	0.01711	8.63	0.01511	8.32	0.01407	8.16
5	26.12	0.01924	8.96	0.01728	8.66	0.01633	8.51

The equilibrium of forces is obtained in iteration #5, showing a difference between the load applied to the connection and the calculated force equal to 0.12 kips.

$\Delta = \mathrm{ABS}\{ 26 - 26.12 \} = 0.12 < (26 * 0.01 = 0.26 \text{ kips})$

When the equilibrium is reached, the total deformation of the connection is calculated as the sum of the deformation of bolt (1) and the elongation of the steel plate located near the applied load.

Deformation of bolt (1) = 0.01924 in. (see Table B.1)
Elongation of steel plate = $26 * 5 / (29000 * 1.5) = 0.00299$ in.
Total deformation of the connection = $0.01924 + 0.00299 = 0.0222$ in.

APPENDIX C

USER'S GUIDE

C.1 Use of the program

The BOLTS program was developed to analyze the behavior and distribution of load to bolts in a multiple-fastener installation. The program was designed to analyze a maximum of 15 bolts aligned in one row. The units for the values in the input data are kips for forces and inches for displacements. Young's Modulus for the steel plate is 29000 ksi.

C.1.1 Program Restrictions

The User has to be aware that the use of the program is restricted to the following conditions:

a) There are several ways to attach steel elements to existing concrete structures using anchor bolts: wedge type anchors and epoxy grouted anchors. The models included in the computer program, and shown in the Main Menu, are restricted to the use of anchor bolts attached to the concrete with structural adhesive epoxy.

b) The anchor bolt on which the analytical models were based is a 3/4 in. diameter mild steel (ASTM A36) threaded rod. For anchor bolts with different characteristics or properties than described above, the user should not use BOLTS, unless the load-deformation response of the anchor bolt in question is known. If the load-deformation response is known, the user can use option #4 (monotonic loading) to analyze the behavior of the connection or can include it in the program following the steps of section C3, How to include a new model.

c) The maximum clamping force applied to a bolt can not be greater than 90% of the yield force of the bolt.

d) The connection behavior has to be ductile. Bolts in the connection should be sufficiently embedded in the concrete structure so that failure occurs by yielding and/or large displacements of the anchor bolts prior to embedment failure.

e) Materials used in the connection, at the interface and annulus, must be:

- any structural epoxy that is solvent-free, moisture insensitive and with compressive modulus of elasticity around 800 ksi.
- or non-shrink grout meeting ASTM C 1107 specifications.

f) The following minimum construction requirements need to be met in the field:

- drilling equipment should be aligned and supported to ensure perpendicular bolt position;
- the holes should be cleaned with a bottle brush and vacuumed after drilling;
- bolts should be brush cleaned to ensure good bond;

- at least 40% of the hole depth should be filled with structural adhesive epoxy;
- the anchor bolt should be set by rotating it while pushing it into the hole;
- excess epoxy should be removed from the concrete surface.

For more information about bolt installation requirements refer to Appendix A of Reference 3.

C.1.2 Special Considerations

The analytical models were based on conditions considered in the experimental program: type and diameter of the bolt (3/4 in.), hole clearance in the steel plate (3/16 in. or 7/16 in.) and clamping force (hand-tightened, 12 or 18 kips) applied to the bolts. Since the tests were carried out using only one type and diameter of anchor bolt and the other two variables (hole diameter and clamping force) were specified, they confine this study to a very small range of cases. In order to enlarge the range of analysis and options (monotonic loading), it was assumed that linear interpolation and/or extrapolation between two or more load-deformation response curves could be used.

Grouted Connections. The surface treatment did not affect the response of grouted connections. The behavior of a grouted connection with an acetone-cleaned surface was similar to the behavior of a grouted connection with a light sandblasted surface treatment. Therefore, the analytical models were based on sandblasting surface treatment results.

The tests of individual bolts showed that grouted connections are not affected by variable clamping force (see Fig. C.1). For the clamping force applied, the response was the same except load at first slip increased proportionally to the difference in the applied force. Thus, the only variable affecting the response was the hole clearance in the steel plate.

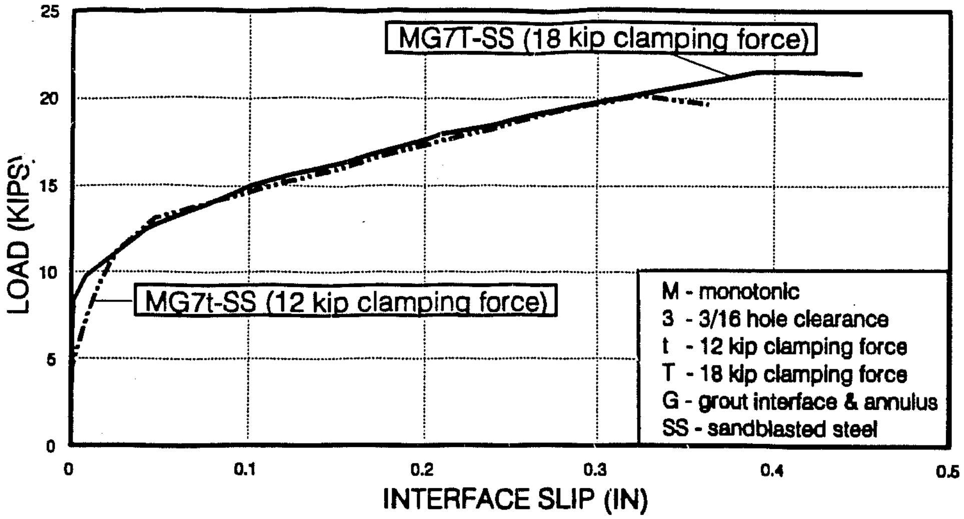


Figure #C.1 Effect of clamping force in a grouted connection

For a connection with 1/4 in. interface material thickness, the load-deformation responses for a 3/16 in. and 7/16 in. hole clearance were available. Therefore, linear interpolation could be used to compute the response of any connection with a hole clearance between 3/16 in. and 7/16 in.. To enlarge the range of options, the range was increased by 1/16 in. at both limits. Therefore, a linear extrapolation could be used to compute the response for any connection with a hole clearance between 1/8 in. and 1/2 in.

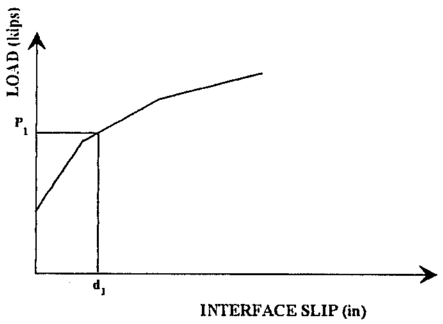
To compute the response for a connection with a hole clearance different than 3/16 in. and 7/16 in. the procedure is the following:

- For any displacement (d_1), compute the load, P1 and P2, for the 3/16 in. and 7/16 in. Load-Deformation Response Curve, respectively. (see Fig. C.2)

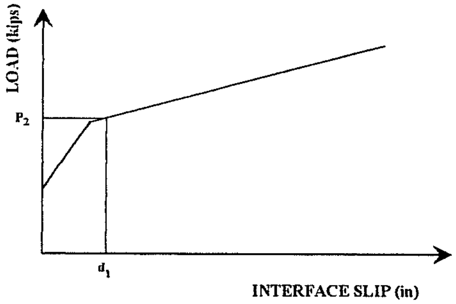
- Compute the load P, load corresponding with the hole clearance specified, interpolating and/or extrapolating according to the hole clearance specified. (see Fig. C.4)

For a connection with 1/2 in. interface material thickness, the information is very limited: only one experimental test was carried out using 3/16 in. hole clearance. As shown in Fig. 3.13, the interface material thickness affected the behavior of connections significantly. For a connection with 1/4 in. interface material thickness, the deformation capacity is 1/3 that of a connection with 1/2 in. interface material thickness. The maximum capacity for a connection with 1/4 in. interface material thickness is 20% greater than a connection with 1/2 in. interface material thickness. Due to the change in the behavior, no modification or interpolation is allowed for this type of connection until future investigations give more information on the effect of the interface thickness.

Epoxy Grouted Connection. For this type of connection, both the hole clearance and clamping force applied to bolts affected the behavior of connections. The load-deformation response of a connection with 3/16 in. and 7/16 in. hole clearance, both tested with a clamping force of 0 (hand-tightened), 12, and 18 kips clamping force, are available. Therefore, linear interpolation



(a) 3/16 hole clearance response curve



(b) 7/16 hole clearance response curve

Figure C.2 Compute P1 and P2, for the 3/16 in. and 7/16 in. load-deformation response curve.

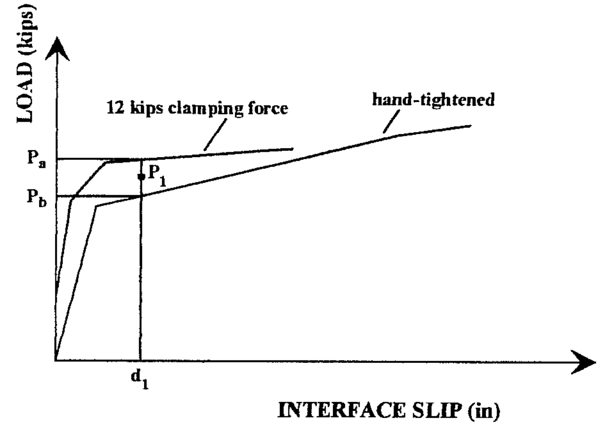
could be used to compute the response of a multiple-fastener connection with a hole diameter different than 3/16 in. and 7/16 in. and clamping force values between hand-tightened and 18 kips. To enlarge the options, the range will be increased by 1/16 in. at both limit values of the hole clearance. Therefore, a linear extrapolation could be used to compute the response for any connection with a hole clearance between 1/8 in. and 1/2 in.

This process can be divided into two steps. The first step considers the interpolation of the clamping force variable (see Fig. C3) and the second considers the interpolation of the hole clearance variable (see. Fig. C4).

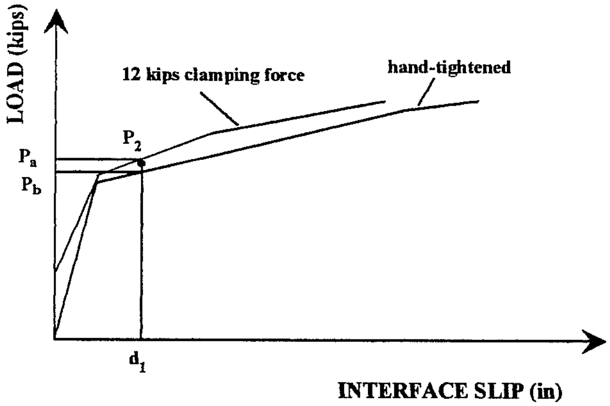
For any bolt of a multiple-fastener connection with a given displacement (d_1), a given clamping force (or friction force), and a given hole clearance, the procedure to compute the shear force in each bolt is the following:

1- If the specified clamping force applied to the bolt is less than 12 kips, the program can calculate, for a given displacement (d_1), the force (Pa) for a connection with 3/16 in. hole clearance and 12 kip clamping force (see Fig. 3.18), and the force (Pb) for a connection with 3/16 in. hole clearance and hand-tightened clamping force (see Fig. 3.16), as shown in Fig. C3(a). Knowing (Pa) and (Pb), a linear interpolation between (Pa) and (Pb) determines the force (P1) for the clamping force specified by the user with a 3/16 in. hole clearance, as shown in Fig. C.3(a). The same procedure computes the force (P2) for a connection with 7/16 in. hole clearance, as shown in Fig. C.3(b). The force (P), for the specified hole clearance is determined by linear interpolation and/or extrapolation between (P1) and (P2) as shown in Fig. C.4.

2- If the specified clamping force is greater than 12 kips, the response is the same as the 12 kip response except for the first slip capacity which increases proportionally with the applied load (see Fig. 3.17). Knowing the value for the specified clamping force, the interpolation procedure for the hole clearance is the same as described in part 1.



(a) 3/16 in. hole clearance



(b) 7/16 in. hole clearance

Figure C.3 Linear interpolation for effect of clamping force for 3/16 in. and 7/16 in. hole clearance.

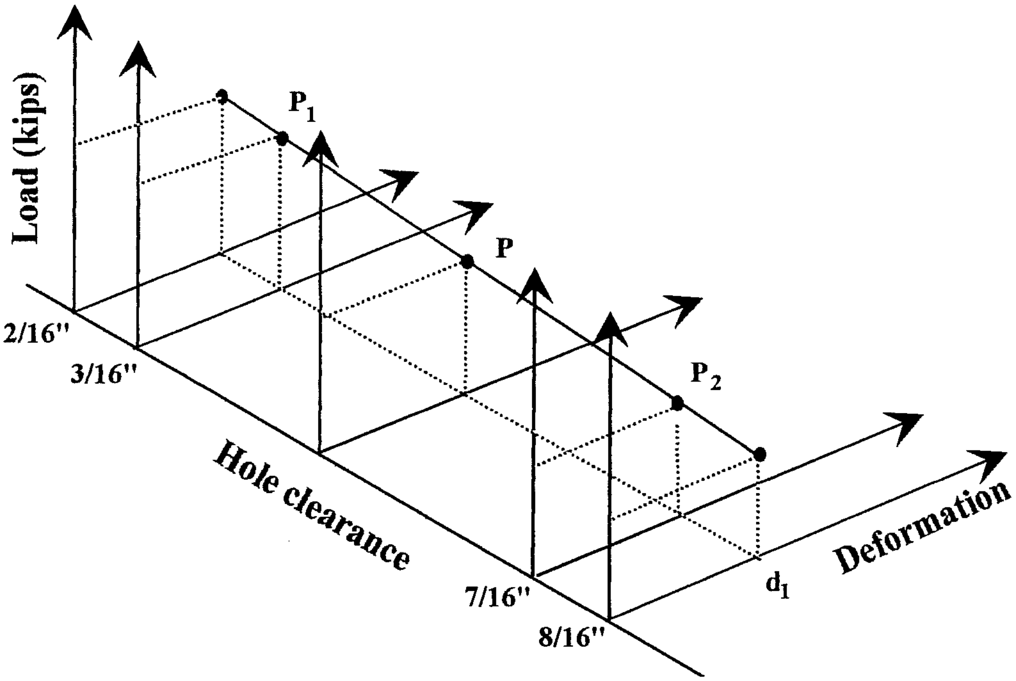


Figure C.4 Linear interpolation and/or extrapolation for any hole clearance for a given clamping force.

The following example explains the procedure described above. The characteristics of the connection are the following:

Type of connection: Epoxy grouted connection
Number of bolts: 3
Spacing between bolts: 5 in.
Clamping force applied per bolt: 8 kips
Friction force: 4 kips (approx..)
Hole clearance: 5/16 in.
Interface thickness: 1/4 in.

Steel plate area:	1.5 in.^{2}
Steel plate grade:	60
Load analyzed:	23 kips

Bolt 1

Hole clearance = 3/16 in.

Deformation (d_1) = 0.01 in.

from Fig. 3.16, the force (Pa) = 3.95 kips.

from Fig. 3.18, the force (Pb) = 12.30 kips

P1 = Pa + (Pb - Pa) * specified friction force / 6

P1 = 3.95 + (12.3 - 3.95) * 4 / 6 = 9.51

Hole clearance = 7/16 in.

Deformation (d_1) = 0.01 in.

from Fig. 3.16, the force (Pa) = 3.95 kips

from Fig. 3.20, the force (Pb) = 8.42 kips

P2 = Pa + (Pb - Pa) * specified friction force / 6

P2 = 3.95 + (8.42 - 3.95) * 4 / 6 = 6.93 kips

P = P2 + (P1 - P2) * ((7/16" * 1/2) - specified hole clearance) / 0.125

P = 6.93 + (9.51 - 6.93) * ((7/16" * 1/2) - (5/16" * 1/2)) / 0.125 = 8.23 kips

Bolt 2

Steel plate elongation = (23 - 8.22) * 5 / (29000*1.5) = 0.00169 in.

Deformation bolt 2 (d_2) = 0.01 - 0.00169 = 0.00831 in.

Hole clearance = 3/16 in.

Deformation (d_2) = 0.00831 in.

from Fig. 3.16, the force (Pa) = 3.31 kips.

from Fig. 3.18, the force (Pb) = 11.28 kips

P1 = Pa + (Pb - Pa) * specified friction force / 6

P1 = 3.31 + (11.28 - 3.31) * 4 / 6 = 8.62 kips

Hole clearance = 7/16 in.

Deformation (d_1) = 0.01 in.

from Fig. 3.16, the force (Pa) = 3.31 kips

from Fig. 3.20, the force (Pb) = 8.03 kips

P2 = Pa + (Pb - Pa) * specified friction force / 6

P2 = 3.31 + (8.03 - 3.31) * 4 / 6 = 6.45 kips

P = P2 + (P1 - P2) * ((7/16" * 1/2) - specified hole clearance) / 0.125

P = 6.45 + (8.62 - 6.45) * ((7/16" * 1/2) - (5/16" * 1/2)) / 0.125 = 7.55 kips

<u>Bolt 3</u>

Repeat the same procedure as for bolts 1 and 2.

Total force = 8.23 + 7.55 + 7.21 = 22.99

Δ = 23 - 22.99 = 0.01 in. < (23 * 0.01 = 0.23 kips)

C.1.3 Input Data

Input data is requested and provided through the terminal screen. The following steps input the data:

1- " Enter output file name: " , output file is the file which will store the results of the analysis. For example: type < **connec.out**>

2- " Enter number of bolts: ", means input the total number of bolts in the connection. For example: type <**4**>

3- " Spacing: ", is the spacing between bolt$_{(i)}$ and bolt$_{(i+1)}$.

4- " Area, Grade: ", are the area and grade of the steel plate

For example: for area type <**1.4**>, for grade type <**60**>

Figure C.5 shows graphically an example of the definition of bolts, spacing of bolts and area of the steel plate of a steel-concrete connection of three anchor bolts.

5- " Loading type: Monotonic (1), Cyclic (2) : ", depending on the required analysis.

C.1.3.1 Monotonic Loading

If "loading type" is (1) then:

a- " Load Increment: ", is the increment of load desired by the user for computing the displacements of the system.

For example: type <**0.5**>

Warning: to avoid any problems running the program, the User must use a load increment of 0.05 for the following cases:

- for a friction force = 0 on the first bolt,
- analyzing the behavior or obtaining the load-deformation of a single bolt,
- analyzing the behavior of a connection with 1/2 in. interface thickness.

b- " Main Menu:

" Type of connection of bolt # : ",

type <**1**>

" (1) Plain Connection ", in this type of connection neither the gap between the anchor bolt and the steel element nor the interface between the concrete block and the steel element were filled with any structural material.

type <**2**>

" (2) Grout Connection ", in this type of connection both the gap between the anchor bolt and the steel element, and the interface between the concrete block and the steel element were filled with non-shrink grout.

type <**3**>

" (3) Epoxy Connection ", in this case, epoxy filled the annulus of the connection.

type <**4**>

" (4) Other Type ", this option gives the possibility to analyze any other model not included in the Main Menu, knowing only the load-deformation response of a single bolt.

type <**5**>

" (5) Help: ", description of options in the Main Menu.

c- Depending of the option chosen from the Main Menu, additional information is request:

For option (1) Plain Connection

- bearing clearance (gap between the anchor bolt and the steel plate)
  For example: type <**0.03**> See example in Fig. C.5

- and friction force between the steel plate and the existing concrete surface produced by the clamping force applied to the bolt
  For example: type <**4**>

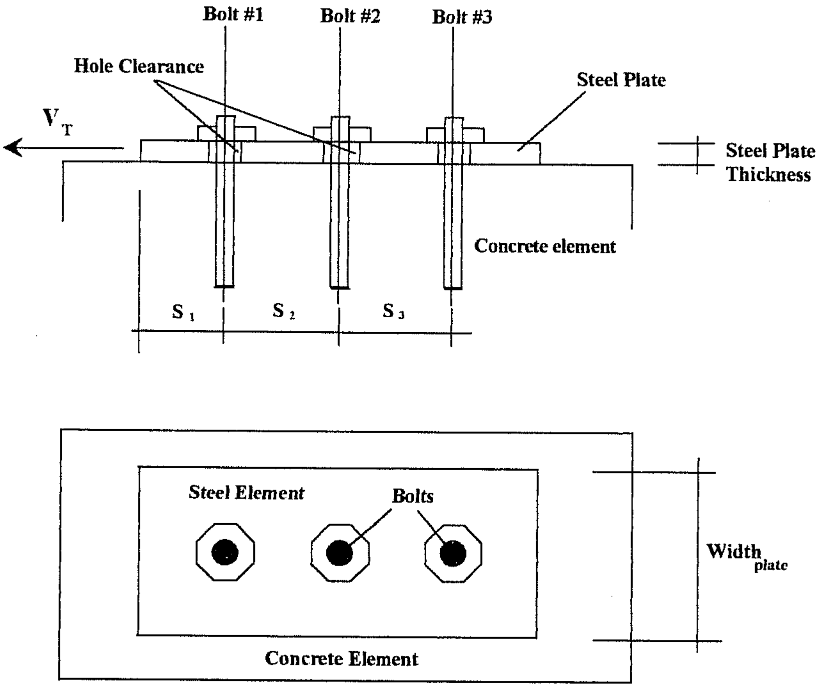


Figure C.5 Input data example.

For option (2) Grouted Connection:

- "Interface Material Thickness: "

  " 1/4 in. (1):"

  " 1/2 in. (2):"

For both options, the bearing clearance and the friction force are requested.

For option (3) Epoxy Connection:

- bearing clearance. See example in Fig. C.5
- friction force

For option (4) Other Type:

- bearing clearance, see example in Fig. C.5
- friction force, and
- coordinates (x-y) of the load-deformation response. See Fig. C.6

d- Depending on the type of information the User needs, there are three options for printing the results:

- Option (1) : Print only the load-deformation response of the connection
- Option (2) : Print only the load-deformation reponse of the bolts
- Option (3) : Print the load-deformation response of both, the connection and the bolts

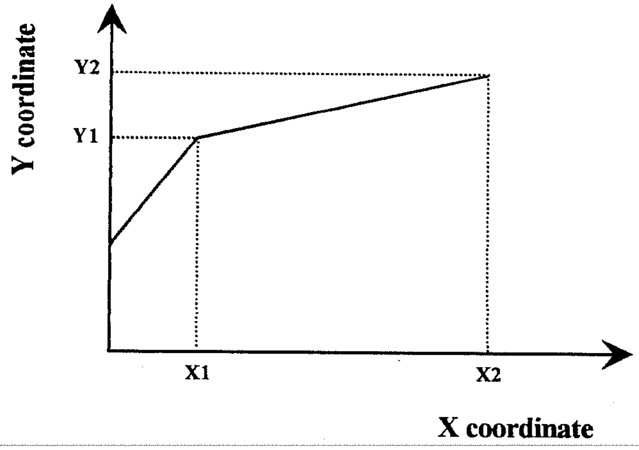


Figure C.6 Coordinates (x-y) of a load-deformation response

C.1.3.2 Cyclic Loading

If "loading type" is (2) then:

a- "Main Menu:

"Type of connection of bolt # : "

type <1>

"(1) Epoxy Connection", in this case, epoxy filled the annulus of the connection.

type <2>

"(2) Help: ", description of options of the Main Menu.

b- Depending on the option chosen from the Main Menu, additional information is requested:

For options (1) :

- friction force between the steel and existing concrete surface produced by the clamping force applied to the bolt,

c- The printing options are the same as monotonic subroutine.

C.2 How to include a new model

To include a new monotonic loading model into the computer program the following steps have to be met:

1- Include the maximum strength capacity of the model in variable xmax( ) define in line 172.

Example:
XMAX(new option number) = maximum load capacity

2- If bolt diameter is different to 3/4 in., include a loop command from line 313 to 345 defining the chosen bolt diameter. Otherwise, define xka = xmax( ) on the correspondence connection type in lines 314 (plain connection), 317 (grouted connection) or 324 (epoxy grouted connection).

3) Refer to subroutine INP (welcomes and stores the input data). If bolt diameter of new model is different to 3/4 in., there is a space reserved for a new bolt diameter in line 1085, labeled as 2000. Otherwise, modify or include any instruction between lines 813 and 1080 (3/4 in. bolt diameter). Line 815 (labeled 1001) is for plain connections, 851 (labeled 1200) for grouted connections, and 983 (labeled 1300) for epoxy grouted connections.

4) Refer to subroutine PFORCE. This subroutine calls any of the subroutines containing the load-deformation response of a single bolt. The linear interpolation between different load-deformation response is

controlled in this subroutine. If bolt diameter of the new model is different to 3/4 in., there is a space reserved for any new information added in line 1191, labeled 2000. Otherwise, modify or include any instruction between lines 1128 and 1186.

Example:

new line number CALL name of the new subroutine (DB(I),P,I)

5) Include the new load-response subroutine. It should follow the same order of any of the subroutines already included in the program. They are:

- Plain1: define a plain connection model
- GroutC31 and GroutC71: define the load-deformation response for a grouted connection with 1/4 in. interface thickness material and 3/16 in. and 7/16 in. hole clearance respectively.
- Gro1: define the load-deformation response for a grouted connection with 1/2 in. interface thickness material.
- EpoxyC1, Epoxy3C12, and Epo7C12: define the load-deformation response for a epoxy grouted connection with hand-tightened clamping force, and 12 kips clamping force for a 3/16 in. and 7/16 in. hole clearance respectively.

6- Save the changes and compile the program.

C.3 Identifiers used in the Computer Program

Identifiers are names for variables, constants or other entities used in the BOLTS program. They are summarized in this section, and for convenience they are listed in alphabetical order. A symbol in the list followed by parentheses denotes a vector (one dimensional array). Variables having names that begin with the letters I, J, K, L, M, and N are taken to be integer numbers which are numbers that do not include a decimal point; while others are assumed to be decimal numbers which are real numbers.

Identifier	Definition
A:	area of the steel plate
AUMEN:	load increment
AV1:	stores the absolute value of the difference between the deformation of bolt one and the and the prior deformation of bolt one
B:	intersection point with Y-axis
CLAM( ):	one dimensional array which stores the clamping force applied to bolts
DANT:	initial displacement
DB( ):	one dimensional array which stores the deformation of each bolt
DIF:	constant to store the difference between the total force applied to the steel plate between to bolts minus the force of the prior bolt

DS( ):	one dimensional array which stores the elongation of the steel plate
DS1:	variable which stores the elongation of the steel plate
DS2:	variable which stores the total deformation of the system
E:	Young Modulus
FORCE:	total force applied to the connection
FS( ):	one dimensional array which stores the force of each bolt
FY:	yield strength of the steel plate
IBOLT:	number of bolts in the connection
ITYPE( ):	one dimensional array which stores the type of connection
K:	counter
KA:	variable which stores the option type of bolt i
OVERS( ):	one dimensional array which stores the hole oversize
OUTPUT:	variable which stores the output file
P:	constant which stores the force applied any bolt
PPLATE:	yield point of the steel plate
SLOPE:	slope of the line
SPAC1( ):	one dimensional array which stores the spacing among bolts
V( ):	one dimensional array which stores the force of each bolts
VANT:	variable to store the prior value of the deformation of bolt one
VT:	constant which stores the sum of bolt forces
VTA:	prior total force applied to the system
XMAX( ):	one dimensional array which stores the maximum load capacity of the bolts
XMAXN( ):	one dimensional array which stores the maximum load capacity of the bolts for the New Curve option

X1( ):	one dimensional array which stores the X-coordinates of the New Curve option
Y1( ):	one dimensional array which stores the Y-coordinates of the New Curve option

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VITA

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