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Earthquake resistant submarine drydock block system design

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DEPARTMENT OF OCEAN ENGINEERING
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EARTHQUAKE RESISTANT SUBMARINE DRYDOCK BLOCK SYSTEM DESIGN

by

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Cornell University (1979)

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Submitted to the Department of Ocean Engineering in partial
fulfillment of the requirements for the degrees of Naval
Engineer and Master of Science in Mechanical Engineering

ABSTRACT

A three degree of freedom submarine drydock blocking system computer aided design package is developed. Differential equations of motion are developed to take into account high blocking systems, wale shores, and side block cap angles. The computer program is verified by a case study involving the earthquake sliding failure of the *USS Leahy* (CG-16). A parametric study is conducted to determine the effects of wale shores, isolators, and block stiffness and geometry variations on system survivability. The effects of using earthquake acceleration time histories with differing frequency spectrums on system survivability is studied.

None of eleven submarine drydock blocking systems studied survive to dry dock failure (0.26 g's) or even meet the Navy's current 0.2 g survival requirement. This shows that current U.S. Navy submarine drydock blocking systems are inadequate to survive expected earthquakes. Two design solutions are found that meet the dry dock failure requirements. The low stiffness solution uses dynamic isolators and rubber caps, and the high stiffness solution uses wale shores and rubber caps. The wale shore solution virtually prevents the submarine from moving horizontally relative to the dock floor. The isolator solution allows relatively large horizontal displacements to occur. Using the wale shore solution, the submarine experiences forces which are an order of magnitude higher than those seen by the isolator solution.

Both of the design solutions can be constructed; however, there are cost and production interference concerns. Considering the almost certain occurrence of a major earthquake in the proximity of a U.S. Naval shipyard where submarines can be drydocked within the next 20 years, the expeditious incorporation of one of these design solutions into U.S. Navy drydocking standards is strongly recommended.

THESIS SUPERVISOR: Dale G. Karr, Ph.D.

TITLE: Associate Professor of Ocean Engineering

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BIOGRAPHICAL NOTE

The author graduated from Cornell University in 1979 with a Bachelor of Science degree in Mechanical Engineering. He received his commission in the United States Navy through the NROTC program at Cornell. After a few Navy schools he joined the precommissioning crew of the USS Stephen W. Groves (FFG-29) in 1981. He served aboard for three years as Damage Control Assistant, Main Propulsion Assistant and Ordnance Officer. In 1984 he transferred to Engineering Duty and served as a Ship Repair Officer at SUPSHIP Jacksonville. He entered the XIII A program at MIT in June 1985.

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CHAPTER 1

INTRODUCTION

1.0 Description of Earthquake Threat to Submarine Drydock Blocking Systems

U.S. Naval shipyards where submarines are drydocked are located in regions of the United States where significant earthquakes are known to occur. These earthquakes produce tremendous forces and ground displacements which seriously threaten the safety of drydocked submarines. They usually occur without any warning, and there is presently no reliable means of predicting their occurrence. Therefore, submarine drydock blocking systems must be designed to resist expected earthquake excitation.

Hepburn [1] described in detail both the nature of the seismic threat to submarines drydocked in U.S. Naval shipyards, and the drydock blocking systems currently in use there. Graving docks at these shipyards are currently designed to withstand earthquake accelerations up to 0.26 g's. Previous research by Sigman [2] and Karr [3] using linear elastic material three degree of freedom models showed that submarine drydock blocking systems would fail due to side block liftoff at accelerations significantly lower than the 0.2 g level required by current Navy drydocking standards [4].

Hepburn's [1] thesis confirmed these results using a bilinear material model for wood which more closely represents its actual behavior. Using this bilinear wood model, it was determined that the submarine drydock blocking systems would fail by side block liftoff at even lower accelerations. Clearly current U.S. Navy submarine drydock blocking systems are inadequate to meet the earthquake threat.

1.1 Summary of Bilinear Material Results

Natural rubber and dynamic isolators were analyzed by Hepburn [1] using bilinear models to determine their potential for increasing system survivability. The rubber was used as a substitute for the Douglas fir soft cap, and the dynamic isolators were used as a substitute for the oak (hard wood) layer of the blocking systems. It was determined that significant increases in survivability occur when rubber and dynamic isolators are incorporated in the blocking systems. Rubber caps and isolators either singly or in combination are very attractive potential solutions to the submarine drydock blocking systems' survivability problem.

This thesis uses the three degree of freedom analysis model previously developed by Sigman [2] and Karr [3] with the bilinear material models developed by Hepburn [1] to design earthquake resistant submarine drydock blocking systems. The

use of natural rubber, dynamic isolators, wale shores, blocking system stiffness, and geometry variations is studied.

1.2 Thesis Outline

Chapter 2 describes improvements made to the three degree of freedom computer program (3DOFRUB) developed jointly by Luchs and Hepburn. The development of a computer aided design package using this program as the core is described. Significant modifications include the use of horizontal and vertical accelerations input and force and displacement output files, and development of miscellaneous support programs.

Chapter 3 describes the changes made in the equations of motion to include the effects of cap angle and side block height. This chapter also describes the effect of adding wale shores to the blocking system. In addition, the side block wedge effect on the sliding failure mode is developed.

The earthquake effects on the USS Leahy (CG-16) drydock blocking system at Long Beach Naval Shipyard is described in a case study in chapter 4. The results of this study are used as a verification of the three degree of freedom drydock blocking system model and computer program. In chapter 5, a parametric study on the effect of wale shores, dynamic isolators, and stiffness and block geometry variations is conducted.

The site specific earthquake effects on drydock blocking system designs is analyzed in chapter 6. A low stiffness dynamic isolator based drydock blocking design is developed in chapter 7. Similarly, in chapter 8 a high stiffness wale shore based drydock blocking design is developed. Finally, a comparison of results, conclusions, and recommendations for further study is included in chapter 9.

CHAPTER 2

DEVELOPMENT OF THE THREE DEGREE OF FREEDOM EARTHQUAKE RESISTANT DRYDOCK BLOCKING DESIGN PACKAGE

2.0 Three Degree of Freedom Computer Program Background

The computer program used to analyze the submarine drydock blocking systems in this thesis was developed jointly with Hepburn [1] and is based on the program developed by Sigman [2]. Many significant modifications are made to Sigman's program and several support programs are written to improve the usefulness of this program as a design tool. The two subroutines developed to model bilinear material properties, "BILINALL" and "RUBBER", are described in detail by Hepburn [1].

The significant modifications made in this thesis include the addition of horizontal and vertical acceleration inputs, force and displacement outputs, and changes to the equations of motion to include more complex geometry. The geometry changes took into account the effects of side block height, cap angle, and the inclusion of wale shores. In addition, the side block wedge effect on the sliding failure mode is included in the program.

The main program, "3DOFRUB", inputs submarine drydock blocking system parameters then calculates the system's modal masses, stiffnesses, damping coefficients, and natural frequencies. The horizontal acceleration time history (and vertical if applicable) are input using the "ACCLINPT" subroutine. The main loop of the program solves the equations of motion using the Fourth Order Runga-Kutta numerical method. The blocking material stiffnesses are recalculated each time step using the appropriate subroutines. At each time step, keel and side block forces are calculated, and the system is tested for failure.

The program begins by using 100 percent of the amplitude of the input acceleration time history. It carries out repeated loops through the whole history each time decreasing the input acceleration. This continues until the system survives a complete loop through the time history. Force and displacement data files as chosen by the user are created using subroutine "RESPALL" for use in plotting system response. The main program, "3DOFRUB", and all four subroutine listings are included in Appendix 1. A sample input data file and output file are also included in this appendix.

2.1 Horizontal and Vertical Acceleration Input

Sigman's program only allowed the input of horizontal earthquake acceleration time histories. Vertical accelerations are input to the program by multiplying the horizontal accelerations by a selected constant. The resulting vertical acceleration is, therefore, identical in wave form with the horizontal acceleration which is not always the case for actual earthquakes. A better way of handling vertical accelerations is to use actual vertical acceleration time histories. The "ACCLINPT" subroutine allows both horizontal and vertical acceleration time histories to be read independently.

The "ACCLINPT" subroutine asks the user for the horizontal acceleration file name and then reads the data into an array. The user is then asked if a vertical acceleration file will be used. If the user chooses to use one, its data is read into a different array. If the user declines to use a vertical acceleration file, the user is asked to provide the vertical to horizontal acceleration ratio. Each horizontal acceleration data point is then multiplied by this ratio to create a vertical acceleration data array.

The subroutine then checks to make sure that if horizontal and vertical acceleration inputs are used, both the inputs are from the same earthquake with the same time step.

Finally, "ACCLINPT" provides the main program, "3DOFRUB", with the earthquake name, the horizontal and vertical earthquake component names, and the acceleration time step used.

2.2 Force and Displacement Output

In order to display the response of the three degree of freedom system, it is essential to create force and displacement output data files. Sigman's [2] computer program included a computer operating system dependent plotting routine. In order to develop a useful and easily portable software package, force and displacement response data is output in ASCII files. This allows the user the option of using a wide variety of plotting programs to display the response data. The main program can then be run on any system, including personal computers, that has a FORTRAN compiler.

The main program, "3DOFRUB", asks the user if response and displacement output files are desired. If these files are desired, the user can chose which of five force components should be output. These force components are (1) keel horizontal force, (2) side block horizontal force, (3) left side block vertical force, (4) right side block vertical force, and (5) keel block vertical force.

The main program calculates the appropriate force and displacements. The program selects the correct displacements corresponding to the chosen force then captures them in arrays. For example, if left side block vertical force is selected, the displacement, YPRIME, is captured. YPRIME includes the vertical displacement of the keel, rotation about the keel times the lever arm to the left side block, and the static deflection of the side block due to submarine weight.

"RESPALL" is the subroutine which creates force and displacement output files. This subroutine asks the user for x displacement, y displacement, rotation, and force output file names. It then writes the force and displacement arrays captured by the main program to these files. The program only creates output data files for an earthquake magnitude that the system survives (where no failures occur). These output files are formatted such that they are directly usable by LOTUS 123 and other graphics programs.

2.3 Development of Miscellaneous Support Programs

Several support programs are developed to produce acceleration time history data files usable by "3DOFRUB". The first program, "V2READS", based on a program provided by Lew 1988 [5], creates three separate single column format acceleration data files. The input for this FORTRAN program is the standard format magnetic media data file containing

three complete earthquake records each provided by the National Geophysical Data Center, Boulder, Colorado [6].

The second program, "ACCELMOD", modifies an acceleration data file in single column format by adding a new data point found by linear interpolation between each original data point. This is necessary in some cases (e.g. the 1 October 1987 Whittier, California earthquake) to improve the accuracy of the numerical computational scheme. The Whittier earthquake was recorded with a 0.02 second time step. The "3DOFRUB" program produces the best results if the time step is 0.01 seconds or less.

The third computer program, "DATINNEW", written in BASIC inputs acceleration data from ASCII data files in either single or multiple column format and modifies it in several ways. First, if desired the program adds character string labels to the first three lines of the output data file. These labels are the name of the earthquake, the acceleration component name, and the acceleration time step. These labels are required in order for the output file to be used directly by "3DOFRUB".

"DATINNEW" allows the user to produce an output data file of any length up to the maximum number of entries in the input data file. The program also allows the user to multiply each data point by a desired constant to produce earthquake time

histories of varying magnitudes. The program gives the user the option of having the output data file be in units of inches per second squared or centimeters per second squared. "3DOFRUB" requires centimeters per second squared data input. "DATINNEW" removes gaps in data files produced by programs such as LOTUS 123. The output of the program is an ASCII data file in single column format.

Another BASIC program, "MAKERUB", is developed to create submarine and blocking system data input files for "3DOFRUB". This program is written based on a BASIC program written by Paz (1986) [7]. This computer program allows the user to prepare new data files or modify existing data files. The program is labeled in detail and identifies all submarine and blocking system data input file entries including their units as used by "3DOFRUB". The program is versatile in that data files can be moved, recalled, and modified quickly and easily.

"MAKERUB" prompts the user for each data entry by description, units, and variable name. The program then creates data files in the exact format required by "3DOFRUB" without the user having to adjust anything. One important feature of this program is that it labels the data files with identifying information so when the data files are displayed the user can see all pertinent information as text. The four programs described in this section are included in Appendix (2).

CHAPTER 3

GEOMETRICAL IMPROVEMENTS TO THE THREE DEGREE OF FREEDOM MODEL AND COMPUTER PROGRAM

3.0 Geometrical Improvements to the Three Degree of Freedom Equations of Motion

The three degree of freedom model of the submarine drydock blocking system at rest as developed by Sigman (1986) [2] and used by Hepburn [1] is the system used as a baseline for this thesis. Figure (3.1) is a two dimensional representation of the submarine and dry dock with the keel and side block piers modeled as horizontal and vertical springs and dashpots.

This figure differs from Sigman's model in several respects. First, wale shores, modeled as horizontal springs and dashpots, at a distance AAA from the keel are added. Second, the height of the side blocks above the keel baseline and the resulting angle alpha between the baseline and a line through the keel and side block point of contact is shown and taken into account in the equations of motion.

The point CG1 is the initial location of the center of gravity of the submarine. The point K is the initial location of the keel of the submarine. The point K', insert figure (3.2), is the location of the keel after horizontal and vertical translation has occurred. Rotation occurs about this point. KG is the distance from the keel to the center of

gravity. The distance br is the transverse distance between the center of the caps of the port and starboard side blocks. The horizontal, vertical, and wale shore spring constants are as designated in the figure.

The system is excited by horizontal and vertical dry dock accelerations $\ddot{x}_g$ and $\ddot{y}_g$ respectively. The entire dry dock and submarine system moves relative to a fixed reference frame. The excited system is shown in figure (3.2). The system of equations are expressed in terms of motion of the submarine relative to the dry dock.

The point CG2 in figure (3.2) is the location of the center of gravity of the submarine relative to the fixed reference frame after horizontal displacement u and vertical displacement v. The point CG3 is the location of the submarine's center of gravity after the additional absolute rotation theta. The insert at the bottom of figure (3.2) is a close up of the keel area of the submarine during this motion. The displacements illustrated are described as follows:

The relative horizontal displacement coordinate x is the displacement of the submarine keel with respect to the dry dock. The displacement u is the position of the keel relative to the fixed reference frame. With ground motion x_g the following equations hold:

$$x = u - x_g$$

$$u = x + x_g$$

$$\ddot{u} = \ddot{x} + \ddot{x}_g \qquad (3.1)$$

Similarly for vertical translation the following equations hold:

$$y = v - y_g$$

$$v = y + y_g$$

$$\ddot{v} = \ddot{y} + \ddot{y}_g \qquad (3.2)$$

The coupled non-linear three degree of freedom equations describing the system motion as developed by Sigman are as follows:

$$M\ddot{x} + M\overline{KG}\ddot{\theta} + C_x\dot{x} + C_{x\theta}\dot{\theta} + (2khs+khk)x = -M\ddot{x}_g \qquad (3.3)$$

$$M\ddot{y} + C_v\dot{y} + (2kvs+kvk)y = -M\ddot{y}_g \qquad (3.4)$$

$$I_k\ddot{\theta} + M\overline{KG}\ddot{x} - M\overline{KG}\ddot{y}\theta + C_\theta\dot{\theta} + C_{\theta x}\dot{x} + [(br^2/2)kvs$$
$$-WKG]\theta = -M\overline{KG}\ddot{x}_g \qquad (3.5)$$

Three Degree of Freedom Submarine Drydock Blocking System Model at Rest

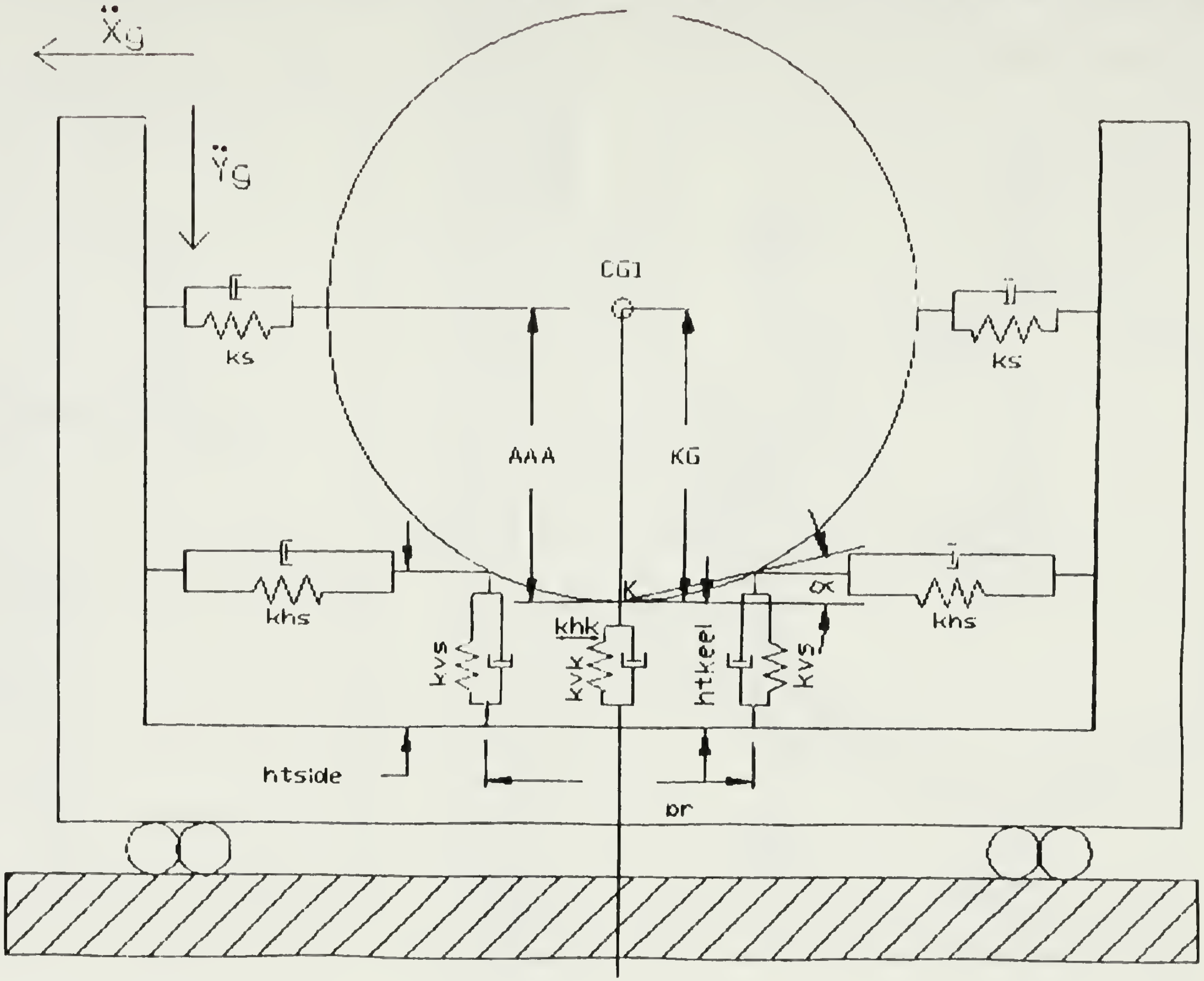


FIGURE 3.1

Three Degree of Freedom Submarine
Drydock Blocking System Model Excited

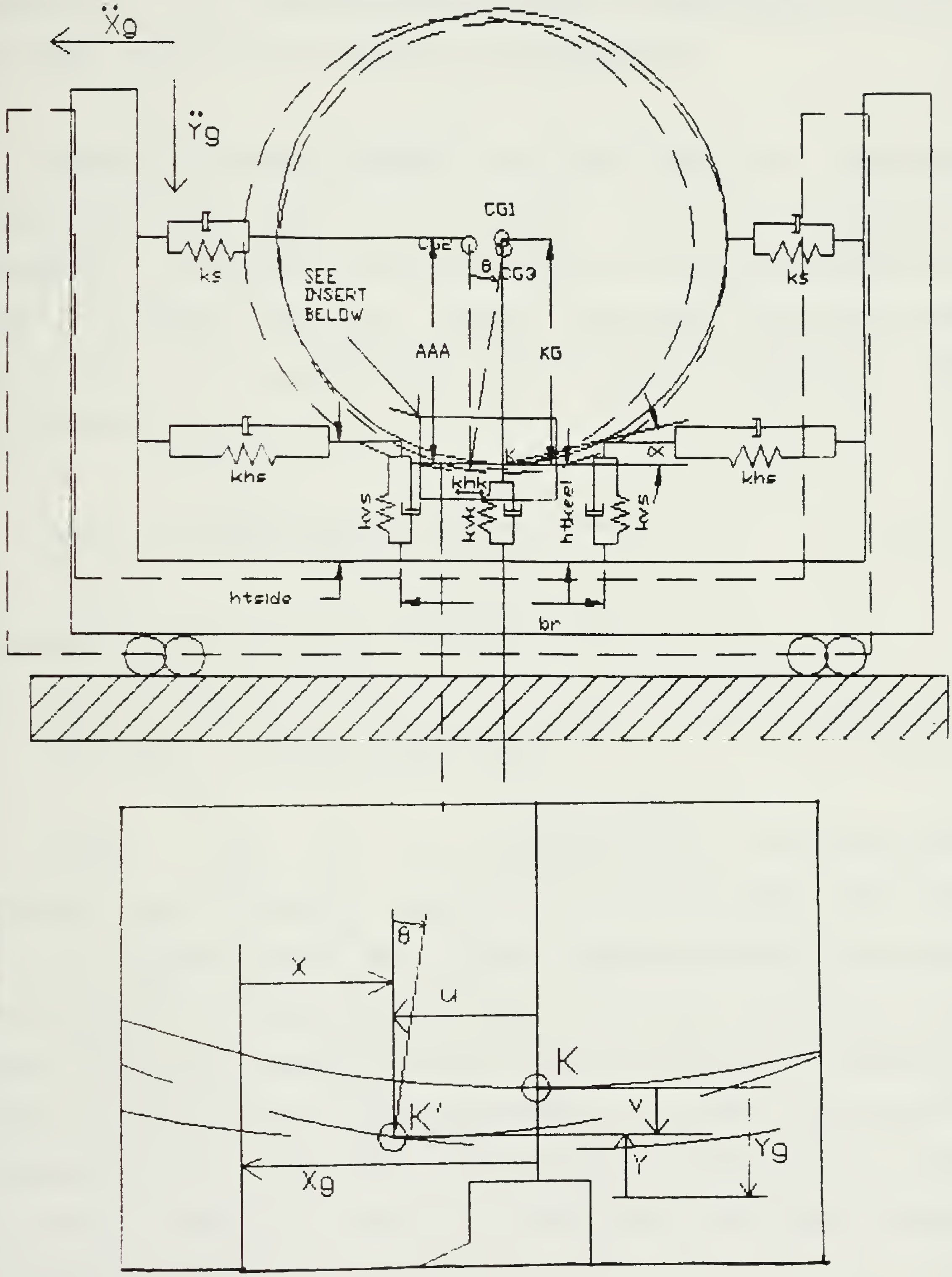


FIGURE 3.2

In equations 3.3 through 3.5, M is the mass of the submarine, Ik is the rotational moment of the submarine about the keel, and W is the weight of the submarine.

Sigman's analysis assumed that the height of the keel blocks was the same as the height of the side blocks. Therefore, the lever arm from the keel to the side block hull point of contact is br/2. Taking the actual height of the side block into account gives the following expression for this lever arm:

$$LLL = ((htside-htkeel)^2 + (br/2)^2)^{1/2} \qquad (3.6)$$

The angle alpha is then:

$$\alpha = SIN^{-1}((htside-htkeel)/LLL) \qquad (3.7)$$

Figure (3.3) is an illustration of the additional vertical and horizontal displacements of the side block cap due to rotation theta (θ) of the submarine about the keel. The insert at the bottom of figure (3.3) is a close-up of the side block cap geometry during submarine rotation. Assuming small angle rotation, the displacement of the cap due to rotation is $L\theta$. The vertical component of $L\theta$ is R. The horizontal component is Z. L in the figure is the same as LLL in equation (3.6).

Vertical and Horizontal Displacements of the Side Block Cap Due to Rotation

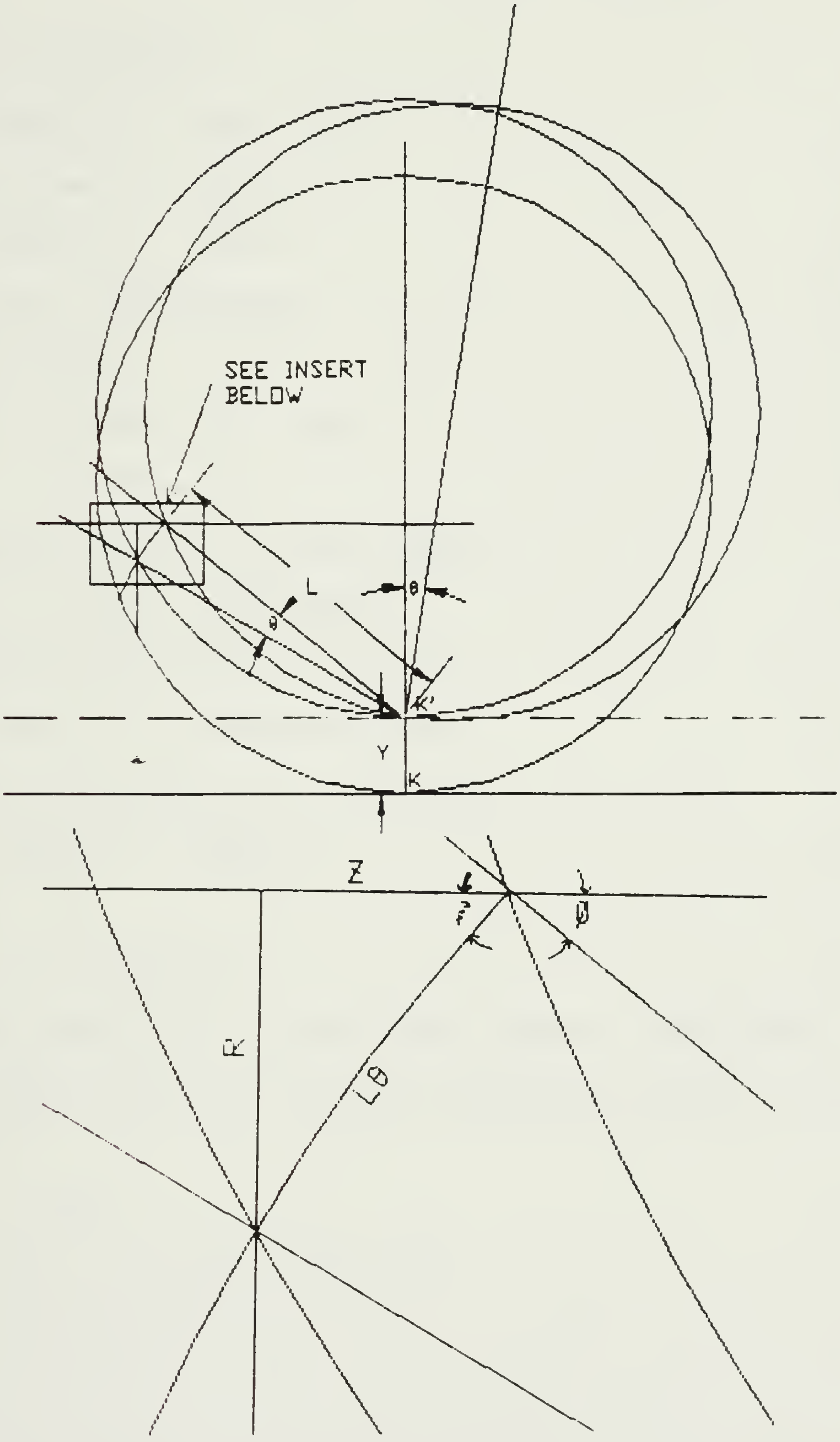


FIGURE 3.3

The expression for R is developed as follows:

$$R = L\theta*\mathrm{SIN}(\zeta) \tag{3.8}$$

$$\mathrm{SIN}(\phi) = (BU + R)/L \tag{3.9a}$$

For small angles of rotation:

$$\mathrm{SIN}(\phi) = (BU)/L \tag{3.9b}$$

$$BU = htside-htkeel \tag{3.10}$$

From figure (3.3):

$$\zeta + 90^\circ + \phi = 180 \tag{3.11}$$

$$\zeta = 90^\circ - \phi \tag{3.12}$$

Combining with equation (3.9b) gives:

$$\zeta = 90^\circ - \mathrm{SIN}^{-1}(BU/L) \tag{3.13}$$

Using a trigonometric identity gives:

$$\mathrm{SIN}(\zeta) = \mathrm{COS}(\mathrm{SIN}^{-1}(BU/L)) \tag{3.14}$$

Substituting in equation (3.7) gives:

$$\mathrm{SIN}(\zeta) = \mathrm{COS}(\alpha) \tag{3.15}$$

Therefore:

$$R = L\theta*\mathrm{COS}(\alpha) \tag{3.16}$$

In the case where BU = 0 (side block height = keel block height) as was the case in Sigman's analysis equation (3.16) reduces to:

$$R = L\theta \tag{3.17}$$

In this case L = br/2 and therefore:

$$R = (br/2)*\theta \tag{3.18}$$

Similarly:

$$Z = L\theta * COS(\zeta) \tag{3.19}$$

$$Z = L\theta * SIN(\alpha) \tag{3.20}$$

In the case where BU = 0 and L = br/2:

$$Z = L\theta * SIN(\text{Ɔ}) = 0 \tag{3.21}$$

R and Z are used in calculating the horizontal and vertical forces on the side blocks. Without these geometric relationships, the horizontal force exerted on the side blocks of submarines due to rotation is not taken into account. Not including this force is a significant underestimate of the true horizontal forces seen by the side blocks. Including this effect represents an important improvement to Sigman's model.

With these equations incorporated into the "3DOFRUB" computer program, the model is now general enough to take into account the high buildups of surface ships. Even though for submarines, including the geometric side block effects only changes the survivability of the systems by approximately one percent, for ships with higher buildups these effects will be larger.

The total blocking system forces are calculated as follows:

Keel block horizontal force:

$$RR1 = khkb*x \tag{3.22}$$

Right and left side block horizontal force:

$$RR2 = khsb*XPRIME \tag{3.23}$$

$$XPRIME = x + Z \tag{3.24}$$

Left side block vertical force:

$$RR3 = kvsb1 * YPRIME1 \tag{3.25}$$

$$YPRIME1 = -y - R + DELTA \tag{3.26}$$

Right side block vertical force:

$$RR4 = kvsb2 * YPRIME2 \tag{3.27}$$

$$YPRIME2 = -y + R + DELTA \tag{3.28}$$

Keel block vertical force:

$$RR5 = kvkb*YPRIME3 \tag{3.29}$$

$$YPRIME3 = -y + DELTA \tag{3.30}$$

Right and left wale shore horizontal force:

$$RR6 = ks*(x + AAA*\theta) \tag{3.31}$$

The total blocking system moments about the keel are calculated as follows:

Right and left side block horizontal moment:

$$MM1 = RR2*LLL*SIN(\alpha) \tag{3.32}$$

Left side block vertical moment:

$$MM2 = RR3*LLL*COS(\alpha) \tag{3.33}$$

Right side block vertical moment:

$$MM3 = RR4*LLL*COS(\alpha) \tag{3.34}$$

Right and left wale shore horizontal moment:

$$MM4 = RR6*AAA \tag{3.35}$$

DELTA is the static deflection of the side and keel blocks due to the submarine's weight. The value of DELTA is calculated in each loop of "3DOFRUB" and depends on the values of the current side block and keel block vertical stiffnesses. All blocking stiffness (e.g. khkb) are those found from appropriate "BILINALL" or "RUBBER" subroutines. If a linear material analysis is selected by the program user, linear material stiffness values are used.

To derive the modified submarine drydock blocking system equations of motion the following procedure is used. First the forces in horizontal direction are summed and equated with the mass times acceleration in that direction. Next, the forces in the vertical direction are summed and equated with

the mass times acceleration in that direction. Finally, the moments are summed about the keel and equated with the rotational inertia times rotational acceleration. After combining terms and simplifying, the modified equations of motion which include wale shore and side block geometric effects are as follows:

$$M\ddot{x} + M\overline{KG}\ddot{\theta} + C_x\dot{x} + C_{x\theta}\dot{\theta} + (2ks+2khs+khk)x$$
$$+ (2ks*AAA + 2khs*LLL*SIN(\alpha))\theta \qquad = -M\ddot{x}_g \qquad (3.36)$$

$$M\ddot{y} + C_y\dot{y} + (2kvs+kvk)y \qquad = -M\ddot{y}_g \qquad (3.37)$$

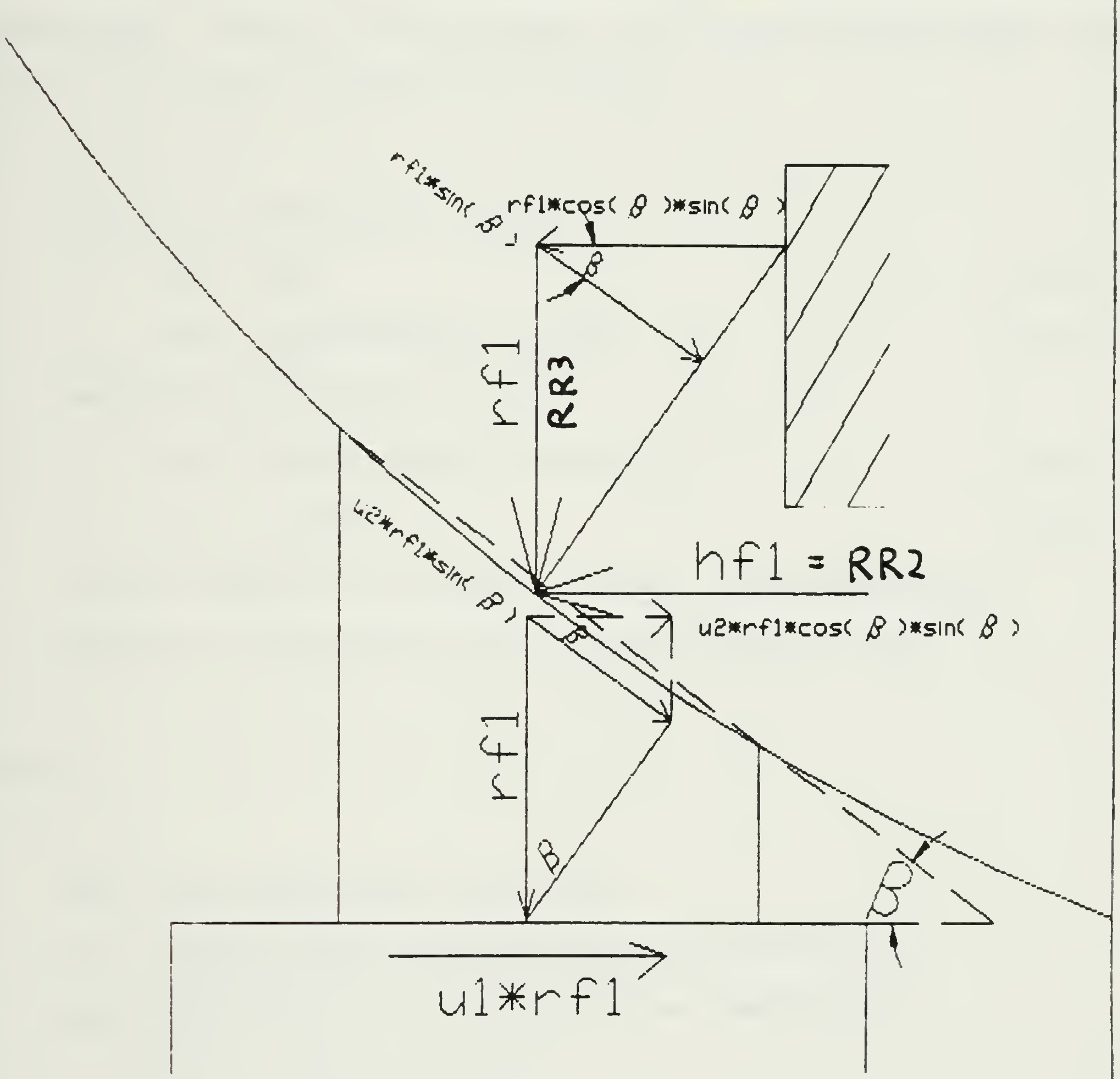
$$I_k\ddot{\theta} + M\overline{KG}\ddot{x} - M\overline{KG}\ddot{y}\theta + C_\theta\dot{\theta} + C_{\theta x}\dot{x}$$
$$+ (2ks*AAA + 2khs*LLL*SIN(\alpha))x$$
$$+ [2ks*AAA^2 \pm 2khs*(LLL*SIN(\alpha))^2$$
$$+ (2*kvs)*(LLL*COS(\alpha))^2 - W\overline{KG}]\theta \qquad = -M\overline{KG}\ddot{x}_g \qquad (3.38)$$

The three degree of freedom equations (3.36 - 3.38) are now stiffness as well as inertially coupled. In matrix form, there are now two new elements in the stiffness matrix (K_{13} = K_{31}), where K_{13} = $(2ks*AAA + 2khs*LLL*SIN(\alpha))$. The first term, $2ks*AAA$, is due to wale shores; and the second term, $2khs*LLL*SIN(\alpha)$, is due to the effect of system rotation on the side blocks. The stiffness matrix elements K_{11} and K_{33} are also modified to include these effects.

3.1 Effect of Side Block Cap Angle on System Sliding Failure Mode

All failure modes incorporated in the "3DOFRUB" computer program are the same as those used by Sigman [2] except the slide block sliding failure mode. A more general approach is used to model the side block sliding forces. This allows this program to be used for surface ship block geometries as well as submarines. One additional data input required by the program is the side block cap angle. An average value of side block cap angles, obtained from the submarine docking drawings, is used in this thesis. It is possible to model the failure of the different side blocks along the length of the submarine or ship by running the program separately for each side block right and left set.

Figure (3.4) shows the geometry used in the modeling of the side block cap. The side block cap is modeled as a wedge using a system illustrated in Marks Handbook [8]. Sigman in his analysis did not include the outward force on the side block caused by the vertical forces.



Side Block Sliding Forces

FIGURE 3.4

This outward force is caused by the relative rigidity of the ship compared to the side blocks. When a vertical force occurs, it tends to push the block outboard rather than move the ship inboard. The equations describing the forces associated with the side blocks due to this wedge effect and other frictional forces are as follows:

Outboard horizontal forces:

$$hf1 = RR2 \qquad (3.39)$$

$$hf2 = RR3*COS(\beta)*SIN(\beta) \qquad (3.40)$$

Resisting horizontal forces:

$$hf3 = u2*RR3*COS(\beta)*SIN(\beta) \qquad (3.41)$$

$$hf4 = u1*RR3 \qquad (3.42)$$

In the figure rf1 is equal to RR3. RR2 and RR3 are defined in equations 3.23 and 3.25 respectively.

Where:

β = the side block cap angle.

u1 = is the block on block friction coefficient.

u2 = is the hull on block friction coefficient.

If rf1 and hf1 are acting in the direction shown in figure (3.4), "3DOFRUB" flags side block sliding failure if hf1 + hf2 is greater than hf3 + hf4.

3.2 Determination of Blocking System Vertical Static Deflection

Due to the changing stiffness of the side and keel blocks during the earthquake because of their non-linear material properties, the static deflection, DELTA, caused by the submarine weight changes throughout the duration of the earthquake. The accurate calculation of DELTA is essential so that "3DOFRUB" correctly handles permanent set and bilinear material properties. For some cases it is possible for the keel or side blocks to start in the second (plastic) stiffness of the bilinear stiffness model if the submarine weight is great enough.

One assumption is made to simplify the calculation of DELTA. It is assumed that the side block caps would never be elastic when the keel block caps are plastic. The equations for calculating DELTA are as follows:

Elastic case:

$$\text{DELTA} = \text{weight}/(2kvs+kvk) \tag{3.43}$$

Plastic case:

$$\text{DELTA} = \text{YEL3} + (\text{weight} - (\text{YEL3}*(2kvs+kvk)))/(2kvsp+kvkp) \tag{3.44}$$

Where:

$$\text{YEL3} = \text{QD4}/(kvk-kvkp) \tag{3.45}$$

QD4 is the keel restoring force, RR5, intercept of the second bilinear stiffness slope. The entire bilinear material model is described by Hepburn [1] in detail.

"3DOFRUB" includes DELTA initialization and recalculation sections. In the initialization section the program first determines whether or not the static deflection has caused the cap material to go plastic or remain elastic. If the material is elastic, then equation (3.43) is utilized to compute DELTA. If the material is plastic, the program uses equation (3.44) to calculate DELTA. If kvk equals kvkp then YEL3 is equal to zero. Then the DELTA equation reduces to the following:

$$DELTA = weight/(2kvsp+kvk) \qquad (3.46)$$

This case occurs when the keel blocks are linear elastic and the side blocks are bilinear rubber. In addition, if either the keel or side blocks are bilinear wood then the elastic case holds initially. For recalculation the same equations are used with the updated stiffness values from the appropriate stiffness subroutines.

CHAPTER 4

USS LEAHY (CG-16) CASE STUDY

4.0 Background

On 1 October 1987, while in graving dock #3 at Long Beach Naval Shipyard (LBNSY), Long Beach, California, the *USS Leahy* (CG-16) experienced an earthquake. The 5.9 magnitude (0.45 g maximum peak acceleration) earthquake had an epicenter located 20 miles to the northeast in Whittier, California [9]. The ship experienced side block sliding and photographs of the drydock blocking system showing the block displacements were taken immediately after the earthquake. In addition, dry docks at LBNSY had been instrumented by accelerographs which recorded the dry dock accelerations (0.05 g peak) seen by the *Leahy* during the earthquake. Because of the recorded displacement and acceleration time histories, the *USS Leahy* was an outstanding case to analyze in order to verify the three degree of freedom model and the "3DOFRUB" computer program.

The October 1st earthquake occurred while this thesis was being researched. Within hours after the earthquake occurred in California, the LBNSY Drydocking Office was contacted and a request for photographs of the blocking system was made. The Docking Officer, Mr. Robert Dixson, reported at that time that the *Leahy's* blocks had shifted outboard during the earthquake,

and four of the side blocks had remained away from the ship after the earthquake was over. Providentially, the ship had recently been sandblasted and painted, and when the earthquake occurred the portions of the hull exposed due to slide block sliding were very evident. Therefore, the exact displacements of several of the side blocks following the earthquake was recorded in the photographs taken on October 1st.

Figure (4.1) is a photograph of the # 14 (second most forward) starboard side block. This photograph clearly shows the outboard displacement of the block. It was reported that several of the steel brackets (dogs) holding the block layers together popped out during the earthquake. These brackets were reattached before the photograph was taken.

LBNSY was visited in late October and the *Leahy's* blocking system was examined. The ship was still in dry dock and the area around the displaced blocks had not been repainted. Therefore, the displacements during the earthquake were still evident. These displacements were measured and recorded. There was no evidence of side block or keel block crushing or keel block sliding. There was slight evidence of side block liftoff. This liftoff apparently slightly skewed some of the side blocks so the inboard face of the side blocks was no longer parallel to the keel line. In addition, the new paint that had been applied just before the earthquake was broken between the hull and block interface.

USS Leahy Side Block # 14

OFFICIAL U.S. NAVY PHOTOGRAPH
1 OCTOBER 1987
LONG BEACH NAVAL SHIPYARD

FIGURE 4.1

Figure (4.2) shows the keel block system of the *USS Leahy* looking forward. Again, there was no evidence of sliding or crushing along the keel line. This figure also shows the high blocking heights used by surface ships. Submarine blocking systems are usually much shorter. For a submarine, the bottom layer of blocks would not be present.

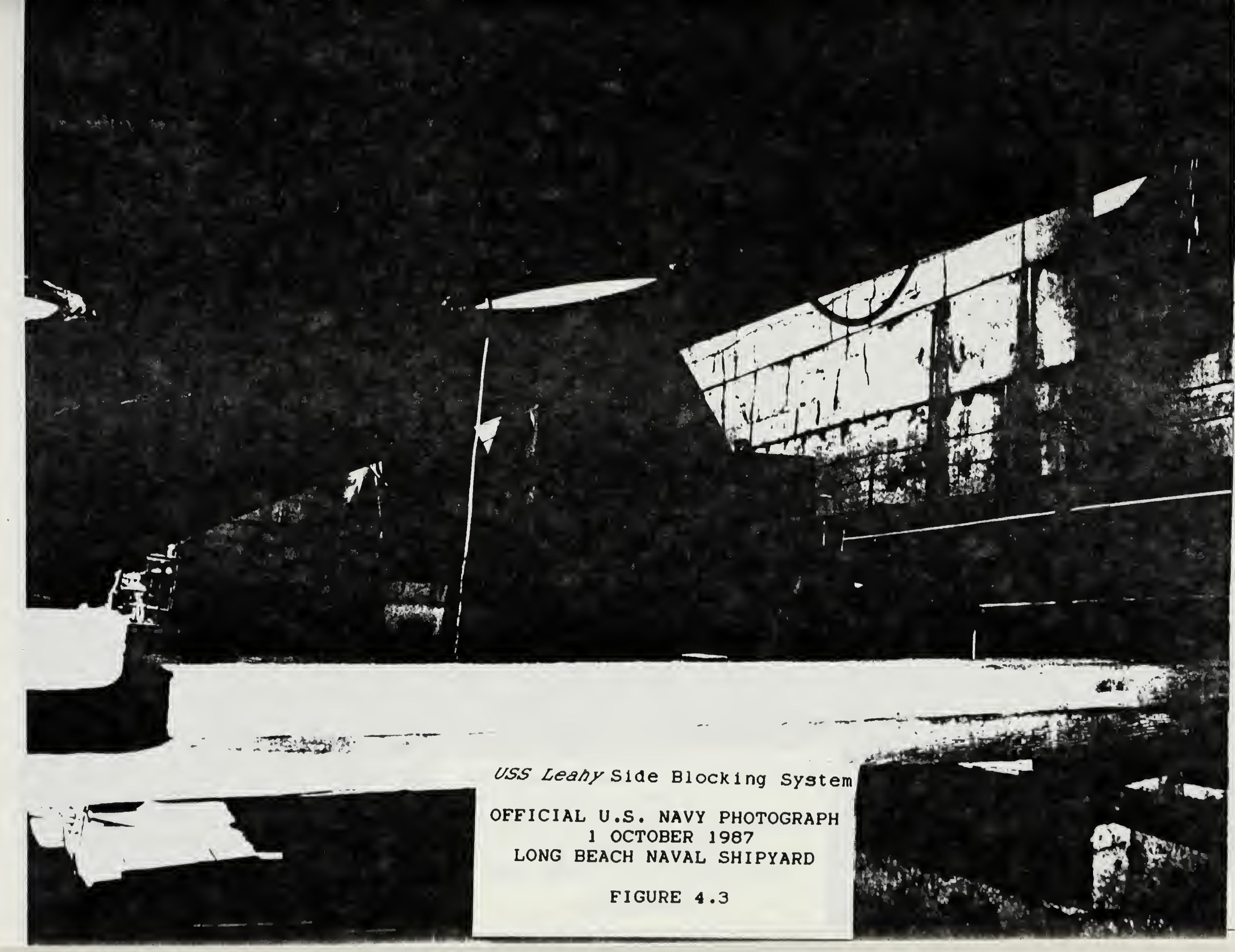
Figure (4.3) is a photograph of the *Leahy's* starboard forward side blocks. These two blocks were pushed away from the *Leahy* entirely and stayed away after the earthquake was over. This was also true for the same two blocks on the port side. The docking crew at LBNSY pushed these blocks back into position as much as possible, however, gaps can still be seen between the hull and the top of the side block cap. There were no such gaps before the earthquake. This photograph is also an excellent illustration of side block build up angle alpha (α) and side block cap angle beta (β). In figure (4.4), a close-up of one of the aftermost starboard side block caps is shown. This photograph is another illustration of the side block sliding which occurred.

The dry docks at LBNSY are some of the only dry docks in the world instrumented with accelerographic equipment. These instruments were installed by the Naval Facilities Engineering Command and monitored by the Naval Civil Engineering Laboratory, Port Hueneme, California.

USS Leahy Keel Blocking System

OFFICIAL U.S. NAVY PHOTOGRAPH
1 OCTOBER 1987
LONG BEACH NAVAL SHIPYARD

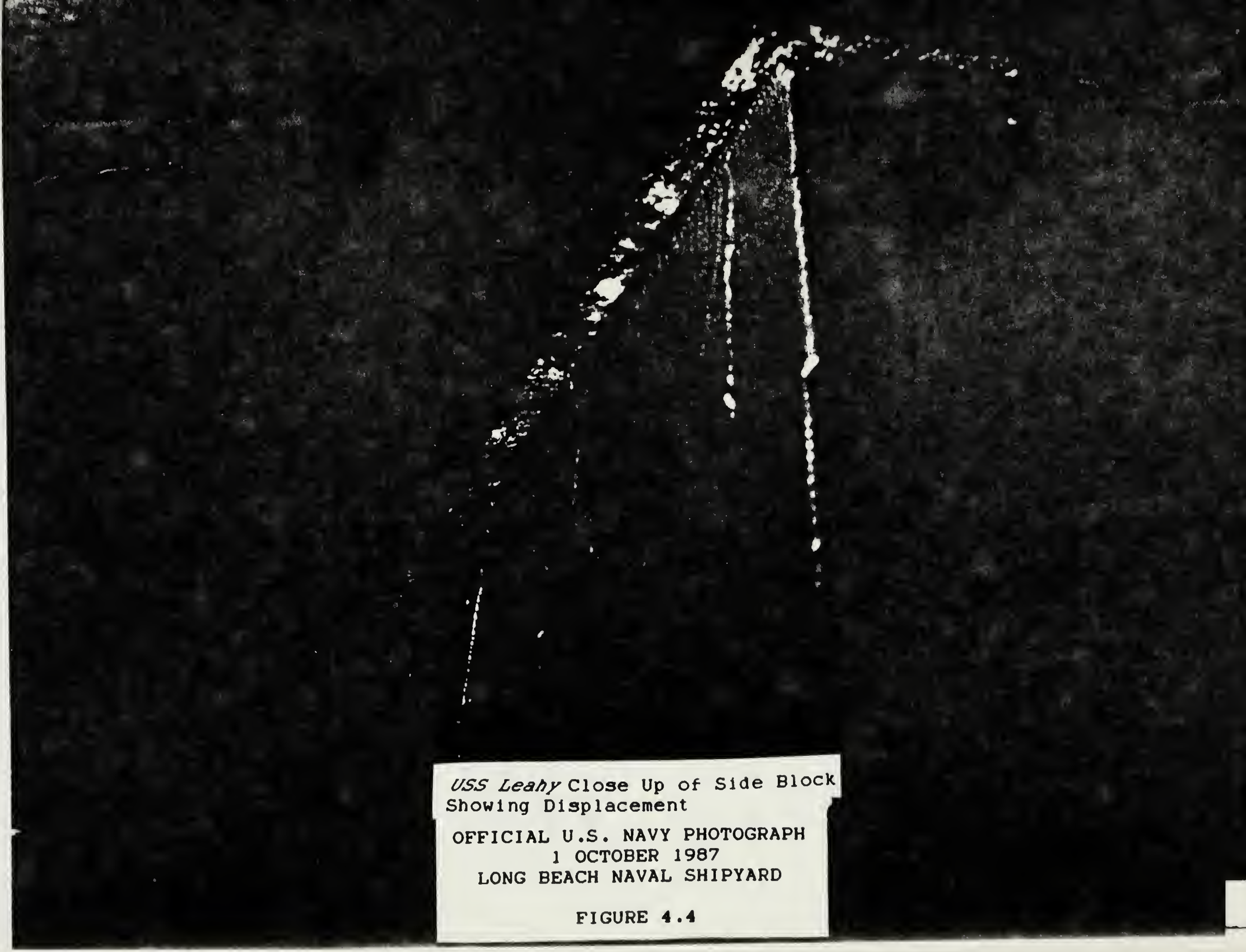
FIGURE 4.2



USS Leahy Side Blocking System

OFFICIAL U.S. NAVY PHOTOGRAPH
1 OCTOBER 1987
LONG BEACH NAVAL SHIPYARD

FIGURE 4.3



USS Leahy Close Up of Side Block Showing Displacement

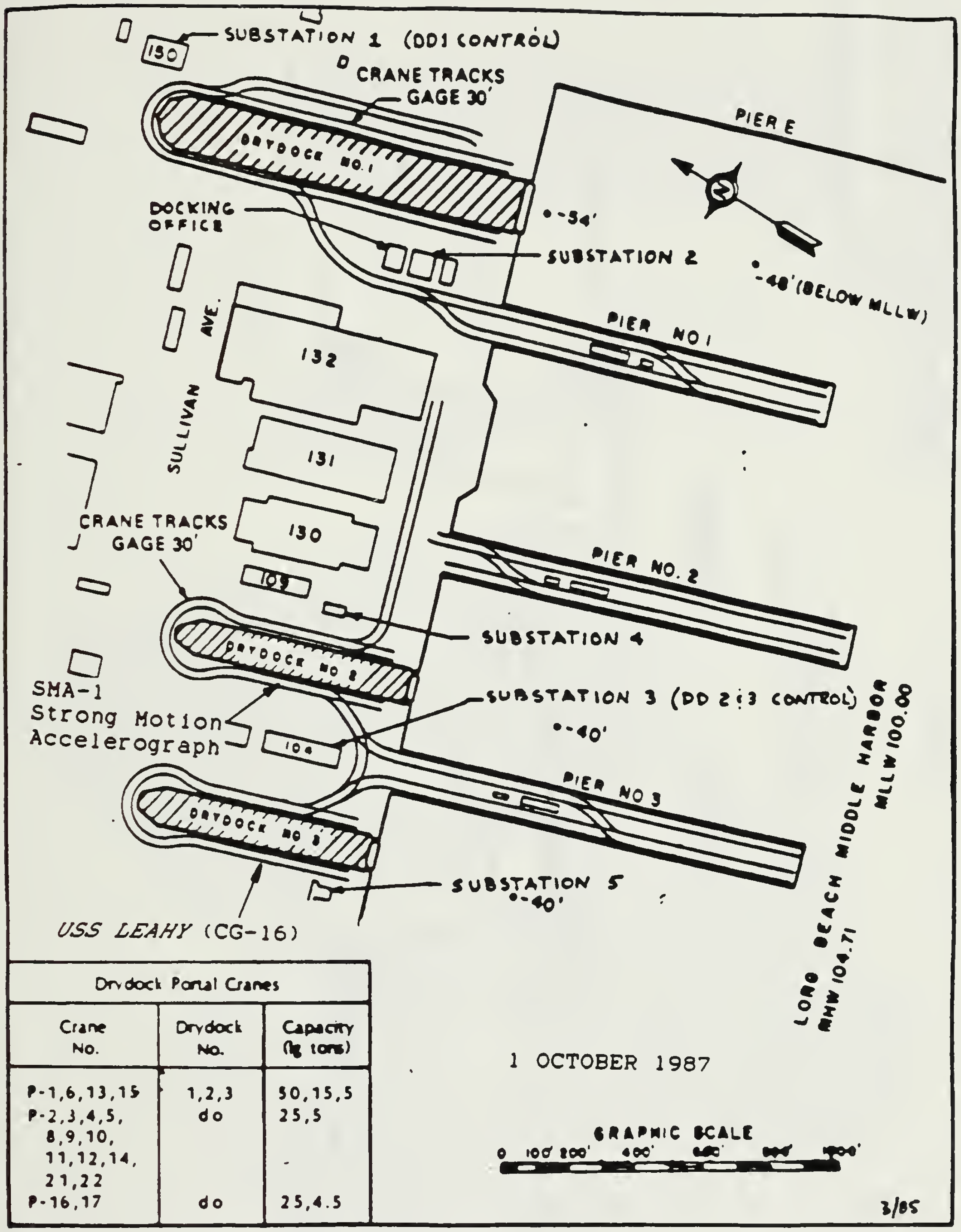
OFFICIAL U.S. NAVY PHOTOGRAPH
1 OCTOBER 1987
LONG BEACH NAVAL SHIPYARD

FIGURE 4.4

When the 1 October 1987 earthquake occurred, all of the acceleration recorders (accelerographs) were triggered in the dry docks at LBNSY. The acceleration time histories were recorded on film in these instruments.

The closest accelerograph to the *USS Leahy* during this earthquake was located in dry dock #2 which is approximately 500 feet to the east of where the ship was drydocked. Dry dock # 2 is virtually identical in size and construction to dry dock # 3 where the *Leahy* was located. Figure (4.5) is a layout of LBNSY [10] waterfront and the location of the accelerograph and the *Leahy* are indicated. Figure (4.6) is a cross-section of dry dock # 3.

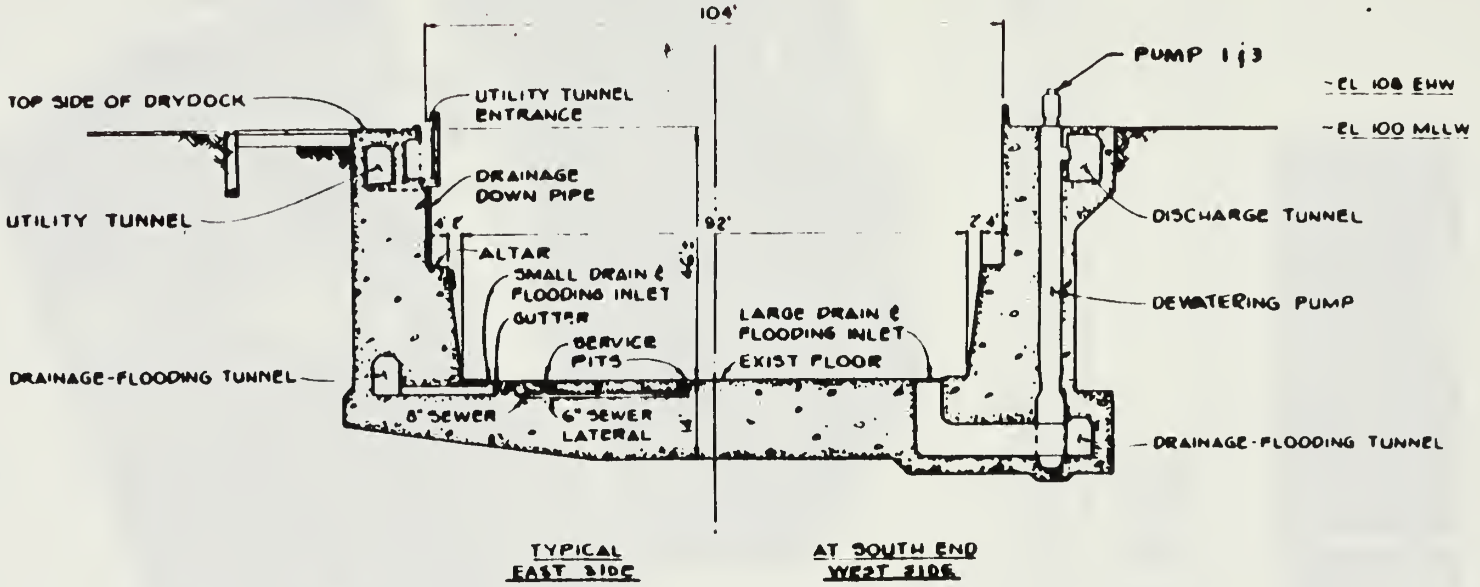
The accelerograph in dry dock # 2 was a SMA-1 Strong Motion Accelerograph. This instrument is a battery operated earthquake recorder designed to measure ground acceleration and structural response from strong local earthquakes. It provides tri-axially (orthogonally arranged longitudinal, vertical, and transverse) measured photographic records of the local acceleration time history [11]. Figure (4.7) is a photograph of this instrument.



Drydock Portal Cranes		
Crane No.	Drydock No.	Capacity (lg tons)
P-1,6,13,15	1,2,3	50,15,5
P-2,3,4,5, 8,9,10, 11,12,14, 21,22	do	25,5
P-16,17	do	25,4.5

FIGURE 4.5

Location of Drydocks, Long Beach Naval Shipyard, Long Beach, California
NAVFAC DM-29.3 (NOV 81)



LONG BEACH NAVAL SHIPYARD
DRY DOCK # 3
CROSS-SECTION

FIGURE 4.6

WOODWARD CLYDE CONSULTANTS

TYPICAL CROSS SECTIONS OF DRYDOCK NO 2
AND 3 - LOOKING SOUTH

Project

Project No.

KINEMETRICS SYSTEMS

SMA-1

Strong Motion Accelerograph

FIGURE 4.7

After the earthquake, the record from the SMA-1 in dry dock # 2 was taken to the Naval Civil Engineering Laboratory where the rough data was analyzed. This data was then corrected and processed by Structural and Earthquake Engineering Consultants, Arcadia, California. The corrections were necessary due to instrument bias and recording errors. The Naval Civil Engineering Laboratory forwarded these results, and they were used in this thesis to analyze the *Leahy's* blocking system response. The results [5] of data processing are called "corrected accelerograms" and are provided in the standard format magnetic media data file as used by the National Geophysical Data Center, Boulder, Colorado. The data provided was further processed for use in "3DOFRUB" using the support programs described in section 2.3. Figure (4.8) shows the corrected data plots provided by the Naval Civil Engineering Laboratory for dry dock # 2's transverse acceleration component. A typical header for one of the data files is included in Appendix 3.

The data from the SMA-1 took months to process due to its analog nature. Digital accelerograph instruments now exist which can provide immediate processed information to users via computer modems in the standard format. But these instruments are not yet installed in dry docks.

WHITTIER EARTHQUAKE OCT 01, 1987 -1442 GMT
JJDD200 87.101.0 002 LBNSY COMP TRAN
ACCELEROGRAM IS BAND-PASS FILTERED BETWEEN .300- .400 AND 25.00-27.00 CYC/SEC.
*PEAK VALUES : ACCELERATION = -50.74 CM/SEC/SEC VELOCITY = 7.14 CM/SEC DISPLACEMENT = 1.33 CM

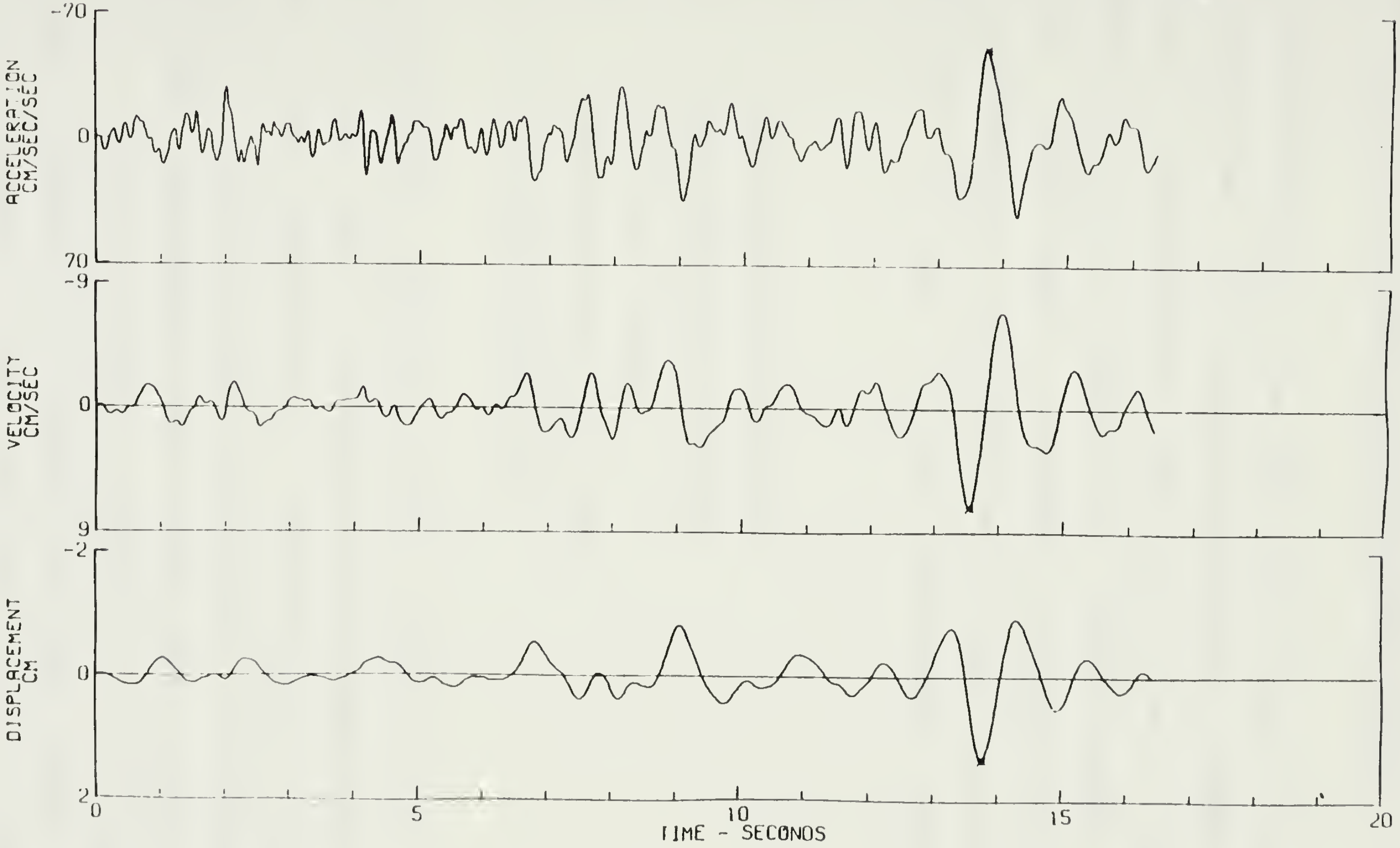


FIGURE 4.8

4.1 Modeling of the *USS Leahy* Drydock Blocking System

The characteristics of the *USS Leahy*'s drydock blocking system were obtained from the Docking Officer at LBNSY, Mr. Robert Dixson. The information used came from a "layout sheet" which was used to construct the blocking system. A copy of this "layout sheet" is included in Appendix 3. The following information is obtained from this sheet and is used in producing an input data file for the "3DOFRUB" computer program:

Side block height (htside)
Keel block height (htkeel)
Numbers of blocks
Side block cap angles (beta)
Side block breadths (br)

The photographs taken and visual inspection of the blocking system are used to determine material quantities and dimensions of each blocking layer. These dimensions are used in the blocking system stiffness spreadsheets. The features of the stiffness spreadsheets used are described in detail by Hepburn [1]. They are included in Appendix 3. The bilinear model is used to describe the Douglas fir caps. Also, in Appendix 3 is a summary of the *USS Leahy's* blocking system stiffnesses and the resulting QD values. This summary sheet

displays the other submarine system stiffnesses as a comparison.

The moment of inertia about the keel for the *Leahy* is calculated using a formula given by Gillmer & Johnson [12] based on the ship's beam for a destroyer type ship. A spreadsheet is used for this calculation and is included in Appendix 3. The ship is modeled as a "rigid body". This is considered reasonable for a cruiser type ship subject to a small earthquake. Since, each set of *Leahy*'s side blocks has different heights, the *Leahy* system is modeled several times using each set's heights. A typical data file for the *Leahy* used by the "3DOFRUB" program is included in Appendix 3.

4.2 Results of the *USS Leahy* Analysis

One of the most interesting things found in examination of the *Leahy's* blocking system is that the outboard displacement varied significantly from block to block. Figure (4.9) is a plot of measured outboard block displacement versus cap angle. This figure shows that as cap angle increases outboard side block displacement increases in a linear fashion. A best fit linear regression line is shown along with the data points.

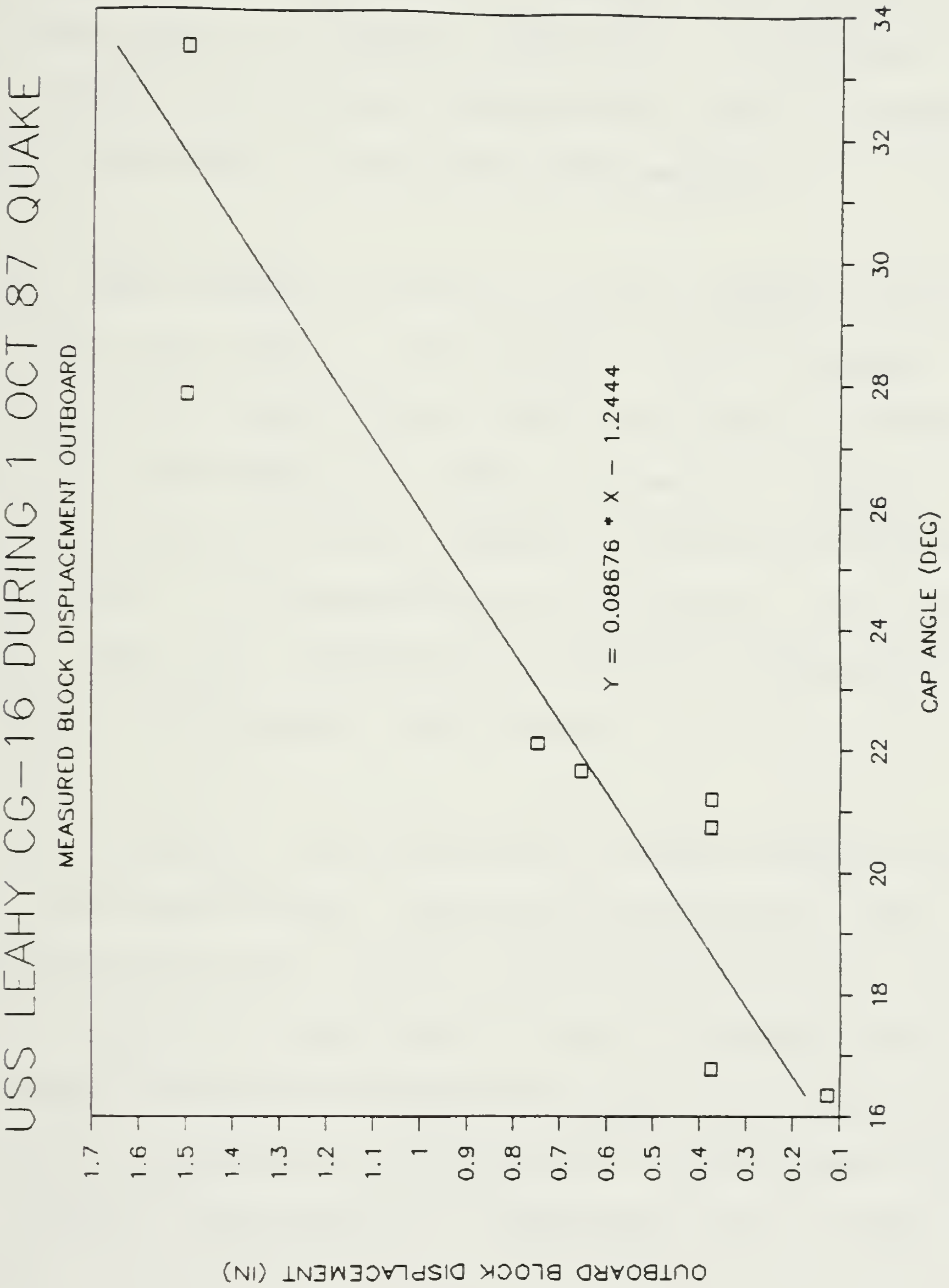

USS LEAHY CG–16 DURING 1 OCT 87 QUAKE
MEASURED BLOCK DISPLACEMENT OUTBOARD
Y = 0.08676 * X – 1.2444
OUTBOARD BLOCK DISPLACEMENT (IN)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
16
18
20
22
24
26
28
30
32
34
CAP ANGLE (DEG)

FIGURE 4.9

This type of behavior is consistent with the side block sliding analysis described in section 3.1 and incorporated in the "3DOFRUB" computer program. However, once sliding occurs, the three degree of freedom model used in "3DOFRUB" breaks down. There is no means incorporated into the program to determine the amount of side block displacement.

The next analysis step is to run "3DOFRUB" using each side block cap angle in the *Leahy's* blocking system. The program is run twelve times each time using a different cap angle. A relationship is found as seen in figure (4.10) between cap angle and the systems survivability when subject the dry dock # 2 acceleration time history. All of the analysis uses the transverse and vertical components of the dry dock # 2 acceleration time history.

It is observed that the block on block surfaces for this system had been painted. According to Rabinowicz (1987) [13], a reasonable estimate for the friction coefficient for this situation is 0.3. This value is used in comparing all of the cap angles. Figure (4.10) shows a linear relationship between earthquake survivability and cap angle. As cap angle increase the system's survivability decreases due to side block sliding.

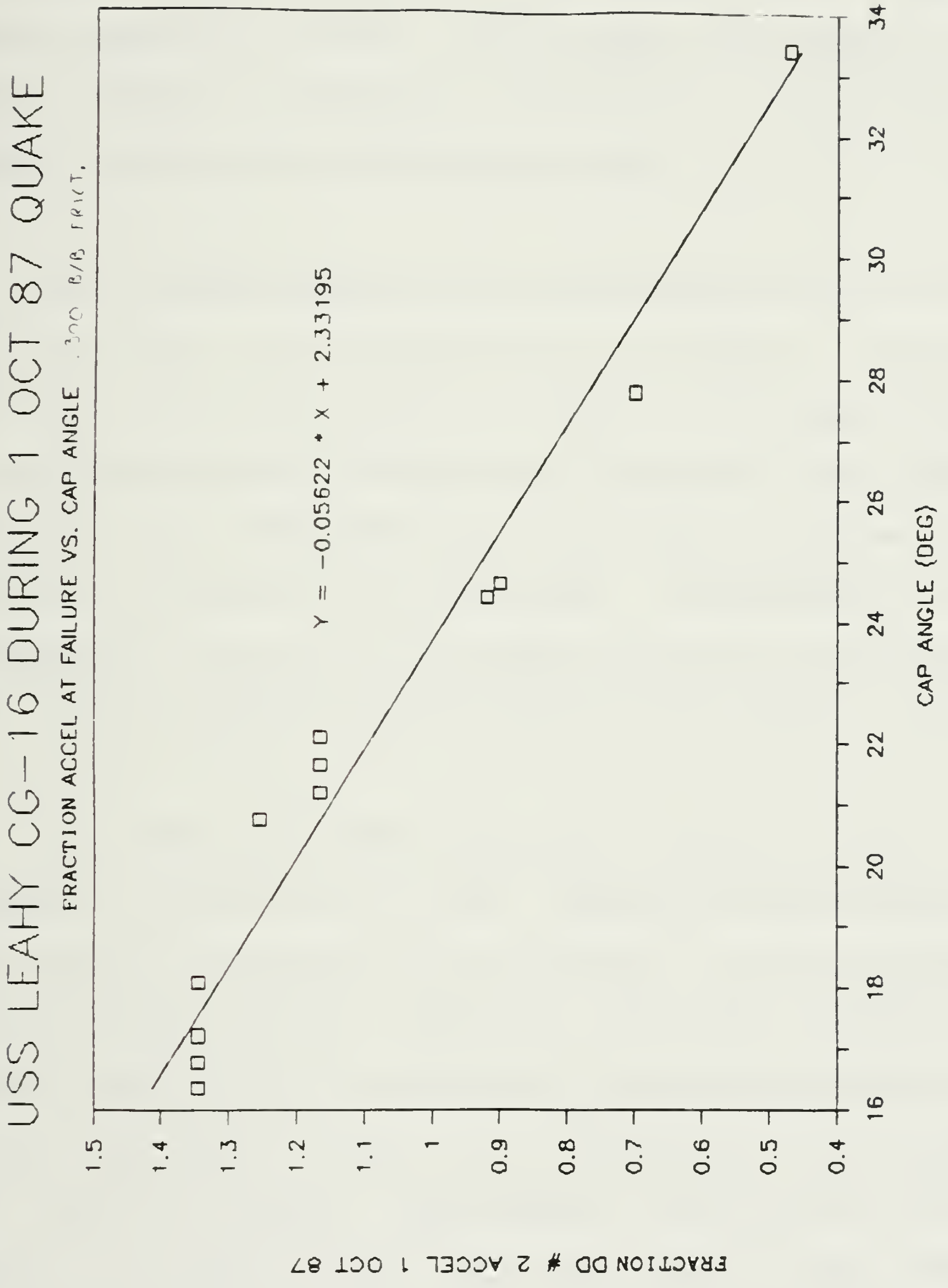

USS LEAHY CG-16 DURING 1 OCT 87 QUAKE
FRACTION ACCEL AT FAILURE VS. CAP ANGLE .300 B/B FRICT.
Y = -0.05622 * X + 2.33195
FRACTION DD # 2 ACCEL 1 OCT 87
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
16
18
20
22
24
26
28
30
32
34
CAP ANGLE (DEG)

FIGURE 4.10

Figure (4.10) predicts that the following side blocks would slide when subject to the dry dock # 2 acceleration time history: (15, 14, 13, 7, 12, 6, 1, 4). All of these blocks were observed to slide. Side blocks are numbered from the stern forward. Blocks 14 and 15 are the farthest blocks forward on the port and starboard side.

The program predicts failure ranging from 47 to 117 % of the dry dock # 2 acceleration time history. The side block systems which are predicted to fail at the lowest acceleration time histories were those side blocks with the highest cap angles. This correlates very well with observed side block sliding failures on the *USS Leahy*. A spreadsheet including a regression analysis of the observed side block displacements for the *USS Leahy*'s blocking system is included in Appendix 3.

The model predicts side block sliding failure as the primary failure mode for the *USS Leahy* system subject to the dry dock # 2 acceleration time history. This is precisely the actual system failure observed. The model also predicts that side block liftoff is the primary failure for side blocks with small cap angles. Again, this is consistent with observations of the side blocks. The observed variations in the data as seen in figure (4.9) could be due to such factors as frictional and material variations among the side block piers.

An analysis is then conducted to determine the effects of varying the frictional coefficient on system survivability. For this study, cap angle is held constant as are all other parameters except the block on block frictional coefficient. Side block # 13 is used in this study. This block has a cap angle of 0.43 radians which is in the middle of the side block cap angle range. The block on block friction coefficient is varied above and below the 0.3 value as shown in figure (4.11).

Figure (4.11) shows that there is a very strong linear dependence of survivability on block on block frictional coefficient. Varying the friction coefficient from 0.22 to 0.43 results in a survivability range of 22 to 175 % of the dry dock # 2 acçeleration time history. The best fit line as well as the data points are shown on the figure. One key result is that it seems that a block on block friction coefficient of 0.3 best fits the observed sliding conditions which occurred on the *USS Leahy*. A 0.3 value corresponds to failure at 80 % of the earthquake which is reasonably close to where the sliding of the side blocks similar to # 13 appeared to occur.

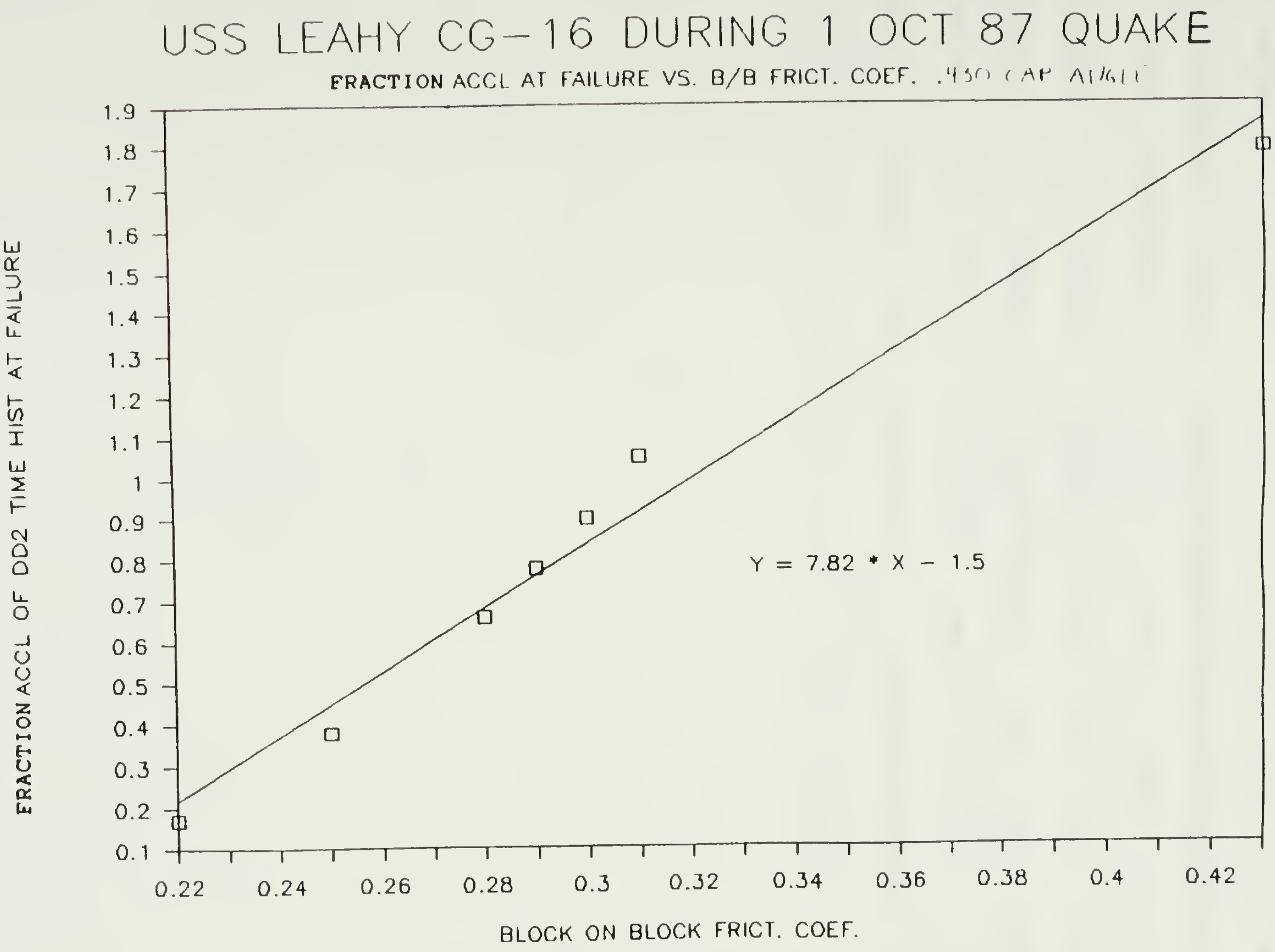

USS LEAHY CG-16 DURING 1 OCT 87 QUAKE
FRACTION ACCL AT FAILURE VS. B/B FRICT. COEF. .450 CAP ANGLE
FRACTION ACCL OF DD2 TIME HIST AT FAILURE
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.22
0.24
0.26
0.28
0.3
0.32
0.34
0.36
0.38
0.4
0.42
Y = 7.82 * X - 1.5
BLOCK ON BLOCK FRICT. COEF.

FIGURE 4.11

Figure (4.12) is the output from "3DOFRUB" for the vertical displacement of the *Leahy's* starboard side blocks (assuming # 13 cap angle and height) during the earthquake. It shows that slight liftoff does occur about 8 seconds into the earthquake where the displacements become negative. This also correlates well with the observed slight liftoff which occurred. A typical "3DOFRUB" output run is included in Appendix 3. Based on these results, the three degree of freedom model and the "3DOFRUB" computer program appear to correctly reflect the behavior of an actual drydock blocking system including the effects of side block geometry.

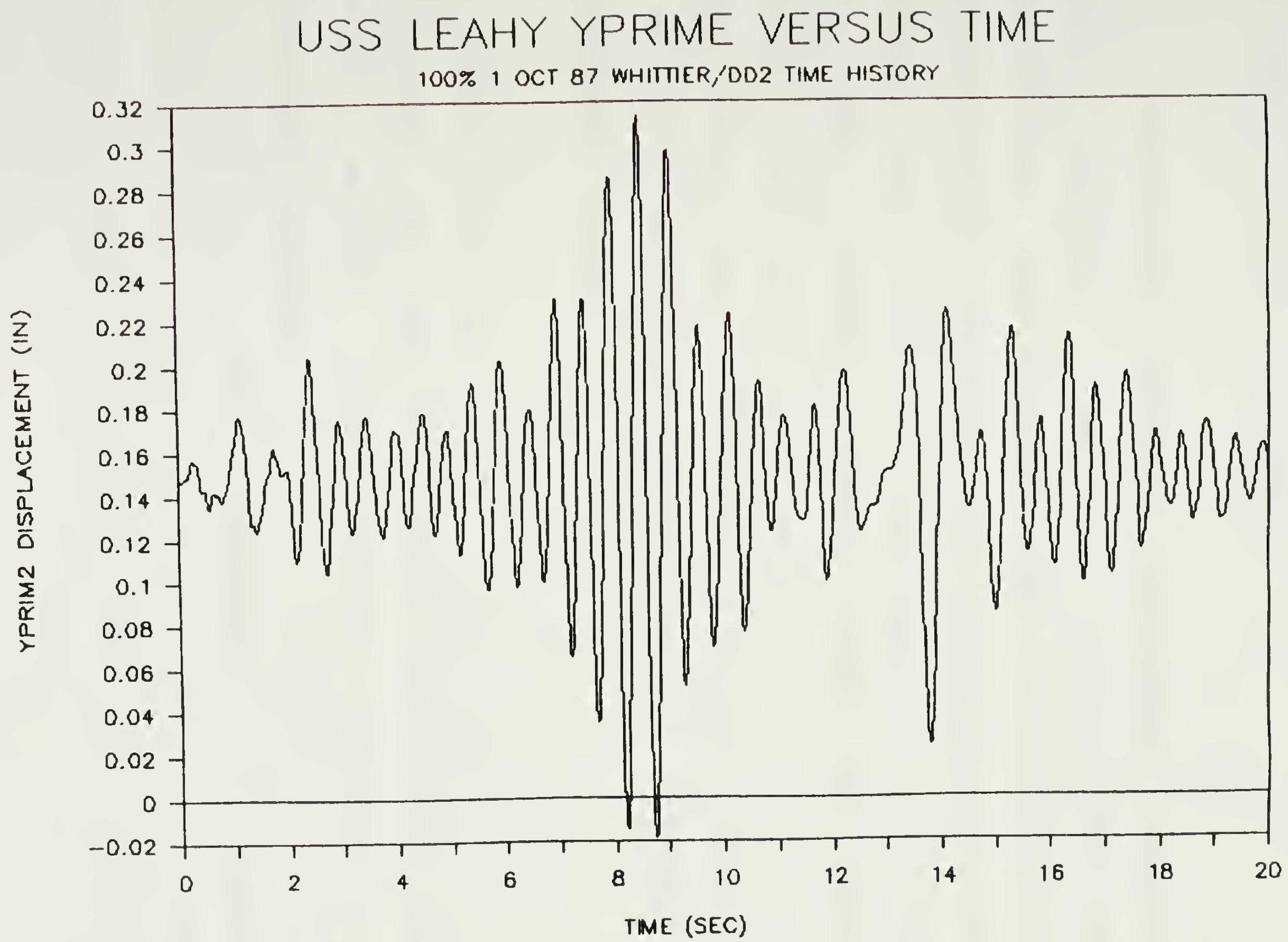


Figure 4.12 *USS Leahy CG-16*
Right Side Block Vertical Displacement vs. Time
100 % 1 October 87 Whittier Time History

CHAPTER 5

WALE SHORE, ISOLATOR, AND BLOCK STIFFNESS/GEOMETRY VARIATION PARAMETRIC STUDIES

5.0 Parametric Study Description

It has already been seen that present U.S. Navy drydock blocking systems are inadequate to resist expected earthquake accelerations. Some potential new materials such as rubber caps and dynamic isolators look promising in correcting this problem. Many other design improvements including the use of wale shores, stiffening the side blocks, and widening the blocking system base show potential. In order to explore these possibilities and establish a feel for the design space, a series of parametric studies using the "3DOFRUB" computer program are conducted.

Due to the high number of runs expected to accomplish this study, the Naval Sea Systems Command main frame (VAX) computer was used. This reduced the run time of "3DOFRUB" from several minutes to seconds. The system portability built into the "3DOFRUB" source code allows it to be recompiled for use on the VAX computer with very few minor changes. These parametric studies took several days and involved several hundred runs.

In order to determine the design space, wale shore stiffness and side block and keel block horizontal and

vertical stiffnesses inputs to "3DOFRUB" are varied. These values are not related to any particular existing or potential blocking system. These values are input directly into the program without first being produced by the stiffness spreadsheets. Submarine drydock blocking system # 1 is used as a baseline for these studies. In all cases except for the study of systems with wale shores and 1 inch rubber block caps (system 50 series), a linear material analysis is used. The 1940 El Centro earthquake acceleration time history used by Hepburn [1] is used throughout this parametric study. For several of these studies, the effect of doubling the keel block widths is investigated.

5.1 Parametric Study Results

The results of system # 1 vertical side block stiffness variations on failure due to the 1940 El Centro earthquake is shown in figure (5.1). Log(kvs) with respect to 1 kip/in is plotted against failure fraction of the earthquake. For each stiffness, failure fractions due to all failure modes present are plotted. The primary failure modes for this system are side block liftoff, keel block overturning, side block overturning, and side block sliding. For this particular study, side block horizontal stiffness is held constant at 100,000 kips/in.

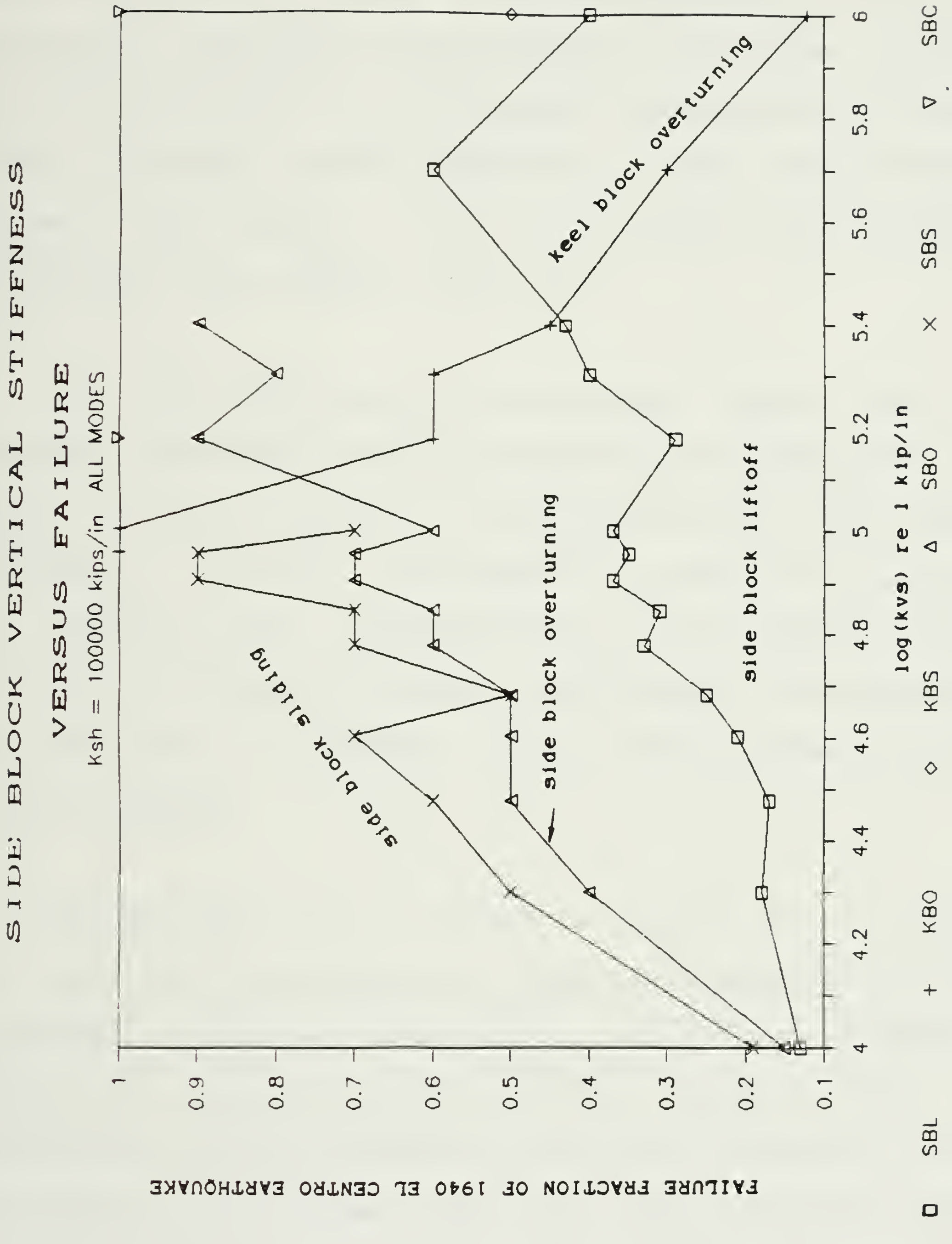

SIDE BLOCK VERTICAL STIFFNESS
VERSUS FAILURE
Ksh = 100000 kips/in ALL MODES
FAILURE FRACTION OF 1940 EL CENTRO EARTHQUAKE
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
4
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
log(kvs) re 1 kip/in
side block sliding
side block overturning
side block liftoff
keel block overturning
□ SBL
+ KBO
◇ KBS
Δ SBO
× SBS
▽ SBC

FIGURE 5.1

Since all failure modes are shown in figure (5.1), their relative dominance can be seen. The curve showing overall system failure for each stiffness consists of the lines connecting the bottom failure modes in the figure. Therefore, the modes of failure which dominate this system are side block liftoff and keel block overturning. Side block liftoff is dominant from log(kvs) = 4 to 5.4, and keel block overturning is dominant from log(kvs) = 5.4 to 6.

The best survivability attained by varying side block vertical stiffness is 40 % of the El Centro earthquake. While there is some promise in increasing side block vertical stiffness, it is still not possible to meet the 0.2 g criteria by increasing this stiffness alone. Also, the horizontal and vertical stiffnesses required are extremely high and may not be practically obtainable in an actual submarine drydock blocking system.

Another key factor evident in figure (5.1) is that side and keel block overturning are important issues. As stiffness increases, side block overturning and sliding become less important; however, above 100,000 kips/in keel block overturning quickly becomes increasingly important until it dominates. It is clear that any design strategy must take into account both preventing side block liftoff and keel block overturning. As one failure mode is eliminated, another will

come to dominate; therefore, a design strategy that overcomes the various failure modes at the same time is required.

Figure (5.2) shows the results of varying side block horizontal stiffness. In this case, kvs is held constant at 70,000 kips/in while khs is varied. As shown in the figure, keel block overturning is the dominant failure mode up to log(khs) = 4.3 after which slide block liftoff became dominant.

Since the failure fraction reaches a plateau at log(khs) = 4.6 up to 5, this appears to be an upper design limit for horizontal stiffness above which little increase in survivability occurs. From these and other parametric studies it is found that for optimal survivability, both horizontal and vertical side block stiffness have to be increased together. Again, this shows that a parallel design effort is required. Varying one parameter alone does not result in a successful design.

Results of using wale shores of various stiffnesses on system # 1 survivability are shown in figure (5.3). Rapid improvements in system survivability occur as wale shore stiffness is increased. To prevent the occurrence of keel block overturning, double width keel blocks are used in this study.

SIDE BLOCK HORIZONTAL
STIFFNESS VERSUS FAILURE

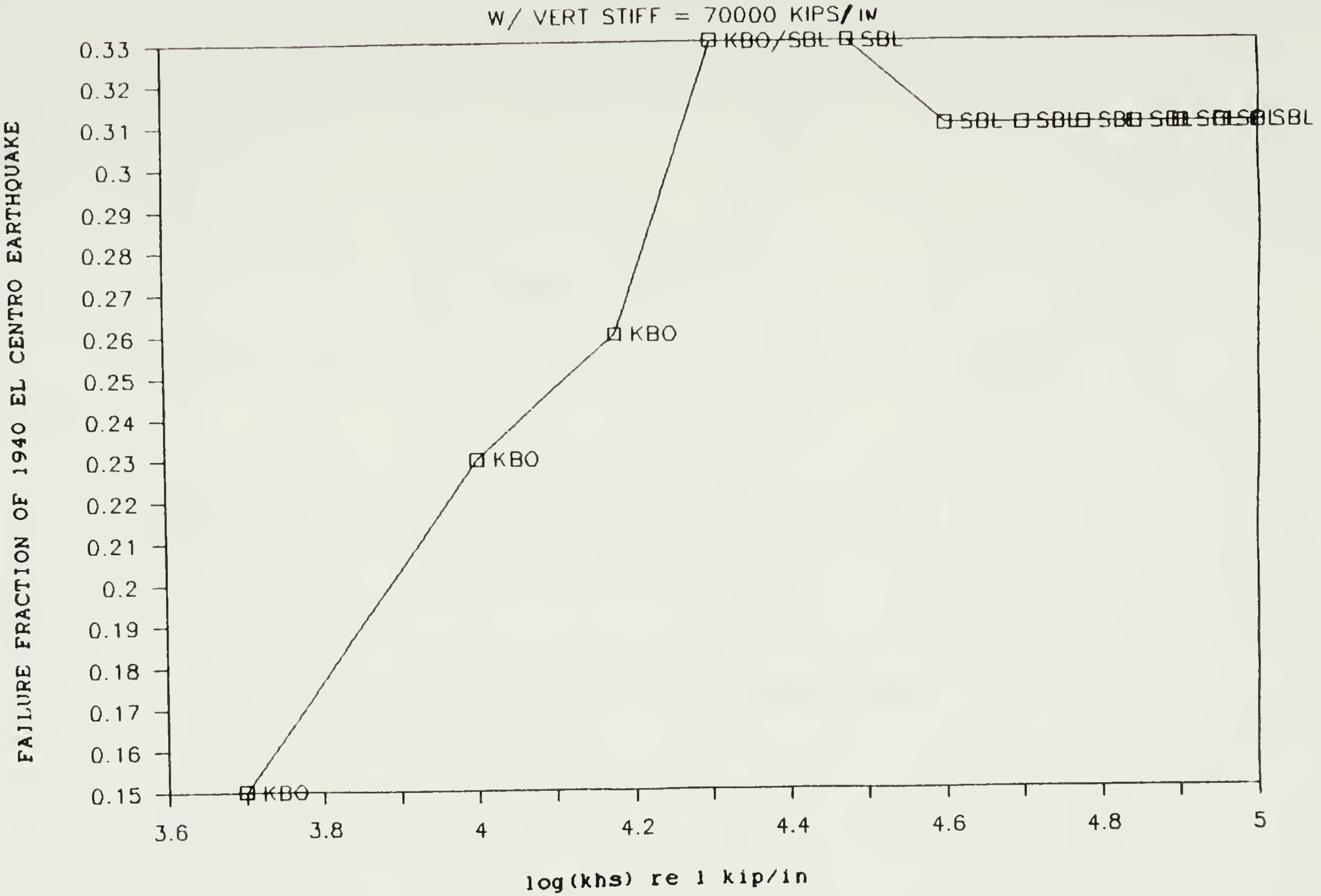


FIGURE 5.2

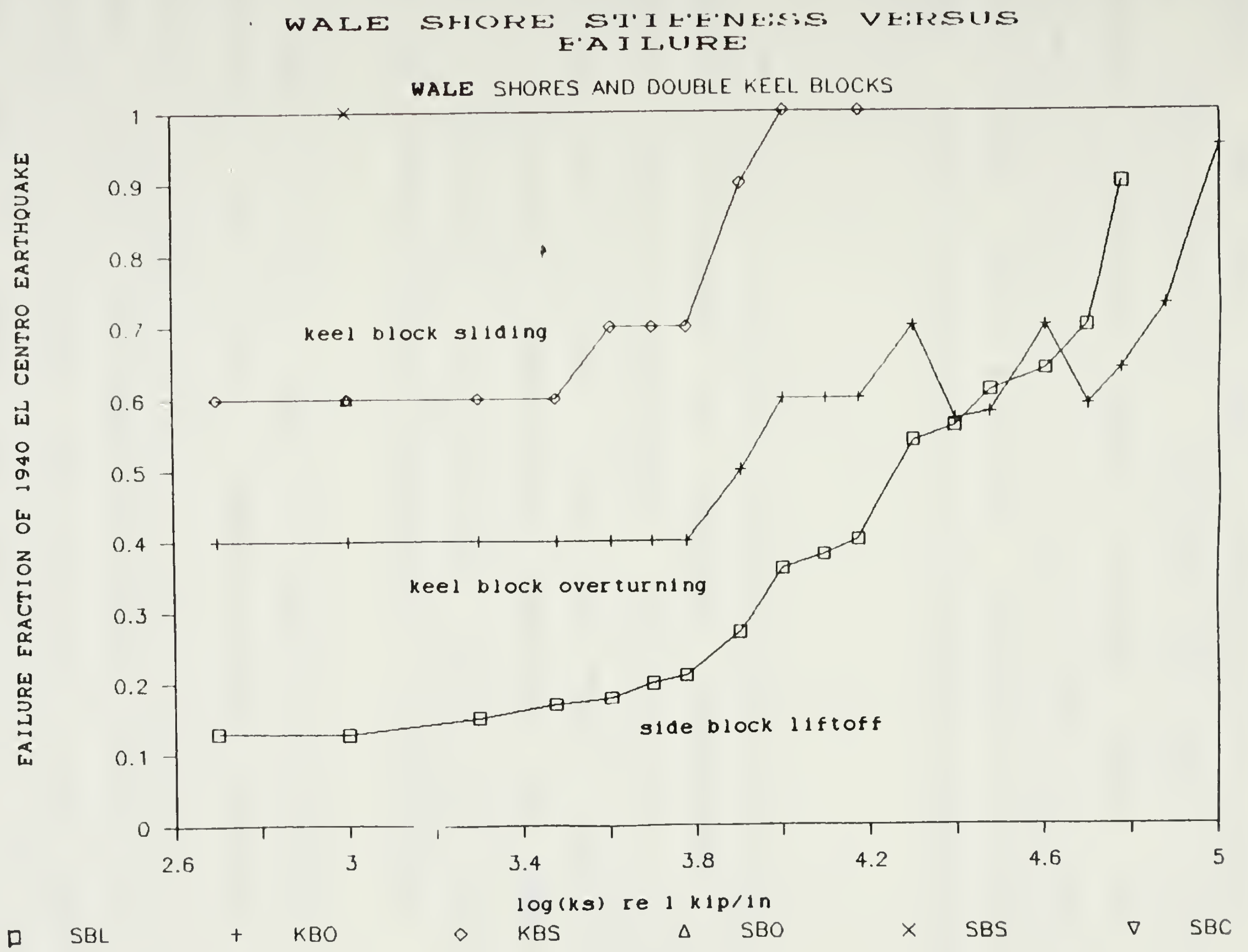

WALE SHORE STIFFNESS VERSUS FAILURE
WALE SHORES AND DOUBLE KEEL BLOCKS
FAILURE FRACTION OF 1940 EL CENTRO EARTHQUAKE
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2.6
3
3.4
3.8
4.2
4.6
5
log(ks) re 1 kip/in
keel block sliding
keel block overturning
side block liftoff
□ SBL
+ KBO
◇ KBS
△ SBO
× SBS
▽ SBC

FIGURE 5.3

As seen in figure (5.3), the three primary failure modes are side block liftoff, keel block overturning, and keel block sliding. Side block liftoff is dominant up to log(ks) = 4.4. Keel block overturning overtook side block liftoff and dominates failure for log(ks) = 4.6 and above. The best survivability seen is 60 % of the El Centro earthquake which is well above the 0.2 g criteria. Therefore, the use of wale shores is quite promising, and the required stiffness appears obtainable.

The use of wale shores increases system survivability by reducing the rotation and horizontal displacement of the submarine during the earthquake. This is due to the large restoring moment provided by the wale shores resulting from their high position above the keel baseline. Wale shores also shift the horizontal and rotational system modal frequencies well above the excitation frequencies of the earthquake.

When the side and keel blocks are prevented from overturning and 1 inch of rubber is added to the block caps, extremely high system survivability can be obtained using wale shores. Figure (5.4) shows the results of varying wale shore stiffness. It is found that the use of 1 inch rubber caps alone more than doubled system survivability. This is due to the rubber cap delaying side block liftoff. The wale stiffness is then varied up to the optimum stiffness values, 30,000 kips/in, shown in figure (5.3).

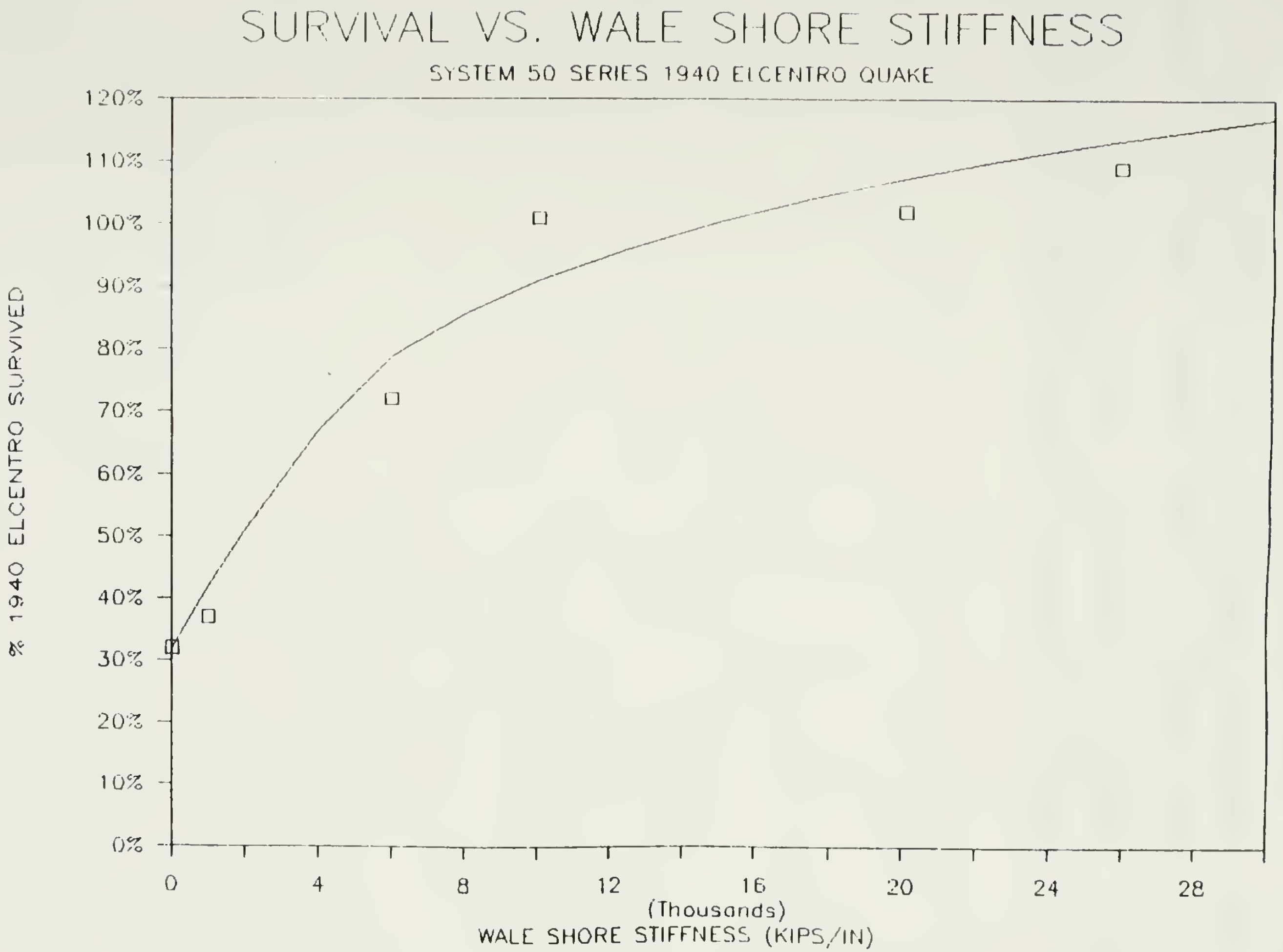

SURVIVAL VS. WALE SHORE STIFFNESS
SYSTEM 50 SERIES 1940 ELCENTRO QUAKE
% 1940 ELCENTRO SURVIVED
120%
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
4
8
12
16
20
24
28
(Thousands)
WALE SHORE STIFFNESS (KIPS/IN)

FIGURE 5.4

By increasing the wale shore stiffnesses, survivability increased quickly up to about 80 % of the El Centro earthquake. After this magnitude of earthquake, increasing wale shore stiffness gave diminishing returns. This study indicates that wale shores are a viable solution to the submarine drydock blocking survivability problem. Details of the wale shore design solution are given in chapter 8.

CHAPTER 6

DRYDOCK BLOCKING SYSTEM SURVIVAL COMPARISONS AND SITE SPECIFIC EFFECTS

6.0 Drydock Blocking System Survival Comparisons

The eleven submarine drydock blocking systems analyzed by Hepburn [1], Sigman [2], and Karr [3] are again analyzed in this thesis to determine the effect of including the geometric modifications described in chapter 3. The "3DOFRUB" computer program is run using the 1940 El Centro earthquake acceleration time history and data files describing each of the eleven systems. For purposes of comparison, the eleven systems are modeled as linear-elastic. The bilinear system data files used by Hepburn [1] are modified by setting QD's equal to zero and setting the plastic stiffness values equal to the elastic values.

Figure (6.1) is a plot comparing the survivability of Sigman's [2] eleven submarine systems to the linear systems. The purpose of this comparison is to determine what effect the side block buildup angle (alpha), side block cap angle (beta), and side block wedge effect has on system survivability. The figure shows that the geometric effects has little impact on overall system survivability. In some cases survivability is improved, and in other cases it is decreased.

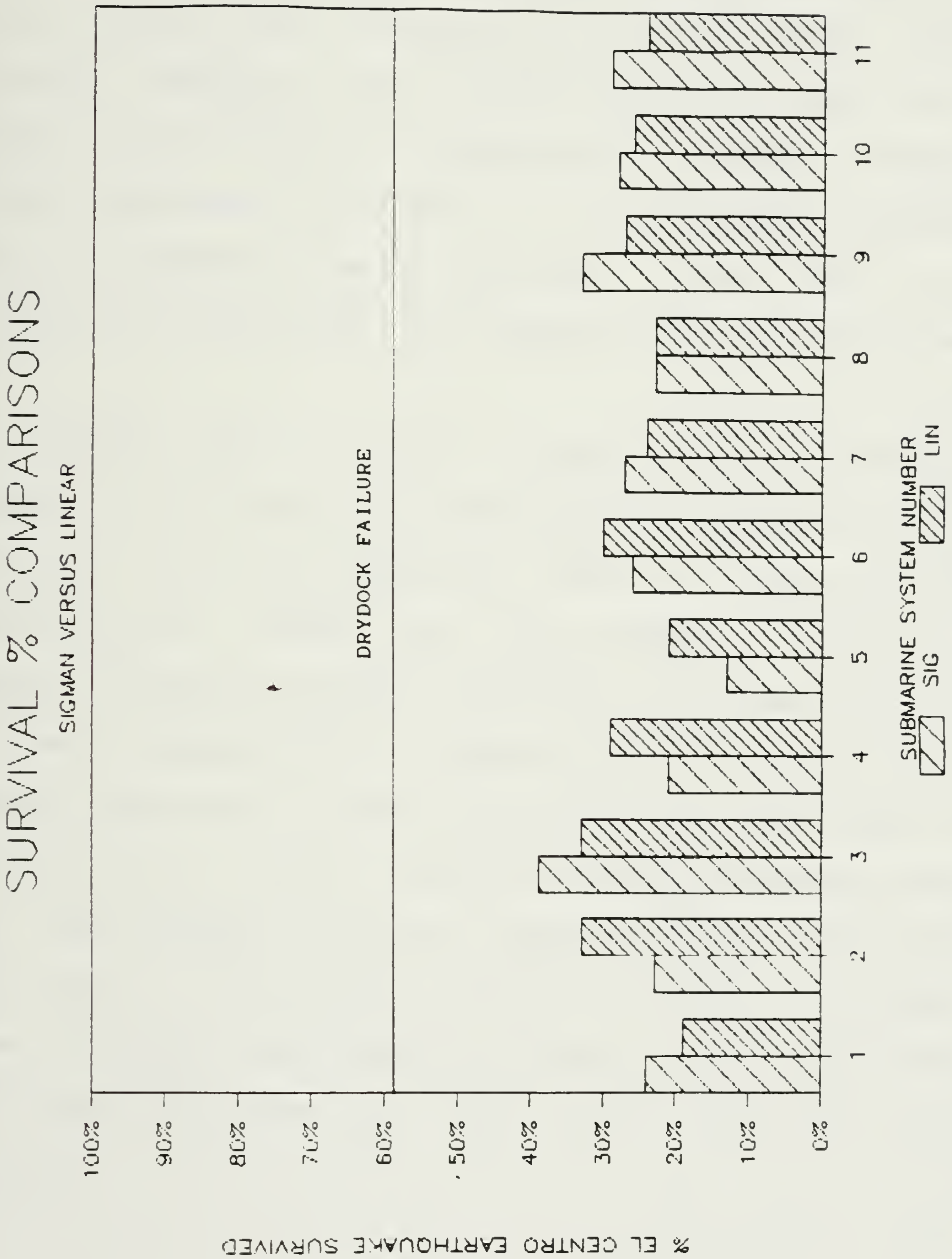

SURVIVAL % COMPARISONS
SIGMAN VERSUS LINEAR
DRYDOCK FAILURE
% EL CENTRO EARTHQUAKE SURVIVED
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
SUBMARINE SYSTEM NUMBER
SIG
LIN

FIGURE 6.1

The average value for survivability for all eleven systems is 26 % for both the linear and Sigman analyses. This is not surprising since submarines have relatively low side block heights above baseline and low cap angles. Therefore, Sigman's assumption that submarines have zero side block height above baseline is reasonable. However, as seen by the *Leahy* case study in chapter 4, the geometric modifications made to "3DOFRUB" become important in the case of surface ships due to high side block heights and large cap angles.

Figure (6.2) is a plot comparing the survivability of Hepburn's [1] eleven bilinear submarine systems to the linear systems. In this comparison there is a clear difference in survivability between the two studies. Overall, linear systems survive a higher earthquake percentage (26 %) than bilinear systems (23 %). There is no case where the bilinear systems survive a larger earthquake than the linear systems. Systems 5, 6, 7,and 8 survive the same earthquake magnitude. For these systems, large cap areas are present and the Douglas fir caps do not undergo plastic deformation. In every other case, the cap does plastically deform causing the Douglas fir to incur permanent set thus causing earlier side block liftoff.

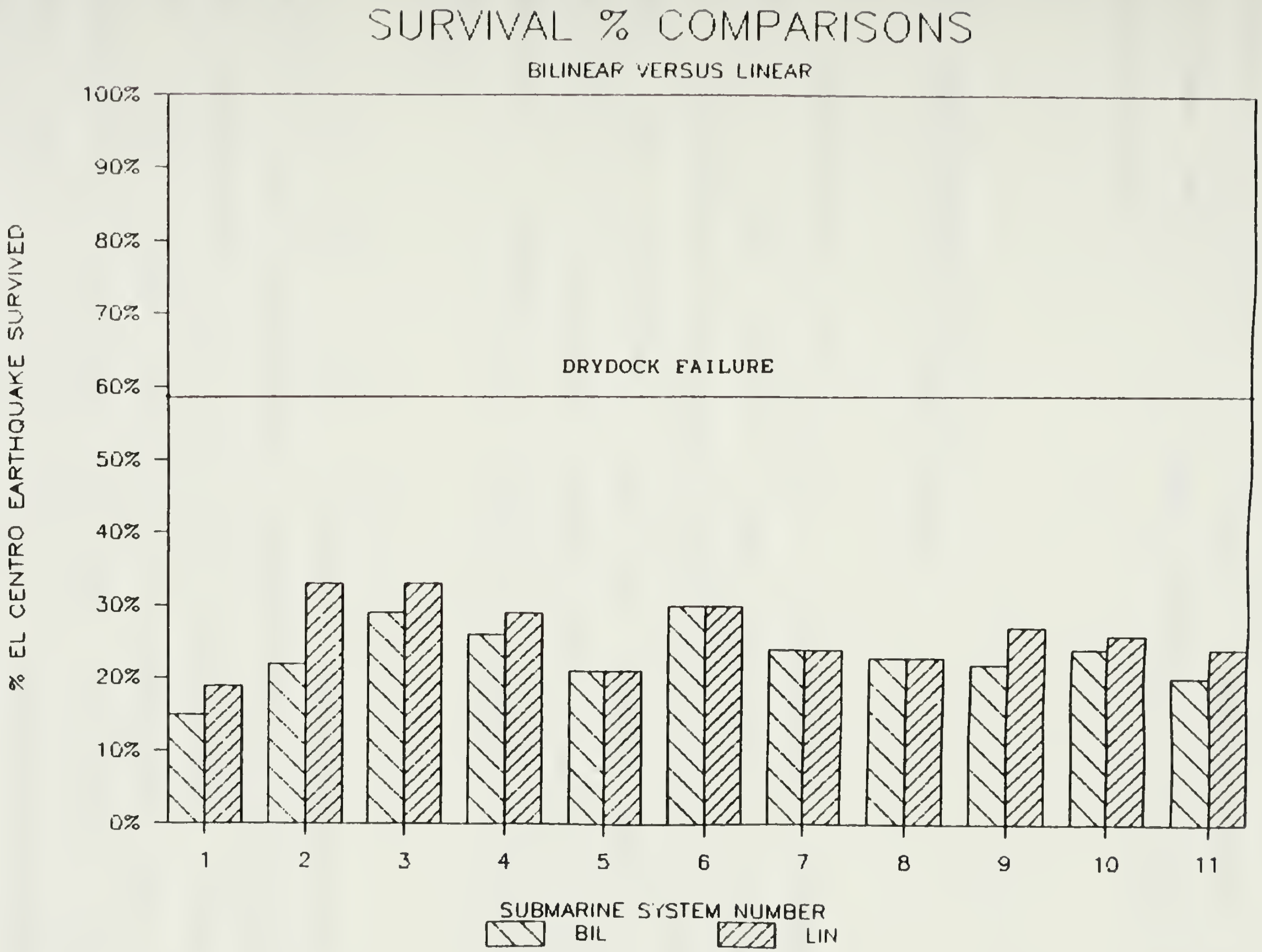

SURVIVAL % COMPARISONS
BILINEAR VERSUS LINEAR
DRYDOCK FAILURE
% EL CENTRO EARTHQUAKE SURVIVED
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
SUBMARINE SYSTEM NUMBER
▧ BIL
▨ LIN

FIGURE 6.2

This comparison shows that Hepburn's [1] bilinear analysis was more conservative by approximately 10 percent. The bilinear analysis is a more cumbersome method. The linear method can be used to approach an adequate design, then the bilinear method can be used to fine tune the design to assure survivability.

6.1 Earthquake Site Specificity

Earthquakes differ widely in magnitude, frequency, and duration. Their effect on local structures is also dependent on the immediate geological characteristics of the surrounding area. For this reason, using the 1940 El Centro earthquake acceleration time history alone is not considered adequate to develop a satisfactory submarine drydock blocking system design.

In the case of the 1 October 1987 Whittier earthquake, measured ground acceleration varied tremendously depending on the distance and direction from the epicenter. In addition, some areas further away from the epicenter felt larger accelerations than closer locations. Appendix 4 contains a report from the California Division of Mines and Geology [9] regarding the data from the Whittier earthquake .

The frequency spectrum of the recorded ground accelerations also depend on local geological conditions [9] [14]. Dry dock # 2 at Long Beach Naval Shipyard, where accelerations were measured, is located approximately 20 miles from the epicenter of the Whittier earthquake [15]. Figure (6.3) is a map produced by the California Division of Mines and Geology [9] which shows the locations of the epicenter and Long Beach Naval Shipyard. The ground acceleration was reduced from 0.45 g's peak acceleration near the epicenter to 0.052 g's peak in dry dock # 2.

In addition the dominant frequency of the earthquake was reduced from approximately 2 HZ near the epicenter to near 1 HZ in dry dock # 2. Mr. Lew from the Naval Civil Engineering Laboratory [14] stated that this reduction in frequency was not unique to the dry dock. This frequency was experienced throughout the Los Angeles harbor area.

Mr. Lew [14] stated that dry dock # 2 is sitting on an aquifer which exhibits dynamic characteristics similar to a solid. Along the sides of the dry dock is a layer of solid material rising approximately 10 feet above the aquifer. A 30 foot deep hydraulic layer exists above this solid material. Above this is a compacted land fill layer. This combination of geological properties around the dry dock contributes to the relatively low ground acceleration frequencies experienced.

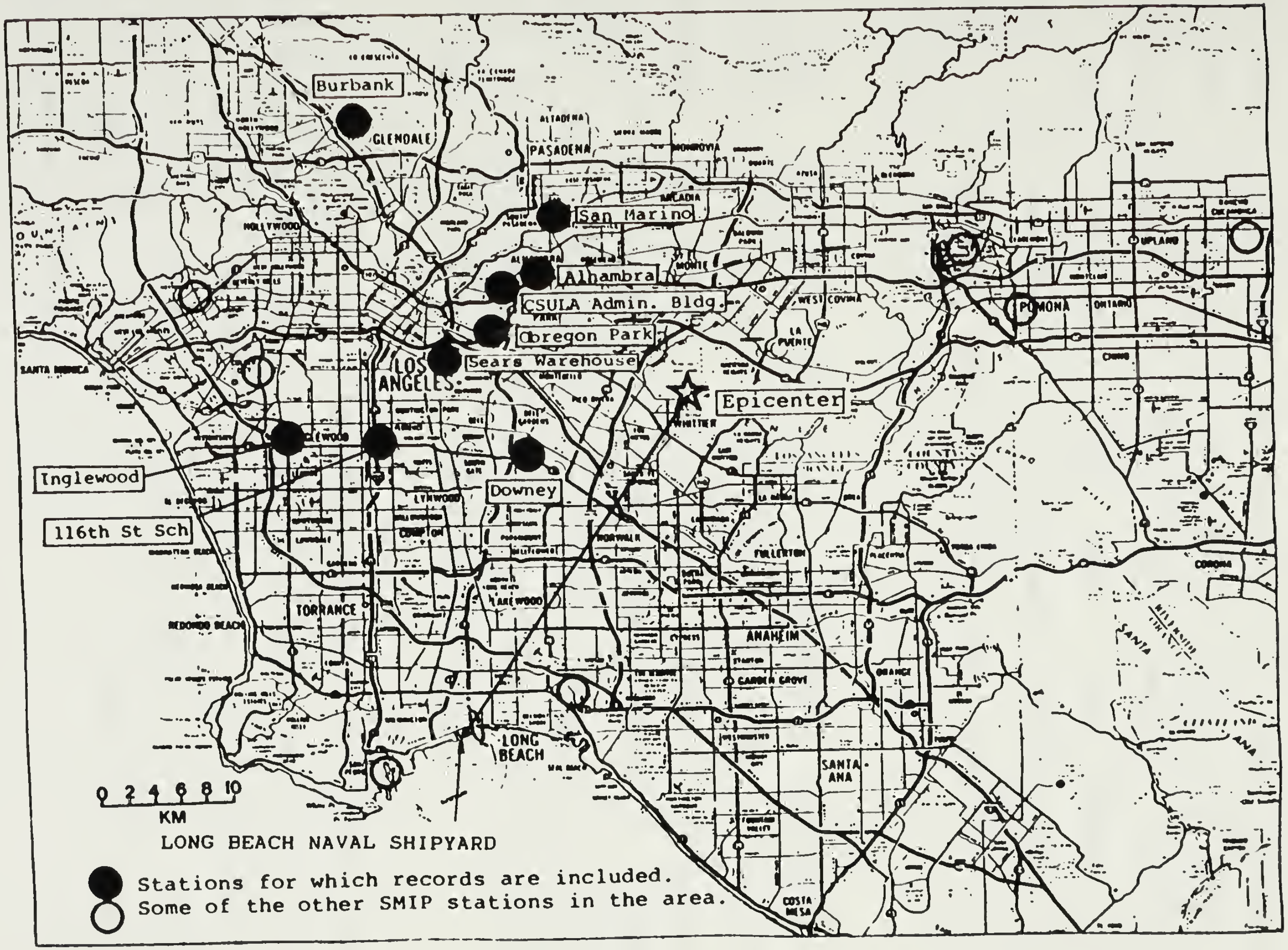


FIGURE 6.3

1 October 87 Whittier Earthquake
Epicenter and Long Beach Naval Shipyard Locations

The geological conditions which exist at Long Beach Naval Shipyard are very similar to conditions at other graving dock locations. Lew [14] also stated that Mare Island Naval Shipyard's can withstand a maximum of 0.26 g's before the construction joints of the dry dock give-way. This value is used as the "dry dock failure" level in this thesis. Mr. Lew stated that the dry docks at Long Beach probably have the same design limitation. The dry docks at both these locations are very similar in construction.

The Nuclear Regulatory Commission requires that earthquake acceleration time histories used in structural analysis incorporate the actual vertical and horizontal acceleration components when available. Otherwise, statistically independent vertical and horizontal acceleration time histories must be used with the vertical being two-thirds the magnitude of the horizontal component [16].

For dry dock # 2 acceleration time histories, both the vertical and horizontal components were available. Figures (6.4) and (6.5) are the acceleration time histories in the horizontal and vertical directions respectively. These two plots show that the two components do substantially differ in magnitude and frequency content.

1 OCT 87 WHITTIER CA EARTHQUAKE

LBNSY DD2 HORIZONTAL COMPONENT

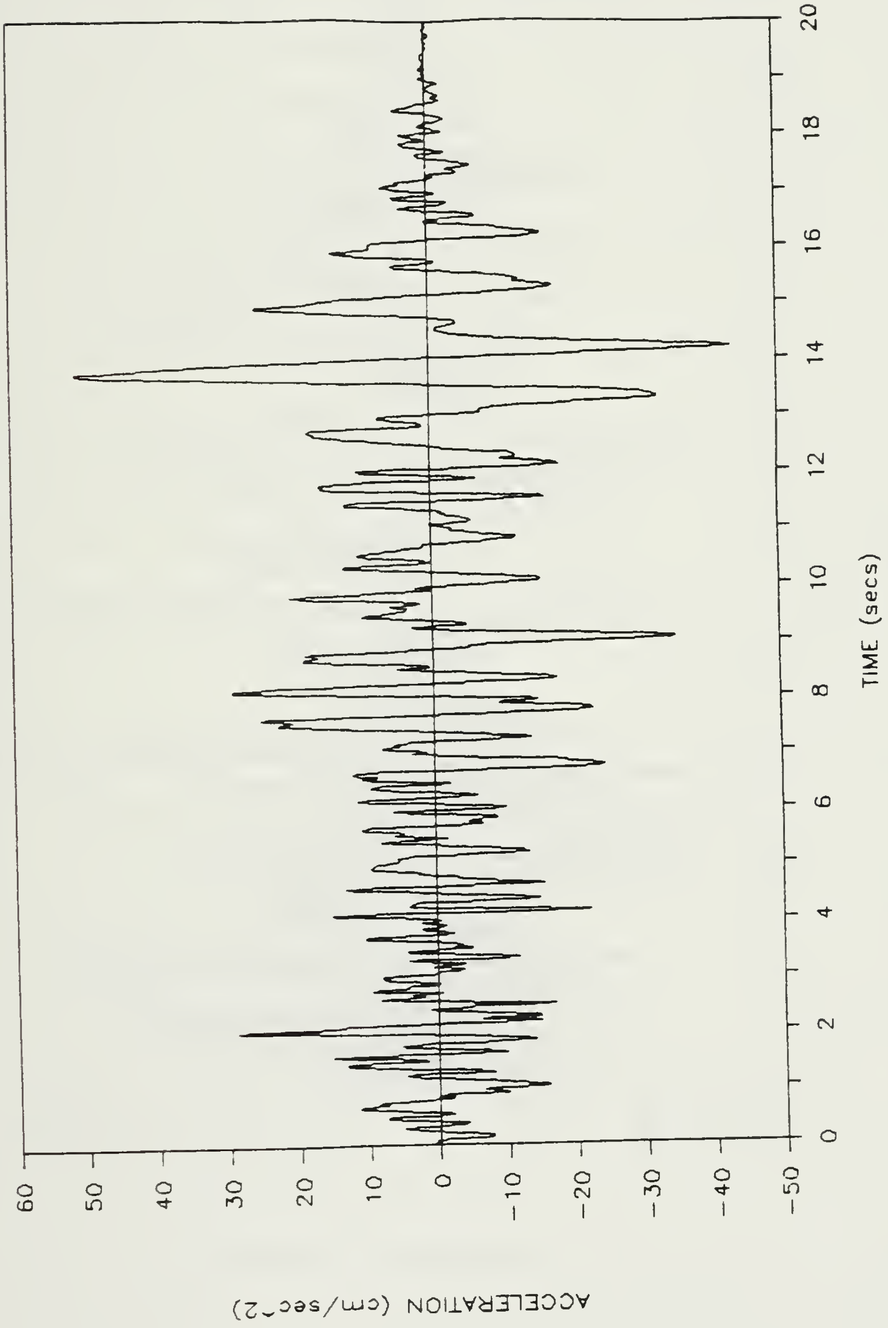


FIGURE 6.4

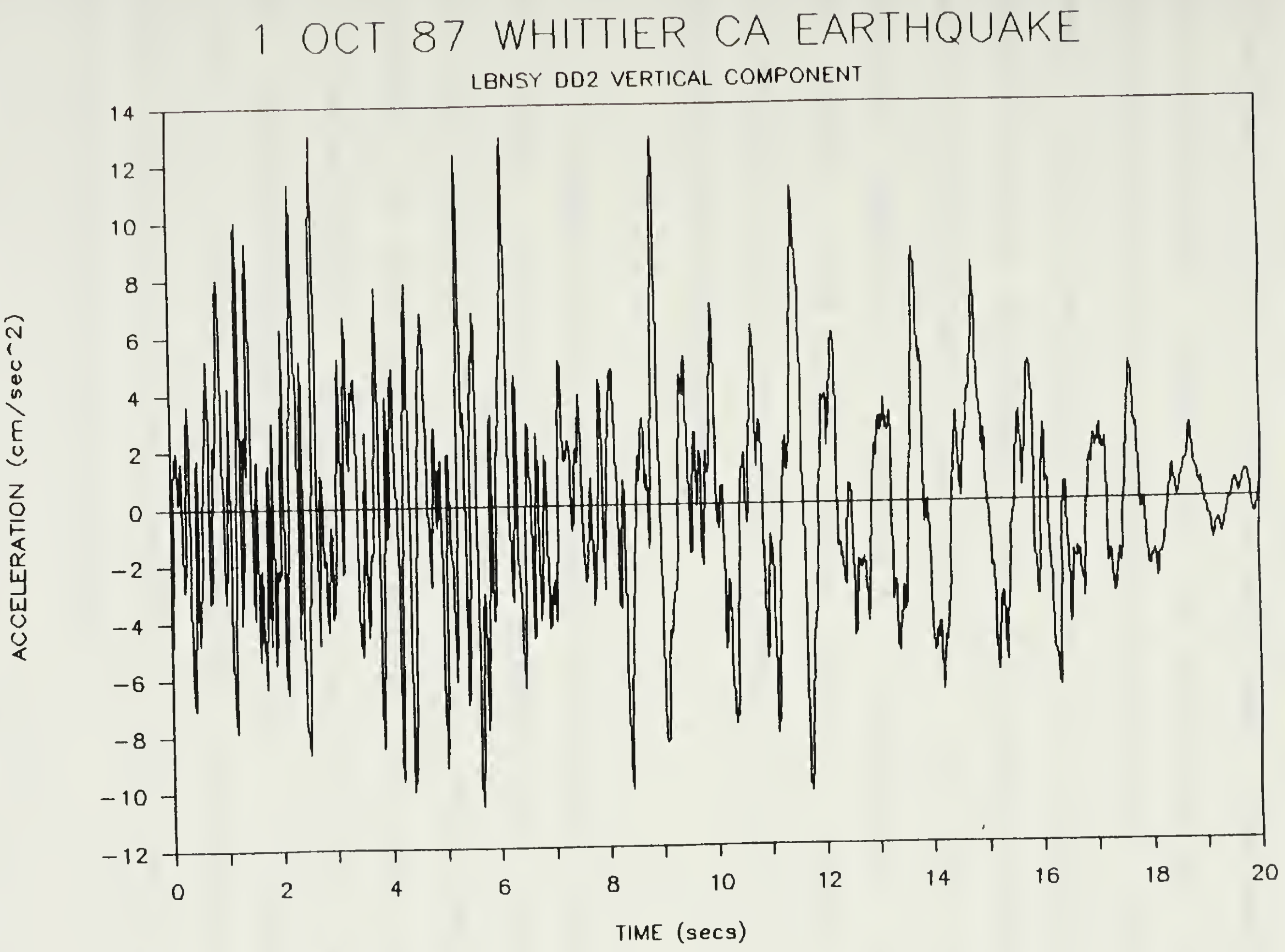

1 OCT 87 WHITTIER CA EARTHQUAKE
LBNSY DD2 VERTICAL COMPONENT
ACCELERATION (cm/sec^2)
14
12
10
8
6
4
2
0
−2
−4
−6
−8
−10
−12
0
2
4
6
8
10
12
14
16
18
20
TIME (secs)

FIGURE 6.5

In order to make a valid comparison between the effects of using the 1940 El Centro earthquake and the dry dock # 2 acceleration time histories, the dry dock's accelerations are normalized to the El Centro's magnitudes. The energy content of an earthquake depends on the magnitude of its ground displacements and the earthquake duration [17]. The amount of energy that an earthquake imparts to a structural system depends on the earthquake's frequency content relative to the natural frequencies of the structure. It also depends on relative impedance or mobility of the structure relative to the ground. The Richter scale, which is measure of the earthquake's energy, is based primarily on the log of the earthquake peak displacement.

To normalize the dry dock # 2 earthquake, the first step is to make the two earthquakes' acceleration time histories the same duration, 20 seconds. The El Centro earthquake is truncated by using the first 20 seconds, the most violent part of the earthquake. The dry dock # 2 acceleration time history was originally approximately 16 seconds in duration. To create a 20 second duration, the last four seconds of the record is multiplied by an exponential decay factor and added on to the end of the existing record.

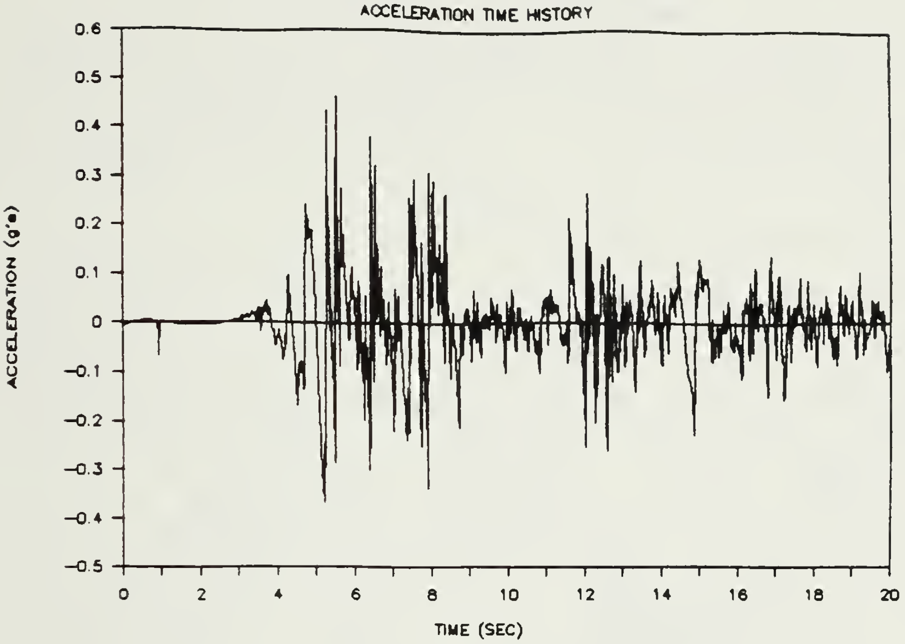
Next, the dry dock # 2 accelerations are normalized to the same magnitude of El Centro by multiplying by a factor of 10.97. This factor is obtained by dividing the peak

displacement of the El Centro earthquake (14.61 cm) by the peak displacement of the dry dock # 2 earthquake (1.33 cm).

Figure (6.6) shows the 1940 El Centro earthquake acceleration time history and the normalized dry dock # 2 acceleration time history. It is clear from these plots that the excitation frequency of the normalized earthquake is much lower than that of the El Centro. These two earthquake acceleration time histories are used in this thesis for system design development.

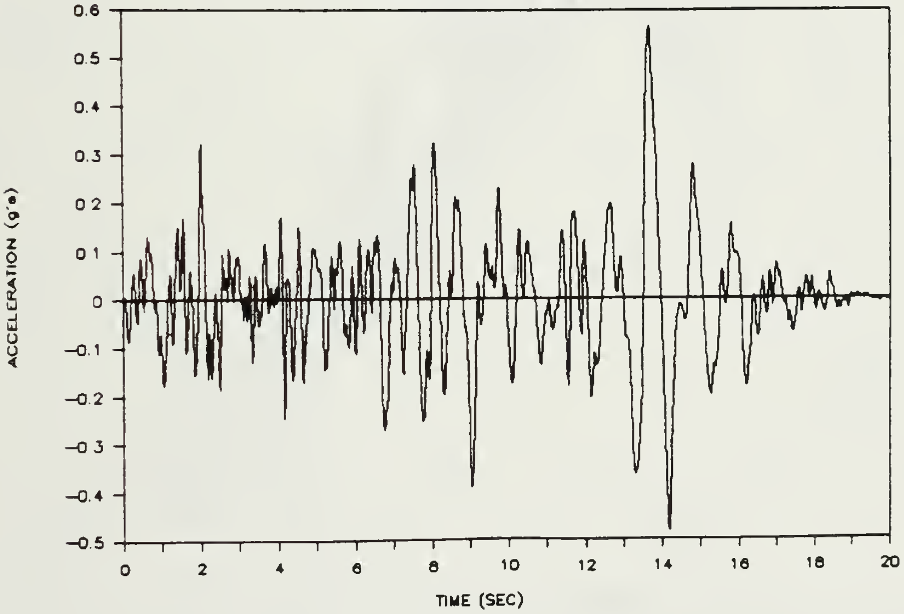
It is clear from previous analysis that both a low stiffness design approach using isolators and a high stiffness design approach using wale shores are both viable. Using a higher frequency earthquake like the El Centro is a more conservative approach for a high stiffness design. Similarly a lower frequency earthquake like the normalized dry dock # 2 accelerations is a more conservative approach for a low stiffness design.

Figures (6.7) and (6.8) are the response (or shock) spectra for the dry dock # 2 and the 1940 El Centro [7] acceleration time history respectively. These figures show the dominant frequencies of these earthquakes. El Centro's dominant frequency is approximately 2 HZ for the 5 % damping case used in this thesis. For dry dock # 2 this dominant frequency is approximately 1 HZ again using 5 % damping.



1940 EL CENTRO EARTHQUAKE

ACCELERATION TIME HISTORY



NORMALIZED DD2 EARTHQUAKE

ACCELERATION TIME HISTORY

FIGURE 6.6

RESPONSE AND FOURIER SPECTRA
WHITTIER EARTHQUAKE OCT 01. 1987 -1442 GMT
IIIDD200 87.101.0 COMP TRAN
DD2 LBNSY
ACCELEROGRAM IS BAND-PASS FILTERED BETWEEN .300- .400 AND 25.00-27.00 CYC/SEC.
DAMPING VALUES ARE 0. 2. 5. 10 & 20 % OF CRITICAL

——— RESPONSE SPECTRA: PSV.PSA & SD — — — FOURIER AMPLITUDE SPECTRUM: FS

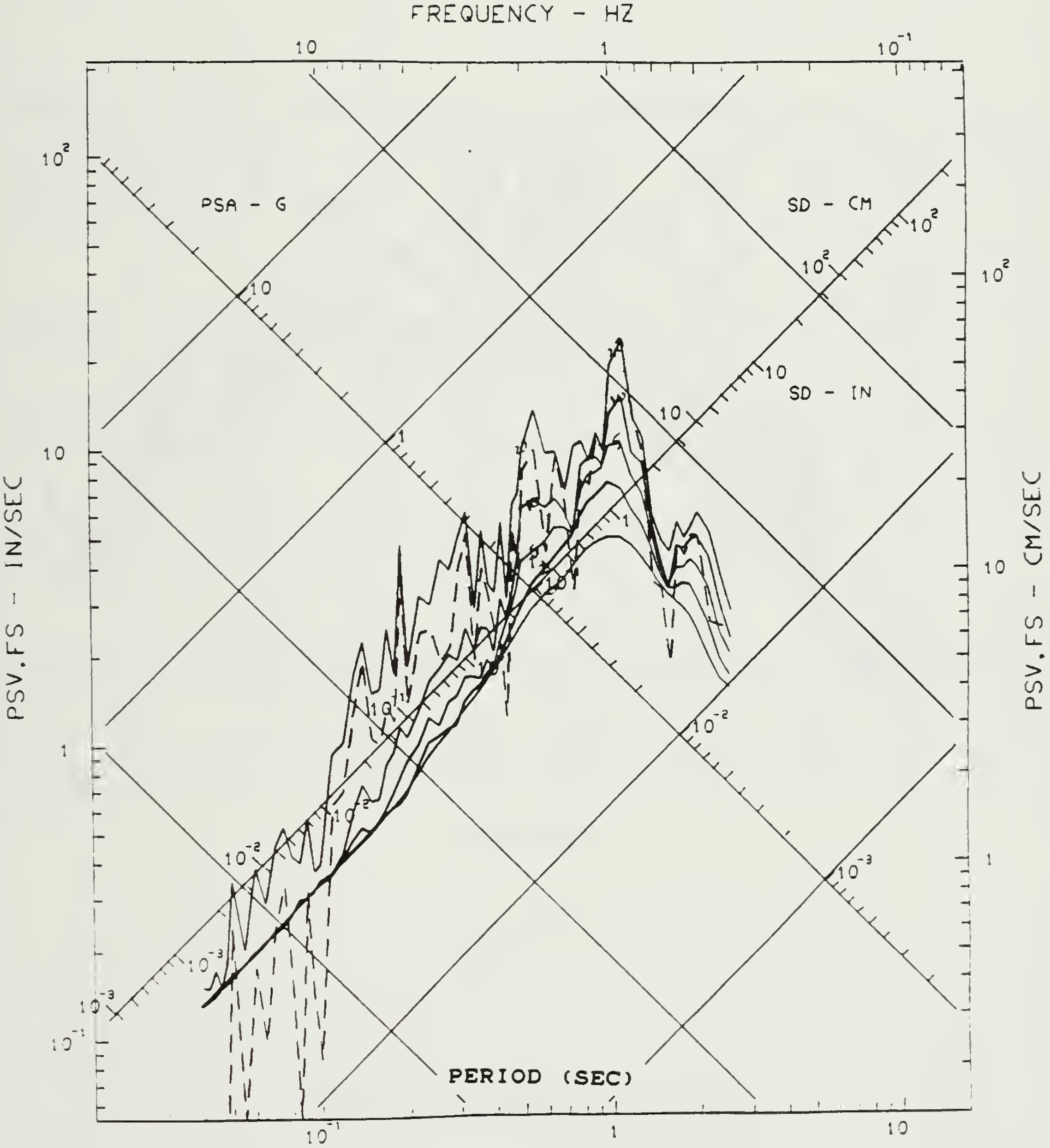
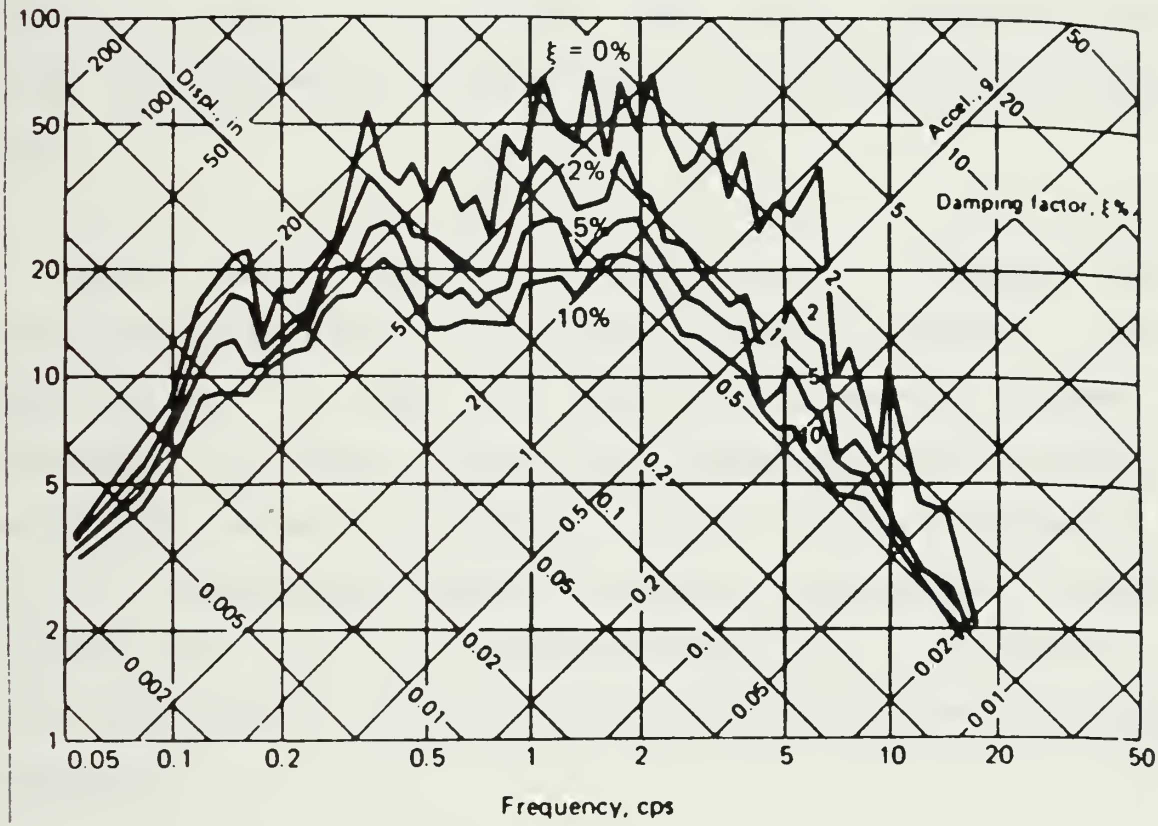


FIGURE 6.7



Response Spectra
1940 El Centro Earthquake

FIGURE 6.8

6.2 System Survivability Frequency Dependence

To determine the dependence of system survivability on system natural frequency, a plot is made, figure (6.9), showing El Centro earthquake survivability versus mode 1 (fundamental) frequency. All eleven systems' mode 1 frequencies using Sigman's, bilinear, linear, and 1 inch rubber cap models are plotted. The natural frequencies for these systems range from 0.4 to 1.6 HZ with an average around 1 HZ.

There is no correlation between mode 1 frequency and earthquake survivability for these systems as shown by the data and the flat best fit line. This is because the mode 1 frequency, the lowest system modal frequency, is sufficiently below the dominant frequency of the El Centro earthquake, 2 HZ. No dynamic amplification occurs. Significant dynamic amplification and thus lowered survivability is expected if the system modal frequency is near the earthquake's dominant frequency.

This is precisely what is found when eleven bilinear systems are excited by the normalized dry dock # 2 earthquake. Figure (6.10) is a plot of normalized dry dock # 2 earthquake survivability versus mode 1 frequency. In this case, the dominant frequency of the earthquake, 1 HZ, corresponds to the average system modal frequency.

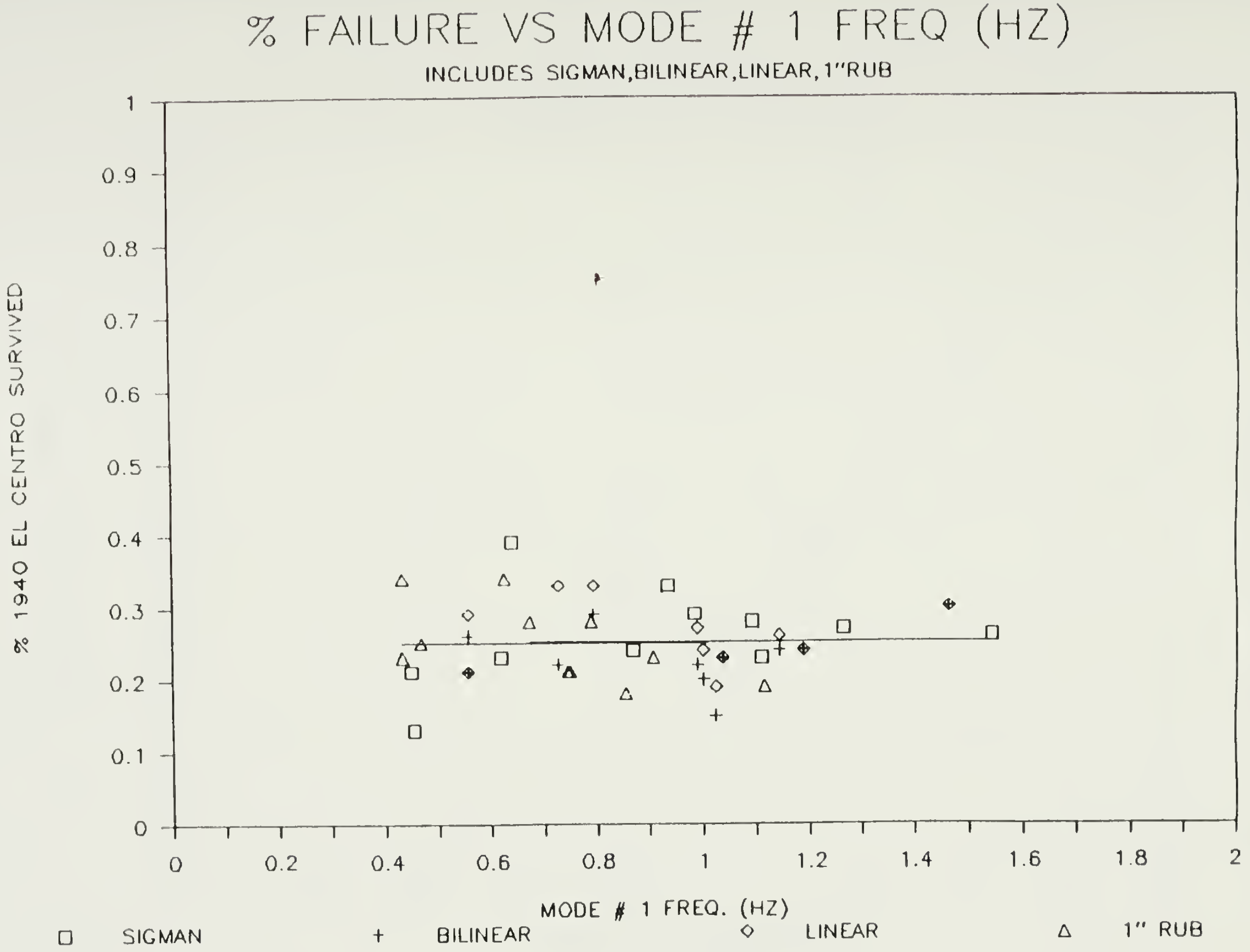

% FAILURE VS MODE # 1 FREQ (HZ)
INCLUDES SIGMAN,BILINEAR,LINEAR,1"RUB
% 1940 EL CENTRO SURVIVED
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
MODE # 1 FREQ. (HZ)
□ SIGMAN
+ BILINEAR
◇ LINEAR
△ 1" RUB

FIGURE 6.9

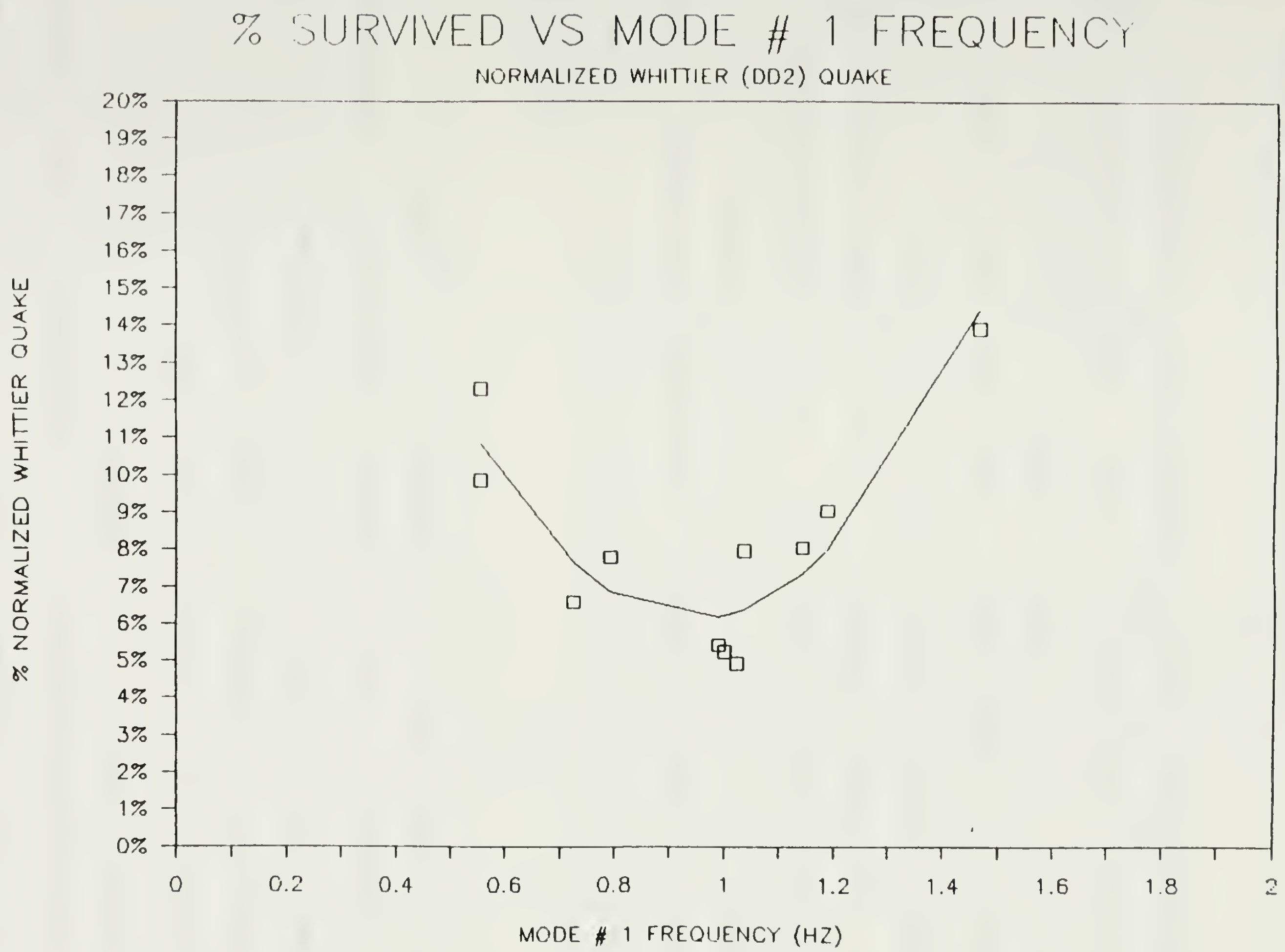

% SURVIVED VS MODE # 1 FREQUENCY
NORMALIZED WHITTIER (DD2) QUAKE
% NORMALIZED WHITTIER QUAKE
20%
19%
18%
17%
16%
15%
14%
13%
12%
11%
10%
9%
8%
7%
6%
5%
4%
3%
2%
1%
0%
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
MODE # 1 FREQUENCY (HZ)

FIGURE 6.10

A clear dependence of system survivability on frequency is shown in the figure by the best fit curve. The systems with natural frequencies closest to that of the normalized dry dock # 2 earthquake has the lowest survivability.

A comparison of the survivability of the eleven submarine drydock blocking systems due to El Centro and normalized dry dock # 2 earthquakes is shown in figure (6.11). The data for this figure as well as other comparisons is included in Appendix 4. This figure clearly illustrates the degradation of system survivability due to resonant frequency effects. All eleven systems fail at much lower levels when excited by the lower frequency normalized dry dock # 2 earthquake. Overall, system survivability is about 8 % for the normalized dry dock # 2 earthquake compared with 23 % for the El Centro earthquake.

It is important to emphasis that these low survivability percentages for submarine drydock blocking systems are based on an actual earthquake acceleration time history measured in a U.S. Naval shipyard dry dock. The validity of this problem is confirmed by the *USS Leahy* case study where a current U.S. Navy ship drydock blocking system failed when subject to a relatively small earthquake (0.05 g peak acceleration). This shows the importance of taking frequency dependence into account when designing an earthquake resistant system.

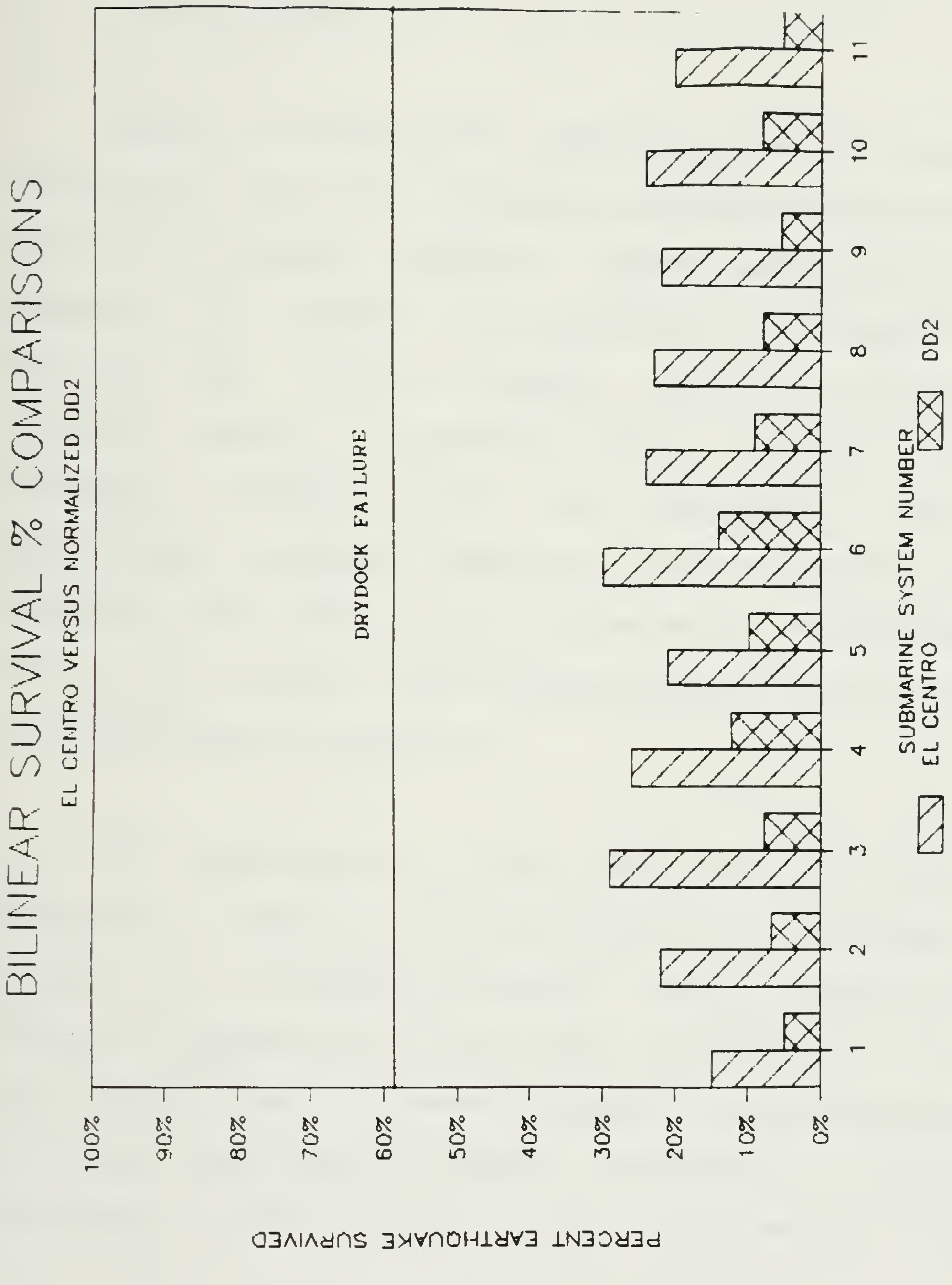

BILINEAR SURVIVAL % COMPARISONS
EL CENTRO VERSUS NORMALIZED DD2
DRYDOCK FAILURE
PERCENT EARTHQUAKE SURVIVED
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
SUBMARINE SYSTEM NUMBER
EL CENTRO
DD2

FIGURE 6.11

CHAPTER 7

ISOLATOR AND RUBBER LOW STIFFNESS DESIGN

7.0 Design Process

Dynamic isolators and rubber caps either singly or in combination are very attractive potential solutions to the submarine drydock blocking system survivability problem. Hepburn [1] studied the properties of Dynamic Isolation Systems Inc. (D.I.S.) dynamic isolators and developed a bilinear model to describe their behavior. Using the "3DOFRUB" program with the "BILINALL" and "RUBBER" subroutines, a design study of a blocking system with D.I.S. isolators and rubber caps is undertaken. The purpose of this study is to find a low stiffness system which survives up to dry dock failure (0.26 g's).

The first step in the study is to install D.I.S. isolators in place of the oak layer in submarine blocking system # 1, the SSBN 616 system used by Hepburn [1]. The isolator parameters are the same as Hepburn's. In addition, one inch of natural rubber is added to the top of the Douglas fir cap. The 1940 El Centro earthquake is the exciting earthquake for the initial portion of this study.

The first result is unexpected. Using the D.I.S. isolators without a rubber cap, Hepburn found that the system

survives 35 % of the earthquake. With one inch rubber cap without isolators, system # 1 survives 32 %. It was expected that the combination would increase survivability. Actually it is found that this combination resulted in lower (20%) survivability.

In general, this decrease is due to the effect of multiple modes of vibration. By using either 1 inch rubber caps or D.I.S. isolators singly, the system's mode 1 frequency is driven well below the fundamental frequency of the El Centro Earthquake. At the same time, the system's mode 2 frequency is driven lower but still remains well above the earthquakes fundamental frequency.

By combining the rubber and isolators, the mode 1 frequency is driven very low, but the mode 2 frequency is driven into resonance. From this it became clear that to develop a successful design, both the mode 1 and 2 system frequencies must be driven well below resonance without driving mode 3 into resonance. While mode 1 and 2 are coupled, mode 1 is primarily the system's rotation, and mode 2 is primarily horizontal displacement. Mode 3 is the system's vertical displacement.

Using "3DOFRUB", several runs are made with progressively less horizontally stiff isolators. To reduce horizontal stiffness the values of khs, khk, khsp, kkhp, and the

associated QD values are decreased. Figure (7.1) is plot of the 1 inch rubber cap/isolator system survivability versus mode 2 frequency. The figure shows that as the systems frequency and horizontal stiffness is decreased, system survivability increases dramatically. The mode 2 frequency is being driven below the earthquakes fundamental frequency.

Figure (7.1) shows that the system survives a 0.26 g earthquake, however, the horizontal stiffness required is reduced by 60 % from the original rubber/isolator horizontal stiffness. To actually construct a system with this horizontal stiffness would require isolators with extremely low horizontal stiffness. These isolators may be impractical to fabricate.

To allow the isolators to have higher horizontal stiffness the effects of using thicker rubber caps is explored. Figure (7.2) is a comparison of system survivability using various rubber cap thicknesses. The use of 3 inches of rubber does not significantly shift the survivability curve toward higher stiffnesses. Therefore, the use of 6 inch rubber caps is investigated. Six inches is considered the practical thickness limit. Rubber caps thicker than this would tend to be vulnerable to wind loads, but the wind load problem is not investigated in this thesis.

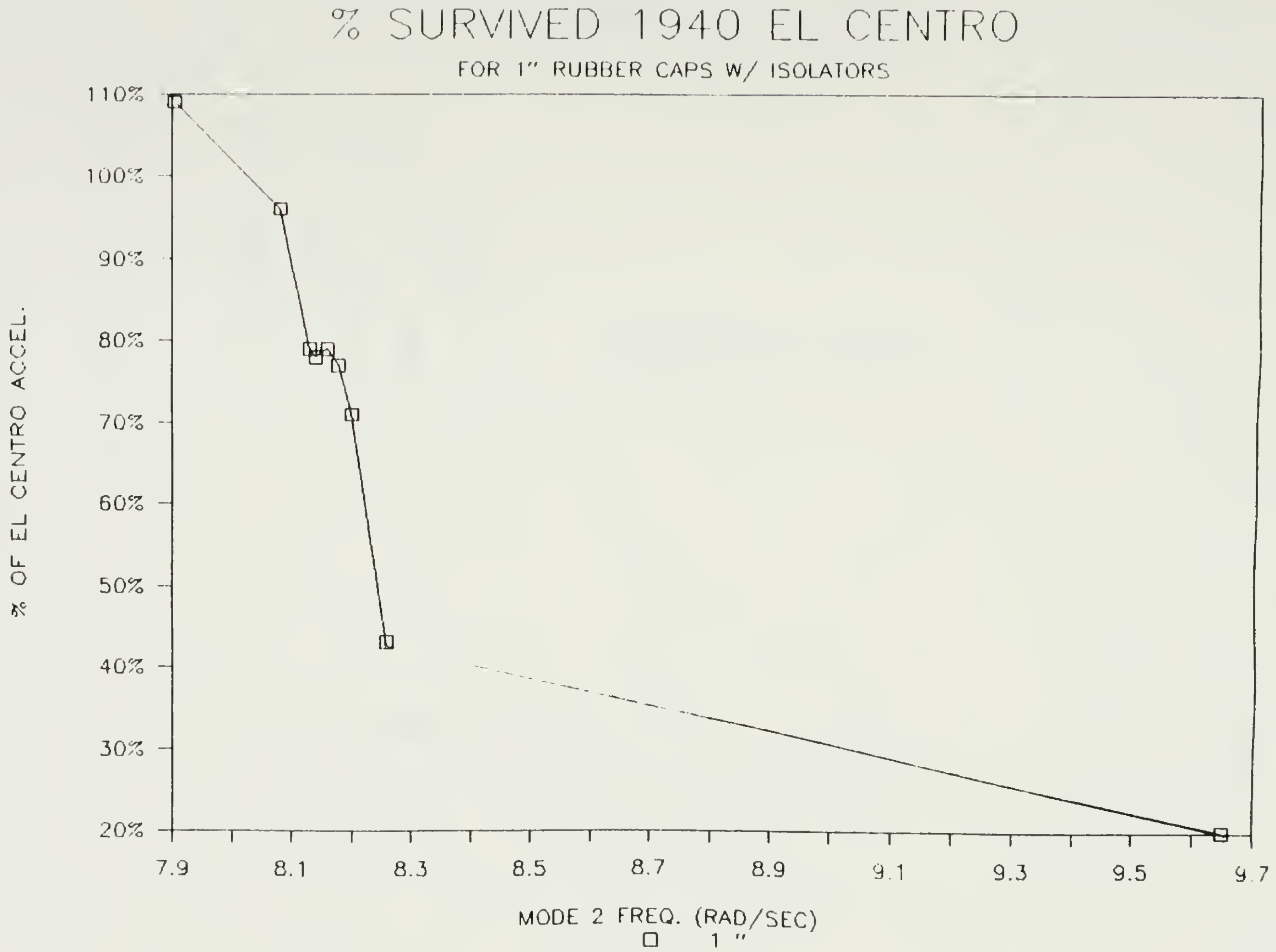

% SURVIVED 1940 EL CENTRO
FOR 1" RUBBER CAPS W/ ISOLATORS
% OF EL CENTRO ACCEL.
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
7.9
8.1
8.3
8.5
8.7
8.9
9.1
9.3
9.5
9.7
MODE 2 FREQ. (RAD/SEC)
□ 1 "

FIGURE 7.1

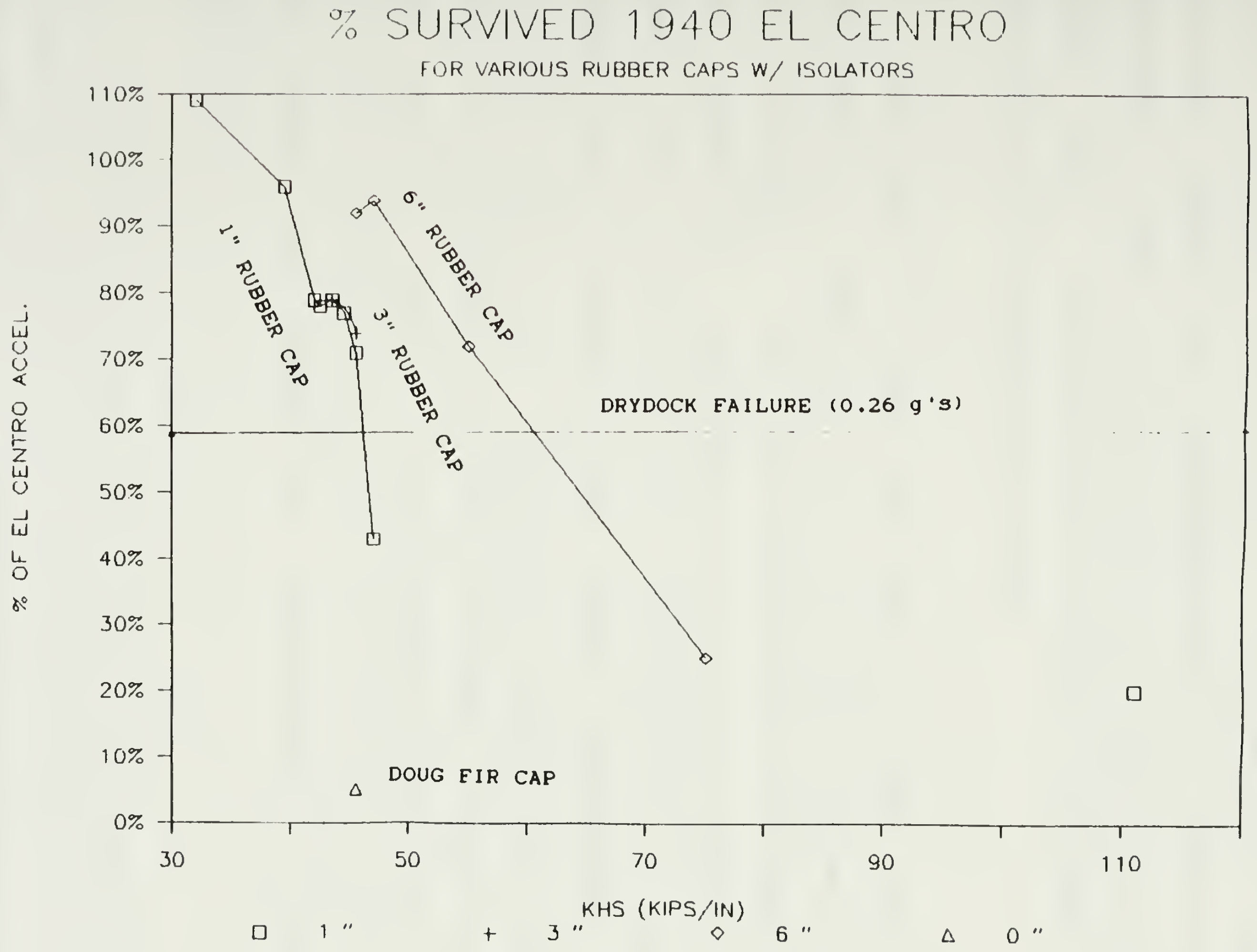

% SURVIVED 1940 EL CENTRO
FOR VARIOUS RUBBER CAPS W/ ISOLATORS
% OF EL CENTRO ACCEL.
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1" RUBBER CAP
3" RUBBER CAP
6" RUBBER CAP
DRYDOCK FAILURE (0.26 g's)
DOUG FIR CAP
30
50
70
90
110
KHS (KIPS/IN)
□ 1 "
+ 3 "
◇ 6 "
△ 0 "

FIGURE 7.2

The use of six inches of rubber significantly shifts the survivability curve to the right as seen in figure (7.2). Therefore, six inches is selected for the final low stiffness design solution. Figure (7.3) is a comparison between the various rubber cap thicknesses for a given horizontal stiffness. This shows the additional benefits of the use of rubber caps. Increasing the thickness of the rubber improves survivability by preventing liftoff.

The use of at least one inch of rubber cap is vital. Survivability jumps from 5% to 70% with the use of just one inch of rubber. The side block horizontal stiffness used for the figure (7.3) comparison is the final design stiffness used. The figure shows that if the rubber cap is removed the system would survive a much smaller earthquake than the original system # 1. However, the rubber caps alone cannot provide a low enough horizontal stiffness to survive up to dry dock failure. The final low stiffness solution using the 1940 El Centro earthquake survives 72 % (0.32 g's). The data file and output from "3DOFRUB" for this solution is included in Appendix 5.

Since the normalized dry dock # 2 earthquake has a lower fundamental frequency, this earthquake is used to test the low stiffness solution. It is found that the horizontal stiffness has to be decreased even further for the system to survive the 0.26 g dry dock survival level.

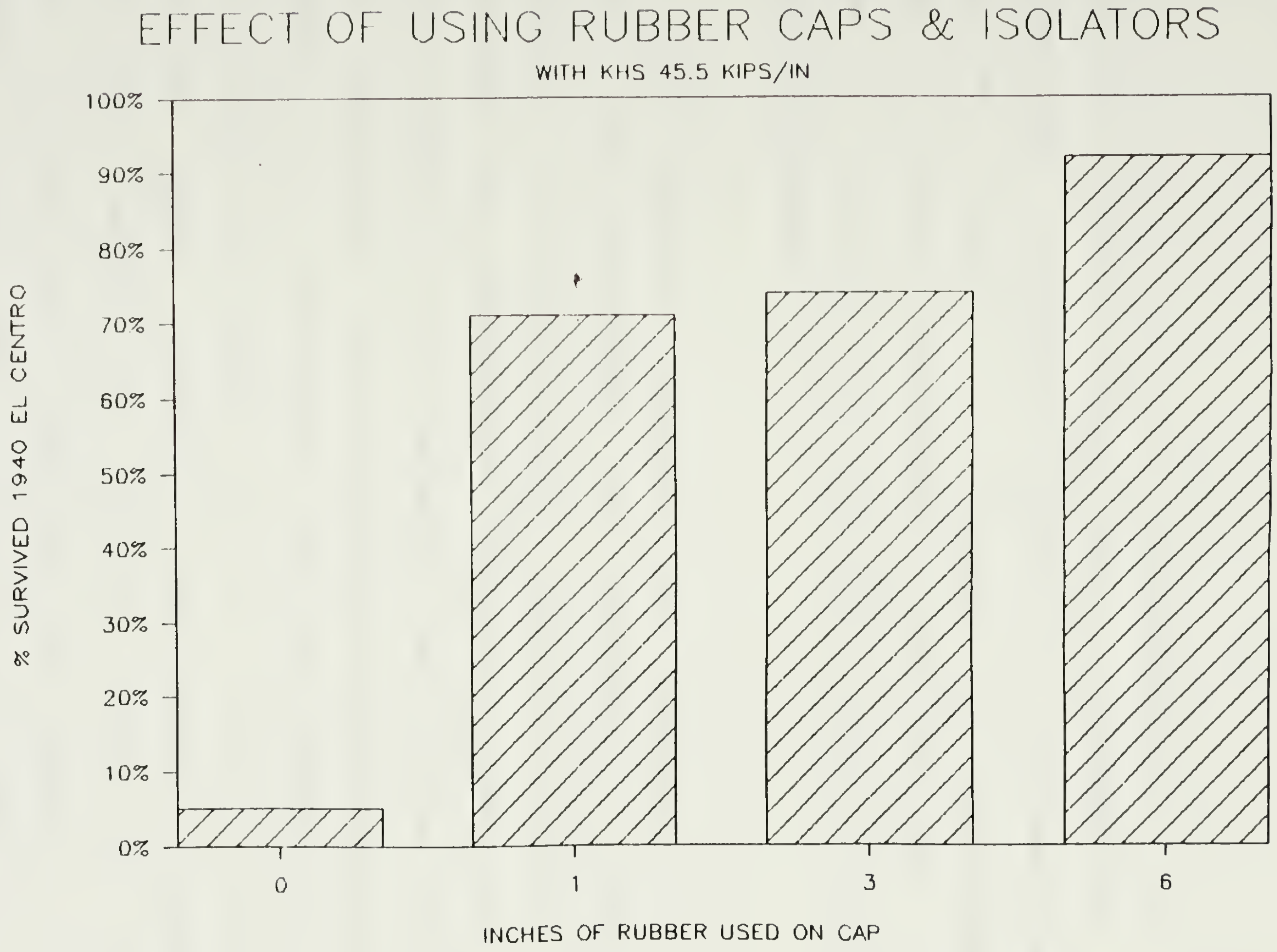

EFFECT OF USING RUBBER CAPS & ISOLATORS
WITH KHS 45.5 KIPS/IN
% SURVIVED 1940 EL CENTRO
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
3
6
INCHES OF RUBBER USED ON CAP

FIGURE 7.3

The final survival level is 0.28 g's (63%). This new low stiffness solution is recommended if the rubber/isolator method is used.

From this solution, the parameters of the required individual dynamic isolators has to be determined. This is accomplished by using the blocking pier stiffness spreadsheets included in Appendix 5. These are the same spreadsheets as used to calculate the blocking pier stiffnesses. They are used to calculate the individual isolator properties by working backwards.

The isolators' parameters are determined as follows. First, the spreadsheet for determining blocking pier horizontal stiffness is used. Knowing the pier's overall stiffness and dimensions and knowing the properties of all the other layers, the only parameter that could be varied to give the proper total pier stiffness is the isolator's modulus of elasticity, E. By varying E until the correct pier stiffness is obtained, the correct value of E for the isolator is obtained. Next, to determine the horizontal stiffness of an individual isolator, all the other blocking pier layers are made infinitely stiff except for the isolator. With the isolator E value known, the value of individual isolator stiffness is given by the spreadsheet. This procedure is used to determine first stiffness line (elastic) and second

stiffness line (plastic) isolator parameters for both the keel and side block systems.

The QD values for the isolators are determined using the following equation:

$$QD = XEL*(KU-KD) \tag{7.1}$$

where:

XEL is the elastic limit for the original isolator, used by Hepburn [1],in inches.

QD is the restoring force intercept of the second stiffness slope for the isolator.

KU is equal to the elastic stiffness of the isolator.

KD is equal to the plastic stiffness of the isolator.

Table 7.1 are the original isolator parameters used by Hepburn [1]. Using the same XEL values as the original isolators the value of QD is determined by applying equation (7.1).

TABLE 7.1

ORIGINAL D.I.S. ISOLATOR PARAMETERS

	SIDE ISOLATOR	KEEL ISOLATOR
XEL:	0.285 in	0.400 in
QD:	4.55 kips	11.03 kips
KU:	17.8 kips/in	31.31 kips/in
KD:	1.83 kips/in	3.72 kips/in
Kvert:	850 kips/in	1845.83 kips/in

(where Kvert is the vertical stiffness of each isolator)

TABLE 7.2

FINAL LOW STIFFNESS DESIGN ISOLATOR PARAMETERS

	SIDE ISOLATOR	KEEL ISOLATOR
XEL:	0.285 in	0.400 in
QD:	0.638 kips	1.15 kips
KU:	2.75 kips/in	3.36 kips/in
KD:	0.51 kips/in	0.49 kips/in
Kvert:	850 kips/in	1845.83 kips/in

The manufacturer (D.I.S.) of the isolators was contacted once the parameters of the required isolators were known. D.I.S. Vice President for Engineering, Buckle [18], stated that an isolator with these required parameters would be impractical to build. However, he stated that an isolation system of equivalent properties could be built using higher stiffness isolators on every fourth block.

The blocks without isolators would have low friction sliders which carry the vertical load and provide no horizontal stiffness. These sliders would be coated with a low friction material such as teflon. Such sliders, according to Buckle, are used extensively in bridge isolation systems. The final low stiffness solution does incorporate sliders.

7.1 Description of the Low Stiffness Solution

Figure (7.4) is a 2D drawing of the recommended low stiffness submarine drydock blocking system solution. This solution survives 63 % (0.28 g's) of the normalized dry dock # 2 earthquake. The design includes the following features:

1. Isolators will be placed in every fourth keel and side blocking pier. All other blocking piers will contain sliders.
2. All keel and side block piers are rigidly attached to the dry dock floor to prevent overturning.
3. A steel carriage is used to rigidly tie the caps together transversely to prevent sliding. It also ties the system together longitudinally so the isolators provide a restoring force to entire system.
4. The steel carriage is only rigidly attached to the blocking piers containing isolators. It is free to slide on all other piers.
5. A 6" rubber cap is used on top of the steel carriage to help prevent liftoff and to aid the isolators in decoupling the submarine from ground acceleration.

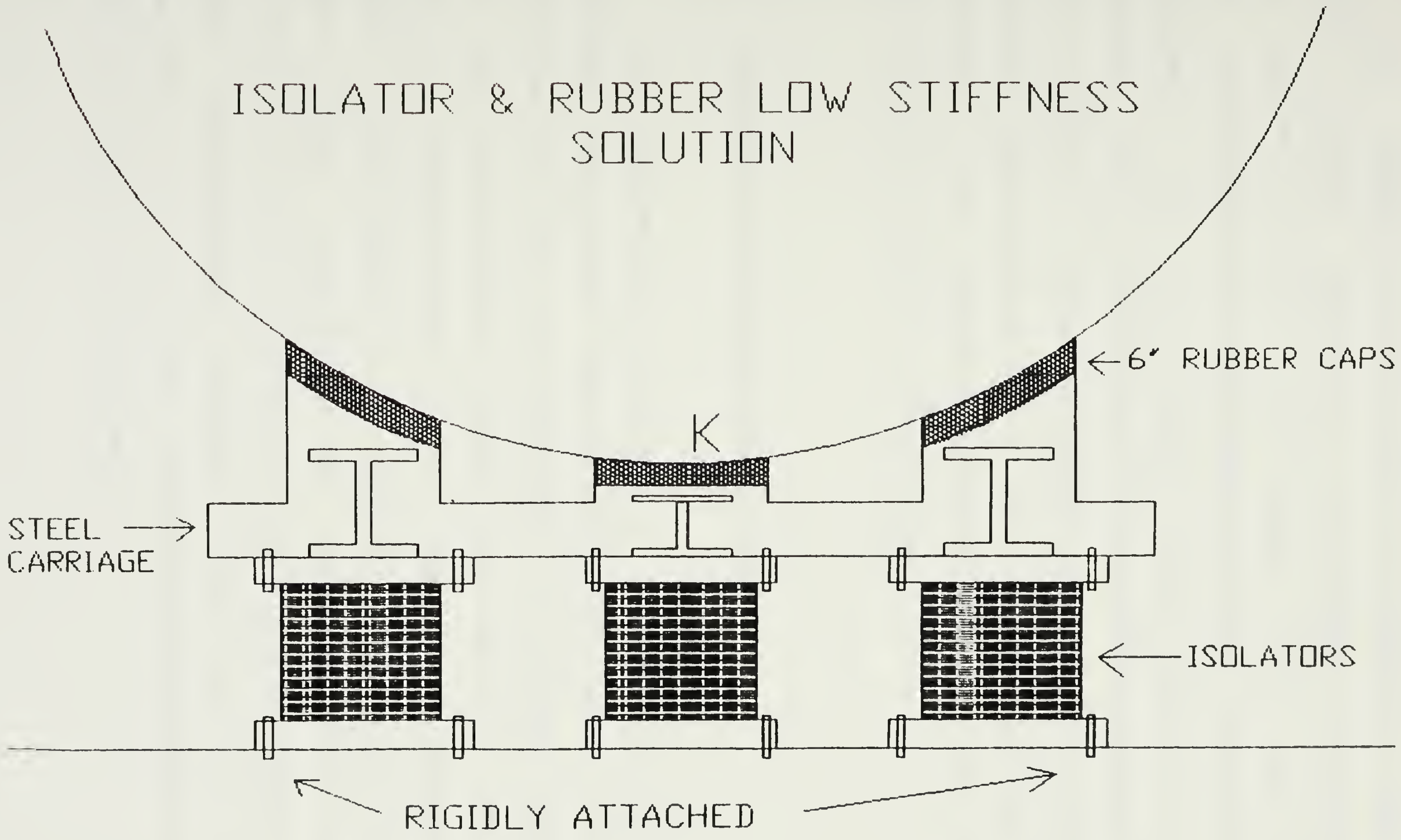

ISOLATOR & RUBBER LOW STIFFNESS SOLUTION
6" RUBBER CAPS
K
STEEL CARRIAGE
ISOLATORS
RIGIDLY ATTACHED

FIGURE 7.4

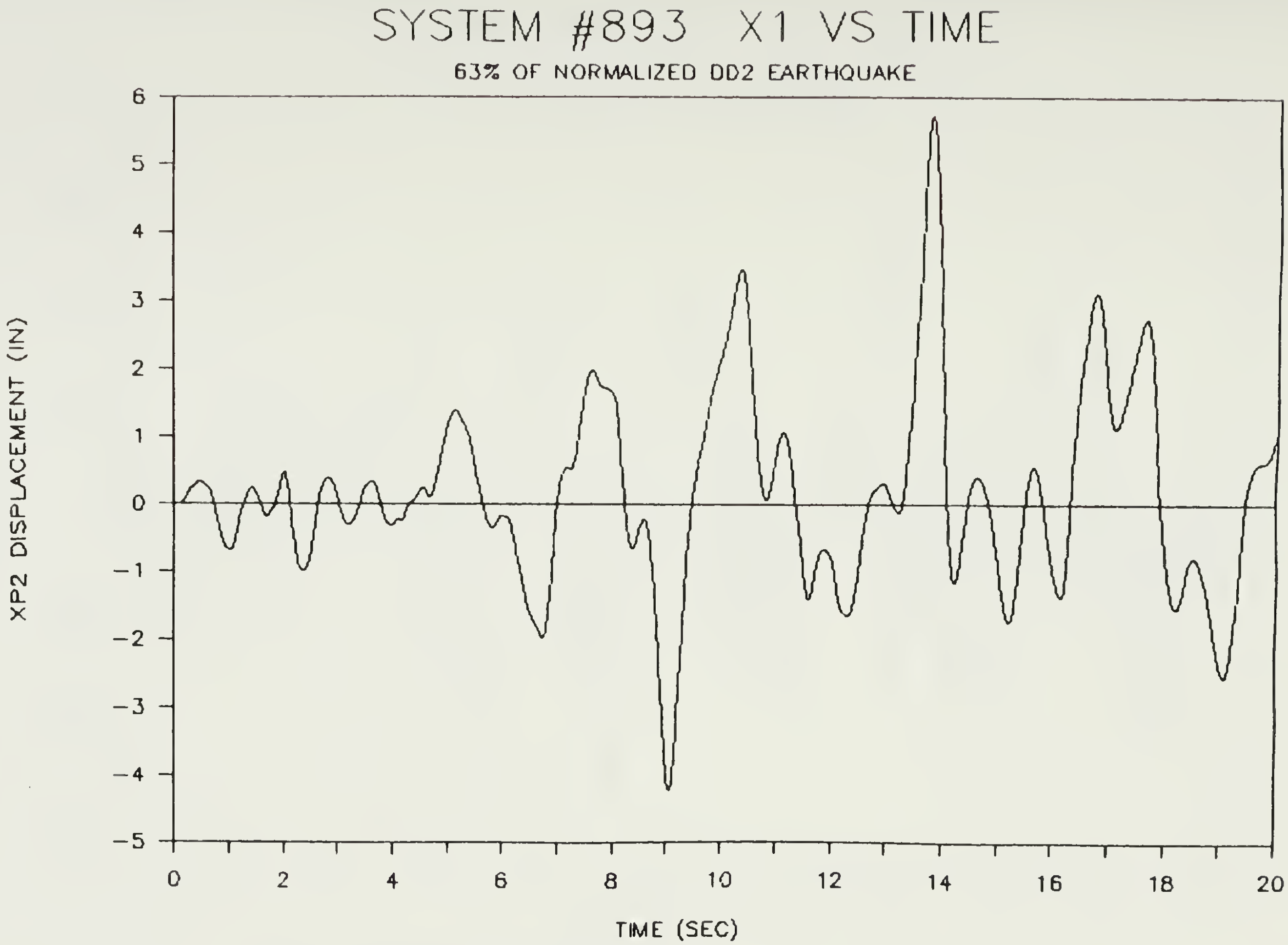
The "3DOFRUB" program could not completely model this system directly. Therefore, a few changes to the data file are required to simulate this system. First, the keel and side block widths are made extremely wide to simulate rigid attachment. The block on block friction coefficient is made extremely high to simulate the caps' rigid attachment to the steel carriage. The model used has the isolators attached to concrete blocks instead of to the dock floor; however, the stiffness of the isolators is so low compared to the concrete that this has no effect on the results.

7.2 Response of the Low Stiffness Solution

The response plots analyzed in this section for the low stiffness solution are due to excitation by 63 % of the normalized dry dock # 2 earthquake. The natural frequencies of the low stiffness solution are such that the lower frequency normalized dry dock # 2 earthquake produced lower levels of survivability, 63%, compared to the higher frequency 1940 El Centro earthquake, 72%. The normalized dry dock # 2 earthquake was used to produce the output plots because it had lower frequencies and produced a lower level survivability; therefore, it was the more conservative earthquake to use in analyzing the low stiffness design.

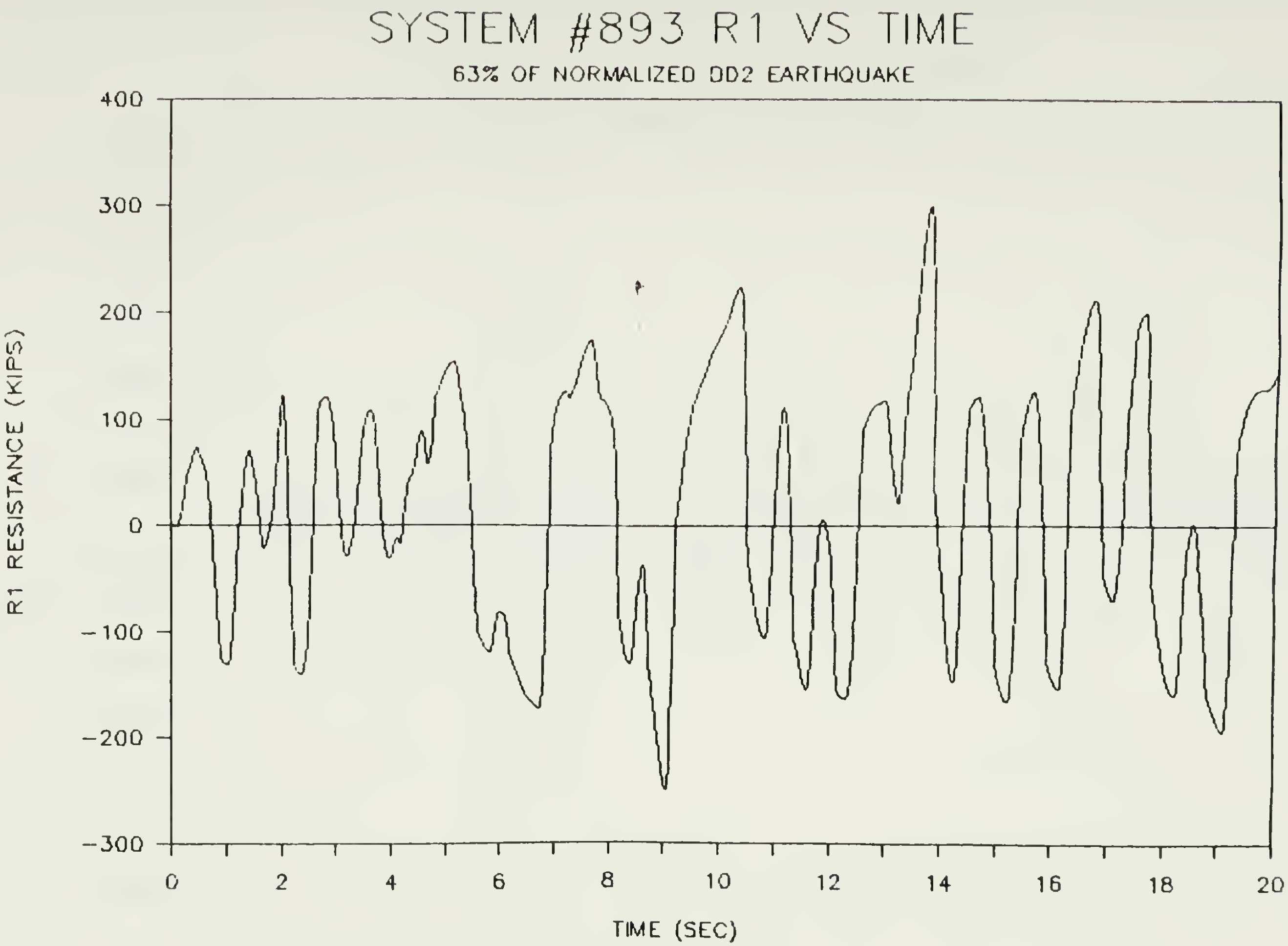
Figure (7.5) is a plot of the keel horizontal displacement relative to the dry dock floor as a function of time. This plot shows that the low stiffness solution has very large horizontal relative displacements associated with it. The maximum keel displacement seen in this figure, about 6 inches, is typical for base isolated structures according to Buckle [18]. The displacements are large; however, they have a low frequency and are smooth which means the submarine is experiencing low velocities and accelerations. This horizontal displacement response is extremely different from that of the exciting acceleration shown in figure (6.6). This illustrates the horizontal decoupling effect of the rubber/isolator systems.

These low accelerations can be seen in the keel block horizontal force versus time plot in figure (7.6). The high stiffness solution discussed in chapter 8 has keel block horizontal forces which are larger by an order of magnitude. Figure (7.7) shows the rotational response of this system. This figure is a plot of the systems rotation about the keel versus time. This plot shows that the rotations are relatively large, but smooth and low in frequency. This response is also extremely different from that of the exciting acceleration and shows the rotational decoupling of the rubber/isolator system. However, figure (7.8) shows that the vertical displacement is more closely coupled with the earthquake's vertical acceleration (figure (6.5)).



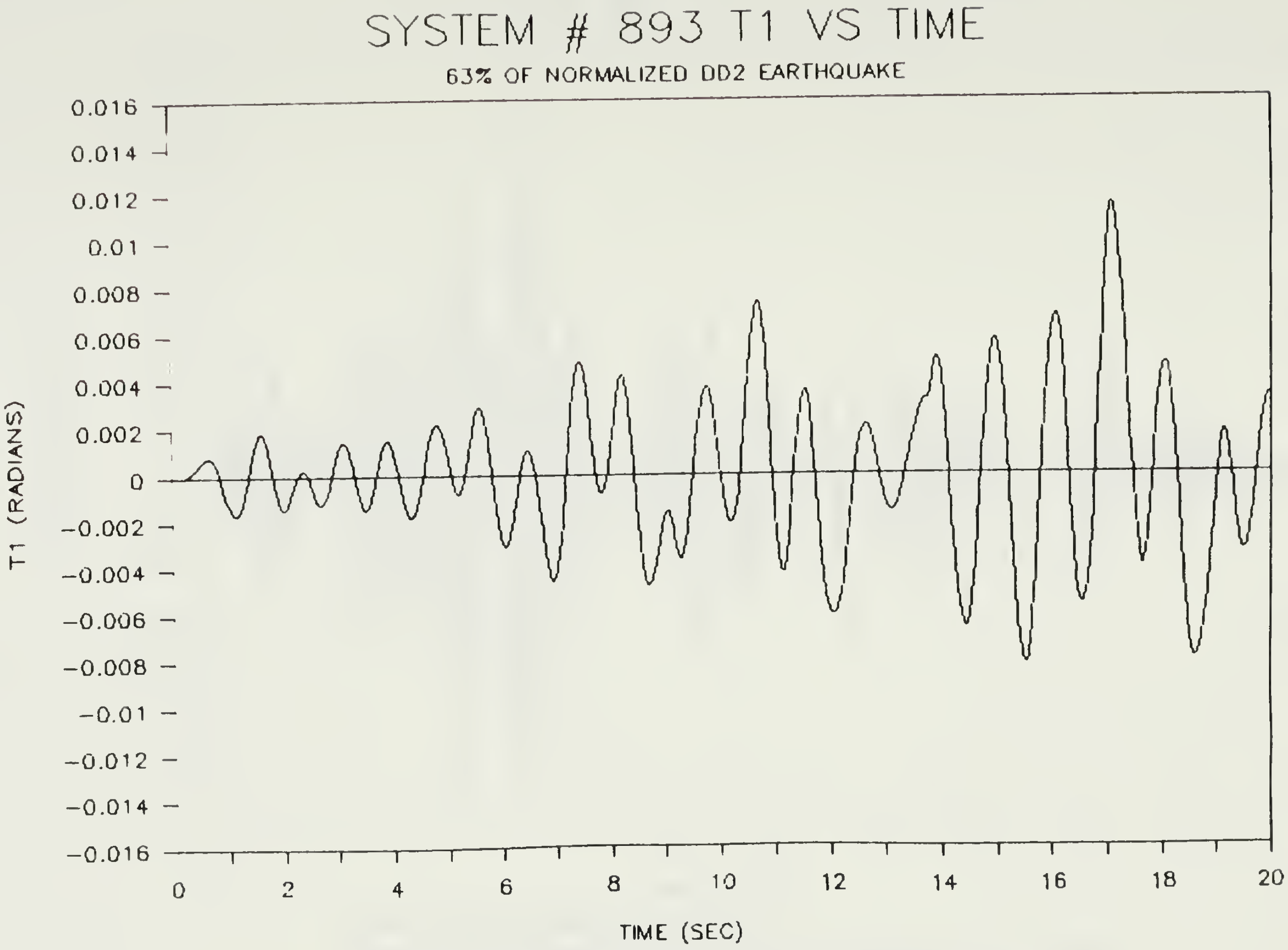
Low Stiffness Solution
Keel Block Horizontal Displacement
vs. Time
63 % of Normalized DD2 Earthquake

Figure 7.5



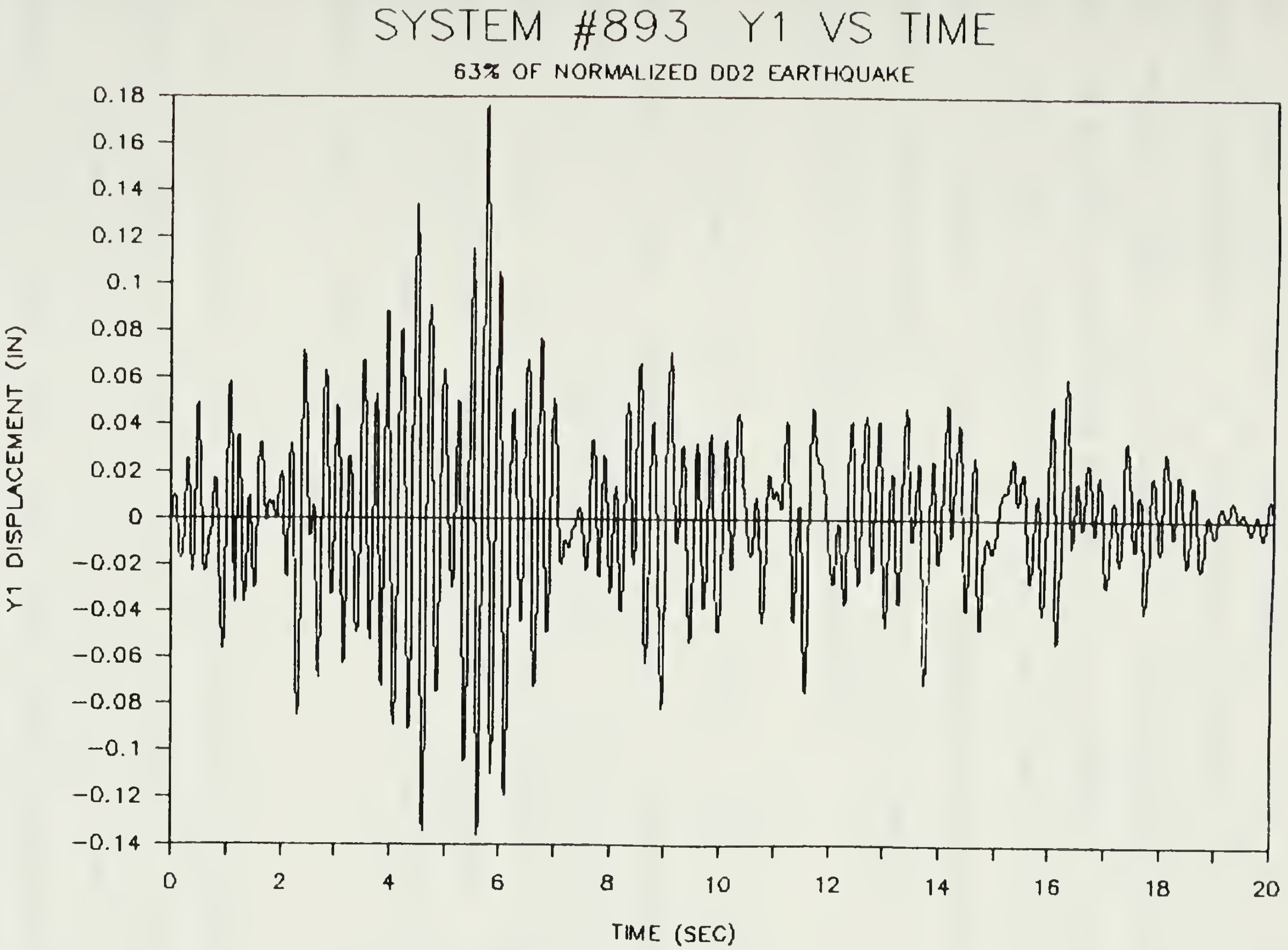
Low Stiffness Solution
Keel Block Horizontal Force vs. Time
63 % of Normalized DD2 Earthquake

Figure 7.6



Low Stiffness Solution Rotation vs. Time
63 % of Normalized DD2 Earthquake

Figure 7.7



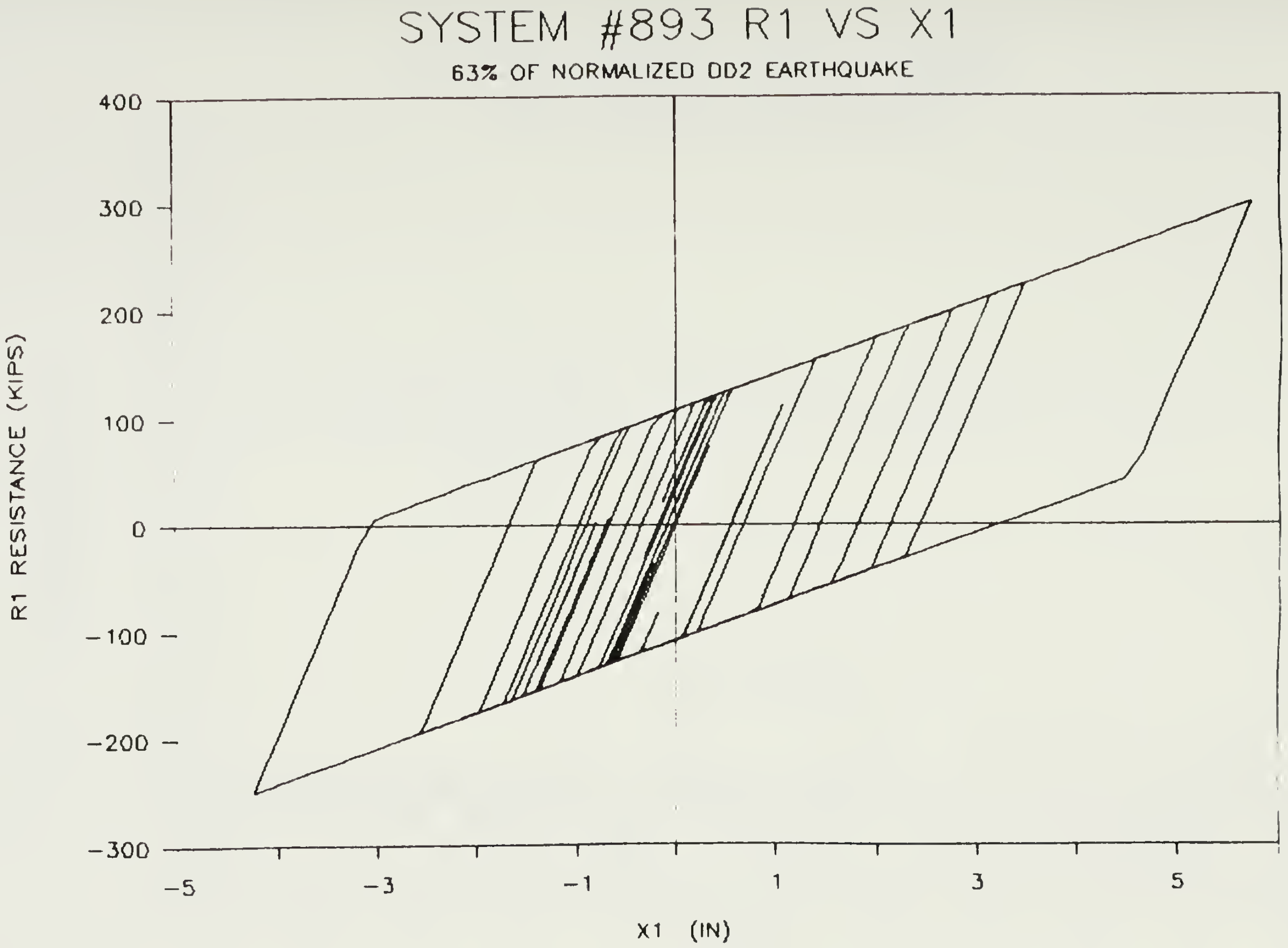
Low Stiffness Solution
Keel Block Vertical Displacement vs. Time
63 % of Normalized DD2 Earthquake

Figure 7.8

The bilinear behavior of the dynamic isolators is clearly shown in figure (7.9). This figure shows the keel restoring force versus horizontal displacement. The two stiffness slopes are evident. If during an earthquake excitation loop the isolator does not go plastic, the force oscillates up and down the elastic stiffness slope as can be seen in the figure. The total area inside all of the hysteresis loops is the amount of energy the isolator dissipates from the system during the earthquake. This hysteretical damping is one of the key benefits of using D.I.S. isolators.

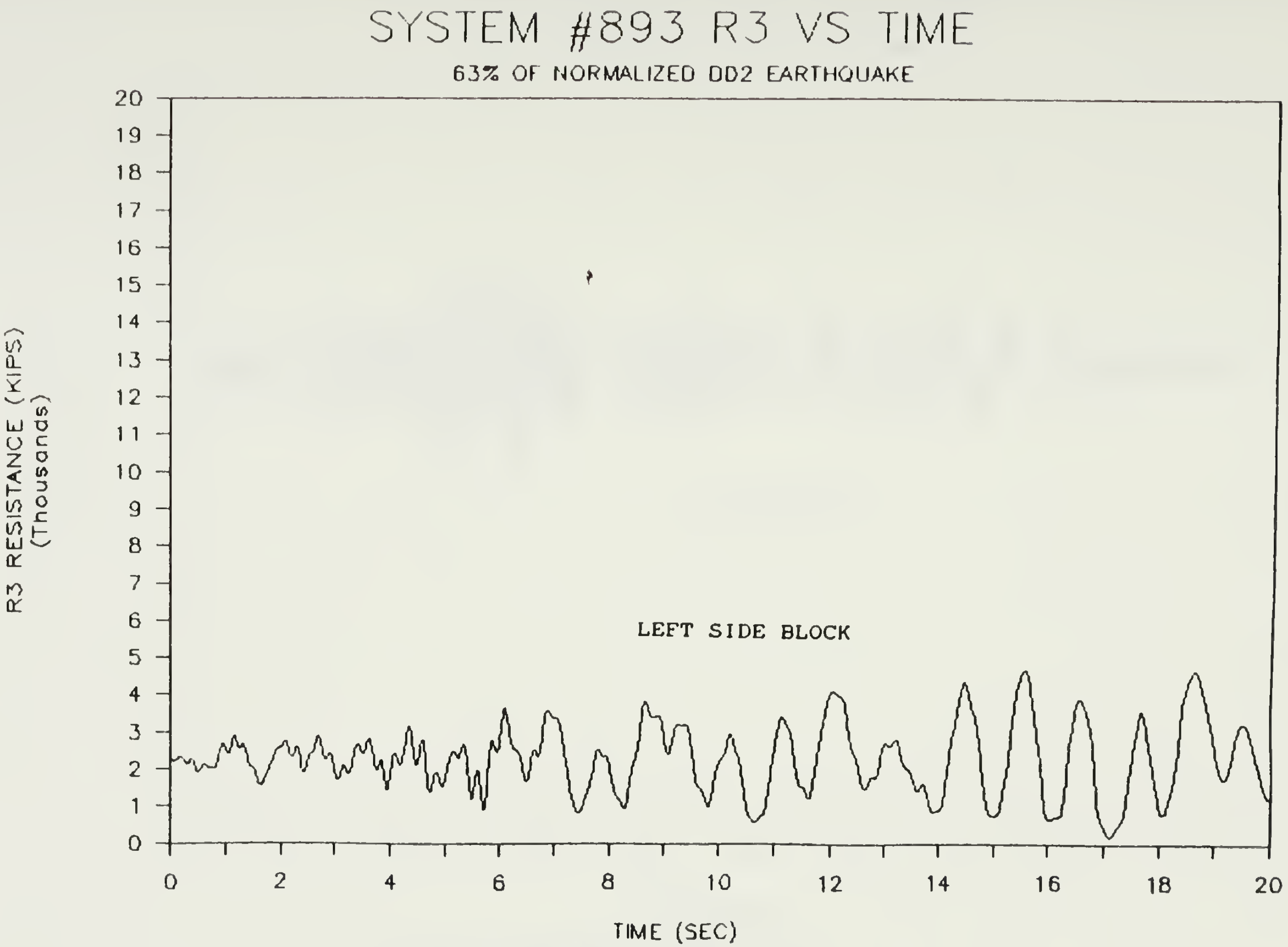
The forces on the left side blocks, keel blocks, and right side blocks are shown in figures (7.10 through 7.12) respectively. The first key thing to note about these three figures is that at time zero the total force on all three blocking systems is the weight of the submarine. The keel block system's load is 12000 kips (70 %), and each side block system's load is 2300 kips (15 %).

The side block force is mostly due to rotation of the submarine as can be seen by its similarity to figure (7.7) which is the plot of system rotation. The other significant feature of the right and left side block plots is that the forces are 180 degrees out of phase which is consistent with the physical situation. The forces on the keel are due to a combination of static load and vertical displacement.



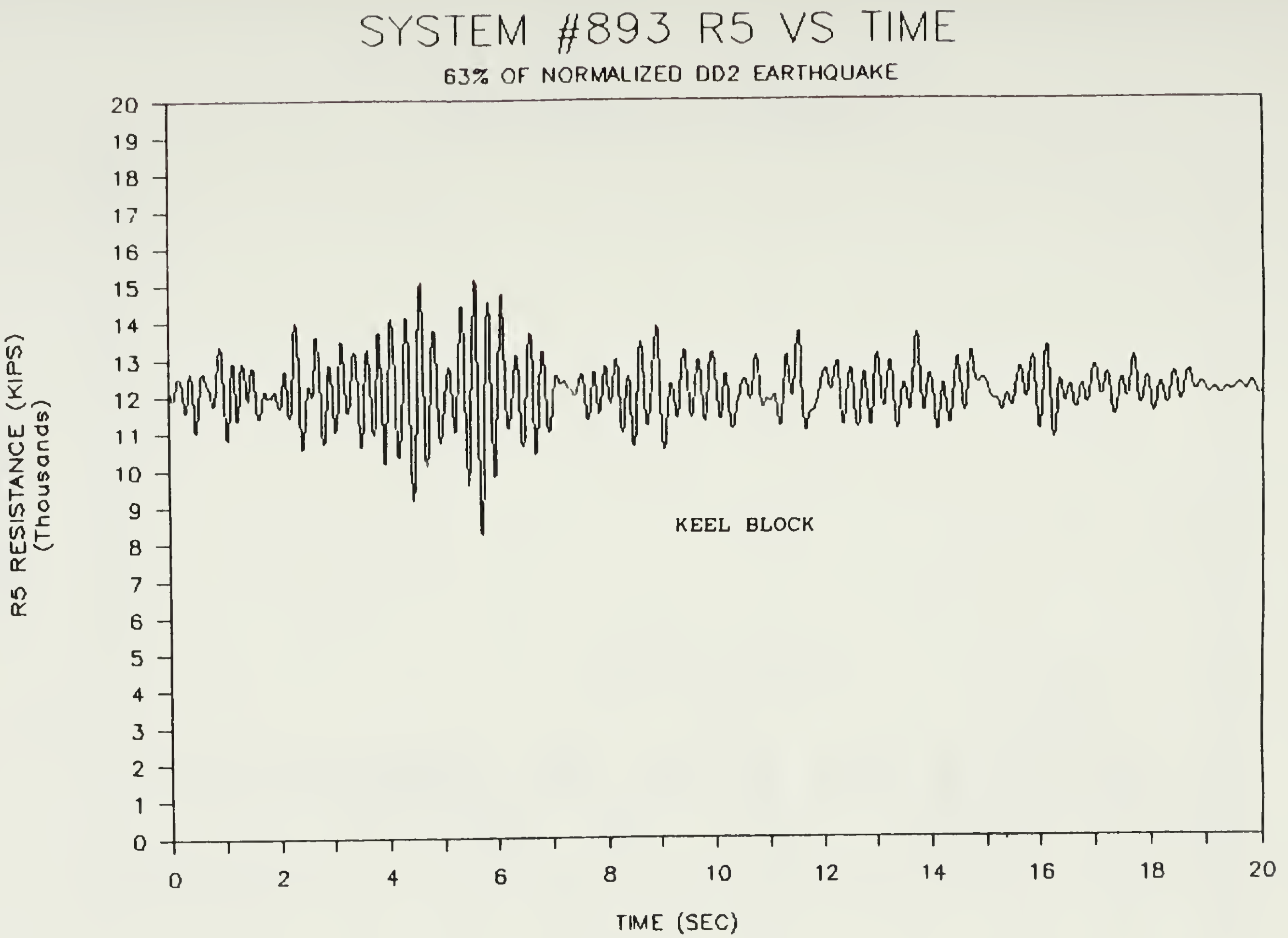
Low Stiffness Solution
Keel Block Horizontal Force
vs. Keel Block Horizontal Displacement
63 % of Normalized DD2 Earthquake

Figure 7.9



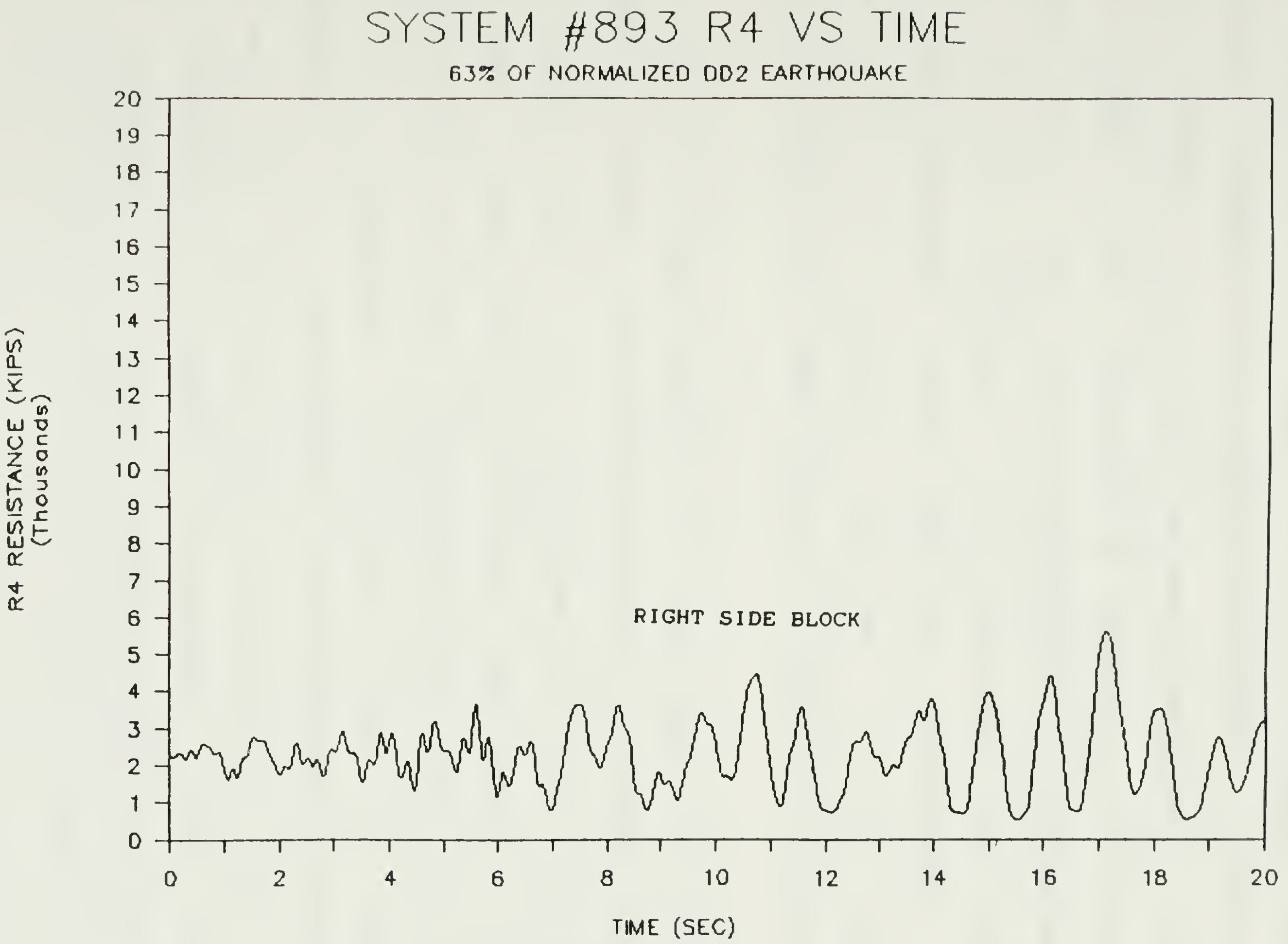
Low Stiffness Solution
Right Side Block Vertical Force vs. Time
63 % of Normalized DD2 Earthquake

Figure 7.10



Low Stiffness Solution
Keel Block Vertical Force vs. Time
63 % of Normalized DD2 Earthquake

Figure 7.11

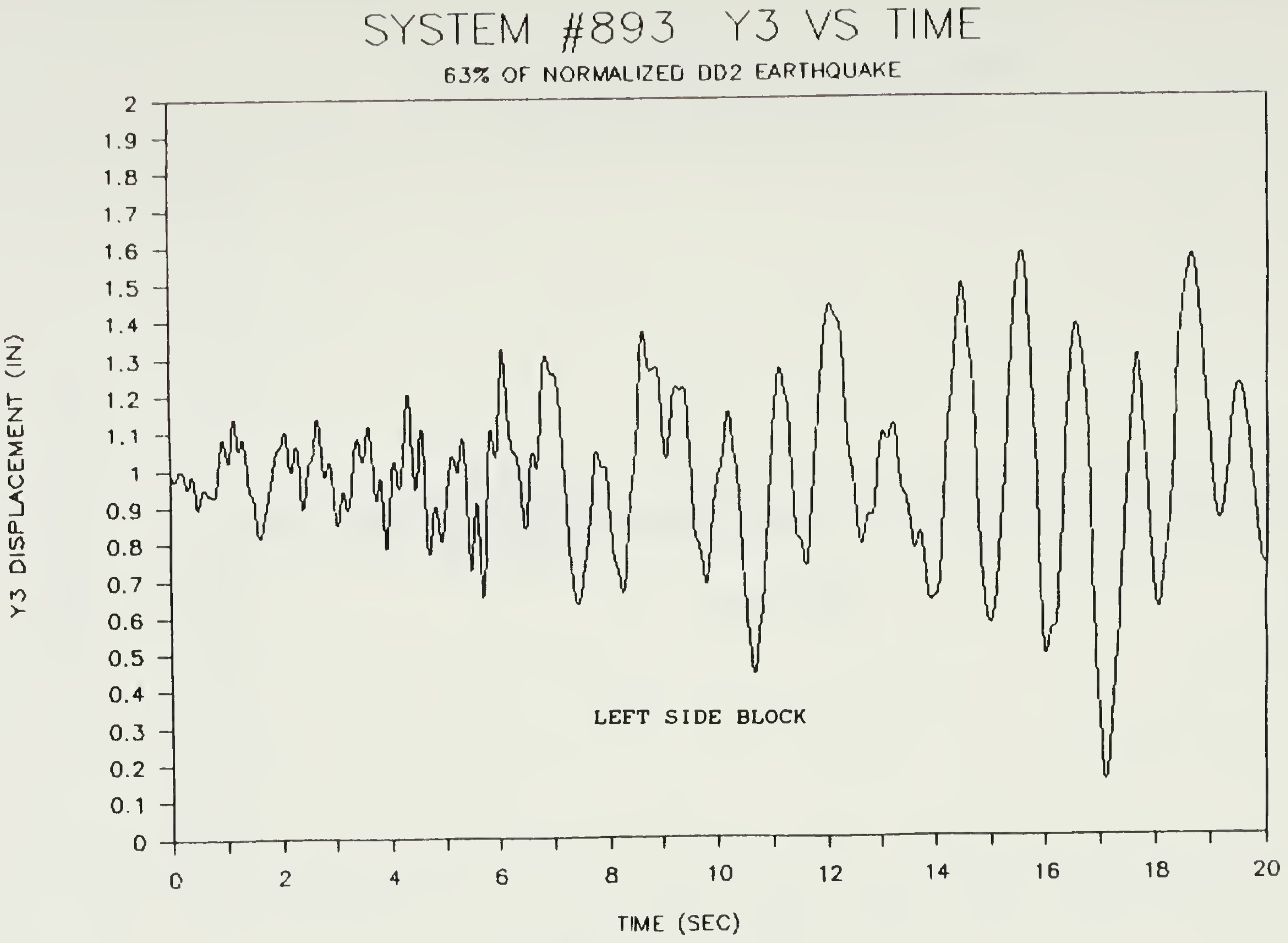


Low Stiffness Solution
Left Side Block Vertical Force vs. Time
63 % of Normalized DD2 Earthquake

Figure 7.12

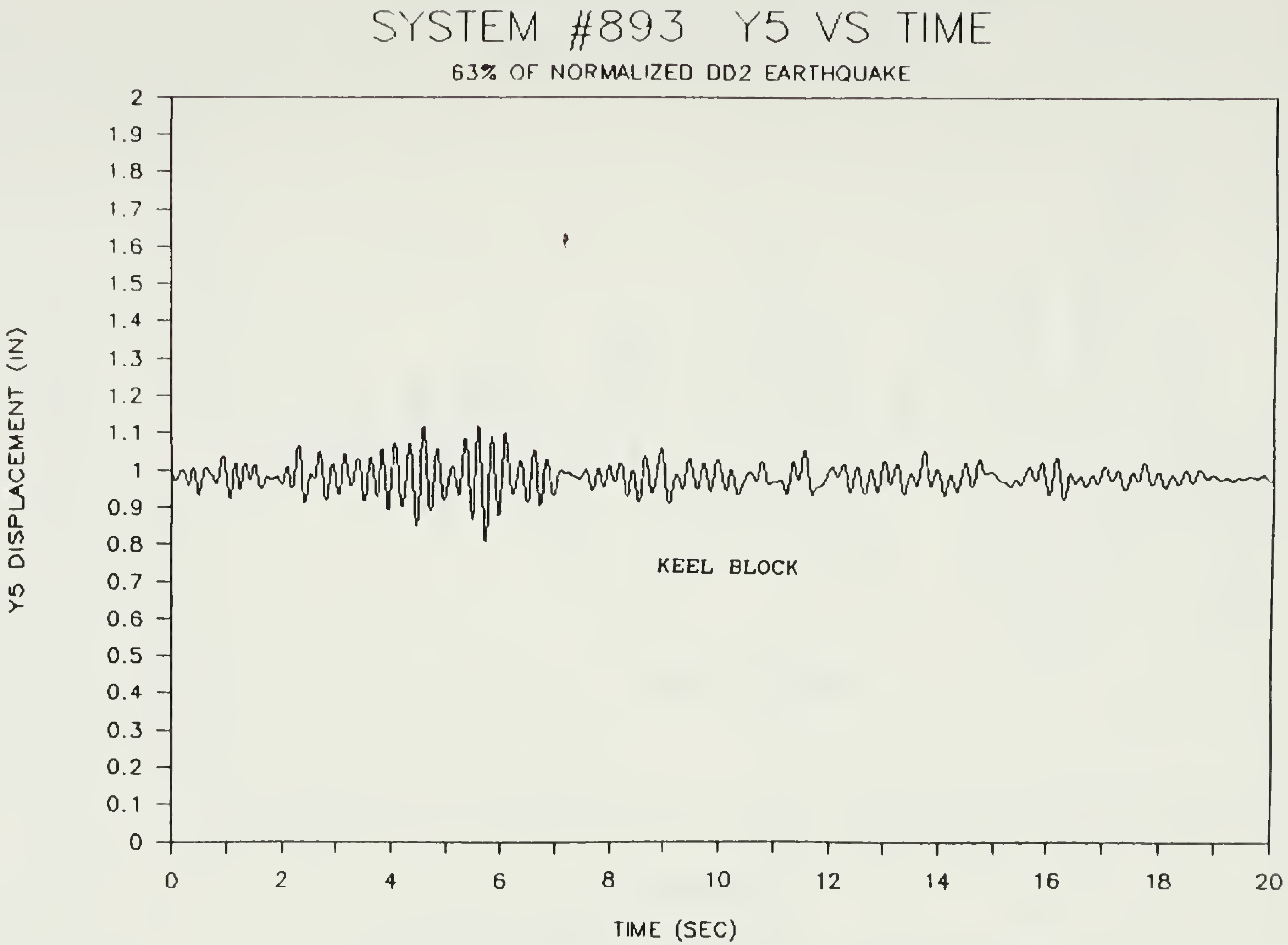
The displacements of the left side blocks, keel blocks, and right side blocks are shown in figures (7.13 through 7.15) respectively. At time zero, the plots represent the static deflection caused by the submarine's weight. In this case all three systems initially have the same displacement. This must be the case if the submarine is assumed to be a rigid body which it is. The initial displacement is approximately one inch into the rubber cap. The plots show that liftoff does not occur; however, for the left side block system liftoff came within 0.15 inches of occurring. For the right side block the system only came within 0.4 inches of liftoff.

The differences between the right and left side block response is due to the random nature of the exciting forces. The overall range of the displacements is very close to being the same. Even though the forces experienced by the keel blocks are much higher than those on side blocks, the relative vertical displacement of the keel blocks is very small compared to the side blocks. This is because the side blocks are much less stiff vertically than the keel blocks, and the keel blocks are not subject to rotation. These plots show that the model is producing reasonable response output. They provided an excellent check of the "3DOFRUB" computer program.



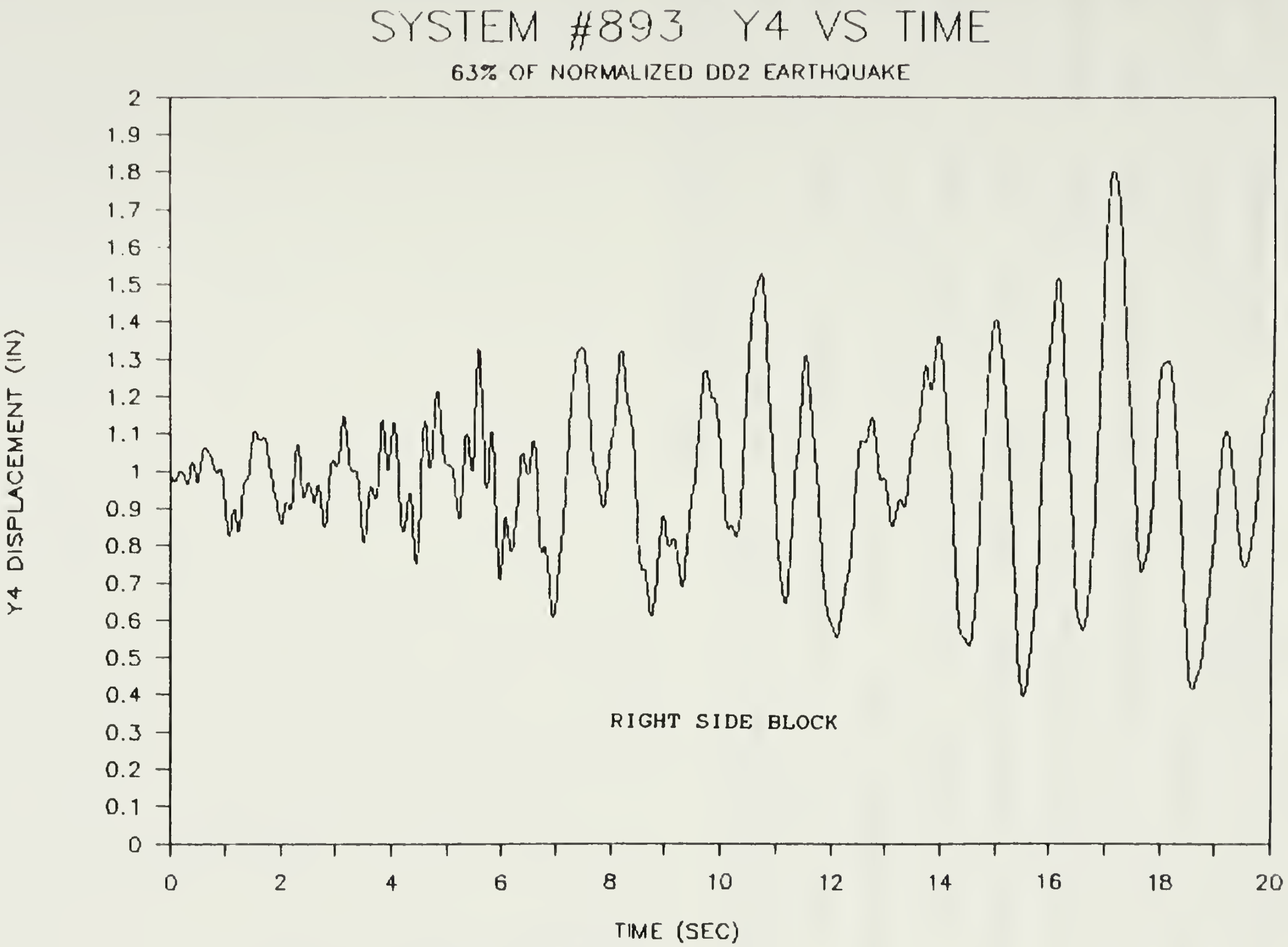
Low Stiffness Solution
Left Side Block Vertical Displacement
vs. Time
63 % of Normalized DD2 Earthquake

Figure 7.13



Low Stiffness Solution
Keel Block Vertical Displacement vs. Time
63 % of Normalized DD2 Earthquake

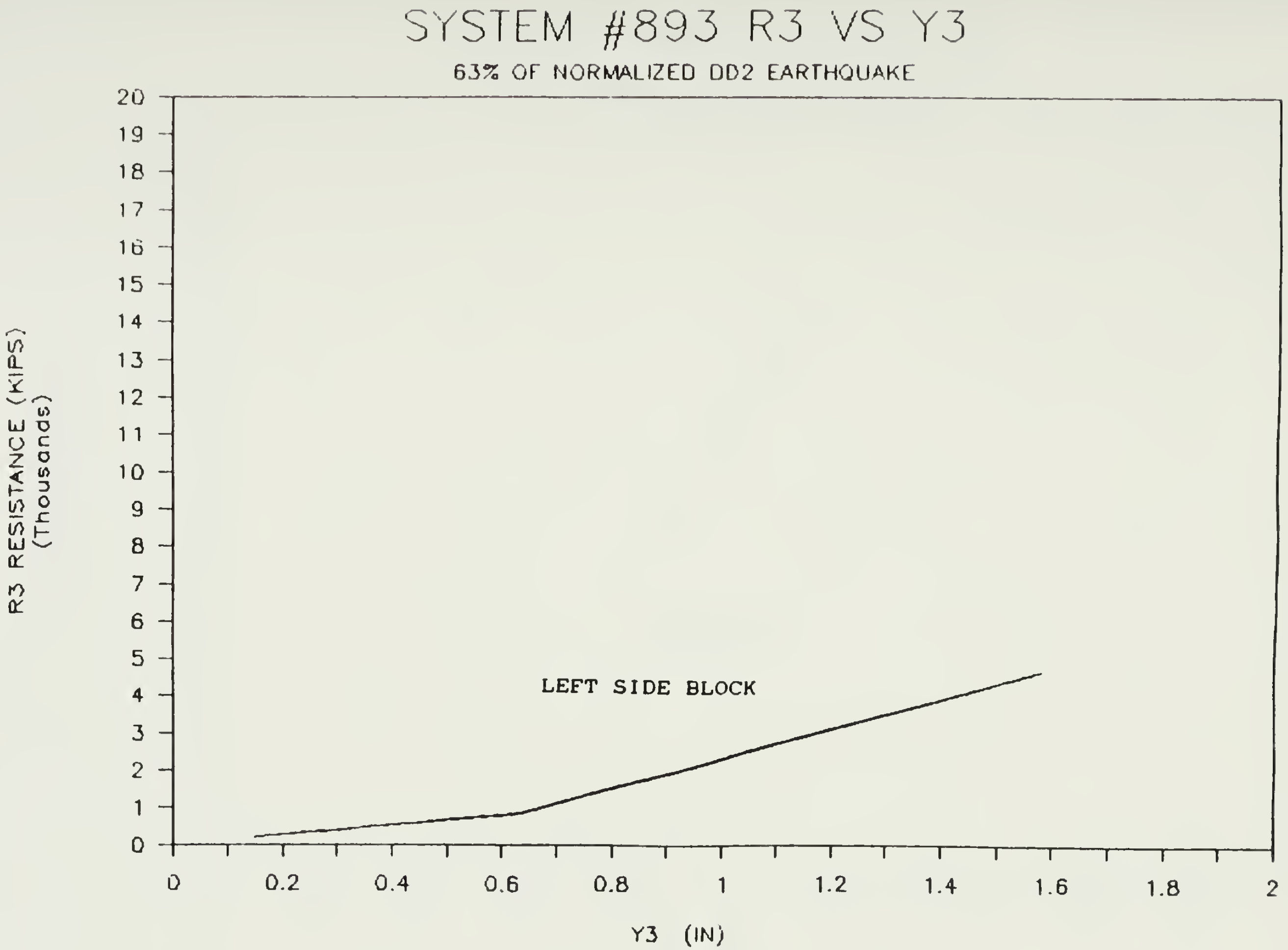
Figure 7.14



Low Stiffness Solution
Right Side Block Vertical Displacement
vs. Time
63 % of Normalized DD2 Earthquake

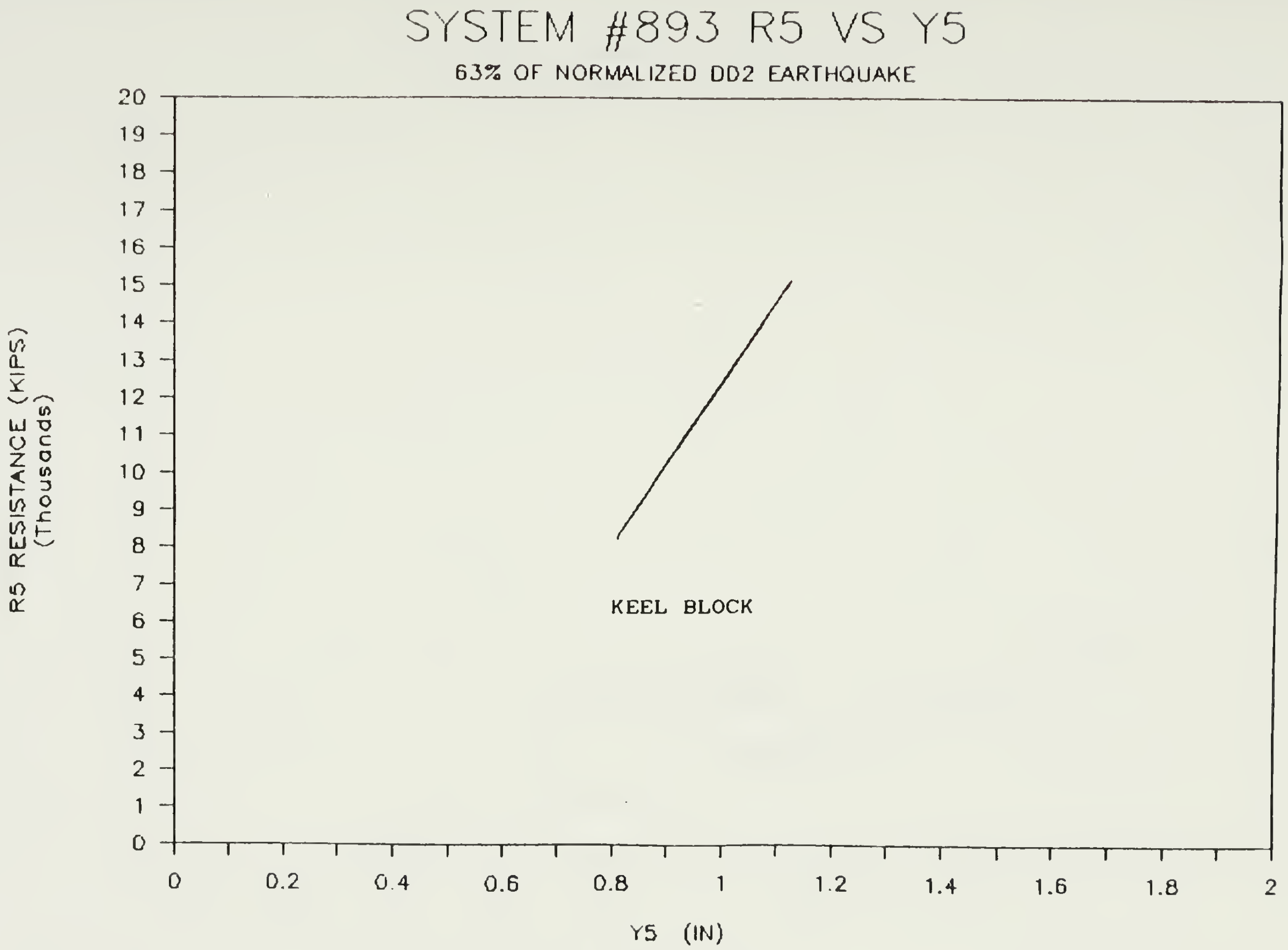
Figure 7.15

Finally, figures (7.16 through 7.18) show the bilinear behavior of the rubber caps. The plots show that the keel blocking system starts out and remains on the second rubber bilinear stiffness slope. For the side blocks, the plots show that both sets of side blocks experienced both rubber bilinear stiffness slopes. One very interesting issue seen in figure (7.16) is that as the left side block system unloaded, the rubber bilinear behavior significantly delays and prevents side block liftoff from occurring. The smaller slope near zero load helps to keep the submarine in the side blocks. This is the primary reason rubber is a superior material for use as a blocking system cap.



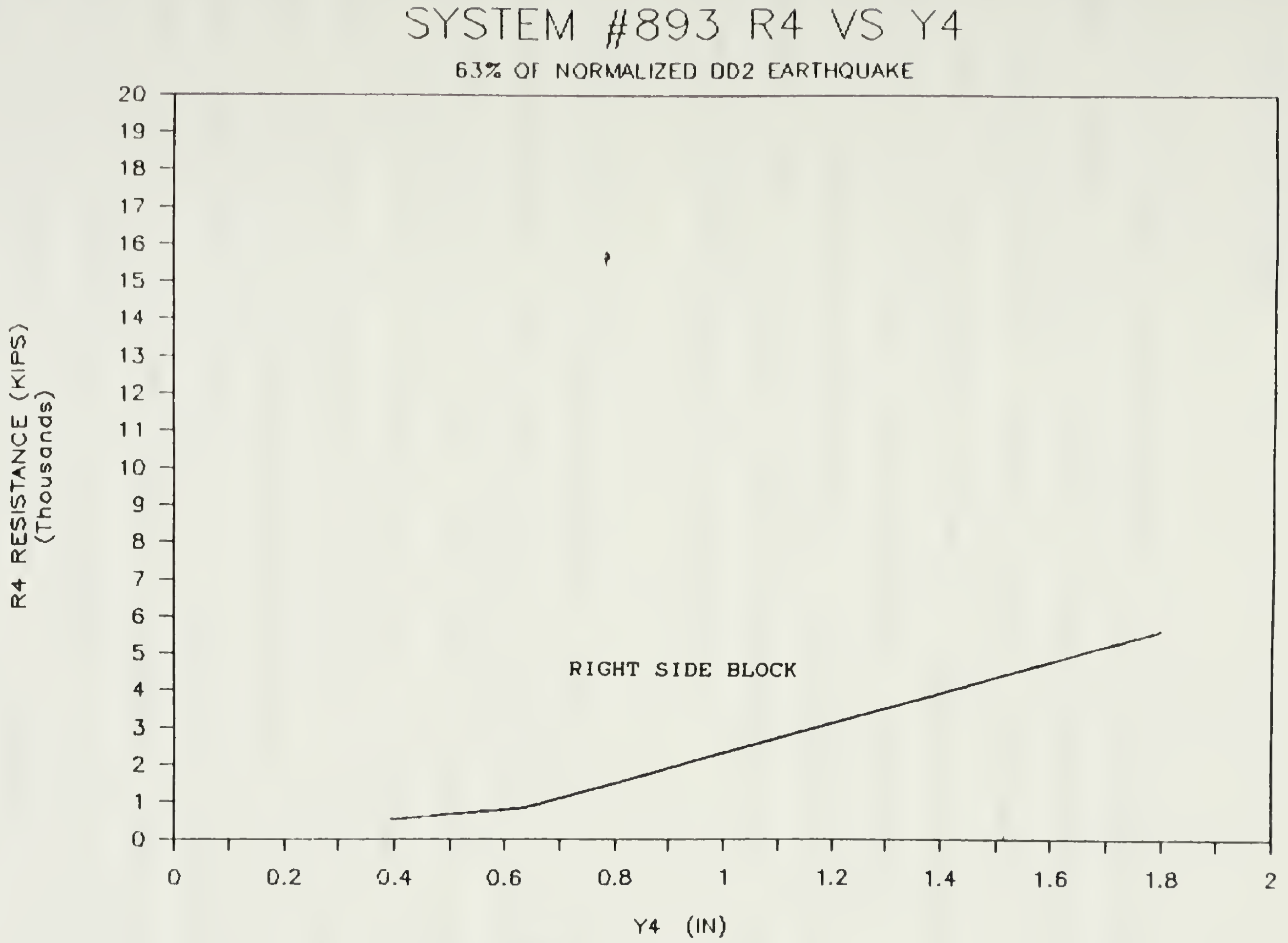
Low Stiffness Solution
Right Side Block Vertical Force
vs. Left Side Block Vertical Displacement
63 % of Normalized DD2 Earthquake

Figure 7.16



Low Stiffness Solution
Keel Block Vertical Force
vs. Keel Block Vertical Displacement
63 % of Normalized DD2 Earthquake

Figure 7.17



Low Stiffness Solution
Left Side Block Vertical Force
vs. Right Side Block Vertical Displacement
63 % of Normalized DD2 Earthquake

Figure 7.18

CHAPTER 8

WALE SHORE HIGH STIFFNESS DESIGN

8.0 Design Process

As was shown in the section 5.1 wale shore parametric study, the use of wale shores is also a promising solution to the submarine drydock blocking system survivability problem. The use of wale shores increases system survivability by reducing the rotation and horizontal displacement of the submarine during the earthquake. Wale shores also shift the horizontal and rotational modal frequencies well above the fundamental frequencies of the earthquake.

From the wale shore parametric study, it is found that using wale shores with stiffnesses greater than or equal to 6000 kips/in along with one inch rubber keel and side block caps produce system survivability well in excess of dry dock failure. This is illustrated in figure (5.4). In order to compare the high stiffness solution with the low stiffness solution described in chapter 7, a system which survives 72 % of the 1940 El Centro earthquake is designed. The input data file and the output file from "3DOFRUB", which realize this level of survivability, is included in Appendix 6. Also included in this appendix is the output file for this system using the normalized dry dock # 2 earthquake excitation.

The 72 % (0.32 g's) survivability level is desirable to give the system a reasonable factor of safety above the 0.26 g dry dock failure level. For the low stiffness design only 63 % (0.28 g's) survivability could be attained due to excitation by the normalized dry dock # 2 earthquake before practical manufacturing limits of the isolator system are reached. This level of survivability is still considered acceptable.

The next step in this study is to determine how to practically realize this design. Once the required total stiffness of the wale shores is determined, the actual number and dimensions of the individual wale shores has to be found. The first assumption made is to design the wale shores for Long Beach Naval Shipyard dry dock # 2, which is a typical U.S. Naval shipyard graving dock. This requires the lengths of the wale shores to be approximately 32 feet when supporting a system 1 submarine.

Since the wale shores are compression elements vulnerable to buckling, based on Hughes [19] wide flange steel sections are chosen for the wale shores. In order to minimize dry dock production interference and to avoid overstressing the submarine, wale shores are only placed over existing side block pier locations. Therefore, the wale shores would bear on the submarine ring stiffeners. To determine the required individual wale stiffness, the number of wale shores is first assumed to be seven. Then a spreadsheet similar to that used

to calculate blocking pier vertical stiffness is used to determine what steel section is required to give the necessary overall wale shore stiffness. This spreadsheet is included in Appendix 6.

It is assumed that each wale shore would consist of a layer of rubber, a half inch steel backing plate, and a wide flange steel beam. To prevent separation of the wale shore from the submarine during the earthquake the wale shore is initially compressed against the submarine using an hydraulic jack. A satisfactory steel section is found using a steel wide flange beam design table in Popov [20].

Once a section is selected, it is tested for buckling survivability using the following procedure:

1. Using Hughes' column design curves [19], a value of ultimate stress for a single wale shore is obtained. The appropriate curve for a wide flange (universal column) is selected. This curve takes into account eccentricities in the beam.
2. To enter the curve a yield stress is required. 33000 psi mild steel is used.
3. Next, a slenderness ratio, Le/r, is needed. This is obtained from Popov [20]. For simply supported conditions Le is equal to the length of the beam.

The value of r, the radius of gyration, is found from Popov's beam design table.

4. The actual stress in the beam then has to be determined. This is accomplished by determining the force in the wale shore and dividing it by the sectional area of the beam, A_{ws}. The equations for the wale shore stress, σ_{ws}, are as follows:

$$\sigma_{ws} = R/A_{ws} \tag{8.1}$$

$$R = ksp'*x'_{max} + F_j \tag{8.2}$$

$$F_j = (D_j - XEL)*ksp' + A_{rub}*\sigma_{rub} \tag{8.3}$$

$$XEL = (A_{rub}*\sigma_{rub})/ks' \tag{8.4}$$

$$D_j = x'_{max} \tag{8.5}$$

where:

R = maximum total force seen by an individual wale shore. It includes the maximum earthquake forces and the initial compressive forces applied by the hydraulic jack.

ksp' is the total stiffness of an individual wale shore when its rubber cap is operating on its second bilinear stiffness slope.

x'_{max} is the maximum horizontal deflection seen by the wale shore as determined from the output of "3DOFRUB" using the height of the wale shore above the keel, AAA, the rotation angle theta, and the keel horizontal displacement x.

F_j, the jacking force, is the initial force applied to wale shore by the hydraulic jack to prevent separation.

D_j is the initial deflection of wale shore caused by the jacking force.

XEL is the elastic limit deflection where the wale shore stiffness changes slope.

A_{rub} is the cross sectional area of the rubber cap of the wale shore.

σ_{rub} is the stress at which the rubber cap changes stiffness.

ks' is the total stiffness of an individual wale shore when its rubber cap is operating on its first bilinear stiffness slope.

5. The final check for buckling requires that σ_{wm} is less than σ_{ult}. In order to meet this requirement and maintain a reasonable wale shore size the number of wale shores has to be increased to 14. Table 8.1 lists the parameters obtained for the final high stiffness wale shore design which satisfies the buckling criteria.

Table 8.1

FINAL HIGH STIFFNESS DESIGN WALE SHORE PARAMETERS

# wale shores:	14 per side
Section:	27x14 WF 145 mild steel
r:	3.09 inches
Length (Le):	385 inches
Le/r:	123.3
ks':	134.15 kips/in
ksp':	437.51 kips/in
XEL:	0.36 inches
σ_{wm}:	9095 psi
σ_{ult}:	13500 psi
F_j:	138.79 kips
D_j.	0.57 inches

It is assumed that during the earthquake the wale shore stiffness remains equal to ksp'. The wale shore is designed so that there is a large enough rubber cap and enough initial compression supplied by the jack so that the wale shore never loses contact with the submarine during maximum horizontal displacement and rotation during the earthquake.

8.1 Description of the High Stiffness Solution

Figure (8.1) is a 2D drawing of the recommended high stiffness submarine dry dock blocking system solution. This solution survives 72 % (0.32 g's) of the 1940 El Centro earthquake and 75 % (0.34 g's) of the normalized dry dock # 2 earthquake. The design includes the following features:

1. 14 wale shores are placed directly over the side block positions at a position half the diameter of the submarine up from the keel. They are attached to the dockside by a hinge-pin-jack assembly as shown in figure (8.2). Cables are used to support and align the the wale shores.
2. Each wale shore is 32 feet long. Table 8.1 describes the steel section used. A three inch rubber cap is placed between a backing plate and the submarine hull. A 70 ton jack is used to pre-compress the wale shore against the submarine to prevent separation during the earthquake.
3. The keel and side concrete blocking piers are rigidly attached to the dry dock floor to prevent overturning.
4. A steel carriage is rigidly attached to the caps and concrete blocking piers to prevent sliding. It also ties the system together longitudinally.
5. A one inch rubber cap is used on top of the steel carriage to help prevent liftoff.

WALE SHORE HIGH STIFFNESS
SOLUTION

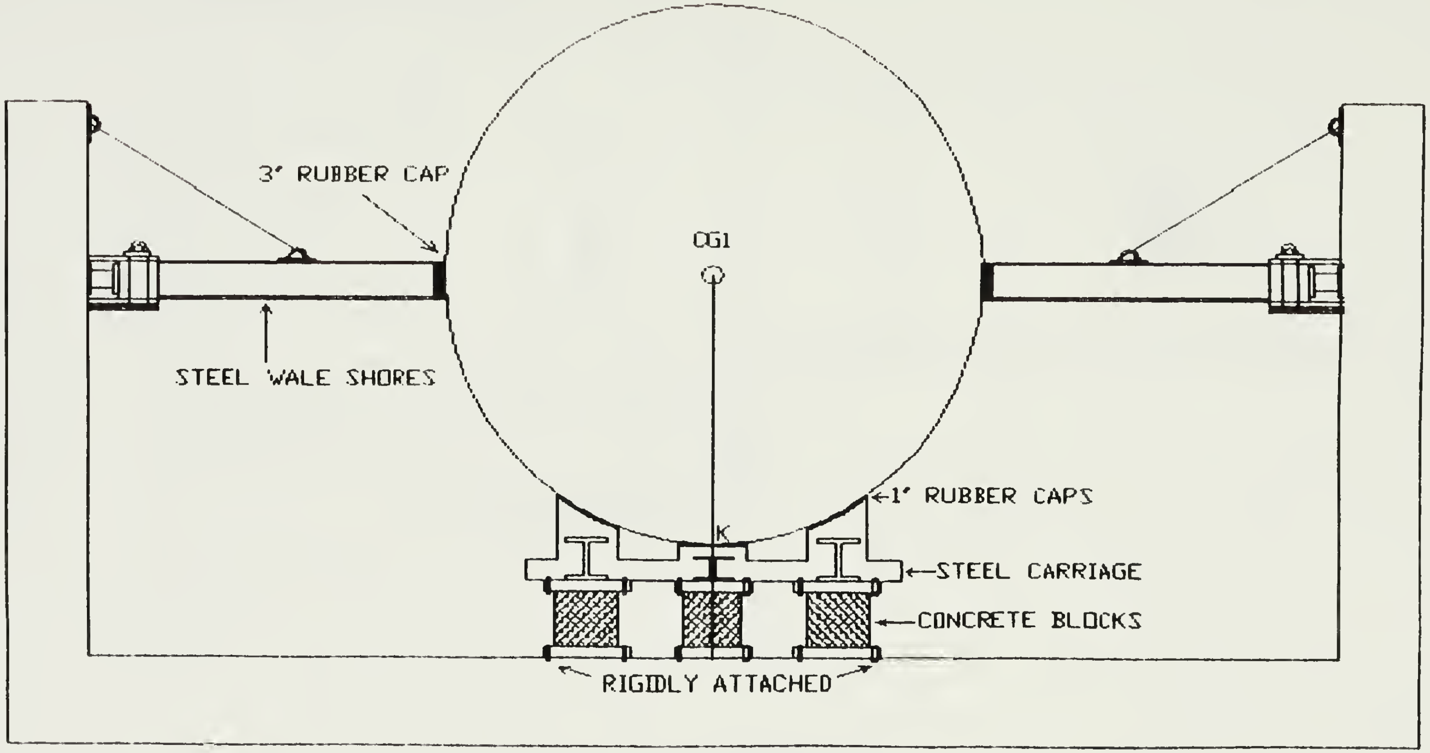


FIGURE 8.1

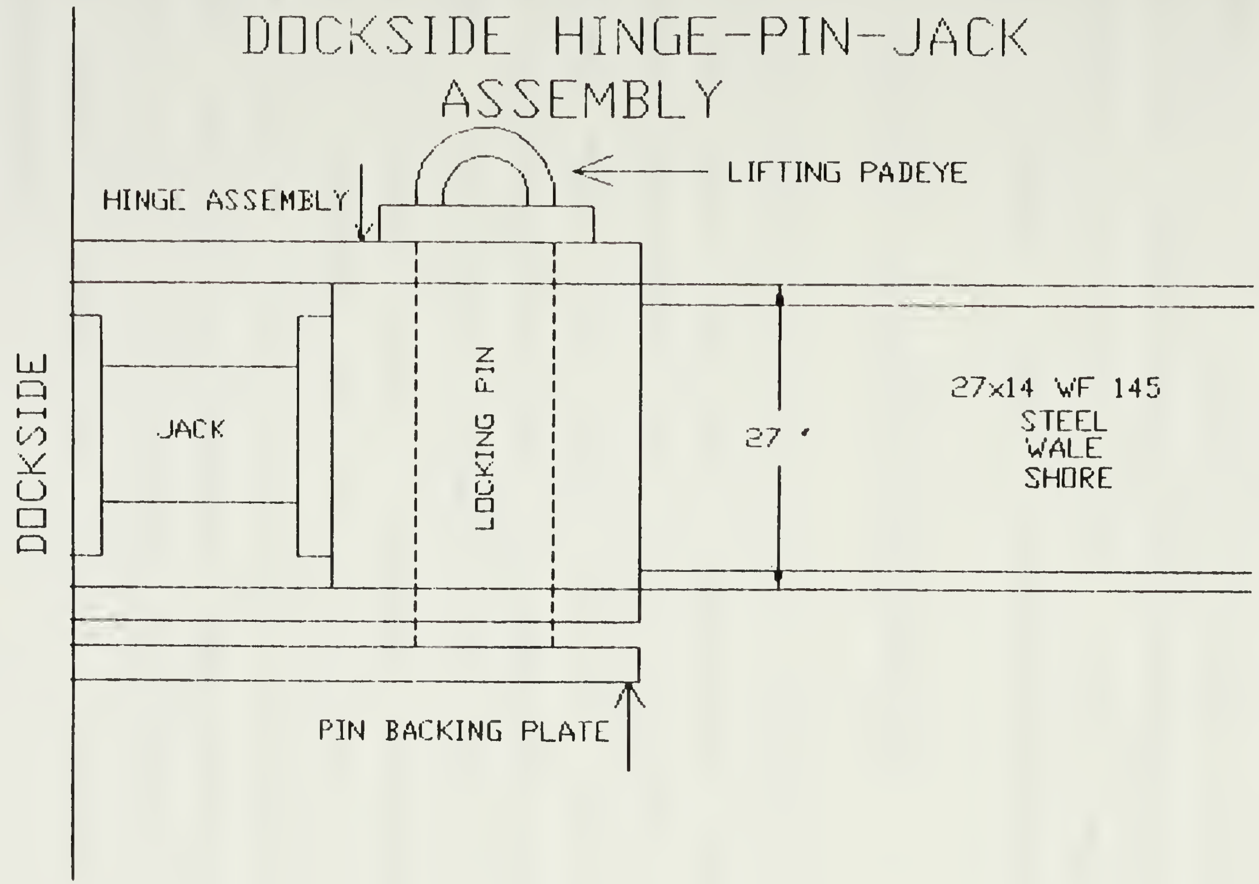

DOCKSIDE HINGE-PIN-JACK ASSEMBLY
LIFTING PADEYE
HINGE ASSEMBLY
DOCKSIDE
JACK
LOCKING PIN
27'
27x14 WF 145 STEEL WALE SHORE
PIN BACKING PLATE

FIGURE 8.2

The "3DOFRUB" program could not completely model this system directly. Therefore, a few changes to the data file are required to simulate this system. First, the keel and side block widths are made extremely wide to simulate rigid attachment. In addition, the block on block friction coefficient is made extremely high to simulate the caps' rigid attachment to the steel carriage. The stiffness of the wale shores is assumed to remain on the second stiffness slope.

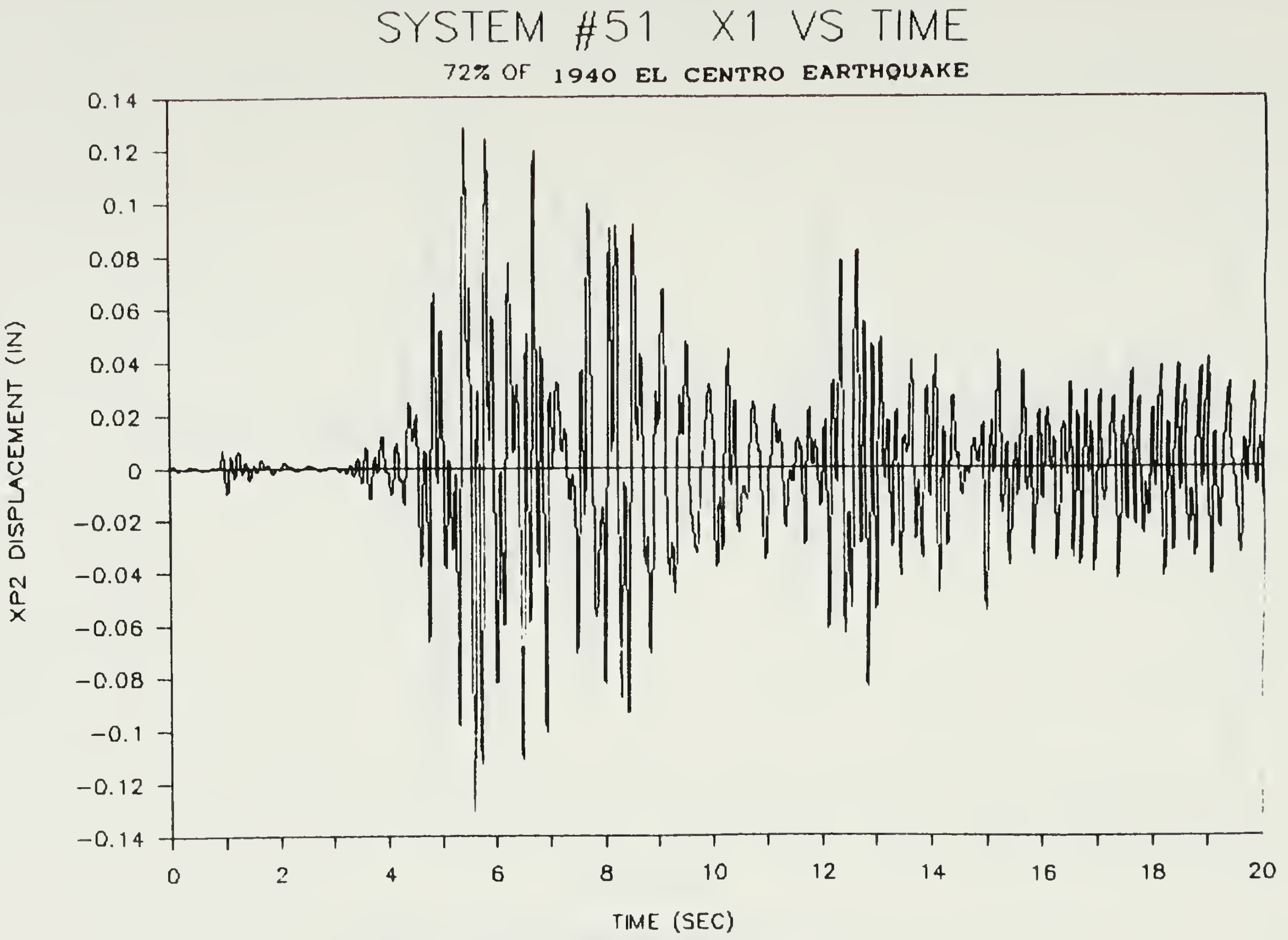
8.2 Response of the High Stiffness Solution

The response plots analyzed in this section for the high stiffness solution are due to excitation by 72 % of the 1940 El Centro earthquake. The natural frequencies of the high stiffness solution are so high that both the 1940 El Centro and the normalized dry dock # 2 earthquake produce similar levels of survivability (72% and 75%). This is an indication that the procedure used in section 6.1 to normalize the dry dock # 2 earthquake with the 1940 El Centro earthquake was done correctly. The 1940 El Centro earthquake is used to produce the output plots because it has higher frequencies and produces a lower level survivability; therefore, it is the more conservative earthquake to use in analyzing the high stiffness design.

Figure (8.3) is a plot of the keel horizontal displacement relative to the dry dock floor as a function of

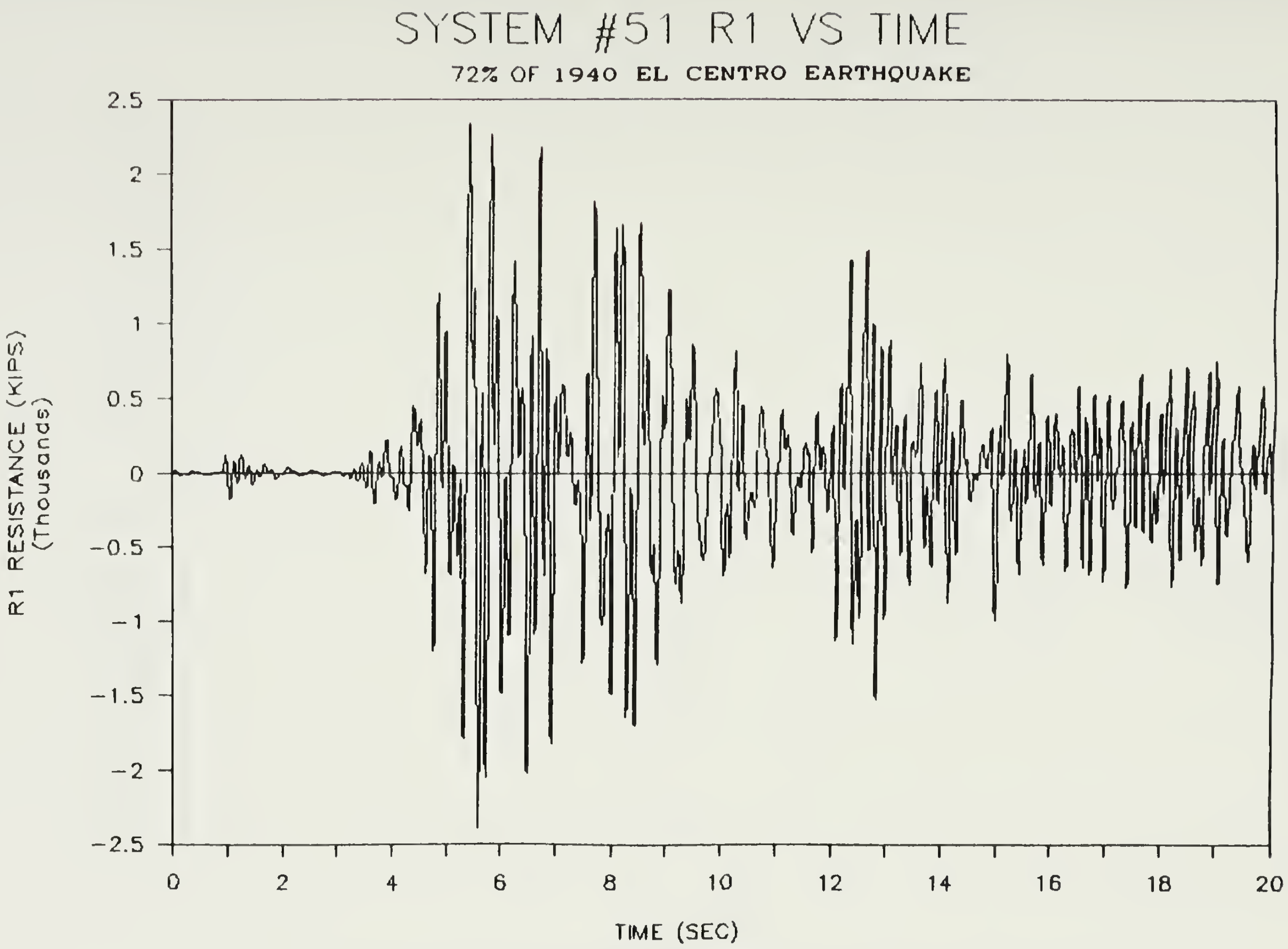
time. This plot shows that the high stiffness solution has relatively small horizontal displacements associated with it. However, the displacements are high in frequency and have abrupt transitions which means the submarine is experiencing high velocities and accelerations. This output is closely coupled to the horizontal earthquake excitation shown in figure (6.6).

These high accelerations can be seen in the keel block horizontal force versus time plot in figure (8.4). The high stiffness solution has keel block horizontal forces which are larger than the low stiffness forces described in chapter 7 by an order of magnitude. Figure (8.5) shows the rotational response of this system. This figure is a plot of the systems rotation about the keel versus time. This plot shows that the rotations are relatively small as is expected with use of wale shores. Figure (8.6) shows that the vertical displacement is coupled with the earthquake's vertical acceleration as is the case for low stiffness solution. Figure (8.7) is a plot of the left wale shore deflection versus time. In this figure, a positive deflection is compression and a negative deflection is expansion. The maximum amount of expansion the wale shores are designed to withstand is 0.57 inches.



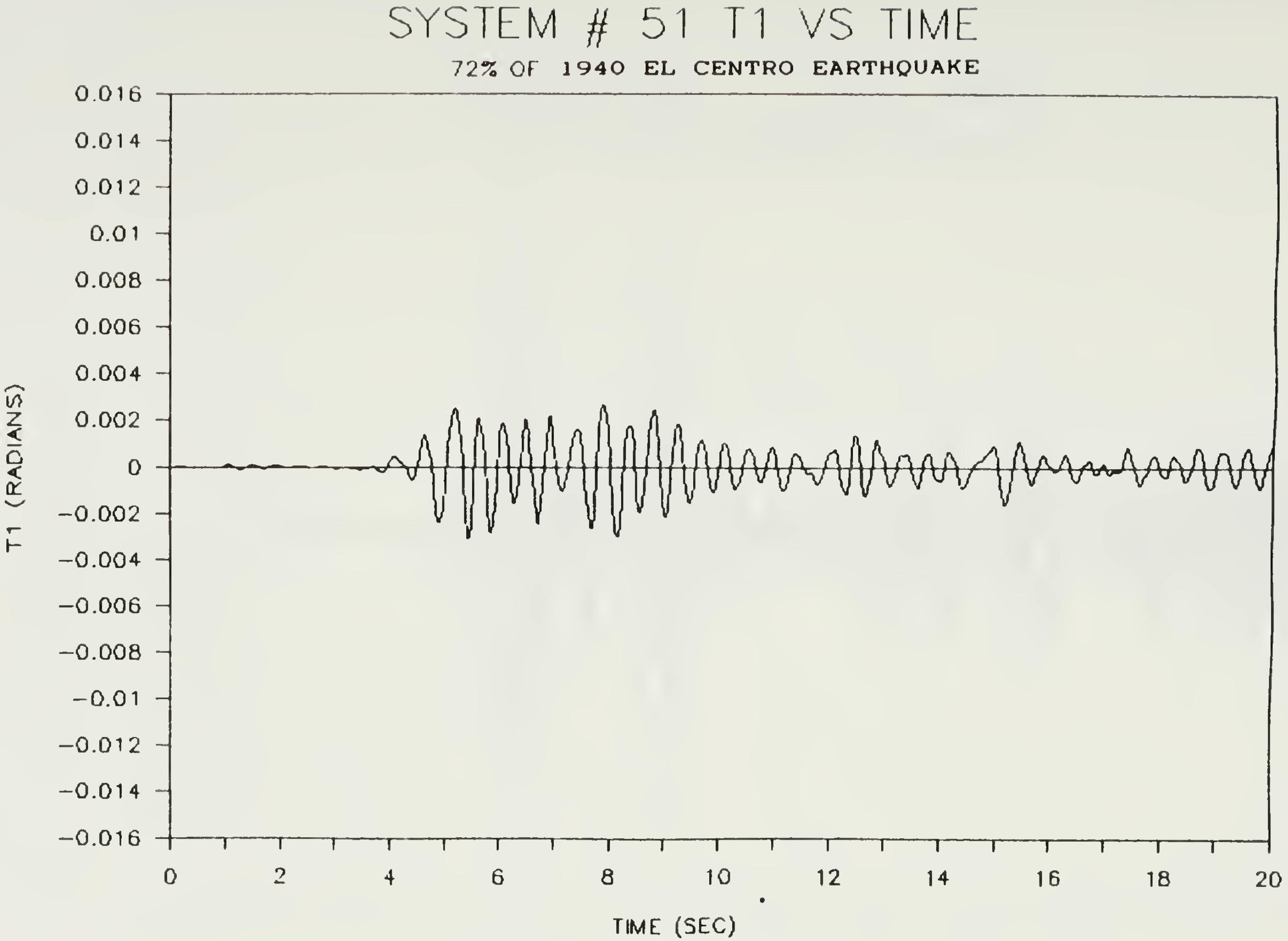
High Stiffness Solution
Keel Block Horizontal Displacement
vs. Time
72 % of 1940 El Centro Earthquake

Figure 8.3



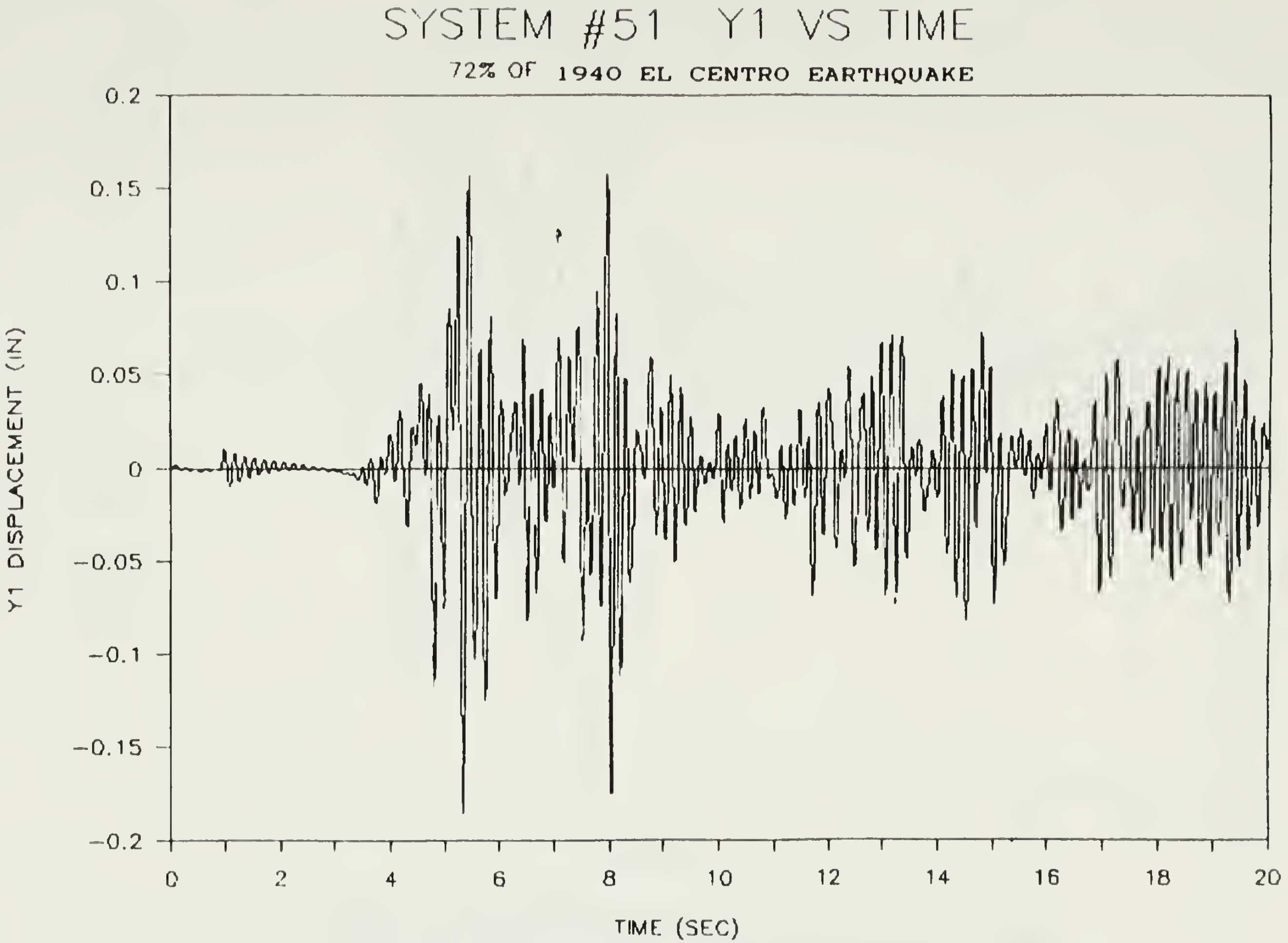
High Stiffness Solution
Keel Block Horizontal Force
vs. Time
72 % of 1940 El Centro Earthquake

Figure 8.4



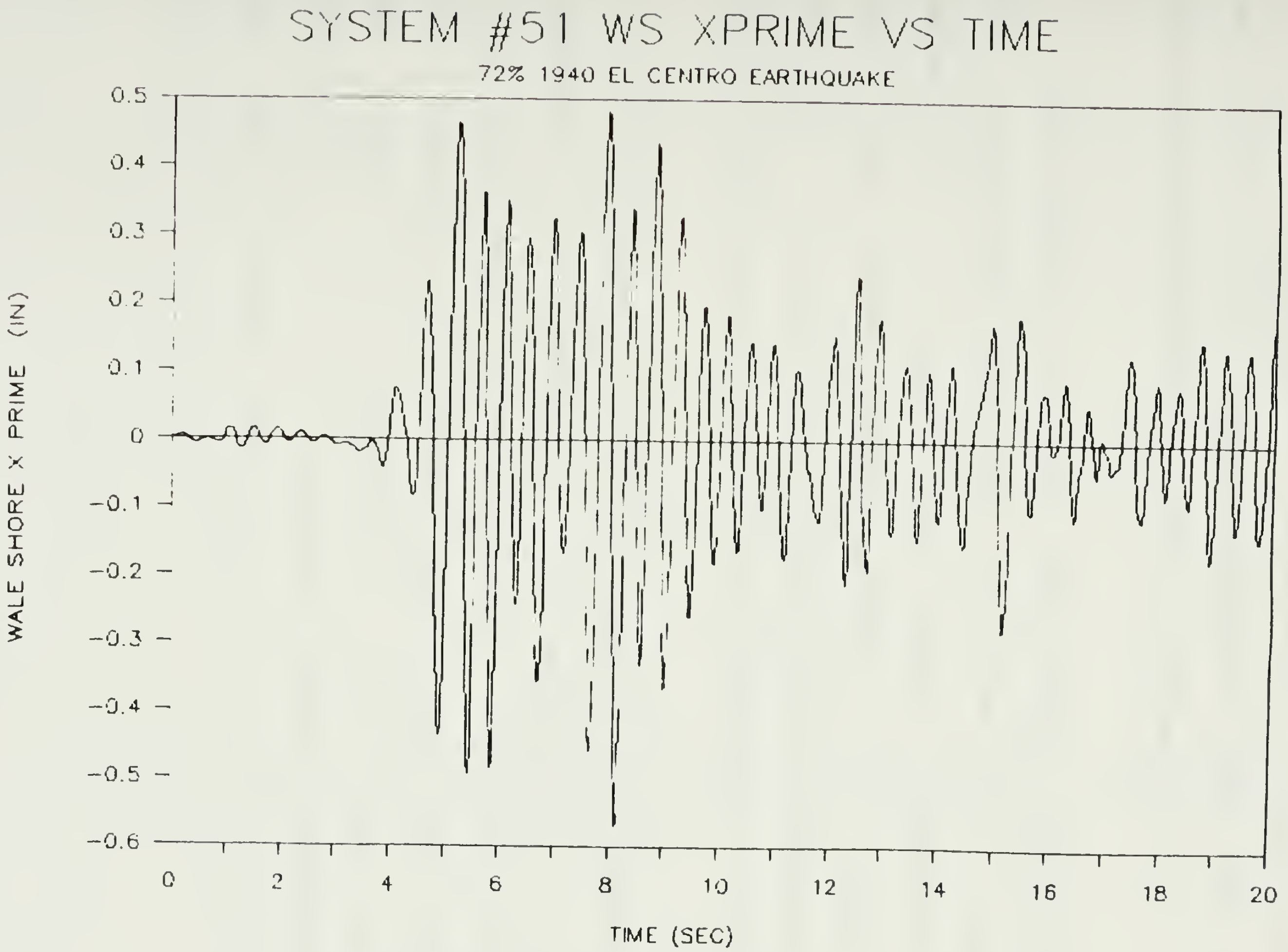
High Stiffness Solution Rotation vs. Time
72 % of 1940 El Centro Earthquake

Figure 8.5



High Stiffness Solution
Keel Block Vertical Displacement vs. Time
72 % of 1940 El Centro Earthquake

Figure 8.6



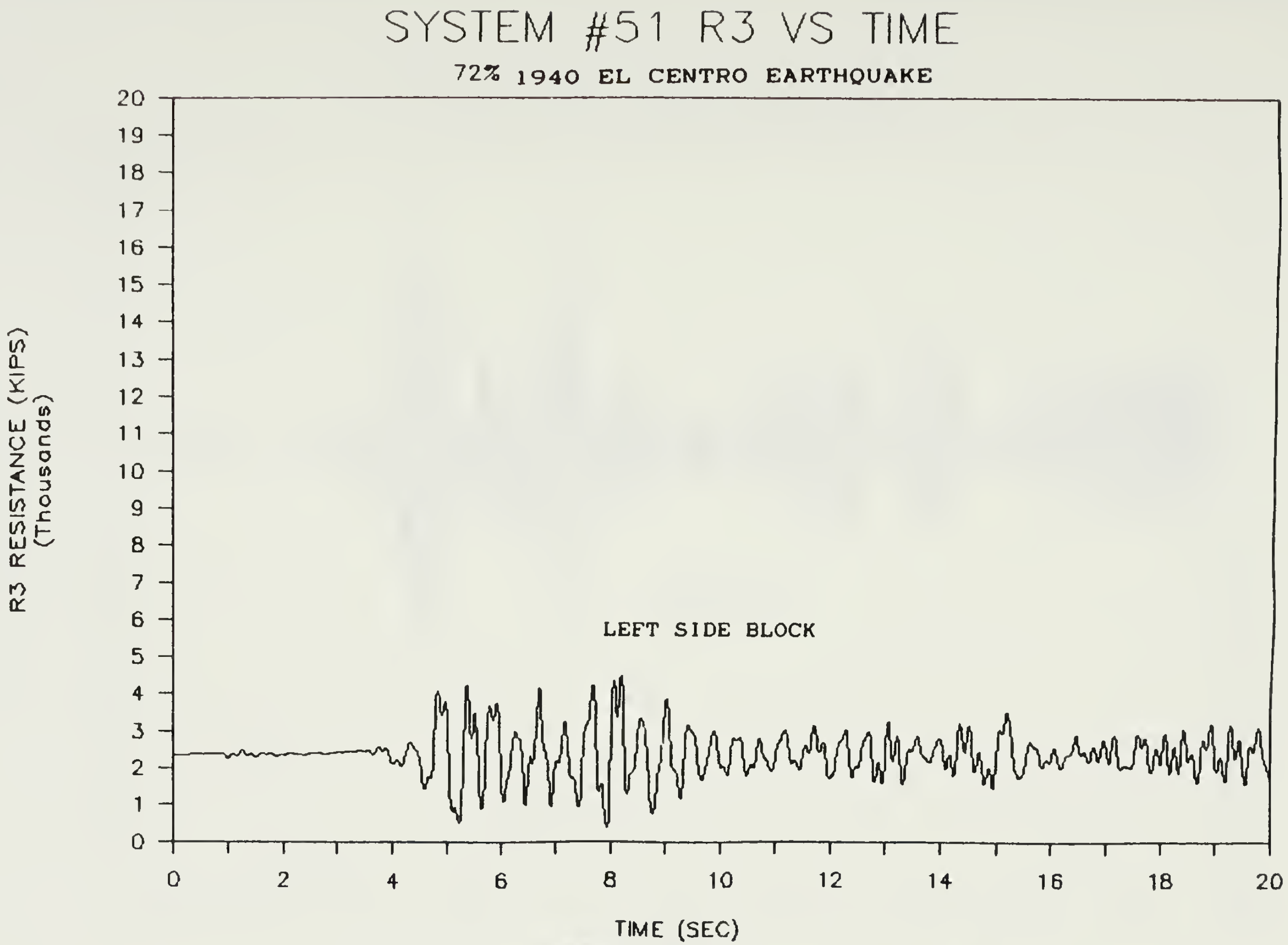
High Stiffness Solution
Wale Shore Horiz. Displacement vs. Time
72 % of 1940 El Centro Earthquake

Figure 8.7

As seen in figure (8.7), the wale shores do not deflect beyond the maximum expansion limit. Therefore, no separation of the wale shores from the submarine occurrs during this earthquake. Without precompression by the jacks, the wale shore would have separated from the submarine.

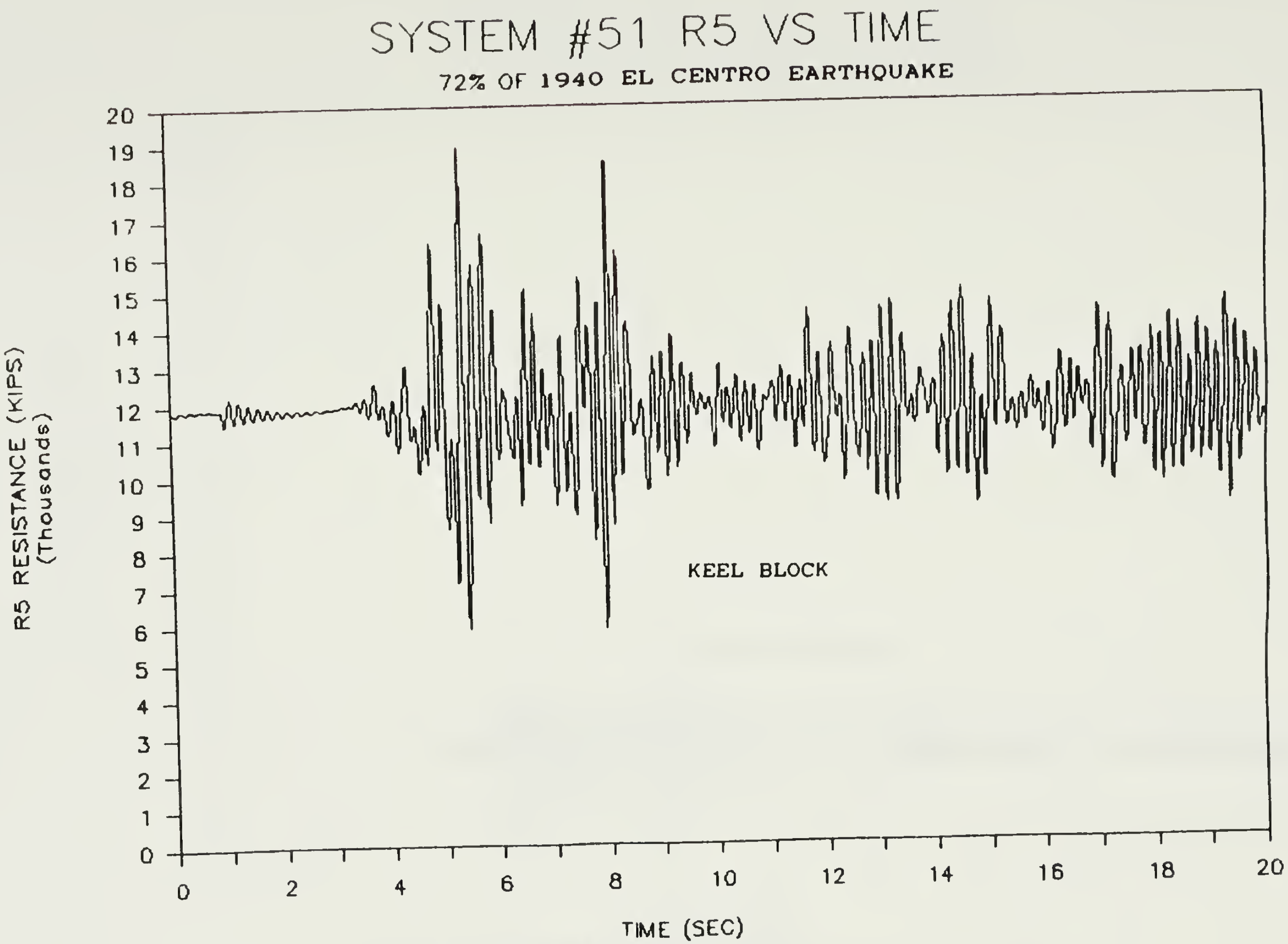
The forces on the left side blocks, keel blocks, and right side blocks are shown in figures (8.8 through 8.10) respectively. In these three figures, at time zero the total force on all three blocking systems is the weight of the submarine. The keel block system's load is 12000 kips (70 %), and each side block system's load is 2300 kips (15 %).

The side block force is mostly due to rotation of the submarine as can be seen by its similarity to figure (8.5) which is the plot of system rotation. The right and left side block plots are 180 degrees out of phase. The forces on the keel are due to a combination of static load and vertical displacement. As is the case with vertical displacement, the keel vertical forces are coupled with the vertical earthquake excitation.



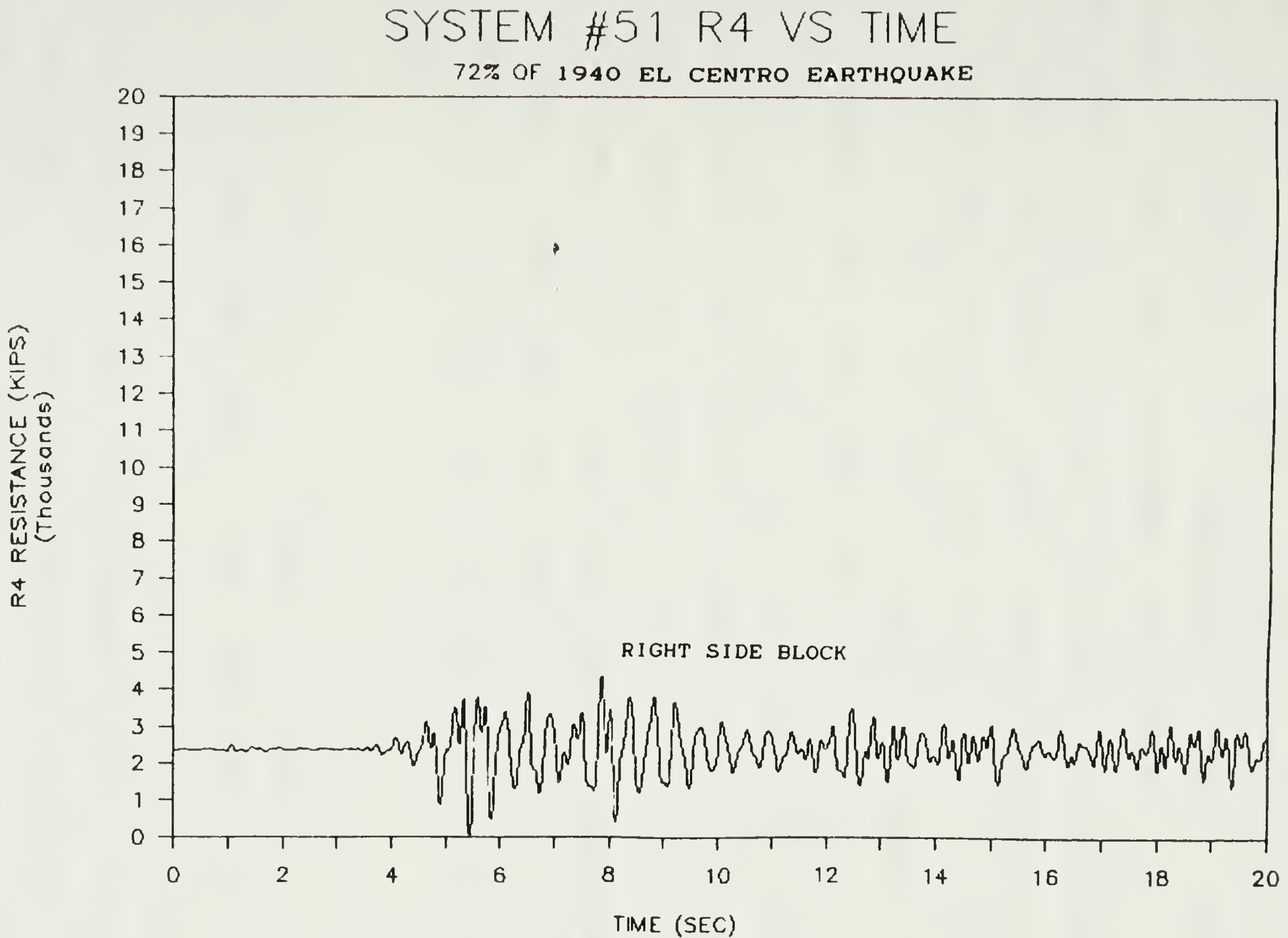
High Stiffness Solution
Right Side Block Vertical Force vs. Time
72 % of 1940 El Centro Earthquake

Figure 8.8



High Stiffness Solution
Keel Block Vertical Force vs. Time
72 % of 1940 El Centro Earthquake

Figure 8.9

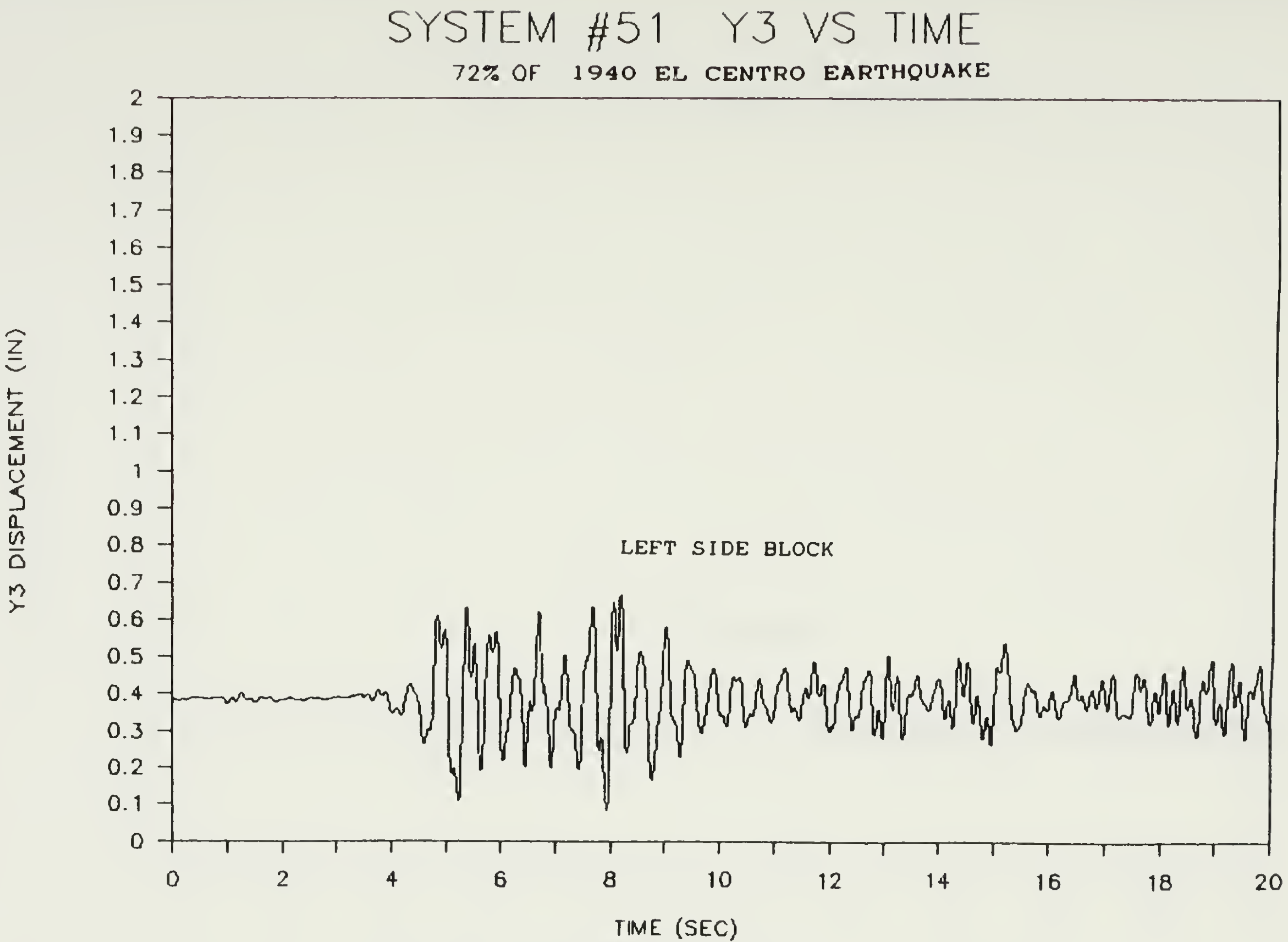


High Stiffness Solution
Left Side Block Vertical Force vs. Time
72 % of 1940 El Centro Earthquake . . . .

Figure 8.10

The displacements of the left side blocks, keel blocks, and right side blocks are shown in figures (8.11 through 8.13) respectively. At time zero, the plots represent the static deflection caused by the submarine's weight. All three systems initially have the same displacement. The initial displacement is approximately 0.38 inches into the rubber cap. This static displacement is only about one-third of that for the low stiffness solution which has 6 inch rubber caps instead of 1 inch. The plots show that liftoff does not occur; however, for the left side block system liftoff came within 0.01 inches of occurring. The right side block system also came within 0.01 inches of liftoff. Even though the high stiffness solution is closer to side block liftoff than the low stiffness solution, since the range of displacement of side blocks is much less for the high stiffness solution the susceptibility of liftoff for both solutions is approximately the same.

Finally, figures (8.14 through 8.16) show the bilinear behavior of the rubber caps. The plots show that the keel blocking system starts out and remains on the second rubber bilinear stiffness slope. For the side blocks, the plots show that both sets of side blocks experience both rubber bilinear stiffness slopes. Figure (8.16) shows how close the right side block is to lifting off. This is reasonable considering failure occurs at a one percent higher earthquake magnitude due to side block liftoff.

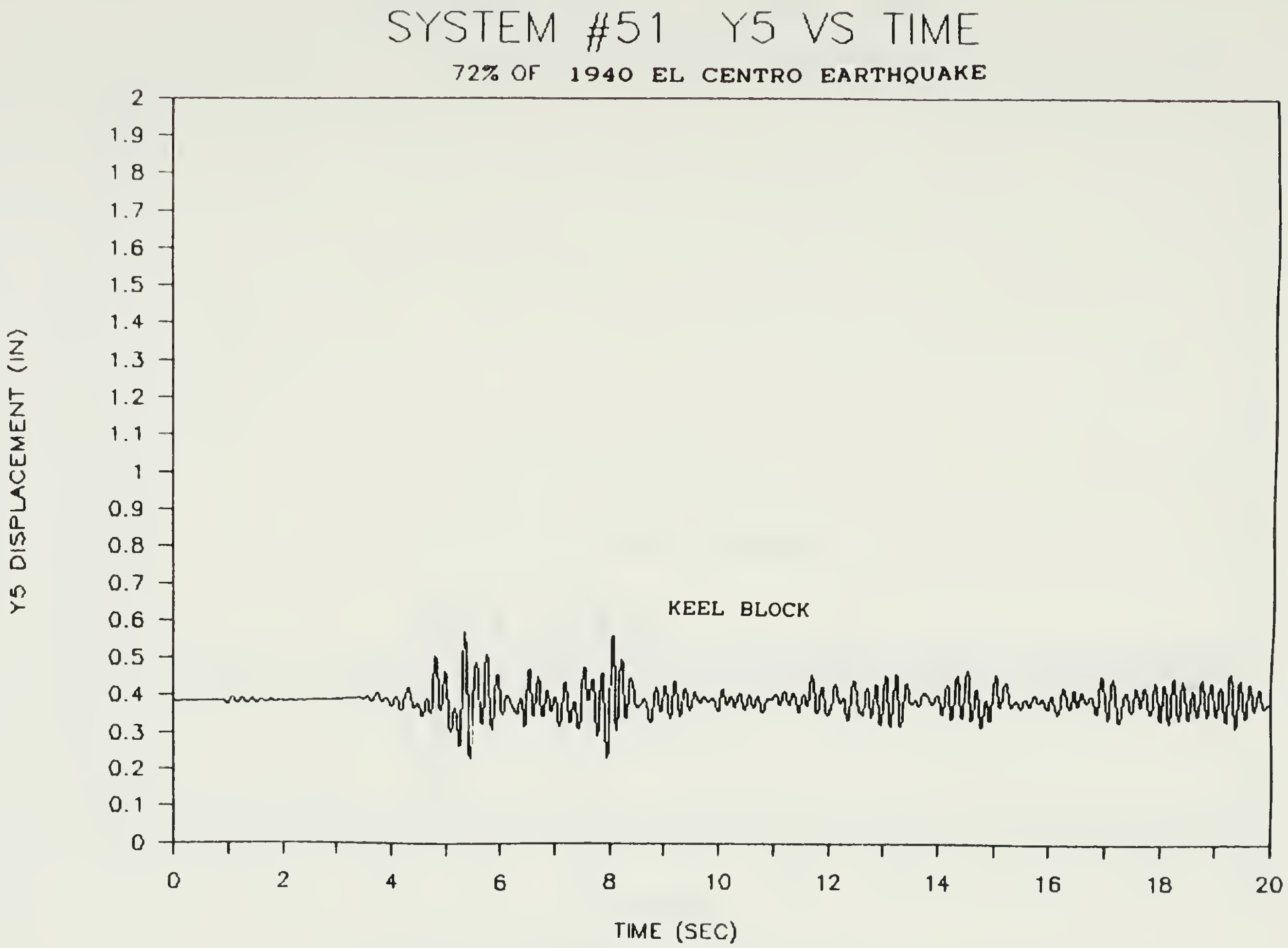


SYSTEM #51 Y3 VS TIME

72% OF 1940 EL CENTRO EARTHQUAKE

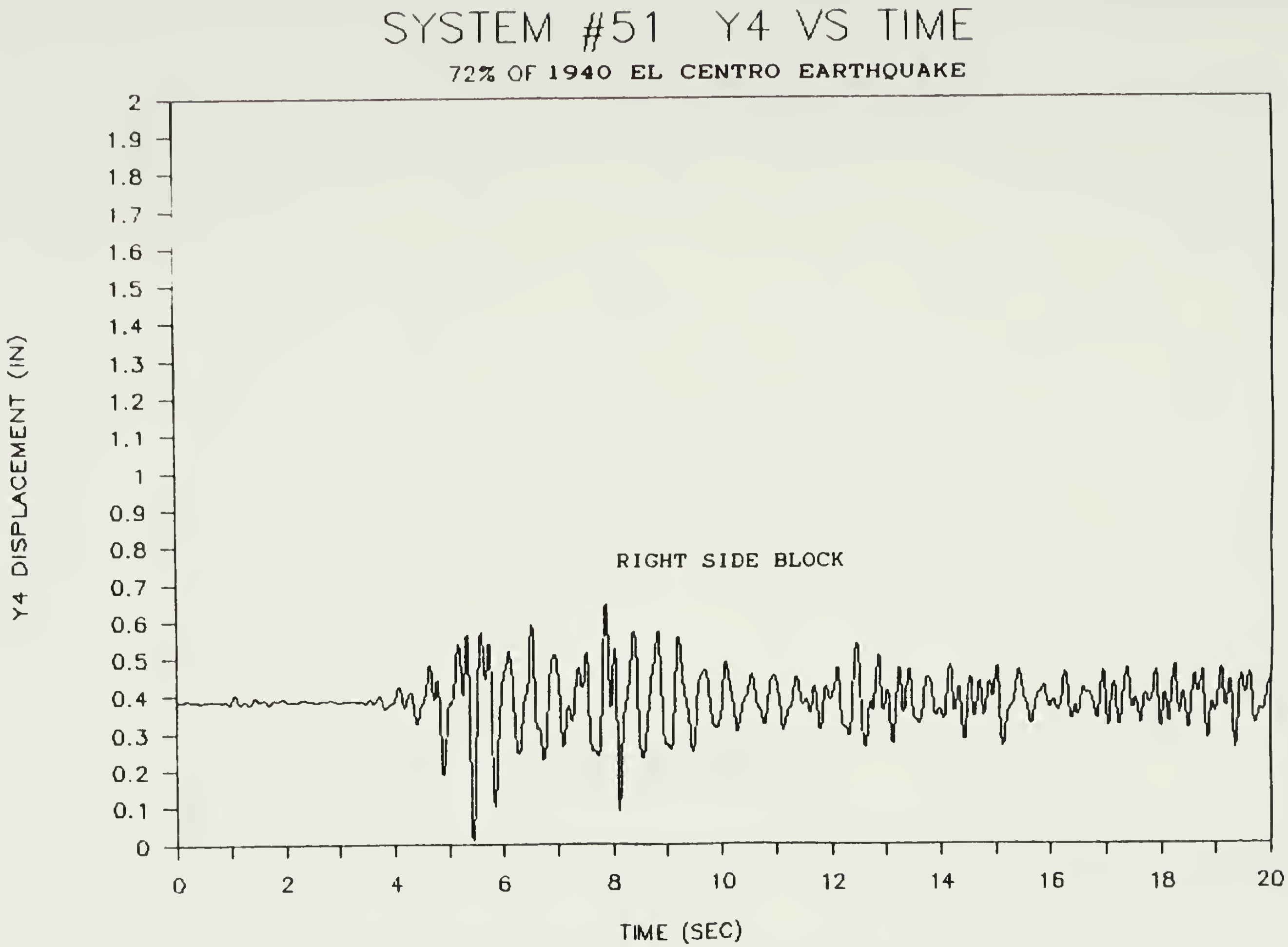
High Stiffness Solution
Left Side Block Vertical Displacement
vs. Time
72 % of 1940 El Centro Earthquake

Figure 8.11



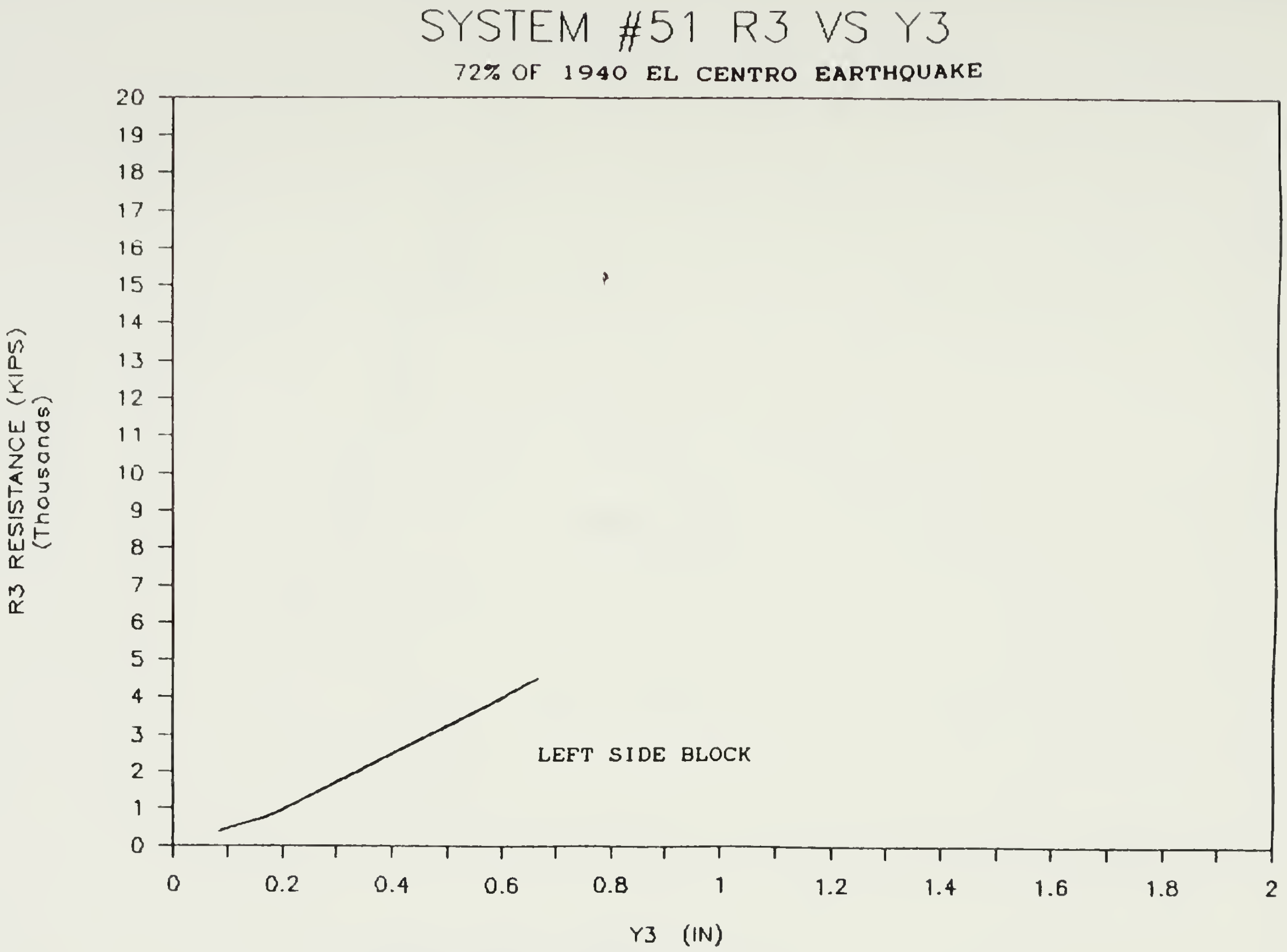
High Stiffness Solution
Keel Block Vertical Displacement vs. Time
72 % of 1940 El Centro Earthquake

Figure 8.12



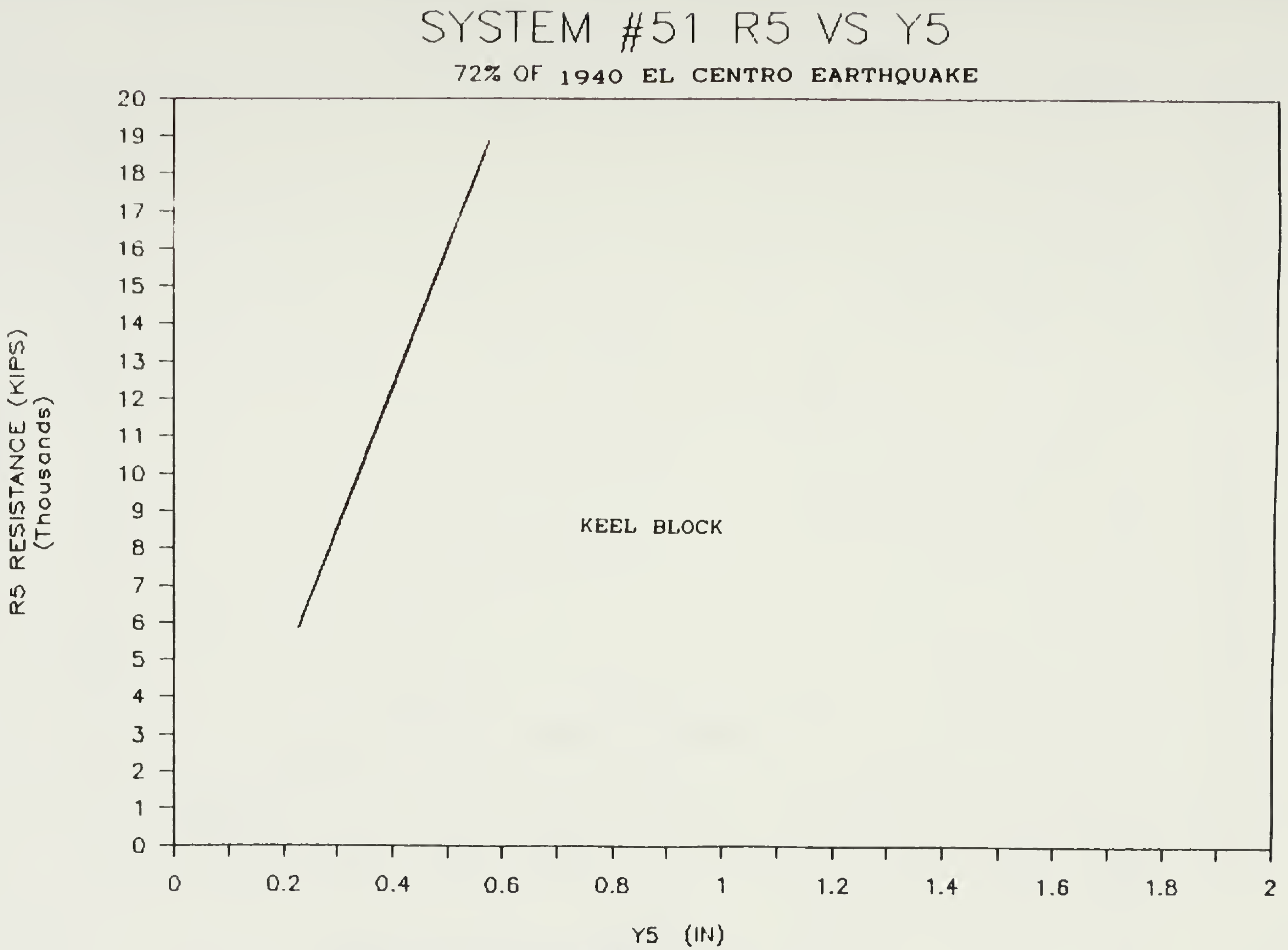
High Stiffness Solution
Right Side Block Vertical Displacement
vs. Time
72 % of 1940 El Centro Earthquake

Figure 8.13



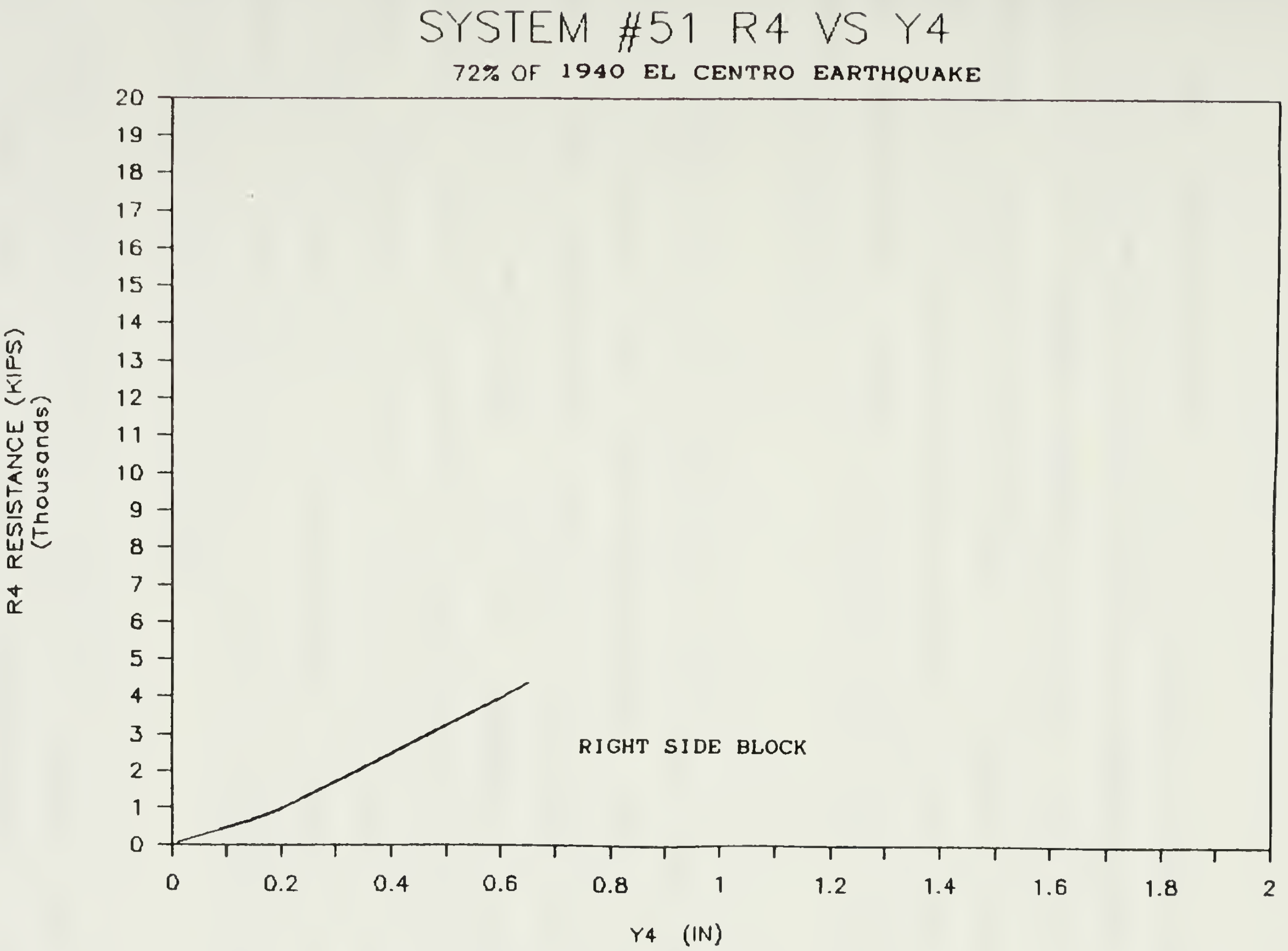
High Stiffness Solution
Right Side Block Vertical Force
vs. Left Side Block Vertical Displacement
72 % of 1940 El Centro Earthquake

Figure 8.14



High Stiffness Solution
Keel Block Vertical Force
vs. Keel Block Vertical Displacement
72 % of 1940 El Centro Earthquake

Figure 8.15



SYSTEM #51 R4 VS Y4

72% OF 1940 EL CENTRO EARTHQUAKE

High Stiffness Solution
Left Side Block Vertical Force
vs. Right Side Block Vertical Displacement
72 % of 1940 El Centro Earthquake

Figure 8.16

CHAPTER 9

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

9.0 Summary of Results

This thesis described the development of the three degree of freedom submarine drydock blocking system design package based on the "3DOFRUB" computer program. The differential equations of motion are developed to include the effect of high blocking systems and wale shores. The sliding failure mode is modified to more accurately take into account the effects of cap angle.

A case study is undertaken involving the earthquake sliding failure of the *USS Leahy* (CG-16) while in a graving dock at Long Beach Naval Shipyard. This study verifies the accuracy and usefulness of the "3DOFRUB" program. A parametric study is conducted to determine the effects of wale shores, isolators, and block stiffness and geometry variations on system survivability. The effects of using earthquake acceleration time histories with differing frequency spectrums on system survivability is studied.

Eleven submarine drydock blocking systems are studied using linear wood caps, bilinear wood caps for two different earthquakes, and one inch bilinear rubber caps. None of these systems survive to dry dock failure (0.26 g's) or even met the

U.S. Navy earthquake acceleration survivability criteria (0.20 g's). This shows that current U.S. Navy submarine drydock blocking systems are inadequate to survive expected earthquakes. Figure (9.1) illustrates the survivability levels of the various systems studied.

Two design solutions are found that met the dry dock failure requirements. The low stiffness solution uses dynamic isolators and rubber caps, and the high stiffness solution uses wale shores and rubber caps. The survivability of these two solutions when excited by the 1940 El Centro Earthquake is plotted in figure (9.2). This figure also includes the survivability of submarine system 1 using linear and bilinear wood, one inch rubber caps, and dynamic isolators. Both of the solutions have the same survivability level, and provide a reasonable margin of safety over the dry dock failure level.

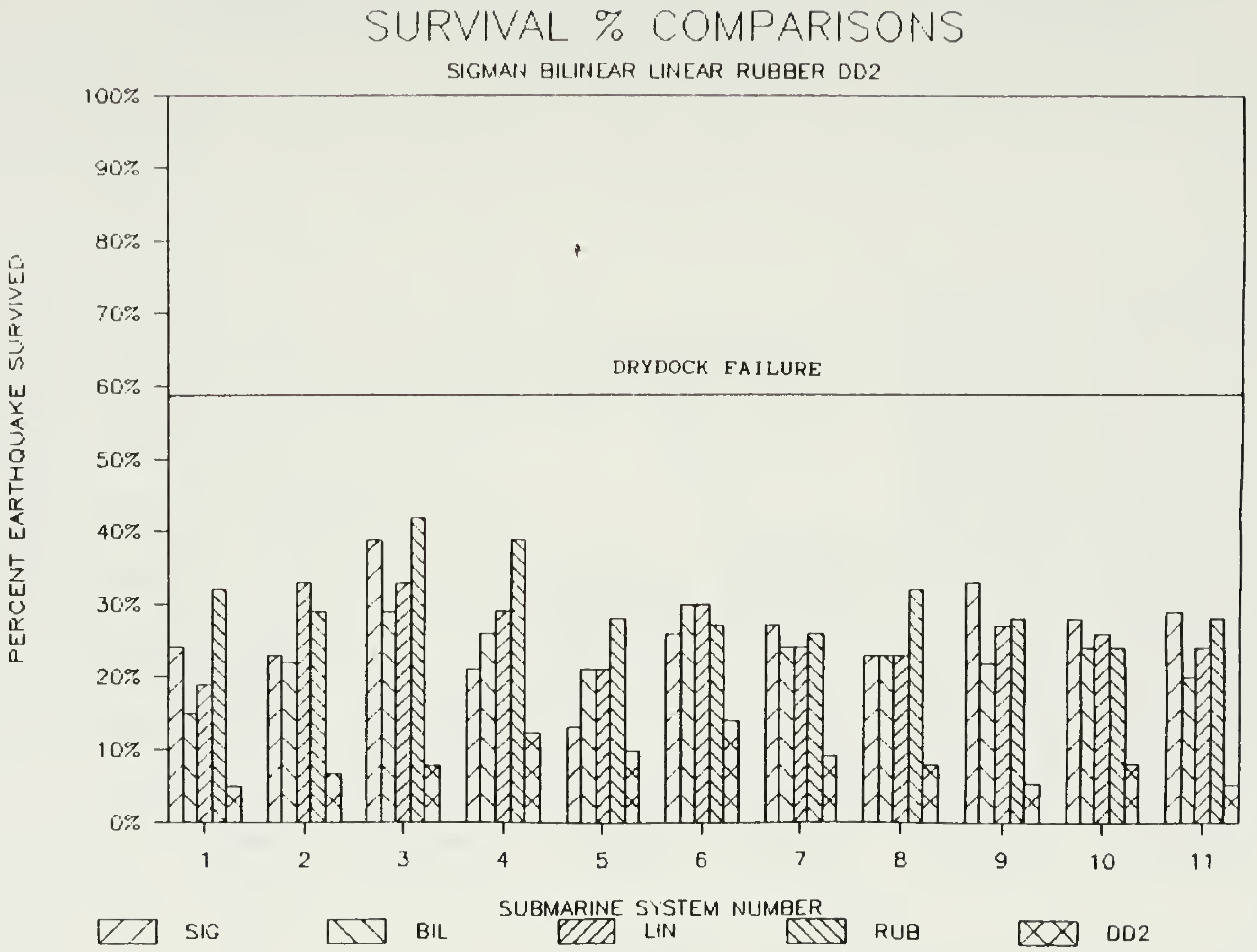

SURVIVAL % COMPARISONS
SIGMAN BILINEAR LINEAR RUBBER DD2
PERCENT EARTHQUAKE SURVIVED
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
DRYDOCK FAILURE
1
2
3
4
5
6
7
8
9
10
11
SUBMARINE SYSTEM NUMBER
SIG
BIL
LIN
RUB
DD2

FIGURE 9.1

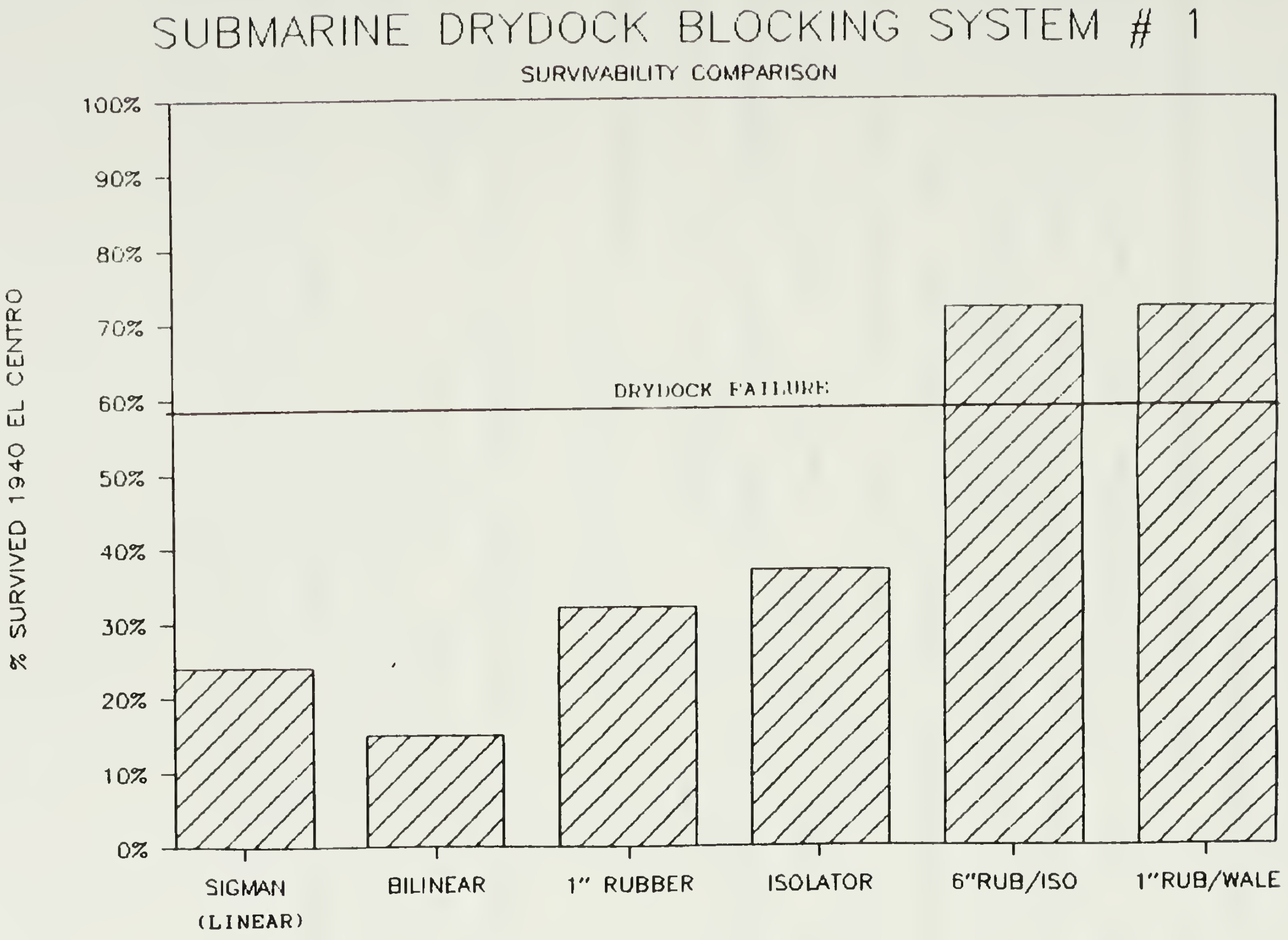
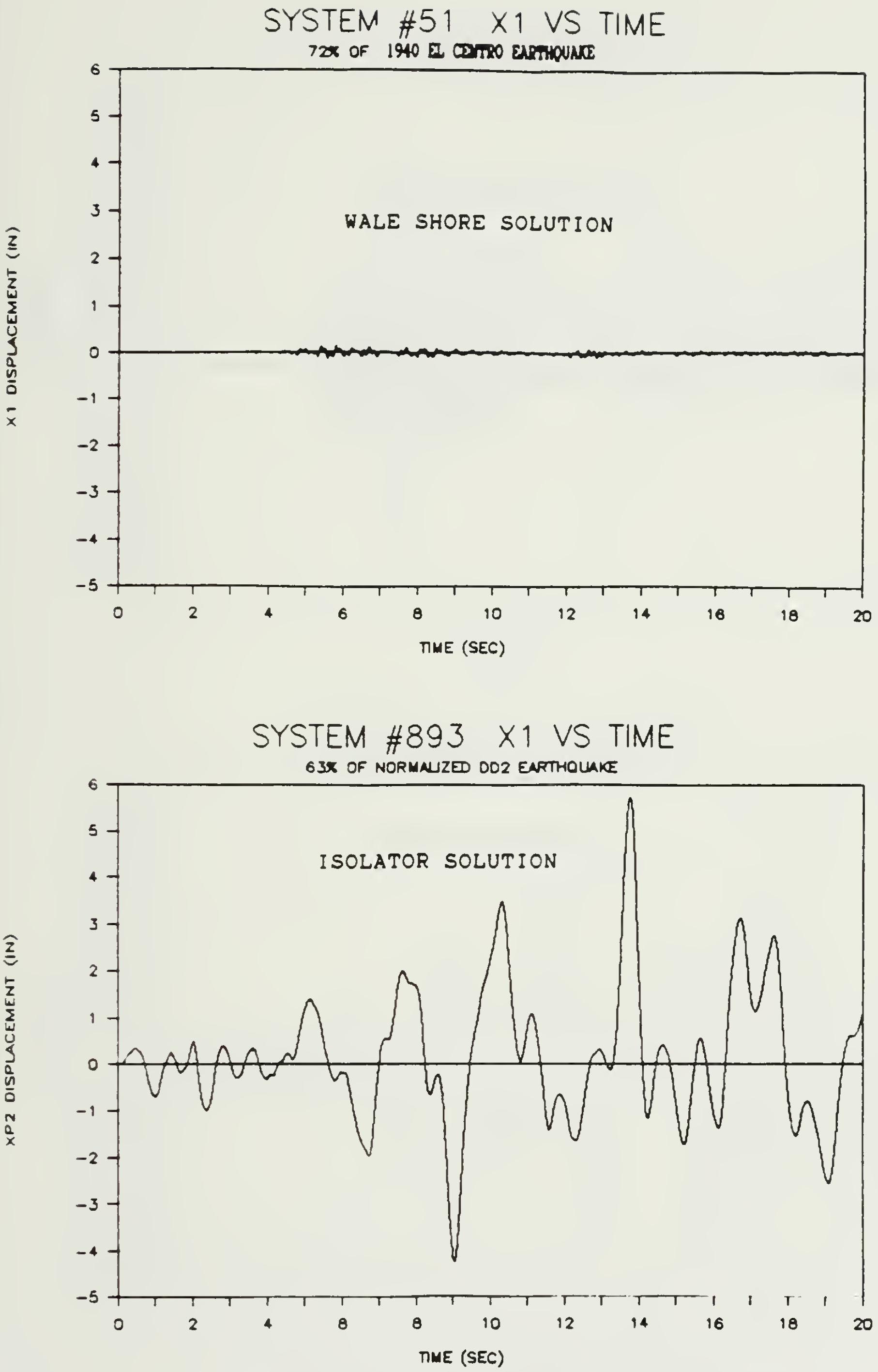

SUBMARINE DRYDOCK BLOCKING SYSTEM # 1
SURVIVABILITY COMPARISON
% SURVIVED 1940 EL CENTRO
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
DRYDOCK FAILURE
SIGMAN (LINEAR)
BILINEAR
1" RUBBER
ISOLATOR
6"RUB/ISO
1"RUB/WALE

FIGURE 9.2

9.1 Conclusions

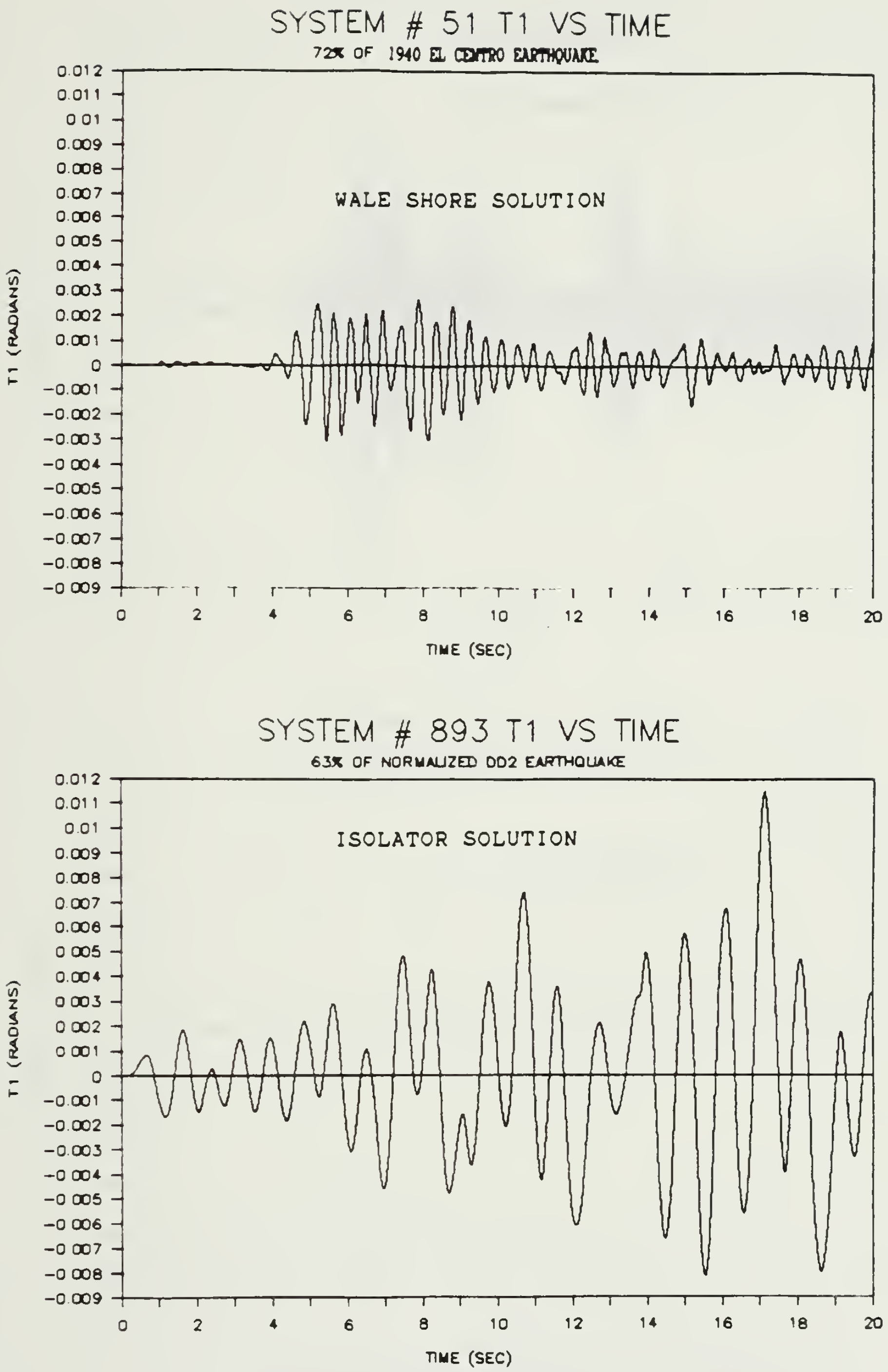
Both of the design solutions survive beyond the dry dock failure level; however, each of the designs have their own advantages and disadvantages. Figure (9.3) is a comparison between the keel block displacements for the wale shore solution and the isolator solution when excited by their respective design earthquakes. It is evident from this figure that the wale shore solution virtually prevents the submarine from moving horizontally relative to the dock floor. The isolator solution allows relatively large horizontal displacements to occur. Figure (9.4) is a comparison of the rotation of these two systems. Again, the wale shores are reducing movement.

The primary difference between the two design solutions is illustrated in figure (9.5). This figure is a comparison between the side block horizontal forces experienced by each solution. As seen in this figure, the wale shore system experiences forces which are an order of magnitude higher than those seen by the isolator solution.



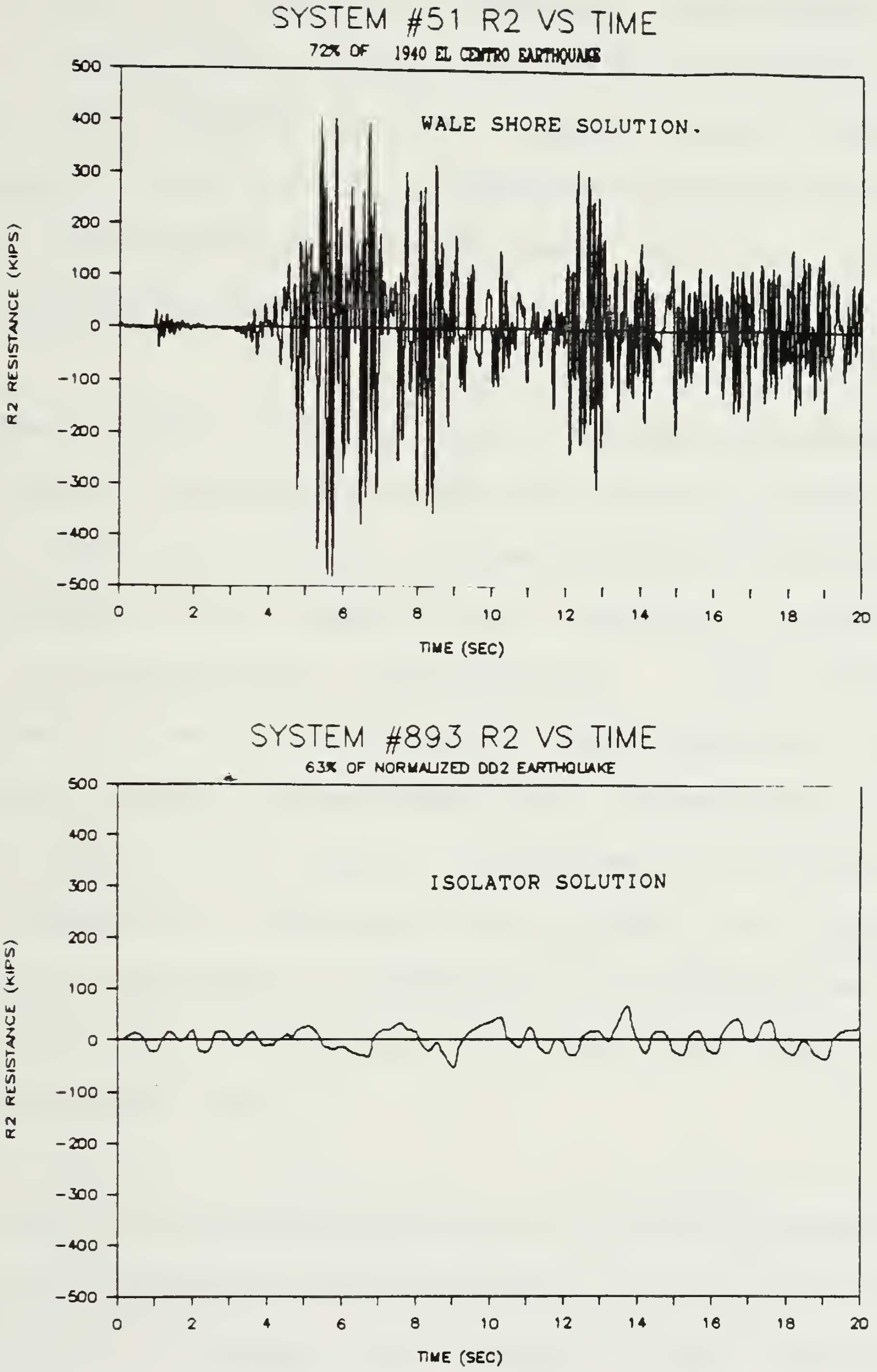
Keel Block Horizontal Displacement
vs. Time Comparison
High Stiffness Solution
and Low Stiffness Solution

Figure 9.3



Rotation vs. Time Comparison
High Stiffness Solution
and Low Stiffness Solution

Figure 9.4



Side Block Horizontal Force vs.
Time Comparison
High Stiffness Solution
and Low Stiffness Solution

Figure 9.5

The forces seen by the wale shore solution are also much more abrupt and higher in frequency. As expected, the wale shore solution very closely follows the earthquake. The wale shore high stiffness solution almost rigidly attaches the submarine to the dry dock. Therefore, personnel and equipment inside the submarine will experience the full acceleration magnitudes of the earthquake.

The isolator solution nearly uncouples the submarine from the dry dock so that the submarine remains almost fixed in space while the dry dock vibrates beneath. The accelerations experienced by the submarine are an order of magnitude less than the earthquake accelerations. This substantially improves the safety of personnel and equipment inside the submarine. Even though submarines are designed to withstand large shock factors, when a submarine is in dry dock much of its equipment and machinery may be open for repairs. In addition, the shocks accompanying an earthquake may last well over one minute as opposed to the very short duration of a an explosion shock wave.

Both of the design solutions can be constructed; however, there are some cost and interference concerns. The wale shore solution will interfere with access to the dry dock to some degree, although the wale shores could be used as utility runs and staging platforms. This solution's impact on the dry dock itself is non-trivial. The installation of 28 hinge

assemblies along the dockside will be a major dry dock modification. In addition, the steel carriage and dry dock floor attachment fixtures are major changes to current drydocking practices and will require significant design and construction efforts.

Most of the modifications required to the blocking system and dry dock are within the capability of shipyards to accomplish. After a drydocking evolution has been completed, many additional manhours will be required to install the wale shores. One wale shore per side can be removed for production reasons while still meeting the survivability criteria. The use of the steel carriage and rubber caps might reduce the hours required to layout a blocking system. The measurements of the system would be locked into the construction, and it would be easier and faster to assemble this blocking system with cranes. The use of rubber and steel in the blocking system is much more reliable than the present oak and Douglas fir.

The isolator solution may be the more expensive solution due to the large number and high cost of the dynamic isolators. However, this solution offers less production interference and a substantial increase in submarine personnel and equipment safety. The actual blocking system size increase will be limited to the cross-connections of the steel carriage, but significant changes will still be required to

the dock floor to allow rigid attachment. Again, the use of the steel carriage and rubber caps should reduce the layout time of the drydock blocking system. Even though the submarine may move up to six inches horizontally during an earthquake using isolators, this motion is acceptable if appropriate precautions are taken in rigging services and platforms.

Considering the almost certain occurrence of a major earthquake in the proximity of a U.S. Naval shipyard where submarines can be drydocked within the next 20 years, the expeditious incorporation of one of these design solutions into U.S. Navy drydocking standards is strongly recommended.

9.2 Recommendations for Further Study

It is highly recommended that the following areas be investigated to further verify the feasibility of the proposed designs:

1. Study the effect of the wide range of existing wood blocking material properties on pier stiffness using statistical analysis.
2. Conduct additional tests on wood blocking materials to determine their properties when loaded at angles to the grain normally seen in a blocking system.

3. Conduct tests on rubber cap material in order determine its stiffness and rigidity behavior under biaxial loading.
4. The specific dynamic isolator and the associated sliders required for the low stiffness solution need to be designed in detail.
5. The steel carriage assembly for both solutions needs to be designed.
6. The required dry dock structural modifications need to be determined.
7. The design solutions need to be verified using model tests employing shaker tables and scale models.
8. A detailed earthquake site specific study needs to be accomplished. This would include the instrumentation of all graving docks susceptible to earthquakes in order to increase the data base. The proposed designs should be checked against a full range of different earthquake acceleration time histories.
9. Surface ship blocking systems need further examination. This should include modeling the flexibility inherent in surface ships. The problem of surface ship's significant longitudinal block loading distribution should also be taken into account.

10. The final design solution for use in Navy dry docks should also take into account the longitudinal excitation and response of the blocking system.

References

1. Hepburn, Richard D., "Non-linear Material Three Degree of Freedom Analysis of Submarine Drydock Blocking Systems", M.I.T. Thesis, May 1988.

2. Sigman, Dale, E., "The Coupled Three Degree of Freedom Motion Response of a Drydocked Submarine to Seismic Load", MIT Thesis, May 1986.

3. Karr, Dale G., "Docking Under Seismic Loads", Final Report to CASDE Corporation for the Naval Sea Systems Command Structural Integrity Division, June 1987.

4. U.S. Navy, ,NAVSEA Technical Manual S9086-7G-STM-000, Chapter 997, Revision 1 "Docking Instructions and Routine Work in Drydock",.

5. Information in enclosure to letter to author from Tingley K. Lew, Structures Division Code L51, Naval Civil Engineering Laboratory, Port Hueneme, California, 19 January 1988.

6. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Geophysical Data Center Code E/GC, "Digital Strong Motion Data", Boulder, Colorado, October 1987.

7. Paz, Mario, Micro Computer-Aided Engineering Structural Dynamics, Von Nostrand Reinhold Company, New York, 1986.

8. Baumeister, Theodore, Editor-in-chief, et al, Marks Standard Handbook for Mechanical Engineers, Eighth Edition, McGraw Hill Book Company, New York, 1978, pp 3-29.

9. Shakal, Tony. "CSMIP Records from Whittier Earthquake of October 1, 1987". California Strong Motion Instrumentation Program (CSMIP), Division of Mines and Geology, Department of Conservation, State of California, October 3, 1987

10. U.S. Department of the Navy, Naval Sea Systems Command, Long Beach Naval Shipyard, "Drydocking Facilities Characteristics", Long Beach Naval Shipyard, March 1985.

11. Kinemetrics Systems brochure, "SMA-1 Strong Motion Accelerograph", Kinemetrics Systems, Pasadena, California, 1986.

12. Gillmer, Thomas C., and Bruce Johnson, Introduction to Naval Architecture,United States Naval Institute, Annapolis, Maryland, 1982, p. 272.

13. Rabinowicz, Ernest, Lecture, "Tribology", M.I.T., Course 2.800, Fall 1987.

14. Telephone conversation between Tingley K. Lew, Structures Division Code L51, Naval Civil Engineering Laboratory, Port Hueneme, California, and LCDR Richard D. Hepburn, M.I.T. Graduate Student, 1 February 1988.

15. Information in enclosure to letter from Tingley K. Lew, Structures Division Code L51, Naval Civil Engineering Laboratory, Port Hueneme, California, to LCDR Richard D. Hepburn, M.I.T. Graduate Student, 19 January 1988.

16. Telephone conversation between Ian G. Buckle, Vice President for Engineering Dynamic Isolation Systems Incorporated, Berkeley, California, and LCDR Richard D. Hepburn, M.I.T. Graduate Student, January 1988.

17 Meirovitch, Leonard, Elements of Vibration Analysis, McGraw Hill Inc., New York, 1975, p. 56-57.

18. Telephone conversation between Ian G. Buckle, Vice President for Engineering Dynamic Isolation Systems Incorporated, Berkeley, California, and LCDR Richard D. Hepburn, M.I.T. Graduate Student, February 1988.

19. Hughes, Owen, Ship Structural Design: A Rationally-Based, Computer-Aided, Optimization Approach, John Wiley & Sons, New York, 1983, pp. 396-399.

20. Popov, Egor P., Introduction to Mechanics of Solids, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1968, pp. 531,557.

APPENDIX 1

1. "3DOFRUB" Computer Program Listing
2. "ACCLINPT","BILINALL","RUBBER", and "RESPALL" Subroutine Listings
3. Sample Input Data File and Output File

"3DOFRUB" Computer Program Listing

```

$title:  '3DOFRUB'
$nofloatcalls
$storage: 2

C-----------------------------------------------------------------

C     NON-LINEAR THREE DEGREE OF FREEDOM SYSTEM RESPONSE
C      USING FOURTH ORDER RUNGE-KUTTA METHOD
C      AND BILINEAR VERTICAL & HORIZONTAL STIFFNESSES
C        WITH HORZ/VERT ACCELERATION INPUT
C        AND DISPLACEMENT OUTPUT FILES
C      (INCLUDES WALE SHORE EFFECTS & HIGH BUILDUPS
C      AND THE USE OF RUBBER CAPS)

C-----------------------------------------------------------------


      integer NN,l,mm,n,hull,nsys,flag10,11
        integer flag1,flag2,flag3,flag4,flag5,flag6,flag7,flag8
      integer KY1,KY2,KY3,KY4,WWW1,YYY1,UUU1,WWW2,YYY2,UUU2,WWW3,YYY3
      integer UUU3,WWW4,YYY4,UUU4,UUU5,WWW5,YYY5,decrr
      real*8 beta,weight,h,Ik,gravity,AAA,Ks,sidearea,keelarea,plside
      real ac(2002),acv(2002),xx(2002),yy(2002),tt(2002),rrr(2002)
      real*8 m(4,4),cx(4,4),k(4,4),ko(4,4),crit2,crit3
        real*8 baseside,basekeel,htside,htkeel
        real*8 dtau,maxx,maxt,maxy,timex,timet
        real*8 rf1,rf2,rf3,hf1,hf2,hf3,ampacc,mass,ampacmax
        real*8 kvs,kvk,kvkp,khs,khk,kshp,kkhp,kvsp,base,counter,time
        real*8 time1,time2,time3,time4,time5,time6,time7,time8
      real*8 x,t,y,xold,told,yold,XSCL(6)
      real*8 bbb,ccc,w12,w1,w22,w2,w32,w3,mode1,mode3
      real*8 mmx1,mmang1,mmx3,mmang3,crit4,alpha,LLL
        real*8 timey,mmmmm1,mmmmm2,mmmmm3,mmmmm4
      real*8 R,S,TAU,A(6),B(6),C(6),D(6),E(6),F(6),G(6),HH(6)
      real*8 br,amp,plkeel,u1,u2,XPRIM,VEL
      real*8 KU1,KD1,khhb,QD1,XEL1,XMAX1,XMIN1,RR1,ZZ1,WZ1,VEL1
      real*8 KU2,KD2,khsb,QD2,XEL2,XMAX2,XMIN2,RR2,ZZ2,WZ2,YPRIM1
      real*8 KU3,KD3,kvsb1,QD3,YEL1,YMAX1,YMIN1,RR3,ZZ3,WZ3,DELTA
      real*8 KU4,KD4,kvsb2,YEL2,YMAX2,YMIN2,RR4,ZZ4,WZ4,YPRIM2,VEL2
      real*8 KU5,KD5,kvkb,QD4,YEL3,YMAX3,YMIN3,RR5,ZZ5,WZ5,YPRIM3
      CHARACTER*40 DEC,DECV,quakname,hname,vname
      character*40 sbfname,aclfname,outfname,vfname



C     READ IN VESSEL AND DRYDOCK DATA: VESSEL WEIGHT,KG,I(ABOUT KEEL),
C     TIME INCREMENT OF DATA POINTS,VERTICAL STIFFNESS OF SIDE AND
C     KEEL PIERS,HORIZONTAL STIFFNESS OF SIDE AND KEEL PIERS,
C     GAVITATIONAL CONSTANT,SIDE BLOCK BASE AND HEIGHT,
C     KEEL BLOCK BASE AND HEIGHT,
C     BLOCK-BLOCK AND BLOCK-HULL FRICTION COEFFICIENTS,
C     SIDE AND KEEL BLOCK'S PROPORTIONAL LIMIT,
C     SIDE PIER-VESSEL CONTACT AREA,KEEL PIER-VESSEL CONTACT AREA,
C     CAP BLOCK INCLINATION ANGLE.

C       OPEN INPUT FILES AND READ DATA

        write(*,'(a)') ' ENTER SHIP/BUILDUP FILE NAME ... '
```

```
D Line# 1      7
             read(*,'(a)') sbfname

             open(4,file= sbfname,status='old',form='formatted')

             read(4,*) weight,h,Ik,kvs,kvsp,kvk,AAA,Ks
           read(4,*) khs,khk,kshp,kkhp,QD1,QD2,QD3,gravity
             read(4,*) baseside, basekeel,htside,htkeel,u1,u2
             read(4,*) br,plside,plkeel,sidearea,keelarea,zeta
           read(4,*) hull,nsys,beta,QD4,kvkp
           CLOSE (4)

           write (*,*) 'DO YOU WANT RESPONSE OUTPUT FILES? (Y OR N)'
           read(*,'(a)') dec
           if (dec.eq.'Y'.or.dec.eq.'y') then
           write(*,*) 'INPUT DESIRED RESISTANCE OUTPUT: (1,2,3,4,5)'
           write(*,*) 'KEEL HORIZONTAL FORCE        = 1'
           write(*,*) 'SIDE BLOCK HORIZONTAL FORCE = 2'
           write(*,*) 'LEFT SIDE BLOCK VERT FORCE  = 3'
           write(*,*) 'RIGHT SIDE BLOCK VERT FORCE = 4'
           write(*,*) 'KEEL BLOCK VERTICAL FORCE   = 5'
           read(*,*) decrr
           endif

           do 12,i=1,3
1          do 13,j=1,3
2          m(i,j)=0.0
2          k(i,j)=0.0
2          cx(i,j)=0.0
2          ko(i,j)=0.0
2      13  continue
1      12  continue


       C   CALCULATE SYSTEM PARAMETERS

           mass=weight/gravity
           LLL=sqrt((htside-htkeel)**2D0+(br/2D0)**2D0)
           alpha=asin((htside-htkeel)/LLL)

           m(1,1)=mass
           m(1,3)=h*mass
           m(2,2)=mass
           m(3,1)=mass*h
           m(3,3)=Ik

           k(1,1)=(2D0*Ks+2D0*khs+khk)
           k(1,3)=(2D0*Ks*AAA+2D0*khs*LLL*sin(alpha))
           k(3,1)=k(1,3)
           k(2,2)=(2D0*kvs+kvk)
           k(3,3)=(2D0*Ks*AAA**2D0+2D0*khs*((LLL*sin(alpha))**2D0)+
          + (2D0*kvs*((LLL*cos(alpha))**2D0)-(weight*h)))
           ko(1,1)=k(1,1)
           ko(1,3)=k(1,3)
           ko(3,1)=k(3,1)
           ko(2,2)=k(2,2)
           ko(3,3)=k(3,3)

       C   DETERMINE NATURAL FREQUENCIES OF SYSTEM
           bbb=-(m(1,1)*k(3,3)+m(3,3)*k(1,1)-m(1,3)*k(3,1)-m(3,1)*k(1,3))
```

```
     + /(m(1,1)*m(3,3)-m(1,3)*m(3,1))
      ccc=(k(1,1)*k(3,3)-k(1,3)*k(3,1))/(m(1,1)*m(3,3)-m(1,3)*m(3,1))
C

C     NATURAL FREQ. MODE #1

      w12=(-bbb-sqrt(bbb**2-4D0*ccc))/2D0
      w1=sqrt(w12)

C     NATURAL FREQ. MODE #2

        w22=k(2,2)/m(2,2)
      w2=sqrt(w22)
C     NATURAL FREQ. MODE #3

        w32=(-bbb+sqrt(bbb**2-4D0*ccc))/2D0
      w3=sqrt(w32)

C     MODE SHAPE #1 & #3

      mode1=(m(1,3)*w12-k(1,3))/(-m(1,1)*w12+k(1,1))
      mode3=(m(1,3)*w32-k(1,3))/(-m(1,1)*w32+k(1,1))
C     DETERMINE C11,C13,C31,C33
      mmx1=m(1,1)+m(1,3)/mode1
      mmang1=mode1*m(3,1)+m(3,3)
      mmx3=m(1,1)+m(1,3)/mode3
      mmang3=mode3*m(3,1)+m(3,3)
      mmmmm1=2D0*zeta*mmx1*w1
      mmmmm2=2D0*zeta*mmx3*w3
      mmmmm3=2D0*zeta*mmang1*w1
      mmmmm4=2D0*zeta*mmang3*w3




      cx(1,3)=(mmmmm1-mmmmm2)/(1/mode1-1/mode3)
      cx(1,1)=mmmmm1-(cx(1,3)/mode1)
      cx(2,2)=2D0*zeta*m(2,2)*w2
      cx(3,1)=(mmmmm3-mmmmm4)/(mode1-mode3)
      cx(3,3)=mmmmm3-(cx(3,1)*mode1)


C     READ IN ACCELERATION DATA

      CALL ACCLINPT(amp,ac,acv,dtau,quakname,hname,vname)

C     ESTABLISH FAILURE CRITERIA AND FLAGS

      crit2=min (u1,u2)
      crit3= (6.6D-1*baseside-1.2D1)/htside
      crit4=basekeel/(6D0*htkeel)
      ampacc=1D0
      counter=0.0
      ampacmax=0.0
10000 continue
        write(*,*) ampacc
      flag1=0
      flag2=0
```

```
      flag3=0
      flag4=0
      flag5=0
      flag6=0
      flag7=0
      flag8=0
      flag10=0
      maxx=0.0
      maxt=0.0
      maxy=0.0
      mm=0
      x=0.0
      y=0.0
      t=0.0
      xold=0.0
      yold=0.0
      told=0.0
      R=0.0
      S=0.0
      TAU=0.0

C     INITIALIZING BILINEAR VARIABLES

C     INITIALIZING DELTA

      if (kvs.eq.kvsp) then
        YEL1=0.0
        elseif (kvs.ne.kvsp) then
        YEL1=QD3/(kvs-kvsp)
      endif
      if (kvk.eq.kvkp) then
        YEL3=0.0
        elseif (kvk.ne.kvkp) then
        YEL3=QD4/(kvk-kvkp)
      endif
      DELTA=weight/(2D0*kvs+kvk)
      if (QD3.ge.0.0.or.QD4.ge.0.0) then
        kvsb1=kvs
        kvkb=kvk
      goto 100
      endif
      if (DELTA.lt.YEL3.and.DELTA.lt.YEL1) then
        kvsb1=kvs
        kvkb=kvk
      elseif (DELTA.ge.YEL3.or.DELTA.ge.YEL1) then
        kvsb1=kvsp
        kvkb=kvkp
        DELTA=YEL3+(weight-(YEL3*(2D0*kvs+kvk)))/(2D0*kvsp+kvkp)
      endif

100   continue

C     INITIALIZING KEEL HORIZONTAL STIFFNESS

      KU1=khk
      KD1=kkhp
      khkb=KU1
      if (QD1 .eq. 0.0) goto 101
      KY1=0
```

```
      XEL1=QD1/(KU1-KD1)
      XMAX1=0.0
      XMIN1=0.0
      RR1=0.0
      ZZ1=0.0
      WZ1=0.0
      WWW1=0.0
      YYY1=0.0
      UUU1=0.0

101   continue

C     INITIALIZING SIDE BLOCK HORIZONTAL STIFFNESS

      KU2=khs
      KD2=kshp
      khsb=KU2
      if (QD2 .eq. 0.0) goto 102
      KY2=0
      XEL2=QD2/(KU2-KD2)
      XMAX2=0.0
      XMIN2=0.0
      RR2=0.0
      ZZ2=0.0
      WZ2=0.0
      WWW2=0.0
      YYY2=0.0
      UUU2=0.0

102   continue

C     INITIALIZING LEFT SIDE BLOCK VERTICAL STIFFNESS

      KU3=kvs
      KD3=kvsp
      if (QD3 .eq. 0.0) goto 103
      KY3=0
      YMAX1=0.0
      YMIN1=0.0
      RR3=kvsb1*DELTA
      ZZ3=0.0
      WZ3=0.0
      WWW3=0.0
      YYY3=0.0
      UUU3=0.0

103   continue

C     INITIALIZING RIGHT SIDE BLOCK VERTICAL STIFFNESS
      KU4=kvs
      KD4=kvsp
      kvsb2=kvsb1
      if (QD3 .eq. 0.0) goto 104
      KY4=0
      YEL2=YEL1
      YMAX2=0.0
      YMIN2=0.0
      RR4=kvsb2*DELTA
      ZZ4=0.0
```

```fortran
      WZ4=0.0
      WWW4=0.0
      YYY4=0.0
      UUU4=0.0

104   continue

C     INITIALIZING KEEL VERTICAL STIFFNESS

      KU5=kvk
      KD5=kvkp
      if (QD4.eq.0.0) goto 105
      KY5=0
      YMAX3=0.0
      YMIN3=0.0
      RR5=kvkb*DELTA
      ZZ5=0.0
      WZ5=0.0
      WWW5=0.0
      YYY5=0.0
      UUU5=0.0

105   continue

C     IMPLEMENTATION OF EQUATIONS OF MOTION INTO THE
C      RUNGE-KUTTA FORMULUS

      do 301,l=1,2000

C     CALCULATE BILINEAR STIFFNESS AND RESISTANCE

C     CALCULATE KEEL HORIZONTAL BILINEAR STIFFNESS

      if (QD1 .eq. 0.0) goto 106

      CALL BILINALL(x,S,khkb,RR1,KD1,QD1,KU1,XEL1,XMAX1,XMIN1,
     +  KY1,ZZ1,WZ1,WWW1,YYY1,UUU1)

106   continue

C     CALCULATE SIDE BLOCK HORIZONTAL BILINEAR STIFFNESS

      XPRIM=+x+LLL*t*sin(alpha)

      if (QD2 .eq. 0.0) goto 107

      VEL=+S+LLL*TAU*sin(alpha)

      CALL BILINALL(XPRIM,VEL,khsb,RR2,KD2,QD2,KU2,XEL2,XMAX2,XMIN2,
     +  KY2,ZZ2,WZ2,WWW2,YYY2,UUU2)

107   continue

C     CALCULATE LEFT SIDE BLOCK VERTICAL BILINEAR STIFFNESS

      YPRIM1=-y-t*LLL*cos(alpha)+DELTA

      if (QD3 .eq. 0.0) goto 108
      if (QD3 .gt. 0.0) then
```

```

      VEL1=-R-TAU*LLL*cos(alpha)

      CALL BILINALL(YPRIM1,VEL1,kvsb1,RR3,KD3,QD3,KU3,YEL1,YMAX1,
     +  YMIN1,KY3,ZZ3,WZ3,WWW3,YYY3,UUU3)

      elseif (QD3 .lt. 0.0) then

      CALL RUBBER(YPRIM1,kvsb1,RR3,KD3,QD3,KU3,YEL1)

      endif

  108 continue

C     CALCULATE RIGHT SIDE BLOCK VERTICAL BILINEAR STIFFNESS

      YPRIM2=-y+t*LLL*cos(alpha)+DELTA

      if (QD3 .eq. 0.0) goto 109
      if (QD3 .gt. 0.0) then

      VEL2=-R+TAU*LLL*cos(alpha)

      CALL BILINALL(YPRIM2,VEL2,kvsb2,RR4,KD4,QD3,KU4,YEL2,YMAX2,
     +  YMIN2,KY4,ZZ4,WZ4,WWW4,YYY4,UUU4)

      elseif (QD3 .lt. 0.0) then

      CALL RUBBER(YPRIM2,kvsb2,RR4,KD4,QD3,KU4,YEL2)

      endif

  109 continue

C     CALCULATE KEEL VERTICAL STIFFNESS

      YPRIM3=-y+DELTA

      if (QD4 .eq. 0.0) goto 110
      if (QD4 .gt. 0.0) then

      CALL BILINALL(YPRIM3,-R,kvkb,RR5,KD5,QD4,KU5,YEL3,YMAX3,
     +  YMIN3,KY5,ZZ5,WZ5,WWW5,YYY5,UUU5)

      elseif (QD4 .lt. 0.0) then

      CALL RUBBER(YPRIM3,kvkb,RR5,KD5,QD4,KU5,YEL3)

      endif

  110 continue


C     RECALCULATION OF DELTA

      if (QD3.ge.0.0.or.QD4.ge.0.0) then
        DELTA=weight/(2D0*kvs+kvk)
        goto 120
      endif
```

```
1        if (kvkb.eq.kvk) then
1          DELTA=weight/(2D0*kvs+kvk)
1        elseif (kvkb.gt.kvk) then
1          DELTA=YEL3+(weight-(YEL3*(2D0*kvs+kvk)))/(2D0*kvsp+kvkp)
1        endif
1
1 120    continue
1
1        if (QD1.eq.0.0.and.QD2.eq.0.0.and.QD3.eq.0.0.
1       +  and.QD4.eq.0.0) goto 111
1
1 C      RECALCULATION OF STIFFNESS MATRIX VALUES
1
1        k(1,1)=(2D0*Ks+2D0*khsb+khkb)
1        k(1,3)=(2D0*Ks*AAA+2D0*khsb*LLL*sin(alpha))
1        k(3,1)=k(1,3)
1        k(2,2)=(kvsb1+kvsb2+kvkb)
1        k(3,3)=(2D0*Ks*AAA**2D0+2D0*khsb*((LLL*sin(alpha))**2D0)+
1       +  ((kvsb1+kvsb2)*((LLL*cos(alpha))**2D0)-(weight*h)))
1
1 111     DO 3000,11=0,5
2          A(11)=0.0
2          B(11)=0.0
2          C(11)=0.0
2          D(11)=0.0
2          E(11)=0.0
2          F(11)=0.0
2          G(11)=0.0
2          HH(11)=0.0
2 3000   CONTINUE
1        mm=mm+1
1           DO 302, NN=1,4
2         IF(NN.EQ.1) THEN
2          FF=0.0
2           ELSE IF (NN.EQ.2 .OR. NN.EQ.3) THEN
2          FF=5D-1
2         ELSE IF (NN.EQ.4) THEN
2          FF=1D0
2         ENDIF
2         A(NN)=dtau*(R+FF*D(NN-1))
2         B(NN)=dtau*(S+FF*E(NN-1))
2         C(NN)=dtau*(TAU+FF*F(NN-1))
2         D(NN)=dtau*((-cx(2,2)/m(2,2))*(R+FF*D(NN-1))-(k(2,2)/m(2,2))
2       +*(y+FF*A(NN-1))-amp*ampacc*acv(1)/2.54D0)
2         G(NN)=dtau*((-cx(1,1)/m(1,1))*(S+FF*E(NN-1))-(cx(1,3)/m(1,1))
2       +*(TAU+FF*F(NN-1))-(k(1,1)/m(1,1))*(x+FF*B(NN-1))
2       +-(k(1,3)/m(1,1))*(t+FF*C(NN-1))-ampacc*ac(1)/2.54D0)
2        HH(NN)=dtau*((-cx(3,3)/m(3,3))*(TAU+FF*F(NN-1))-(cx(3,1)/m(3,3))
2       +*(S+FF*E(NN-1))-(k(3,3)/m(3,3))*(t+FF*C(NN-1))+(m(3,1)/m(3,3))
2       +*((-cx(2,2)/m(2,2))*(R+FF*D(NN-1))-(k(2,2)/m(2,2))*(y+FF*A(NN-
2       +1)))*(t+FF*C(NN-1))
2       +-(k(3,1)/m(3,3))*(x+FF*B(NN-1))
2       +-(m(3,1)/m(3,3))*ampacc*ac(1)/2.54D0)
2
2        E(NN)=(m(1,1)*m(3,3)*G(NN)-m(1,3)*m(3,3)*HH(NN))/
2       +(m(3,3)*m(1,1)-m(1,3)*m(3,1))
2        F(NN)=(HH(NN)-(m(3,1)/m(3,3))*E(NN))
2 302    continue
1
```

```
C     DETERMINING SYSTEM RESPONSE

      yold=y
      y=yold+(A(1)+2D0*A(2)+2D0*A(3)+A(4))/6D0

      xold=x
      x=xold+(B(1)+2D0*B(2)+2D0*B(3)+B(4))/6D0

      told=t
      t=told+(C(1)+2D0*C(2)+2D0*C(3)+C(4))/6D0

      R=R+(D(1)+2D0*D(2)+2D0*D(3)+D(4))/6D0

      S=S+(E(1)+2D0*E(2)+2D0*E(3)+E(4))/6D0

      TAU=TAU+(F(1)+2D0*F(2)+2D0*F(3)+F(4))/6D0

C     MAXIMUM VALUES FOR TRANSLATIONS AND ROTATION

      if (abs(xold).gt.abs(maxx)) then
       timex=dtau*(l-1)
       maxx=xold
      endif
      if (abs(told).gt.abs(maxt)) then
       timet=dtau*(l-1)
       maxt=told
      endif
      if (abs(yold).gt.abs(maxy)) then
       timey=dtau*(l-1)
       maxy=yold
      endif

C     CALCULATE VERTICAL AND HORIZONTAL FORCES CAUSED BY VESSEL,
C     TEST FOR FAILURE

C     CALCULATE FORCES ON SIDE/KEEL BLOCKS
      if (QD3.eq.0.0) then
      rf1=kvs*((weight/k(2,2))-yold-(LLL*cos(alpha))*told)
      rf2=kvs*((weight/k(2,2))-yold+(LLL*cos(alpha))*told)
      elseif (QD3.ne.0.0) then
           rf1=RR3
           rf2=RR4
      endif

      if (QD4.eq.0.0) then
      rf3=kvk*((weight/k(2,2))-yold)
      elseif (QD4.ne.0.0) then
           rf3=RR5
      endif

      if (QD2.eq.0.0) then
      hf1=khs*(xold+LLL*told*sin(alpha))
      hf2=khs*(xold+LLL*told*sin(alpha))
      elseif (QD2.gt.0.0) then
           hf1=RR2
           hf2=RR2
      endif

      if (QD1.eq.0.0) then
```

```
      hf3=khk*(xold)
      elseif (QD1.gt.0.0) then
           hf3=RR1
      endif

C     TEST FOR SIDE BLOCK SLIDING

      if (flag1.eq.1) then
       go to 400
      else if (hf1.lt.0.0.and.rf1.gt.0.0
     + .and. u1*rf1+hf1+u2*rf1*cos(beta)*sin(beta)
     + -rf1*cos(beta)*sin(beta) .lt. 0.0) then
       time1= dtau*(l-1)
       flag1=1
      else if (hf2.gt.0.0.and.rf2.gt.0.0
     + .and. -u1*rf2+hf2-u2*rf2*(cos(beta)*sin(beta))
     + +rf2*cos(beta)*sin(beta) .gt. 0.0) then
       time1=dtau*(l-1)
       flag1=1
      endif
      x1=xold
      y1=yold
      t1=told
  400 continue

C     TEST FOR KEEL BLOCK SLIDING

      if (flag2.eq.1) then
       go to 410
      else if (rf3.gt.0.0.and.abs(hf3/rf3).gt.crit2) then
       time2=dtau*(l-1)
       flag2=1
      endif
      x2=xold
      y2=yold
      t2=told
  410 continue
C     TEST FOR SIDE BLOCK OVERTURNING

      if (flag3.eq.1) then
       go to 420
      else if (hf1.lt.0.0.and.rf1.gt.0.0.and.abs(hf1/rf1).gt.crit3) then
       time3= dtau*(l-1)
       flag3=1
      else if (hf2.gt.0.0.and.rf2.gt.0.0.and.abs(hf2/rf2).gt.crit3) then
       time3=dtau*(l-1)
       flag3=1
      endif
      x3=xold
      y3=yold
      t3=told
  420 continue

C     TEST FOR KEEL BLOCK OVERTURNING

      if (flag4.eq.1) then
       go to 430
      else if (rf3.gt.0.0.and.abs(hf3/rf3).gt.crit4) then
       time4=dtau*(l-1)
```

```
D Line# 1      7
1   591         flag4=1
1   592        endif
1   593        x4=xold
1   594        y4=yold
1   595        t4=told
1   596 430    continue
1   597
1   598 C      TEST FOR SIDE BLOCK LIFTOFF
1   599
1   600        if (flag5.eq.1) then
1   601         go to 440
1   602        else if (rf1.lt.0.0 .or. rf2.lt.0.0) then
1   603         time5=dtau*(l-1)
1   604         flag5=1
1   605        endif
1   606        x5=xold
1   607        y5=yold
1   608        t5=told
1   609 440    continue
1   610
1   611 C      TEST FOR KEEL BLOCK LIFTOFF
1   612
1   613        if (flag6.eq.1) then
1   614         go to 450
1   615        else if (rf3.lt.0.0) then
1   616         time6=dtau*(l-1)
1   617         flag6=1
1   618        endif
1   619        x6=xold
1   620        y6=yold
1   621        t6=told
1   622 450    continue
1   623
1   624 C      TEST FOR SIDE BLOCK CRUSHING
1   625
1   626        if (flag7.eq.1) then
1   627         go to 460
1   628        else if (rf1.gt.0.0 .and. (rf1/sidearea).gt.plside) then
1   629         flag7=1
1   630         time7=dtau*(l-1)
1   631
1   632          else if (rf2.gt.0.0 .and. (rf2/sidearea).gt.plside) then
1   633         flag7=1
1   634         time7=dtau*(l-1)
1   635        endif
1   636        x7=xold
1   637        y7=yold
1   638        t7=told
1   639 460    continue
1   640
1   641 C      TEST FOR KEEL BLOCK CRUSHING
1   642
1   643        if (flag8.eq.1) then
1   644         go to 470
1   645        else if (rf3.gt.0.0 .and. (rf3/keelarea).gt.plkeel) then
1   646         flag8=1
1   647         time8=dtau*(l-1)
1   648        endif
1   649        x8=xold
```

```
      y8=yold
      t8=told
470   continue

C     CAPTURE OF DISPLACEMENT, ROTATION & RESISTANCE OUTPUT:

      if (dec.ne.'Y'.and.dec.ne.'y') goto 301
      xx(mm)=xold
      tt(mm)=told
      goto (501,502,503,504,505),decrr
501   if (QD1.eq.0.0) then
      rrr(mm)=hf3
      elseif (QD1.gt.0.0) then
      rrr(mm)=RR1
      endif
      yy(mm)=yold
      goto 506
502   if (QD2.eq.0.0) then
      rrr(mm)=hf1
      elseif (QD2.gt.0.0) then
      rrr(mm)=RR2
      xx(mm)=XPRIM
      endif
      yy(mm)=yold
      goto 506
503   if (QD3.eq.0.0) then
      rrr(mm)=rf1
      elseif (QD3.ne.0.0) then
      rrr(mm)=RR3
      endif
      yy(mm)=YPRIM1
      goto 506
504   if (QD3.eq.0.0) then
      rrr(mm)=rf2
      elseif (QD3.ne.0.0) then
      rrr(mm)=RR4
      endif
      yy(mm)=YPRIM2
      goto 506
505   if (QD4.eq.0.0) then
      rrr(mm)=rf3
      elseif (QD4.ne.0.0) then
      rrr(mm)=RR5
      endif
      yy(mm)=YPRIM3

506   continue

301   continue

      go to 999

60000 continue
      if(dec.ne.'Y'.and.dec.ne.'y') then
      write(*,'(A)') ' I AM FINISHING. '
      goto 20000
      endif

C     CREATION OF DISPLACEMENT, ROTATION, & RESISTANCE OUTPUT FILES:
```

```

      CALL RESPALL(xx,yy,tt,rrr,dtau)

998   go to 20000

999   CONTINUE

      if(ampacc.eq.1D0) then

        write(*,'(a)') ' ENTER OUTPUT FILENAME ...'
        read(*,'(a)') outfname
        open(46,file=outfname,status='new',form='formatted')


      write(46,4000) nsys
4000  format(1x,/,28x,'**** System ',I2,1x,'****')
      write(46,4050) hull
4050  format(1x,/,30x,'** Hull ',I3,1x,'**')
      write(46,4100)
4100  format(1x,//,28x,'* Ship Parameters *')
      write(46,4150)
4150  format(1x,/,5x,'Weight',8x,'Moment of Inertia',9x,'K.G.')
      write(46,4200) weight,Ik,h
4200  format(1x,f9.1,1x,'kips',1x,f11.1,1x,'kips-in-sec2',
     +3x,f6.1,1X,'ins')
      write(46,4250)
4250  format(1x,//,26x,'* Drydock Parameters *')
      write(46,4300)
4300  format(1x,/,1x,'Side Block Height',3x,'Side Block Width',
     +3x,'Keel Block Height',3x,'Keel Block Width')
      write(46,4350) htside,baseside,htkeel,basekeel
4350  format(2x,f6.1,1x,'ins',11x,f6.1,1x,'ins',11x,f6.1,1x,'ins',
     +9x,f6.1,1x,'ins')
      write(46,4400)
4400  format(1x,/,1x,'Side-to-Side Pier Distance',3x,'Wale Shore Ht.'
     + ,3x,'Wale Shore Stiffness',2x,'Cap Angle')
      write(46,4450) br,AAA,Ks,beta
4450  format(1x,t7,f6.1,1x,'ins',17x,f6.1,1x,'ins',8x,f8.1,1x,
     + 'kips/in',1x,f5.3,1x,'rad')
      write(46,4470)
4470  format(1x,/,' 1Side Side Pier Contact Area'
     +,3x,'Total Keel Pier Contact Area',6X,'kkhp')
      write(46,4475) sidearea,keelarea,kkhp
4475  format(1x,8x,f11.1,1x,'in2',14x,f11.1,1x,'in2',10x,f7.1,1x,
     + 'kips/in')
      write(46,4500)
4500  format(1x,/.1x,'B/B Friction Coeff',3x,
     +'H/B Friction Coeff',5x,'kshp',10x,'kvsp')
      write(46,4550) u1,u2,kshp,kvsp
4550  format(6x,f7.3,13x,f7.3,7x,f7.1,1x,'kips/in',1x,f7.1,1x,
     +  'kips/in')
      write(46,4600)
4600  format(1x,/,1x,'Side Pier Fail Stress Limit',4x,'Keel Pier'
     +,' Fail Stress Limit',6x,'kvkp')
      write(46,4650) plside,plkeel,kvkp
4650  format(1x,10x,f7.3,1x,'kips/in2'15x,f7.3,1x,'kips/in2',
     + 6x,f7.1,1x,'kips/in')
      write(46,4700)
4700    format(1x,/,1x,'Side Pier Vertical Stiffness',3x,'Side Pier',
```

```
             +' Horizontal Stiffness')
              write(46,4750) kvs,khs
       4750     format(1x,3x,f11.1,1x,'kips/in',11x,f11.1,1x,'kips/in')
                write(46,4775)
       4775     format(1x,/,1x,'Keel Pier Vertical Stiffness',3x,
             +'Keel Pier Horizontal Stiffness')
              write(46,4780) kvk,khk
       4780     format(1x,3x,f11.1,1x,'kips/in',11x,f11.1,1x,'kips/in')
              write(46,4782)
       4782   format(1x,/,6x,'QD1',17x,'QD2',18x,'QD3',17x,'QD4')
              write(46,4785) QD1,QD2,QD3,QD4
       4785   format(2x,f8.1,1x,'kips',7x,f8.1,1x,'kips',8x,f8.1,1x,'kips',
             +7x,f8.1,1x,'kips')
              write(46,4800)
       4800   format(1x,//,20x,'* System Parameters and Inputs *')
              write(46,4850) quakname
       4850     format(1x,/,1x,'Earthquake Used is ',A40)
              write(46,4852) hname
       4852   format(1x,/,1x,'Horizontal acceleration input is ',A40)
              write(46,4854) vname
       4854   format(1x,/,1x,'Vertical acceleration input is ',A40)
              write(46,4875)
       4875   format(1x,20x,' Earthquake Acceleration Time History.')

              write(46,4995)
       4995   format(1x,/,1x,'Vertical/Horizontal Ground Acceleration Ratio'
             +,3x,'Data Time Increment')
              write(46,4990) amp,dtau
       4990   format(1x,10x,f6.3,t55,f6.3,1X,'sec')
              write(46,4900)
       4900   format(1x,/,1x,'Gravitational Constant',3x,'% System Damping')
              write(46,4950) gravity,zeta*100.
       4950   format(1x,7x,f6.2,1x,'in/sec2',10x,f6.2,1x,'%')
              write(46,5000)
       5000   format(1x,/,25x,'Mass Matrix',/)
              do 5100 i=1,3
1             write(46,5050) m(i,1),m(i,2),m(i,3)
1      5050   format(1x,f15.4,5x,f15.4,5x,f15.4)
1      5100   continue
              write(46,5200)
       5200   format(1x,/,25x,'Damping Matrix',/)
              do 5300 i=1,3
1             write(46,5250) cx(i,1),cx(i,2),cx(i,3)
1      5250   format(1x,f15.4,5x,f15.4,5x,f15.4)
1      5300   continue
              write(46,5400)
       5400   format(1x,/,25x,'Stiffness Matrix',/)
              do 5500 i=1,3
1             write(46,5450) ko(i,1),ko(i,2),ko(i,3)
1      5450   format(1x,f15.4,5x,f15.4,5x,f15.4)
1      5500   continue
              write(46,5700)
       5700     format(1x,//)
              WRITE(46,6000)
       6000     FORMAT(1X,'Undamped Natural Frequencies',t35,'Mode #1',t50,
             +'Mode #2',t65,'Mode #3')
              write(46,6001) w1,w3,w2
       6001   format(1x,t31,f7.3,1x,'rad/sec',t46,f7.3,1x,'rad/sec',t62,f7.3,
             +' rad/sec')
```

```
      WRITE(46,6002)
6002    FORMAT(1X,'Damped Natural Frequencies',t35,'Mode #1',t50,
     +'Mode #2',t65,'Mode #3')
      WRITE(46,6500) w1*sqrt(1-zeta**2),w3*sqrt(1-zeta**2),
     +w2*sqrt(1-zeta**2)
6500  format(1x,t31,f7.3,1x,'rad/sec',t46,f7.3,1x,'rad/sec',t62,f7.3,
     +' rad/sec')
      endif

      write(46,10500) ampacc*100,quakname
10500   format(1x,///,1x,'For Earthquake Acceleration of ',f6.2,' % '
     +,'of the ',A40,/)

      write(46,25000)
25000   format(1x,'Maximums/Failures',t26,'X (ins)',t36,'Y (ins)',t51,
     +'Theta (rads)',t65,'Time (sec)')
      write(46,25001)
25001 format(1x,'-----------------',t25,'--------',t35,'--------',t50,
     +'-------------',t64,'------------')
      write (46,310) maxx,timex
310   format (1x,' Maximum X',t25,f9.6,t65,f5.2)
      write (46,311) maxy,timey
 311  format (1x,' Maximum Y',t35,f9.6,t65,f5.2)
      write (46,312) maxt,timet
312   format (1x,' Maximum Rotation',t50,f9.6,t65,f5.2)

      if (flag1.eq.1) then
      flag10=flag10+1
       write (46,313) x1,y1,t1,time1
313   format (1x,'Side block sliding' ,t25,f9.6,t35,f9.6,t50,f9.6,
     +t65,f5.2)

      endif

      if (flag2.eq.1) then
      flag10=flag10+1
       write (46,314) x2,y2,t2,time2
314   format (1x,'Keel block sliding' ,t25,f9.6,t35,f9.6,t50,f9.6,
     +t65,f5.2)
      endif

      if (flag3.eq.1) then
      flag10=flag10+1
       write (46,315) x3,y3,t3,time3
315   format (1x,'Side block overturning' ,t25,f9.6,t35,f9.6,t50,f9.6,
     +t65,f5.2)
      endif

      if (flag4.eq.1) then
      flag10=flag10+1
       write (46,316) x4,y4,t4,time4
316   format (1x,'Keel block overturning' ,t25,f9.6,t35,f9.6,t50,f9.6,
     +t65,f5.2)
      endif

      if (flag5.eq.1) then
      flag10=flag10+1
       write (46,317) x5,y5,t5,time5
317   format (1x,'Side block liftoff' ,t25,f9.6,t35,f9.6,t50,f9.6,
```

```
     +t65,f5.2)
      endif

      if (flag6.eq.1) then
      flag10=flag10+1
       write (46,318) x6,y6,t6,time6
 318  format (1x,'Keel block liftoff' ,t25,f9.6,t35,f9.6,t50,f9.6,
     +t65,f5.2)
      endif

      if (flag7.eq.1) then
      flag10=flag10+1
       write (46,319) x7,y7,t7,time7
 319  format (1x,'Side block crushing' ,t25,f9.6,t35,f9.6,t50,f9.6,
     +t65,f5.2)
      endif

      if (flag8.eq.1) then
      flag10=flag10+1
       write (46,320) x8,y8,t8,time8
 320  format (1x,'Keel block crushing' ,t25,f9.6,t35,f9.6,t50,f9.6,
     +t65,f5.2)
      endif

      if(flag10.eq.0) then
      write(46,11000)
 11000  format(1x,/,1x,'No failures occurred.')
      if(counter.eq.1.0 .and. flag10.eq.0) then
      go to 60000
      endif
      if(counter.eq.0.0) then
      ampacmax=ampacc
      ampacc=ampacc+1D-1
        counter=1.0
      write(*,'(A)') ' In secondary looping stage. '
      endif
      endif
      if(ampacc.le.ampacmax) go to 20000
      if(counter.eq.1.0) then
      ampacc=ampacc-1D-2
      else if(counter.eq.0.0) then
      ampacc=ampacc-1D-1
      endif
      go to 10000
 20000 continue
      stop
      end
```

```
Name    Type        Offset P Class

A       REAL*8        48946
AAA     REAL*8        49082
ABS                            INTRINSIC
AC      REAL          32882
ACLFNA  CHAR*40       *****
ACV     REAL          40890
ALPHA   REAL*8        49344
AMP     REAL*8        49496
AMPACC  REAL*8        49656
```

```
AMPACM REAL*8          49672
ASIN                                INTRINSIC
B      REAL*8          48898
BASE   REAL*8          *****
BASEKE REAL*8          49170
BASESI REAL*8          49162
BBB    REAL*8          49352
BETA   REAL*8          49258
BR     REAL*8          49210
C      REAL*8          32834
CCC    REAL*8          49360
COS                                 INTRINSIC
COUNTE REAL*8          49664
CRIT2  REAL*8          49632
CRIT3  REAL*8          49640
CRIT4  REAL*8          49648
CX     REAL*8          32658
D      REAL*8          32786
DEC    CHAR*40         49282
DECRR  INTEGER*2       49322
DECV   CHAR*40         *****
DELTA  REAL*8          49812
DTAU   REAL*8          49504
E      REAL*8          32562
F      REAL*8          32610
FF     REAL            50266
FLAG1  INTEGER*2       49680
FLAG10 INTEGER*2       49696
FLAG2  INTEGER*2       49682
FLAG3  INTEGER*2       49684
FLAG4  INTEGER*2       49686
FLAG5  INTEGER*2       49688
FLAG6  INTEGER*2       49690
FLAG7  INTEGER*2       49692
FLAG8  INTEGER*2       49694
G      REAL*8          32514
GRAVIT REAL*8          49154
H      REAL*8          49042
HF1    REAL*8          50318
HF2    REAL*8          50326
HF3    REAL*8          50334
HH     REAL*8          32466
HNAME  CHAR*40         49552
HTKEEL REAL*8          49186
HTSIDE REAL*8          49178
HULL   INTEGER*2       49254
I      INTEGER*2       49324
IK     REAL*8          49050
J      INTEGER*2       49326
K      REAL*8          32338
KD1    REAL*8          49844
KD2    REAL*8          49924
KD3    REAL*8          50004
KD4    REAL*8          50068
KD5    REAL*8          50148
KEELAR REAL*8          49242
KHK    REAL*8          49106
KHKB   REAL*8          49852
KHS    REAL*8          49098
```

```
KHSB    REAL*8          49932
KKHP    REAL*8          49122
KO      REAL*8          32210
KS      REAL*8          49090
KSHP    REAL*8          49114
KU1     REAL*8          49836
KU2     REAL*8          49916
KU3     REAL*8          49996
KU4     REAL*8          50060
KU5     REAL*8          50140
KVK     REAL*8          49074
KVKB    REAL*8          49828
KVKP    REAL*8          49274
KVS     REAL*8          49058
KVSB1   REAL*8          49820
KVSB2   REAL*8          50076
KVSP    REAL*8          49066
KY1     INTEGER*2       49860
KY2     INTEGER*2       49940
KY3     INTEGER*2       50012
KY4     INTEGER*2       50084
KY5     INTEGER*2       50156
L       INTEGER*2       50204
LL      INTEGER*2       50262
LLL     REAL*8          49336
M       REAL*8          32082
MASS    REAL*8          49328
MAXT    REAL*8          49706
MAXX    REAL*8          49698
MAXY    REAL*8          49714
MIN                             INTRINSIC
MM      INTEGER*2       49722
MMANG1  REAL*8          49440
MMANG3  REAL*8          49456
MMMMM1  REAL*8          49464
MMMMM2  REAL*8          49472
MMMMM3  REAL*8          49480
MMMMM4  REAL*8          49488
MMX1    REAL*8          49432
MMX3    REAL*8          49448
MODE1   REAL*8          49416
MODE3   REAL*8          49424
N       INTEGER*2       *****
NN      INTEGER*2       50264
NSYS    INTEGER*2       49256
OUTFNA  CHAR*40         50502
PLKEEL  REAL*8          49226
PLSIDE  REAL*8          49218
QD1     REAL*8          49130
QD2     REAL*8          49138
QD3     REAL*8          49146
QD4     REAL*8          49266
QUAKNA  CHAR*40         49512
R       REAL*8          49772
RF1     REAL*8          50294
RF2     REAL*8          50302
RF3     REAL*8          50310
RR1     REAL*8          49886
RR2     REAL*8          49966
```

```
D Line# 1      7
RR3     REAL*8          50030
RR4     REAL*8          50110
RR5     REAL*8          50174
RRR     REAL            24074
S       REAL*8          49780
SBFNAM  CHAR*40         48994
SIDEAR  REAL*8          49234
SIN                             INTRINSIC
SQRT                            INTRINSIC
T       REAL*8          49740
T1      REAL            50358
T2      REAL            50378
T3      REAL            50398
T4      REAL            50418
T5      REAL            50438
T6      REAL            50458
T7      REAL            50478
T8      REAL            50498
TAU     REAL*8          49788
TIME    REAL*8          *****
TIME1   REAL*8          50342
TIME2   REAL*8          50362
TIME3   REAL*8          50382
TIME4   REAL*8          50402
TIME5   REAL*8          50422
TIME6   REAL*8          50442
TIME7   REAL*8          50462
TIME8   REAL*8          50482
TIMET   REAL*8          50278
TIMEX   REAL*8          50270
TIMEY   REAL*8          50286
TOLD    REAL*8          49764
TT      REAL            16066
U1      REAL*8          49194
U2      REAL*8          49202
UUU1    INTEGER*2       49914
UUU2    INTEGER*2       49994
UUU3    INTEGER*2       50058
UUU4    INTEGER*2       50138
UUU5    INTEGER*2       50202
VEL     REAL*8          50214
VEL1    REAL*8          50230
VEL2    REAL*8          50246
VFNAME  CHAR*40         *****
VNAME   CHAR*40         49592
W1      REAL*8          49376
W12     REAL*8          49368
W2      REAL*8          49392
W22     REAL*8          49384
W3      REAL*8          49408
W32     REAL*8          49400
WEIGHT  REAL*8          49034
WWW1    INTEGER*2       49910
WWW2    INTEGER*2       49990
WWW3    INTEGER*2       50054
WWW4    INTEGER*2       50134
WWW5    INTEGER*2       50198
WZ1     REAL*8          49902
WZ2     REAL*8          49982
```

```
D Line# 1      7
WZ3     REAL*8          50046
WZ4     REAL*8          50126
WZ5     REAL*8          50190
X       REAL*8          49724
X1      REAL            50350
X2      REAL            50370
X3      REAL            50390
X4      REAL            50410
X5      REAL            50430
X6      REAL            50450
X7      REAL            50470
X8      REAL            50490
XEL1    REAL*8          49862
XEL2    REAL*8          49942
XMAX1   REAL*8          49870
XMAX2   REAL*8          49950
XMIN1   REAL*8          49878
XMIN2   REAL*8          49958
XOLD    REAL*8          49748
XPRIM   REAL*8          50206
XSCL    REAL*8          16018
XX      REAL                2
Y       REAL*8          49732
Y1      REAL            50354
Y2      REAL            50374
Y3      REAL            50394
Y4      REAL            50414
Y5      REAL            50434
Y6      REAL            50454
Y7      REAL            50474
Y8      REAL            50494
YEL1    REAL*8          49796
YEL2    REAL*8          50086
YEL3    REAL*8          49804
YMAX1   REAL*8          50014
YMAX2   REAL*8          50094
YMAX3   REAL*8          50158
YMIN1   REAL*8          50022
YMIN2   REAL*8          50102
YMIN3   REAL*8          50166
YOLD    REAL*8          49756
YPRIM1  REAL*8          50222
YPRIM2  REAL*8          50238
YPRIM3  REAL*8          50254
YY      REAL             8010
YYY1    INTEGER*2       49912
YYY2    INTEGER*2       49992
YYY3    INTEGER*2       50056
YYY4    INTEGER*2       50136
YYY5    INTEGER*2       50200
ZETA    REAL            49250
ZZ1     REAL*8          49894
ZZ2     REAL*8          49974
ZZ3     REAL*8          50038
ZZ4     REAL*8          50118
ZZ5     REAL*8          50182
```

```
Name     Type           Size   Class

ACCLIN                         SUBROUTINE
BILINA                         SUBROUTINE
MAIN                           PROGRAM
RESPAL                         SUBROUTINE
RUBBER                         SUBROUTINE


 Pass One    No Errors Detected
            932 Source Lines
```

"ACCLINPT","BILINALL","RUBBER", and "RESPALL" Subroutine Listings . . . . . .

```
                                                              Page    1
                                                              01-20-88
                                                              14:47:36
D Line# 1     7                          Microsoft FORTRAN77 V3.20 02/84

    $title:  'acclinpt'
    $storage: 2
    $nofloatcalls


    C-----------------------------------------------------------------

    C     SUBROUTINE WHICH PROMPTS FOR AND READS IN HORIZONTAL
    C      AND VERTICAL ACCELERATION TIME HISTORY FILES
    C      AND THE TIME STEP AND EARTHQUAKE NAME

    C-----------------------------------------------------------------

          SUBROUTINE ACCLINPT(amp,ac,acv,dtau,quakname,hname,vname)
          integer n
            real ac(2002),acv(2002)
          real*8 amp,dtau,dtauh,dtauv
          character*40 aclfname,vfname,decv,quakname,hname,vname
          character*40 hquaknam,vquaknam

    C     READ IN ACCELERATION DATA

    C       HORIZONTAL ACCELERATION
    700   write(*,'(a)') ' ENTER HORIZONTAL ACCELERATION FILE NAME...'
            read(*,'(a)') aclfname
            open(44,file=aclfname,status='old',form='formatted')
            write(*,'(a)') ' READING HORIZONTAL ACCELERATION FILE...'
          read(44,'(a)') hquaknam
          read(44,'(a)') hname
          read(44,'(f9.4)') dtauh
          do 300,n=1,2000
1         read (44,*) ac(n)
1   300     continue

    C       VERTICAL ACCELERATION
    307   write(*,'(a)') ' WILL YOU USE A VERTICAL ACCELERATION FILE? '
          write(*,'(a)') ' (Y/N) '
          read(*,'(a)') decv
          if (decv.eq.'Y') then
               write(*,'(a)') ' ENTER VERTICAL ACCELERATION FILE NAME...'
             read(*,'(a)') vfname
             open(45,file=vfname,status='old',form='formatted')
             write(*,'(a)') ' READING VERTICAL ACCELERATION FILE...'
             amp=1.0
          read(45,'(a)') vquaknam
          read(45,'(a)') vname
          read(45,'(f9.4)') dtauv
```

```
               if (dtauh .ne. dtauv .or. vquaknam .ne. hquaknam) then
                 write(*,'(a)') ' INCOMPATIBLE ACCELERATION FILES !!! '
                 write(*,'(a)') ' REINPUT COMPATIBLE FILES '
                 goto 700
               endif
               do 305,n=1,2000
1              read (45,*) acv(n)
1     305      continue
            endif

            if (decv.eq.'N') then
               do 306,n=1,2000
1                acv(n)=ac(n)
1     306      continue
               write(*,'(a)') ' INPUT DESIRED VERT/HORZ ACCEL RATIO: '
               read(*,*) amp
            endif

            if (decv.ne.'Y' .and. decv.ne.'N') then
               write(*,'(a)') ' TRY AGAIN '
               goto 307
            endif

            quakname=hquaknam
            dtau=dtauh
            CLOSE (44)
            CLOSE (45)

            RETURN
            END

Name    Type        Offset P Class

AC     REAL            4 *
ACLFNA CHAR*40         2
ACV    REAL            8 *
AMP    REAL*8          0 *
DECV   CHAR*40        92
DTAU   REAL*8         12 *
DTAUH  REAL*8         82
DTAUV  REAL*8        212
HNAME  CHAR*40        20 *
HQUAKN CHAR*40        42
N      INTEGER*2      90
QUAKNA CHAR*40        16 *
VFNAME CHAR*40       132
VNAME  CHAR*40        24 *
VQUAKN CHAR*40       172
```

```
$debug
$title:  'bilinall'
$storage: 2
$nofloatcalls


C-----------------------------------------------------------------

C     SUBROUTINE WHICH CALCULATES THE BILINEAR HORIZONTAL
C      OR VERTICAL STIFFNESS AND RESISTANCE

C-----------------------------------------------------------------

      SUBROUTINE BILINALL(U,V,PK,RR,KD,QD,KU,UEL,UMAX,UMIN,KY,ZZ,WZ,
     +  WWW,YYY,UUU)

      real*8 U,V,RR,KD,QD,KU,UEL,PK
      real*8 UMAX,UMIN,ZZ,WZ
      integer WWW,YYY,UUU,KY

C     BEGINNING OF BILINEAR LOGIC

C     CHECK IF RESPONSE STILL ON INITIAL ELASTIC LINE

        if (KY .lt. 0) goto 4040
        if (KY .gt. 0) goto 3480
        RR=KU*U
        PK=KU

C      CHECK IF THE RESPONSE HAS GONE PLASTIC

        if (U .gt. -UEL .and. U .lt. UEL) goto 4720

C      RESPONSE IS NOW PLASTIC

        if (U .lt. -UEL) goto 4040

C      RESPONSE IS ON THE TOP PLASTIC LINE

3220    KY=1
        PK=KD
        RR=KD*U+QD
        WWW=0
        YYY=0
        ZZ=0.0
        goto 4720

```

```
C      CHECK IF VELOCITY SHIFTS FROM POSITIVE TO NEGATIVE

3480    if (V .gt. 0) goto 3720

C      CHECK IF ON THE RIGHT ELASTIC LINE

        if (YYY .gt. 0) goto 3630

C      CALCULATE VALUE OF UMAX

        ZZ=U
3630    YYY=1
        UMAX=ZZ

C      CHECK IF RESPONSE SHIFTS TO LOWER PLASTIC LINE

3720    if (U .lt. (UMAX-2*UEL)) goto 4040

C      CHECK IF RESPONSE SHIFTS TO TOP PLASTIC LINE

        if (U .gt. UMAX) goto 3220

C      CHECK IF RESPONSE RETURNS TO TOP PLASTIC LINE

        if (YYY .eq. 0) goto 3220

C      RESPONSE IS ON THE RIGHT ELASTIC LINE

        KY=1
        PK=KU
        RR=KU*U+(KD-KU)*UMAX+QD
        goto 4720

C      CHECK IF VELOCITY SHIFTS TO POSITIVE

4040    if (V .gt. 0) goto 4350

C      CHECK IF RESPONSE REMAINS ELASTIC

        if (WWW .eq. 1) goto 4350

C      RESPONSE IS ON THE BOTTOM PLASTIC LINE

4150    KY=-1
        PK=KD
        RR=KD*U-QD
        UUU=0
        WZ=0.0
        goto 4720

```

```
C     CHECK IF RESPONSE IS ON THE LEFT ELASTIC LINE

4350   if (UUU .gt. 0) goto 4370
       WZ=U
4370   UUU=1
       UMIN=WZ

C     CHECK IF RESPONSE RETURNS TO TOP PLASTIC LINE

       if (U .gt. (UMIN+2*UEL)) goto 3220

C     CHECK IF RESPONSE RETURNS TO BOTTOM PLASTIC LINE

       if (U .lt. UMIN) goto 4150

C     RESPONSE IS ON THE LEFT ELASTIC LINE

       WWW=1
       RR=KU*U+(KD-KU)*UMIN-GD
       PK=KU

4720  continue
      RETURN
      END

Name    Type        Offset P Class

KD     REAL*8          16 *
KU     REAL*8          24 *
KY     INTEGER*2       40 *
PK     REAL*8           8 *
GD     REAL*8          20 *
RR     REAL*8          12 *
U      REAL*8           0 *
UEL    REAL*8          28 *
UMAX   REAL*8          32 *
UMIN   REAL*8          36 *
UUU    INTEGER*2       60 *
V      REAL*8           4 *
WWW    INTEGER*2       52 *
WZ     REAL*8          48 *
YYY    INTEGER*2       56 *
ZZ     REAL*8          44 *



Name    Type          Size  Class

BILINA                      SUBROUTINE


 Pass One    No Errors Detected
            121 Source Lines
```

```
                                                                          Page   1
                                                                          01-29-88
                                                                          16:45:08
D Line# 1     7                                     Microsoft FORTRAN77 V3.20 02/84
      1 $debug
      2 $title:  'rubber'
      3 $nofloatcalls
      4
      5
      6 C-------------------------------------------------------------------
      7
      8 C     SUBROUTINE WHICH CALCULATES THE RUBBER CAP VERTICAL
      9 C      STIFFNESS AND RESISTANCE
     10
     11 C-------------------------------------------------------------------
     12
     13       SUBROUTINE RUBBER(U,PK,RR,KD,QD,KU,UEL)
     14
     15       real*8 U,RR,KD,QD,KU,UEL,PK
     16
     17 C     BEGINNING OF RUBBER LOGIC
     18
     19 C     CHECK IF RESPONSE STILL ON INITIAL ELASTIC LINE
     20
     21         if (U .gt. UEL) goto 3220
     22         RR=KU*U
     23         PK=KU
     24         goto 4720
     25
     26 C      RESPONSE IS ON THE 2ND ELASTIC LINE
     27
     28 3220    continue
     29         PK=KD
     30         RR=KD*U+QD
     31
     32 4720  continue
     33       RETURN
     34       END

Name    Type        Offset P Class

KD     REAL*8          12 *
KU     REAL*8          20 *
PK     REAL*8           4 *
QD     REAL*8          16 *
RR     REAL*8           8 *
U      REAL*8           0 *
UEL    REAL*8          24 *
```

```
                                                        Page   1
                                                        01-20-88
                                                        14:20:02
D Line# 1     7                       Microsoft FORTRAN77 V3.20 02/84

        $title:  'RESPALL'
        $storage: 2
        $nofloatcalls


        C-----------------------------------------------------------------

        C     SUBROUTINE WHICH CREATES VERTICAL, ROTATIONAL,
        C      HORIZONTAL DISPLACEMENT AND DESIGNATED
        C      RESISTANCE OUTPUT FILES

        C-----------------------------------------------------------------

              SUBROUTINE RESPALL(xx,yy,tt,rrr,dtau)
              real xx(2002),tt(2002),yy(2002),rrr(2002)
              real*8 dtau,time
              character*40 xname,yname,tname,rrname
              integer n

        C     CREATION OF DISPLACEMENT & ROTATION OUTPUT FILES:

              write(*,'(a)') ' ENTER X OUTPUT FILE NAME...'
              read(*,'(a)') xname
              open(47,file=xname,status='new',form='formatted')

              write(*,'(a)') ' ENTER Y DISPL OUTPUT FILE NAME...'
              read(*,'(a)') yname
              open(48,file=yname,status='new',form='formatted')

              write(*,'(a)') ' ENTER THETA OUTPUT FILE NAME...'
              read(*,'(a)') tname
              open(49,file=tname,status='new',form='formatted')

              write(*,'(a)') ' ENTER RESISTANCE OUTPUT FILE NAME...'
              read(*,'(a)') rrname
              open(41,file=rrname,status='new',form='formatted')


              do 308,n=1,2000
1                time=dtau*(n-1)
1                write(47,7000) time,xx(n)
1       7000       format(f7.3,10x,e13.6)
1
1                write(48,7010) time,yy(n)
1       7010     format(f7.3,10x,e13.6)
```

```
 1    47
 1    48          write(49,7020) time,tt(n)
 1    49 7020     format(f7.3,10x,e13.6)
 1    50
 1    51          write(41,7030) time,rrr(n)
 1    52 7030     format(f7.3,10x,e13.6)
 1    53
 1    54 308   CONTINUE
      55
      56       RETURN
      57       END

Name    Type        Offset P Class

DTAU   REAL*8          16 *
N      INTEGER*2      162
RRNAME CHAR*40        122
RRR    REAL            12 *
TIME   REAL*8         164
TNAME  CHAR*40         82
TT     REAL             8 *
XNAME  CHAR*40          2
XX     REAL             0 *
YNAME  CHAR*40         42
YY     REAL             4 *


     58

Name    Type          Size   Class

RESPAL                       SUBROUTINE


 Pass One    No Errors Detected
             58 Source Lines
```

Sample Input Data File and Output File. .

```
    ***SHIP/SUB DRYDOCK BLOCKING SYSTEM***  DATA FILE: A:S1ORBILN.DAT

          ***INPUT FILE DATA***


SHIP NAME:   LAFAYETTE SSBN 616
DISCRIPTION OF ISOLATORS IF USED: NO ISOLATOR ALL BILINEAR
DISCRIPTION OF BUILDUP: 8 SPACING COMPOSITE
DISCRIPTION OF WALE SHORES USED: NO WALE SHORES
DISCRIPTION OF DAMPING: 5 % DAMPING
LOCATION OF DRYDOCK BEING STUDIED: NO SPECIFIC LOCATION
NAVSEA DOCKING DRAWING NUMBER: 845-2006640
REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: S1KHORIG.WK1 & S1SHORIG.WK1
MISC. COMMENTS: S1ORBILN.DAT  1839 4 MAR 88

SHIP WEIGHT  (KIPS)                                  W= 16369.9
HEIGHT OF KG (IN)                                    H= 193
MOMENT OF INERTIA  (KIPS*IN*SEC^2)                  Ik= 2410451
SIDE PIER VERTICAL STIFFNESS (KIPS/IN)             Kvs= 10113.39
SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)    Kvsp= 4025.64
KEEL PIER VERTICAL STIFFNESS (KIPS/IN)             KVK= 46808.74
KEEL PIER VERTICAL PLASTIC STIFFNESS(KIPS/IN)     KVKP= 46808.74
HEIGHT OF WALE SHORES  (IN)                        AAA= 0
WALE SHORE STIFFNESS (KIPS/IN)                      KS= 0
SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN)           KHS= 5825.13
KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN)           KHK= 59223.08
SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KSHP= 2212.17
KEEL PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KKHP= 38434.86
RESTORING FORCE AT 0 DEFLECT KEEL HORIZ   (KIPS) QD1= 18098.07
RESTORING FORCE AT 0 DEFLECT SIDE HORIZ   (KIPS) QD2= 4817.6
RESTORING FORCE AT 0 DEFLECT SIDE VERT    (KIPS) QD3= 2262.37
RESTORING FORCE AT 0 DEFLECT KEEL VERT    (KIPS) QD4= 0
GRAVITATIONAL CONSTANT (IN/SEC^2)                GRAV= 386.09

SIDE BLOCK WIDTH  (IN)                             SBW= 42
KEEL BLOCK WIDTH  (IN)                             KBW= 48
SIDE BLOCK HEIGHT (IN)                             SBH= 74
KEEL BLOCK HEIGHT (IN)                             KBH= 60
BLOCK ON BLOCK FRICTION COEFFICIENT                 U1= .43
HULL ON BLOCK FRICTION COEFFICIENT                  U2= .53
SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN)     BR= 144
SIDE PIER CAP PROPORTIONAL LIMIT                  SCPL= .7
KEEL PIER CAP PROPORTIONAL LIMIT                  KCPL= .45
TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN^2) SAREA= 8352
TOTAL KEEL PIER CONTACT AREA   (IN^2)           KAREA= 55440
PERCENT CRITICAL DAMPING                          ZETA= .05
HULL NUMBER (XXXX)                                HULL= 616
SYSTEM NUMBER (XXX)                               NSYS= 1
CAP ANGLE (RAD)                                   BETA= .377
```

```
16369.9 193.0 2410451  10113.39   4025.64  46808.74   0.0      0.0
  5825.13  59223.08   2212.17  38434.86 18098.07  4817.60  2262.37 386.09
 42.00  48.00  74.00  60.00 0.43 0.53
 144.00 0.70 0.45   8352.0  55440.0 0.050
 616   1 0.377      0.00  46808.74
```

```
LAFAYETTE SSBN 616
NO ISOLATOR ALL BILINEAR
8 SPACING COMPOSITE
NO WALE SHORES
5 % DAMPING
NO SPECIFIC LOCATION
845-2006640
S1KHORIG.WK1 & S1SHORIG.WK1
S1ORBILN.DAT  1839 4 MAR 88
```

```
                    **** System  1 ****

                      ** Hull 616 **


                    * Ship Parameters *

    Weight       Moment of Inertia        K.G.
  16369.9 kips   2410451.0 kips-in-sec2    193.0 ins


                  * Drydock Parameters *

Side Block Height   Side Block Width   Keel Block Height   Keel Block Width
   74.0 ins             42.0 ins              60.0 ins           48.0 ins

Side-to-Side Pier Distance   Wale Shore Ht.   Wale Shore Stiffness  Cap Angle
      144.0 ins                     .0 ins              .0 kips/in  .377 rad

1Side Side Pier Contact Area   Total Keel Pier Contact Area      kkhp
            8352.0 in2                   55440.0 in2         38434.9 kips/in

B/B Friction Coeff   H/B Friction Coeff     kshp           kvsp
       .430                .530        2212.2 kips/in  4025.6 kips/in

Side Pier Fail Stress Limit    Keel Pier Fail Stress Limit      kvkp
            .700 kips/in2                .450 kips/in2      46808.7 kips/in

Side Pier Vertical Stiffness   Side Pier Horizontal Stiffness
       10113.4 kips/in               5825.1 kips/in

Keel Pier Vertical Stiffness   Keel Pier Horizontal Stiffness
       46808.7 kips/in              59223.1 kips/in

     QD1               QD2               QD3               QD4
  18098.1 kips      4817.6 kips       2262.4 kips          .0 kips


              * System Parameters and Inputs *

Earthquake Used is 1940 EL CENTRO

Horizontal acceleration input is HORIZONTAL

Vertical acceleration input is
                    Earthquake Acceleration Time History.

Vertical/Horizontal Ground Acceleration Ratio   Data Time Increment
          1.000                                       .010 sec

Gravitational Constant   % System Damping
       386.09 in/sec2           5.00 %
```

```
                        Mass Matrix

        42.3992               .0000           8183.0420
          .0000             42.3992               .0000
      8183.0420               .0000        2410451.0000

                        Damping Matrix

       118.1018               .0000           5027.6454
          .0000            168.5898               .0000
      5027.6454               .0000        1549181.3597

                        Stiffness Matrix

     70873.3400               .0000         163103.6400
          .0000          67035.5200               .0000
    163103.6400               .0000       99931610.6070


Undamped Natural Frequencies     Mode #1        Mode #2        Mode #3
                               6.425 rad/sec 69.650 rad/sec  39.763 rad/sec
Damped Natural Frequencies       Mode #1        Mode #2        Mode #3
                               6.416 rad/sec 69.563 rad/sec  39.713 rad/sec


For Earthquake Acceleration of 100.00 % of the 1940 EL CENTRO

Maximums/Failures       X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------      --------  --------       ------------- -----------
 Maximum X              -.243397                               11.22
 Maximum Y                        -.202029                      8.01
 Maximum Rotation                                 .048797      14.44
Side block sliding      -.103557   .033213       -.021226       6.24
Keel block sliding      -.095723   .021787       -.021704       6.23
Side block overturning   .082442  -.061166        .011885       5.61
Keel block overturning   .020393   .052877        .001717       4.71
Side block liftoff      -.007883  -.103857       -.003915       4.96
Side block crushing     -.009432   .021336        .009388       5.46
```

```
For Earthquake Acceleration of  90.00 % of the 1940 EL CENTRO

Maximums/Failures        X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------       --------  --------       ------------- -----------
 Maximum X              -.246421                                 16.51
 Maximum Y                        -.181860                        8.01
 Maximum Rotation                                 -.049806       13.83
Side block sliding       .000484  -.055408         .002296        5.77
Keel block sliding      -.087291   .019017        -.019629        6.23
Side block overturning   .000484  -.055408         .002296        5.77
Keel block overturning  -.031319  -.030563         .001947        4.75
Side block liftoff      -.002232  -.081113        -.003868        4.97
Side block crushing     -.011740  -.012852         .009220        5.48
```

```
For Earthquake Acceleration of  80.00 % of the 1940 EL CENTRO

Maximums/Failures        X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------       --------  --------       ------------- -----------
 Maximum X              -.250337                                 16.51
 Maximum Y                        -.161793                        8.01
 Maximum Rotation                                  .049040       19.75
Side block sliding       .000027  -.051407         .001472        5.77
Keel block sliding      -.088423   .009133        -.017334        6.22
Side block overturning   .000027  -.051407         .001472        5.77
Keel block overturning  -.021642   .058728        -.005154        5.03
Side block liftoff       .001236  -.051243        -.003723        4.98
Side block crushing      .008197  -.014721         .008773        5.50
```

```
For Earthquake Acceleration of  70.00 % of the 1940 EL CENTRO

Maximums/Failures        X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------       --------  --------       ------------- -----------
 Maximum X              -.248603                                 13.79
 Maximum Y                        -.145349                        8.01
 Maximum Rotation                                  .049499       14.38
Side block sliding      -.026676   .040248        -.009791        6.28
Keel block sliding      -.083862   .039448        -.019523        7.37
Side block overturning  -.018619   .034936        -.011260        6.26
Keel block overturning  -.029241  -.004233         .007959        5.54
Side block liftoff      -.000110  -.023437        -.003463        4.99
Side block crushing     -.011305  -.039360        -.008468        5.92
```

```
For Earthquake Acceleration of  60.00 % of the 1940 EL CENTRO

Maximums/Failures       X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------      --------  --------        ------------- -----------
 Maximum X              -.252173                                13.78
 Maximum Y                        -.116732                       8.00
 Maximum Rotation                                  .049920      19.65
Side block sliding      -.003131   .021628        -.004153       6.30
Keel block sliding       .061008   .097166         .017490       7.93
Side block overturning  -.036400   .021380        -.007884       6.24
Keel block overturning   .022516   .054039         .004804       5.42
Side block liftoff      -.003402   .000282        -.003089       5.00
Side block crushing      .001256  -.018646        -.008745       5.96


For Earthquake Acceleration of  50.00 % of the 1940 EL CENTRO

Maximums/Failures       X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------      --------  --------        ------------- -----------
 Maximum X               .246529                                19.66
 Maximum Y                        -.094418                       8.00
 Maximum Rotation                                  .049232      19.61
Side block sliding      -.015797   .008866        -.002023       6.31
Keel block sliding      -.093131  -.025568        -.026015       8.50
Side block overturning  -.015797   .008866        -.002023       6.31
Keel block overturning   .029000   .008726         .004903       5.52
Side block liftoff      -.014161   .033488        -.003067       5.03
Side block crushing     -.000834  -.062532         .008307       6.50


For Earthquake Acceleration of  40.00 % of the 1940 EL CENTRO

Maximums/Failures       X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------      --------  --------        ------------- -----------
 Maximum X               .241724                                19.55
 Maximum Y                        -.071379                       8.00
 Maximum Rotation                                  .048794      19.50
Side block sliding       .032752   .002736         .006452       7.86
Keel block sliding       .084762   .009522         .023788       9.05
Side block overturning   .008986   .014682        -.001517       7.34
keel block overturning   .027507   .013162         .007261       6.60
Side block liftoff      -.004834   .006973         .002687       5.38
Side block crushing      .000491  -.013729         .009022       7.53
```

```
For Earthquake Acceleration of  30.00 % of the 1940 EL CENTRO

Maximums/Failures       X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------       --------  --------       ------------- -----------
 Maximum X              -.031730                                 8.07
 Maximum Y                        -.040973                       8.00
 Maximum Rotation                                 .005341        7.51
Keel block overturning  -.028676   .012919       -.003477        8.06
Side block liftoff      -.009727   .017853       -.002363        5.84


For Earthquake Acceleration of  20.00 % of the 1940 EL CENTRO

Maximums/Failures       X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------       --------  --------       ------------- -----------
 Maximum X              -.018083                                 7.97
 Maximum Y                        -.026897                       8.00
 Maximum Rotation                                 .003646        7.50
Side block liftoff        .002507   .019660       .002589        6.42


For Earthquake Acceleration of  10.00 % of the 1940 EL CENTRO

Maximums/Failures       X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------       --------  --------       ------------- -----------
 Maximum X              -.008056                                 7.98
 Maximum Y                        -.013437                       4.79
 Maximum Rotation                                 .001623        7.45

No failures occurred.


For Earthquake Acceleration of  19.00 % of the 1940 EL CENTRO

Maximums/Failures       X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------       --------  --------       ------------- -----------
 Maximum X              -.017166                                 7.97
 Maximum Y                        -.025552                       8.00
 Maximum Rotation                                 .003456        7.50
Side block liftoff        .002767   .020286       .002591        6.43
```

```
For Earthquake Acceleration of  18.00 % of the 1940 EL CENTRO

Maximums/Failures        X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------       --------  --------        ------------- -----------
 Maximum X              -.015413                                  7.97
 Maximum Y                        -.024186                        4.79
 Maximum Rotation                                  .003294        7.49
Side block liftoff       .010977  -.002288         .002979        6.54


For Earthquake Acceleration of  17.00 % of the 1940 EL CENTRO

Maximums/Failures        X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------       --------  --------        ------------- -----------
 Maximum X              -.014521                                  7.97
 Maximum Y                        -.022842                        4.79
 Maximum Rotation                                  .003091        7.49
Side block liftoff      -.002400  -.002636        -.002636        6.99


For Earthquake Acceleration of  16.00 % of the 1940 EL CENTRO

Maximums/Failures        X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------       --------  --------        ------------- -----------
 Maximum X              -.013572                                  7.97
 Maximum Y                        -.021499                        4.79
 Maximum Rotation                                  .002858        7.49
Side block liftoff      -.003316   .016301        -.002449        7.90


For Earthquake Acceleration of  15.00 % of the 1940 EL CENTRO

Maximums/Failures        X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------       --------  --------        ------------- -----------
 Maximum X               .013488                                  7.53
 Maximum Y                        -.020155                        4.79
 Maximum Rotation                                  .002624        7.48

No failures occurred.
```

APPENDIX 2

1. "V2READS" and"ACCELMOD" FORTRAN Program ListingsSample Vertical and Horizontal
2. "DATINNEW" and "MAKERUB" BASIC Program Listingss

"V2READS" and "ACCELMOD" FORTRAN Program Listings. . . . .

```
                                                                    Page    1
                                                                    01-22-88
                                                                    15:25:26
D Line# 1      7                                     Microsoft FORTRAN77 V3.20 02/84
      1 c         *******************************
      2 c         v2reads.for
      3 c         *******************************
      4 c         main program to read the Volume2 data.
      5 c         n  =  # of accel., velocity and displ. data
      6 c
      7 c         common/xyaxis/ixaxis,iyaxis,ixy
      8           integer cortil(1000),icor(100),cor(40)
      9           real y(5001),fcor(100)
     10           open(2,file='acc.dat',status='old')
     11           open(3,file='acc1.out',status='new')
     12         open(4,file='acc2.out',status='new')
     13         open(5,file='acc3.out',status='new')
     14           do 10 j=1,3
1    15           read(2,11)cortil
1    16           read(2,12)icor
1    17           read(2,13)fcor
1    18           n=icor(53)
1    19 c         Read the acceleration data:
1    20           read(2,11)cor
1    21         goto (100,200,300),j
1    22 100       read(2,13)(y(i),i=1,n)
1    23           write(3,14)(y(i),i=1,n)
1    24         goto 400
1    25 200     read(2,13)(y(i),i=1,n)
1    26         write(4,14)(y(i),i=1,n)
1    27         goto 400
1    28 300     read(2,13)(y(i),i=1,n)
1    29         write(5,14)(y(i),i=1,n)
1    30 400     continue
1    31 c         Read the velocity data:
1    32           read(2,11)cor
1    33           read(2,13)(y(i),i=1,n)
1    34 c         Read the displacement data:
1    35           read(2,11)cor
1    36           read(2,13)(y(i),i=1,n)
1    37 c         Read the "end of file" mark
1    38           read(2,11)ief
1    39 11        format(40a2)
1    40 12        format(16i5)
1    41 13        format(8f10.3)
1    42 14      format(f10.3)
1    43 10        continue
     44           end

Name    Type          Offset P Class

COR     INTEGER*4      24806
CORTIL  INTEGER*4          2
FCOR    REAL           24406
I       INTEGER*4      24974
ICOR    INTEGER*4       4002
IEF     INTEGER*4      24982
J       INTEGER*4      24966
N       INTEGER*4      24970
Y       REAL            4402
```

```
                                                                    Page   1
                                                                    01-23-88
                                                                    15:42:48
D Line# 1      7                           Microsoft FORTRAN77 V3.20 02/84
      1 c      acceleration data modification program
      2
      3        real a(2006),b(2006)
      4        integer n,i,j
      5        character*40 fname
      6
      7        write(*,*) 'INPUT FILE YOU WISH TO MODIFY...'
      8        read(*,'(a)') fname
      9        write(*,*) 'INPUT NUMBER OF DATA POINTS IN INPUT FILE ...'
     10        read(*,*) n
     11        open(2,file=fname,status='old')
     12        open(3,file='acc.mod',status='new')
     13
     14        do 10 j=1,n
1    15         read(2,*)a(j)
1    16 10     continue
     17 14     format(f9.4)
     18
     19        b(1)=a(1)
     20        do 20 i=1,1002
1    21         b(2*i)=(a(i)+a(i+1))/2
1    22         b(2*i+1)=a(i+1)
1    23 20     continue
     24
     25        do 30 j=1,2004
1    26         write(3,14)b(j)
1    27 30     continue
     28        end

Name    Type        Offset P Class

A      REAL              2
B      REAL           8026
FNAME  CHAR*40       16050
I      INTEGER*4     16162
J      INTEGER*4     16094
N      INTEGER*4     16090


Name    Type           Size   Class

MAIN                          PROGRAM

 Pass One    No Errors Detected
             28 Source Lines
```

"DATINNEW" and "MAKERUB" BASIC Program Listings. . . . . . .

```
10 SCREEN 0: WIDTH 80
20 CLS
30 F=0
40 D$="####.####"
50 '
60 PRINT "***************************************************************"
70 '
80 PRINT:PRINT "           ****SHIP DRYDOCK BLOCKING SYSTEM****       "
90 PRINT:PRINT "        **ACCELERATION DATA FILE CREATION PROGRAM**      "
100 PRINT:PRINT "       **FOR BILINEAR 3DOF QUAKE RESPONSE PROGRAM**     "
110 '
120 PRINT "***************************************************************"
130 '
140 '
150 INPUT " INPUT NAME OF ACCELERATION FILE YOU WISH TO MODIFY: ",ACOLD$
160 INPUT " HOW MANY DATA ENTRIES ARE IN THE INPUT DATA FILE? ",N
170 INPUT " HOW MANY DATA ENTRIES DO YOU WANT IN THE OUTPUT FILE? ",M
180 DIM AD(3000)
190 DIM AC(3000)
200 INPUT " WHAT PERCENT OF THE ORIGINAL ACCEL. DO YOU WANT ? (.XX) ",PP
210 INPUT " INPUT NAME OF OUTPUT ACCELERATION FILE: ",ACNEW$
220 INPUT " DO YOU WANT OUTPUT IN INCHES/SEC^2 ???  (Y/N) ";A$
230 IF A$="Y" OR A$="y" THEN F=1
240 INPUT " DO YOU WANT TO ADD LABELS TO THIS DATA FILE? (Y/N) ";B$
250 IF B$<>"Y" AND B$<>"y" THEN 300
260 FF=1
270 INPUT " INPUT THE NAME OF THE EARTHQUAKE:  ";Q$
280 INPUT " INPUT THE ACCELERATION COMPONENT NAME: ";C$
290 INPUT " INPUT THE ACCELERATION DATA TIME STEP: (SEC) ";DTAU
300 OPEN ACOLD$ FOR INPUT AS #1
310 Z=1
320 GG=0
330 FOR I=1 TO N
340 INPUT #1,AD$
350 IF VAL(AD$)=0 AND I=1 THEN GG=1
360 IF GG=1 AND I=3 THEN 420
370 IF VAL(AD$)=0 THEN GOTO 420
380 AB=VAL(AD$)
390 IF AB=-9999 THEN 430
400 IF F=1 THEN AC(Z)=AB/2.54 ELSE AC(Z)=AB
410 Z=Z+1
420 NEXT I
430 CLOSE #1
440 OPEN ACNEW$ FOR OUTPUT AS #1
450 IF FF<>1 THEN 490
460 PRINT#1,Q$
470 PRINT#1,C$
480 PRINT#1, USING D$;DTAU
490 FOR I=1 TO M
500 PRINT#1, USING D$;AC(I)*PP
510 NEXT I
520 CLOSE #1
530 END
```

```
10 SCREEN 0: WIDTH 80
20 CLS
30 PRINT "*****************************************************************"
40 '
50 PRINT:PRINT "         ****SHIP DRYDOCK BLOCKING SYSTEM***      "
60 PRINT:PRINT "      ****INPUT DATA FILE CREATION PROGRAM****   "
70 PRINT:PRINT "   ****FOR BILINEAR 3DOF QUAKE RESPONSE PROGRAM****":PRINT
80 '
90 PRINT "********************************************************************"
100 '
110 '
120 GRAV=32.174*12
130 A$=" #####.# ###.# ####### ######.## ######.## ######.## ###.# ######.# "
140 B$=" ######.## ######.## ######.## ######.## #####.## #####.## #####.## ###.
## "
150 C$=" ###.## ###.## ###.## ###.## #.## #.## "
160 D$=" ####.## #.## #.## ######.# ######.# #.### "
170 E$=" #### ### #.### ######.## ######.##"
180 PRINT:PRINT
190 PRINT " SELECT ONE OF THE FOLLOWING MAKEDATA OPTIONS: ":PRINT
200 '
210 PRINT " 1. PREPARE NEW DATA FILE":PRINT
220 PRINT " 2. MODIFY EXISTING DATA FILE":PRINT
230 INPUT "       SELECT NUMBER";NN
240 PRINT: INPUT "   DRIVE USED FOR DATA FILES (A:,B:,C:,D:,E:,F:):";ABC$
250 INPUT "            FILE NAME ( OMIT DRIVE LETTER )";F4$
260 F4$=ABC$+F4$
270 CLS
280 ON NN GOTO 300,350
290 '
300 GOSUB 480:' CALL SUBROUTINE "INPUT DATA"
310 GOSUB 1010:' CALL SUBROUTINE "PRINT DATA"
320 GOSUB 1620:' CALL SUBROUTINE "STORE DATA"
330 GOTO 410
340 '
350 GOSUB 1930:' CALL SUBROUTINE "RECALL DATA"
360 GOSUB 2190:' CALL SUBROUTINE "MODIFY DATA"
370 GOSUB 1010 :' CALL SUBROUTINE "PRINT DATA"
380 GOSUB 1620 :' CALL SUBROUTINE "STORE DATA"
390 GOTO 410
400 '
410 CLS: PRINT
420 INPUT" DO YOU WANT TO CREATE ANOTHER DATA FILE? (Y/N) ";DEC$
430 IF DEC$="Y" OR DEC$="y" THEN 20
440 END
450 '
460 '************************************************************************
470 '
480 CLS:' SUROUTINE "INPUT DATA"
490 PRINT "     INPUT THE FOLLOWING DATA:":PRINT
500 INPUT " SHIP NAME: ";SHIP$
510 INPUT " DISCRIPTION OF ISOLATORS IF USED ";ISO$
520 INPUT " DISCRIPTION OF BUILDUP: ";BUILD$
530 INPUT " DISCRIPTION OF WALE SHORES USED: ";WALE$
540 INPUT " DISCRIPTION OF DAMPING: ";DAMP$
550 INPUT " LOCATION OF DRYDOCK BEING STUDIED: ";DOCK$
560 INPUT " NAVSEA DOCKING DRAWING NUMBER: ";SEA$
570 INPUT " REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: ";STIF$
580 INPUT " MISC. COMMENTS: ";COMM$
590 '
600 INPUT " SHIP WEIGHT  (KIPS)                                W=";W
610 INPUT " HEIGHT OF KG (IN)                                  H=";H
620 INPUT " MOMENT OF INERTIA  (KIPS*IN*SEC^2)                Ik=";IK
630 INPUT " SIDE PIER VERTICAL STIFFNESS (KIPS/IN)           Kvs=";KVS
640 INPUT " SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)  Kvsp=";KVSP
```

```
650 INPUT " KEEL PIER VERTICAL STIFFNESS (KIPS/IN)              KVK=";KVK
660 INPUT " KEEL PIER VERTICAL PLAS STIFFNESS(KIPS/IN)         KVKP=";KVKP
670 INPUT " HEIGHT OF WALE SHORES  (IN)                          AAA=";AAA
680 INPUT " WALE SHORE STIFFNESS (KIPS/IN)                        KS=";KS
690 INPUT " SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN)             KHS=";KHS
700 INPUT " KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN)             KHK=";KHK
710 INPUT " SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KSHP=";KSHP
720 INPUT " KEEL PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KKHP=";KKHP
730 INPUT " RESTORING FORCE AT 0 DEFLECT KEEL HORIZ   (KIPS) QD1=";QD1
740 INPUT " RESTORING FORCE AT 0 DEFLECT SIDE HORIZ   (KIPS) QD2=";QD2
750 INPUT " RESTORING FORCE AT 0 DEFLECT SIDE VERT    (KIPS) QD3=";QD3
760 INPUT " RESTORING FORCE AT 0 DEFLECT KEEL VERT    (KIPS) QD4=";QD4
770 INPUT " SIDE BLOCK WIDTH  (IN)                               SBW=";SBW
780 INPUT " KEEL BLOCK WIDTH  (IN)                               KBW=";KBW
790 INPUT " SIDE BLOCK HEIGHT (IN)                               SBH=";SBH
800 INPUT " KEEL BLOCK HEIGHT (IN)                               KBH=";KBH
810 INPUT " BLOCK ON BLOCK FRICTION COEFFICIENT                   U1=";U1
820 INPUT " HULL ON BLOCK FRICTION COEFFICIENT                    U2=";U2
830 INPUT " SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN)   BR=";BR
840 INPUT " SIDE PIER CAP PROPORTIONAL LIMIT                   SCPL=";SCPL
850 INPUT " KEEL PIER CAP PROPORTIONAL LIMIT                   KCPL=";KCPL
860 INPUT " TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN^2) SAREA=";SAREA
870 INPUT " TOTAL KEEL PIER CONTACT AREA   (IN^2)          KAREA=";KAREA
880 INPUT " PERCENT CRITICAL DAMPING                           ZETA=";ZETA
890 INPUT " HULL NUMBER (XXXX)                                 HULL=";HULL
900 INPUT " SYSTEM NUMBER (XXX)                                NSYS=";NSYS
910 INPUT " CAP ANGLE (RAD)                                    BETA=";BETA
920 PRINT:PRINT
930  INPUT " ARE THE ABOVE VALUES CORRECT  Y/N";YN$
940  IF YN$="N" THEN GOTO 270
950 CLS :PRINT
960 PRINT:PRINT
970 PRINT " SHIP/SYSTEM DATA FILE INPUT COMPLETE "
980 RETURN
990 '*************************************************************************
1000 '
1010 CLS: 'SUBROUTINE "PRINT DATA"
1020 PRINT:PRINT "      ***SHIP/SUB DRYDOCK BLOCKING SYSTEM***  DATA FILE: ";F4$
1030 PRINT:PRINT "              ***INPUT FILE DATA***"
1040 PRINT:PRINT
1050 PRINT " SHIP NAME: ",SHIP$
1060 PRINT " DISCRIPTION OF ISOLATORS IF USED: ";ISO$
1070 PRINT " DISCRIPTION OF BUILDUP: ";BUILD$
1080 PRINT " DISCRIPTION OF WALE SHORES USED: ";WALE$
1090 PRINT " DISCRIPTION OF DAMPING: ";DAMP$
1100 PRINT " LOCATION OF DRYDOCK BEING STUDIED: ";DOCK$
1110 PRINT " NAVSEA DOCKING DRAWING NUMBER: ";SEA$
1120 PRINT " REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: ";STIF$
1130 PRINT " MISC. COMMENTS: ";COMM$
1140 PRINT
1150 PRINT
1160 PRINT " PRESS ANY KEY TO CONTINUE... "
1170 F$=INKEY$:IF F$="" THEN 1170
1180 CLS:PRINT
1190 '
1200 PRINT " SHIP WEIGHT  (KIPS)                                      W=";W
1210 PRINT " HEIGHT OF KG (IN)                                        H=";H
1220 PRINT " MOMENT OF INERTIA  (KIPS*IN*SEC^2)                      Ik=";IK
1230 PRINT " SIDE PIER VERTICAL STIFFNESS (KIPS/IN)                 Kvs=";KVS
1240 PRINT " SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)  Kvsp=";KVSP
1250 PRINT " KEEL PIER VERTICAL STIFFNESS (KIPS/IN)                 KVK=";KVK
1260 PRINT " KEEL PIER VERTICAL PLASTIC STIFFNESS(KIPS/IN)   KVKP=";KVKP
1270 PRINT " HEIGHT OF WALE SHORES  (IN)                            AAA=";AAA
1280 PRINT " WALE SHORE STIFFNESS (KIPS/IN)                          KS=";KS
1290 PRINT " SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN)               KHS=";KHS
1300 PRINT " KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN)               KHK=";KHK
1310 PRINT " SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KSHP=";KSHP
```

```
1310 PRINT " SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KSHP=";KSHP
1320 PRINT " KEEL PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KKHP=";KKHP
1330 PRINT " RESTORING FORCE AT 0 DEFLECT KEEL HORIZ    (KIPS) QD1=";QD1
1340 PRINT " RESTORING FORCE AT 0 DEFLECT SIDE HORIZ    (KIPS) QD2=";QD2
1350 PRINT " RESTORING FORCE AT 0 DEFLECT SIDE VERT     (KIPS) QD3=";QD3
1360 PRINT " RESTORING FORCE AT 0 DEFLECT KEEL VERT     (KIPS) QD4=";QD4
1370 PRINT " GRAVITATIONAL CONSTANT (IN/SEC^2)               GRAV=";GRAV
1380 PRINT:PRINT " PRESS ANY KEY TO CONTINUE... "
1390 F$=INKEY$:IF F$="" THEN 1390
1400 CLS:PRINT
1410 '
1420 PRINT " SIDE BLOCK WIDTH  (IN)                            SBW=";SBW
1430 PRINT " KEEL BLOCK WIDTH  (IN)                            KBW=";KBW
1440 PRINT " SIDE BLOCK HEIGHT (IN)                            SBH=";SBH
1450 PRINT " KEEL BLOCK HEIGHT (IN)                            KBH=";KBH
1460 PRINT " BLOCK ON BLOCK FRICTION COEFFICIENT                U1=";U1
1470 PRINT " HULL ON BLOCK FRICTION COEFFICIENT                 U2=";U2
1480 PRINT " SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN)   BR=";BR
1490 PRINT " SIDE PIER CAP PROPORTIONAL LIMIT                 SCPL=";SCPL
1500 PRINT " KEEL PIER CAP PROPORTIONAL LIMIT                 KCPL=";KCPL
1510 PRINT " TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN^2) SAREA=";SAREA
1520 PRINT " TOTAL KEEL PIER CONTACT AREA   (IN^2)          KAREA=";KAREA
1530 PRINT " PERCENT CRITICAL DAMPING                         ZETA=";ZETA
1540 PRINT " HULL NUMBER (XXXX)                               HULL=";HULL
1550 PRINT " SYSTEM NUMBER (XXX)                              NSYS=";NSYS
1560 PRINT " CAP ANGLE (RAD)                                  BETA=";BETA
1570 PRINT:PRINT " PRESS ANY KEY TO CONTINUE... "
1580 F$=INKEY$:IF F$="" THEN 1580
1590 RETURN
1600 '*********************************************************************
1610 '
1620 'SUBROUTINE "STORE DATA"
1630 IF NN<>2 THEN 1670
1640 CLS:PRINT
1650 INPUT " INPUT THE NAME OF THE MODIFIED DATA FILE: ",MD$
1660 F4$=ABC$+MD$
1670 OPEN F4$ FOR OUTPUT AS #1
1680 PRINT#1,USING A$;W;H;IK;KVS;KVSP;KVK;AAA;KS
1690 PRINT#1,USING B$;KHS;KHK;KSHP;KKHP;QD1;QD2;QD3;GRAV
1700 PRINT#1,USING C$;SBW;KBW;SBH;KBH;U1;U2
1710 PRINT#1,USING D$;BR;SCPL;KCPL;SAREA;KAREA;ZETA
1720 PRINT#1,USING E$;HULL;NSYS;BETA;QD4;KVKP
1730 PRINT#1," "
1740 PRINT#1," "
1750 PRINT#1," "
1760 PRINT#1," "
1770 PRINT#1," "
1780 PRINT#1,SHIP$
1790 PRINT#1,ISO$
1800 PRINT#1,BUILD$
1810 PRINT#1,WALE$
1820 PRINT#1,DAMP$
1830 PRINT#1,DOCK$
1840 PRINT#1,SEA$
1850 PRINT#1,STIF$
1860 PRINT#1,COMM$
1870 '
1880 CLOSE #1
1890 RETURN
1900 '
1910 '********************************************************************
1920 '
1930 CLS: 'SUBROUTINE "RECALL DATA"
1940 PRINT "WAIT!!!! INPUTING PREVIOUS DATA FILE ----- "
1950 OPEN F4$ FOR INPUT AS #1
1960 INPUT#1,W,H,IK,KVS,KVSP,KVK,AAA,KS
1970 INPUT#1,KHS,KHK,KSHP,KKHP,QD1,QD2,QD3,GRAV
```

```
1980 INPUT#1,SBW,KBW,SBH,KBH,U1,U2
1990 INPUT#1,BR,SCPL,KCPL,SAREA,KAREA,ZETA
2000 INPUT#1,HULL,NSYS,BETA,QD4,KVKP
2010 INPUT#1,NULL$
2020 INPUT#1,NULL$
2030 INPUT#1,NULL$
2040 INPUT#1,NULL$
2050 INPUT#1,NULL$
2060 INPUT#1,SHIP$
2070 INPUT#1,ISO$
2080 INPUT#1,BUILD$
2090 INPUT#1,WALE$
2100 INPUT#1,DAMP$
2110 INPUT#1,DOCK$
2120 INPUT#1,SEA$
2130 INPUT#1,STIF$
2140 INPUT#1,COMM$
2150 CLOSE #1
2160 RETURN
2170 '
2180 '************************************************************************
2190 CLS: 'SUBROUTINE "MODIFY DATA"
2200 PRINT " SHIP WEIGHT  (KIPS)                                    W=";W
2210 INPUT "NEW VALUE:*NO CHANGE: PRESS ENTER*   W=";I$:IF I$<>""THEN W=VAL(I$)
2220 PRINT " HEIGHT OF KG (IN)                                      H=";H
2230 INPUT "NEW VALUE: *NO CHANGE PRESS ENTER*  H=";Q$:IF Q$<>""THEN H=VAL(Q$)
2240 PRINT " MOMENT OF INERTIA  (KIPS*IN*SEC^2)                    Ik=";IK
2250 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  Ik=";Q$:IF Q$<>""THEN IK=VAL(Q$)
2260 PRINT " SIDE PIER VERTICAL STIFFNESS (KIPS/IN)               Kvs=";KVS
2270 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* Kvs=";Q$:IF Q$<>""THEN KVS=VAL(Q$)
2280 PRINT " SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)  Kvsp=";KVSP
2290 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* Kvsp=";Q$:IF Q$<>""THEN KVSP=VAL(Q
$)
2300 PRINT " KEEL PIER VERTICAL STIFFNESS (KIPS/IN)               KVK=";KVK
2310 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* Kvk=";Q$:IF Q$<>""THEN KVK=VAL(Q$)
2320 PRINT " KEEL PIER VERTICAL PLASTIC STIFFNESS(KIPS/IN)          KVKP=";KVKP
2330 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* Kvkp=";Q$:IF Q$<>""THEN KVKP=VAL(Q
$)
2340 PRINT " HEIGHT OF WALE SHORES  (IN)                          AAA=";AAA
2350 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* AAA=";Q$:IF Q$<>""THEN AAA=VAL(Q$)
2360 PRINT " WALE SHORE STIFFNESS (KIPS/IN)                        KS=";KS
2370 INPUT "NEW VALUE *NO CHANGE: PRESS ENTER* KS=";Q$:IF Q$<>""THEN KS=VAL(Q$)
2380 PRINT " SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN)             KHS=";KHS
2390 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* Khs=";Q$:IF Q$<>""THEN KHS=VAL(Q$)
2400 PRINT " KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN)             KHK=";KHK
2410 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KHK=";Q$:IF Q$<>""THEN KHK=VAL(Q$)
2420 PRINT " SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KSHP=";KSHP
2430 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KSHP=";Q$:IF Q$<>""THEN KSHP=VAL(Q
$)
2440 PRINT " KEEL PIER HORIZONTAL PLATIC STIFFNESS(KIPS/IN) KKHP=";KKHP
2450 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KKHP=";Q$:IF Q$<>""THEN KKHP=VAL(Q
$)
2460 PRINT " RESTORING FORCE AT 0 DEFLECT KEEL HORIZ  (KIPS) QD1=";QD1
2470 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  QD1=";Q$:IF Q$<>""THEN QD1=VAL(Q$
)
2480 PRINT " RESTORING FORCE AT 0 DEFLECT SIDE HORIZ  (KIPS) QD2=";QD2
2490 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  QD2=";Q$:IF Q$<>""THEN QD2=VAL(Q$
)
2500 PRINT " RESTORING FORCE AT 0 DEFLECT SIDE VERT   (KIPS) QD3=";QD3
2510 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  QD3=";Q$:IF Q$<>""THEN QD3=VAL(Q$
)
2520 PRINT " RESTORING FORCE AT 0 DEFLECT KEEL VERT   (KIPS) QD4=";QD4
2530 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  QD4=";Q$:IF Q$<>""THEN QD4=VAL(Q$
)
2540 PRINT " GRAVITATIONAL CONSTANT (IN/SEC^2)                   GRAV=";GRAV
2550 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* GRAV=";Q$:IF Q$<>""THEN GRAV=VAL(Q
```

```
2560 PRINT " SIDE BLOCK WIDTH  (IN)                              SBW=";SBW
2570 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* SBW=";Q$:IF Q$<>""THEN SBW=VAL(Q$)
2580 PRINT " KEEL BLOCK WIDTH  (IN)                              KBW=";KBW
2590 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KBW=";Q$:IF Q$<>""THEN KBW=VAL(Q$)
2600 PRINT " SIDE BLOCK HEIGHT (IN)                              SBH=";SBH
2610 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* SBH=";Q$:IF Q$<>""THEN SBH=VAL(Q$)
2620 PRINT " KEEL BLOCK HEIGHT (IN)                              KBH=";KBH
2630 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KBH=";Q$:IF Q$<>""THEN KBH=VAL(Q$)
2640 PRINT " BLOCK ON BLOCK FRICTION COEFFICIENT                  U1=";U1
2650 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  U1=";Q$:IF Q$<>""THEN U1=VAL(Q$)
2660 PRINT " HULL ON BLOCK FRICTION COEFFICIENT                   U2=";U2
2670 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  U2=";Q$:IF Q$<>""THEN U2=VAL(Q$)
2680 PRINT " SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN)   BR=";BR
2690 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  BR=";Q$:IF Q$<>""THEN BR=VAL(Q$)
2700 PRINT " SIDE PIER CAP PROPORTIONAL LIMIT                   SCPL=";SCPL
2710 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* SCPL=";Q$:IF Q$<>""THEN SCPL=VAL(Q
$)
2720 PRINT " KEEL PIER CAP PROPORTIONAL LIMIT                   KCPL=";KCPL
2730 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KCPL=";Q$:IF Q$<>""THEN KCPL=VAL(Q
$)
2740 PRINT " TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN^2) SAREA=";SAREA
2750 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* SAREA=";Q$:IF Q$<>""THEN SAREA=VAL
(Q$)
2760 PRINT " TOTAL KEEL PIER CONTACT AREA   (IN^2)          KAREA=";KAREA
2770 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KAREA=";Q$:IF Q$<>""THEN KAREA=VAL
(Q$)
2780 PRINT " PERCENT CRITICAL DAMPING                           ZETA=";ZETA
2790 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* ZETA=";Q$:IF Q$<>""THEN ZETA=VAL(Q
$)
2800 PRINT " HULL NUMBER (XXXX)                                 HULL=";HULL
2810 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  HULL=";Q$:IF Q$<>""THEN HULL=VAL(
Q$)
2820 PRINT " SYSTEM NUMBER (XXX)                                NSYS=";NSYS
2830 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* NSYS=";Q$:IF Q$<>""THEN NSYS=VAL(Q
$)
2840 PRINT " CAP ANGLE     (RAD)                                BETA=";BETA
2850 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* BETA=";Q$:IF Q$<>""THEN BETA=VAL(Q
$)
2860 PRINT " SHIP NAME: ",SHIP$
2870 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  SHIP$=";Q$:IF Q$<>""THEN SHIP$=Q$
2880 PRINT " DISCRIPTION OF ISOLATORS IF USED: ";ISO$
2890 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  ISO$=";Q$:IF Q$<>""THEN ISO$=Q$
2900 PRINT " DISCRIPTION OF BUILDUP: ";BUILD$
2910 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  BUILD$=";Q$:IF Q$<>""THEN BUILD$=
Q$
2920 PRINT " DISCRIPTION OF WALE SHORES USED: ";WALE$
2930 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  WALE$=";Q$:IF Q$<>""THEN WALE$=Q$
2940 PRINT " DISCRIPTION OF DAMPING: ";DAMP$
2950 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  DAMP$=";Q$:IF Q$<>""THEN DAMP$=Q$
2960 PRINT " LOCATION OF DRYDOCK BEING STUDIED: ";DOCK$
2970 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  DOCK$=";Q$:IF Q$<>""THEN DOCK$=Q$
2980 PRINT " NAVSEA DOCKING DRAWING NUMBER: ";SEA$
2990 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  SEA$=";Q$:IF Q$<>""THEN SEA$=Q$
3000 PRINT " REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: ";STIF$
3010 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  STIF$=";Q$:IF Q$<>""THEN STIF$=Q$
3020 PRINT " MISC. COMMENTS: ";COMM$
3030 INPUT "NEW VALUE *NO CHANGE PRESS ENTER*  COMM$=";Q$:IF Q$<>""THEN COMM$=Q$
3040 RETURN
3050 '
3060 '************************************************************************
```

APPENDIX 3

1. Typical Accelerogram Header
2. Layout Sheet for *USS Leahy* Long Beach Dry Dock # 3
3. *Leahy* Horizontal and Vertical Stiffness Spreadsheets
4. System 1-11 and *USS Leahy* Stiffness Table
5. *Leahy* XEL, QD, KU, and KD Values for Bilinear Douglas Fir Caps
6. Rotational Moment of Inertia Calculation for *USS Leahy*
7. "3DOFRUB" *USS Leahy* Input Data File
8. *Leahy* Cap Angle Regression Analysis
9. "3DOFRUB" *USS Leahy* Output File

Typical Accelerogram Header

```
 ORRECTED ACCELEROGRAM  IIDD200  87.101.0 COMP VERT   FILE   0  CORRESPONDING T
  LE      0 OF UNCORRECTED ACCELEROGRAM DATA OF VOLUME I:
WHITTIER EARTHQUAKE                                                          19
OCT 01, 1987 -1442 GMT                                                       22
IDD200  87.101.0 N                                                           18
STATION DD2L 0001   33 45 14N  118 13 48W                                    39
DD2 LBNSY                                                                     9
COMP VERT                                                                     9
WHITTIER EARTHQUAKE   OCT 01, 1987 -1442 GMT                                 44
EPICENTER -   34 03 29N  118 04 30W                                          35
INSTR PERIOD =  .037 SEC   DAMPING =  .590   SENSITIVITY =  1.78 CM/G   69
NO. OF POINTS =   3250      DURATION =  16.354 SEC                           50
UNITS ARE SEC AND G/10                                                       22
RMS ACCLN. OF COMPLETE RECORD =     .051 G/10                                45
ACCELEROGRAM IS BAND-PASS FILTERED BETWEEN  .300- .400 AND 25.00-27.00 CYC/SEC.
   819  INSTRUMENT AND BASELINE CORRECTED DATA
AT EQUALLY-SPACED INTERVALS OF    .020  SEC.
PEAK  ACCELERATION =   -13.05000  CMS/SEC/SEC AT    2.620   SEC.
PEAK   VELOCITY   =    -1.08100    CMS/SEC   AT   11.640   SEC.
PEAK DISPLACEMENT =      .17300      CMS     AT   14.760   SEC.
INITIAL VELOCITY  =     -.0220  CMS/SEC;  INITIAL DISPLACEMENT =    -.0320  CMS
WHITTIER EARTHQUAKE   OCT 01, 1987 -1442 GMT
MAGNITUDE =  5.9    EPICENTRAL DISTANCE =  36.74 KM    M.M.I. =  0.
IIDD200  87.101.0   DD2 LBNSY     COMP VERT

    0    4    4  200   87  101    0    1    1   33   45   14  118   13   48   34
    3   29  118    4   30   10    1 1987 1442    4  500 3250   19    9   44    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0 3250 3250  819    4   10   10    1    0   44   43   10   10    2  410
    5  164    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0
      .037       .590     16.354       .051       .100      1.780     34.058    118.075
    33.754    118.230     36.736      5.900       .000      5.000       .000       .000
      .000       .000       .000       .000       .000       .000       .000       .000
      .000       .000       .000       .000       .000       .000       .000       .000
      .000       .000       .000       .000       .000       .000       .000       .000
      .000       .000       .000       .000       .000       .000       .000       .000
      .000       .000      1.000     98.067       .005     16.354    169.816      1.000
     1.000     27.000      2.000     16.360       .020       .400       .100       .000
     2.620    -13.050     11.640     -1.081     14.760       .173      -.022       .400
    25.000       .200       .200      -.032     11.640     -1.081     14.800       .170
```

Layout Sheet for *USS Leahy*
Long Beach Dry Dock # 3 . .

BUILD KEEL HEIGHT TO
10'-6" (ON DECLIVITY)

OK
7-30-87

8/4/87

BUSHIPS 1948741 REV. 1

USS LEAHY CG-16 DRYDOCK NUMBER 3 ON CENTERLINE BOW SOUTH POSITION NUMBER 2
LOA 532'-6 5/16" BEAM 54'-9"
RUDDER 7'-9" TO 22'-3" FROM SRP ON CENTERLINE-------- 30 3/4" BELOW BASE
PROPS 31'-6" FROM SRP 10'-6" OFF CENTERLINE P/S------ 3'-3 7/8" BELOW BASE
AFT KNUCKLE 103'-0" FROM SRP------------------------- OMIT PIERS AFT
CENTERLINE NUMBER 1 BILGE BLOCKS 178'-0" FROM SRP---- BATTENS AFT SIDE
ROD METER 294'-11" FROM SRP 3'-3 1/2" TO PORT-------- OMIT PIERS 2'-0" F&A
FWD KNUCKLE 466'-6" FROM SRP------------------------- OMIT PIERS FWD
SONAR DOME 468'-10" TO 506'-4" FROM SRP-------------- 5'-5" BELOW BASE
FWD PERPENDICULAR 513'-11" FROM STERN REFERENCE POINT

DOCKSIDES

AOA 581'-9"
RUDDER 574'-0" TO 559'-6"
PROPS 550'-3"
AFT KNUCKLE 478'-9"
C/L NO. 1 BILGE BLOCKS 403'-9"
ROD METER 286'-10"
FWD KNUCKLE 115'-3"
SONAR DOME 112'-11" TO 75'-5"
FWD PERPENDICULAR 67'-10"
FOA 49'-2 11/16"

KEEL RISE

RISE	SRP	DOCK SIDE
0"	376'-6"	205'-3"
+3/16"	401'-6"	180'-3"
+9/16"	426'-6"	155'-3"
+1 1/2"	451'-6"	130'-3"
+1 9/16"	459'-0"	122'-9"
+1 9/16"	466'-6"	115'-3"

7-30-87 [illegible]

USS LEAHY CG-16

SIDE BLOCKS

NO.	B-HB	PORT 18" B-HT	PORT 18" C-HT	STBD 18" B-HT	STBD 18" C-HT	LAP ANGLE
1	13-3-5+	3-9-6	4-4-1	3-9-6	4-4-1	.370
2	13-5-4	3-3-3	3-9-5	3-3-3	3-9-5	.362
3	13-7-2	2-10-2	3-4-4	2-10-2	3-4-4	.362
4	13-9-0	2-6-0	3-0-3	2-6-2	3-0-6	.370
5	13-10-2+	2-3-1	2-9-3	2-3-3	2-9-7	.362
6	13-11-3	2-0-6	2-7-2	2-1-0	2-7-5	.374
7	14-0-1	1-11-7	2-6-4	2-0-0	2-6-5	[illegible]
8	11-8-0	1-3-1	1-8-2	1-3-3	1-8-4	.293
9	11-7-6+	1-3-4	1-8-6	1-3-7	1-9-1	[illegible]
10	11-7-5	OMIT	OMIT	1-5-0	1-10-4	.315
11	11-7-1	1-7-0	2-0-0	1-6-6	2-0-5	.255
12	11-6-4	1-9-0	2-3-5	1-9-0	2-3-5	.346
13	11-5-3	1-11-5	2-6-7	OMIT	OMIT	.426
14	11-3-5+	2-3-1	2-11-2	2-3-1	2-11-3	[illegible]
15	11-1-1	2-6-6	3-4-2	2-7-1	3-4-4	[illegible]

USS LEAHY
KEEL BLOCK
HORIZONTAL
PLASTIC
STIFFNESS
(K) 302.37 KIPS/IN

Leahy Horizontal and Vertical Stiffness Spreadsheets. . . .

27-Jan-88

```
HORIZONTAL STIFFNESS MATRIX FOR 4 LAYERS        ORIGINAL PER DOCKING DRAWING

USS LEAHY PLASTIC
THIS IS A KEEL SYSTEM FOR USS LEAHY CG-16 WITH 12 FT BUILDUP
12 FOOT CENTERS


    ELEMENT # 1    CONCRETE
                       DEPTH       TRANSVERSE                      HEIGHT
        E1              B1             H1            I1              L1
       (PSI)           (IN)           (IN)         (IN^4)           (IN)
    -----------------------------------------------------------------------

         4000000              42            96        3096576               48

    -----------------------------------------------------------------------

    12E1I1/L1^3    6E1I1/L1^2     4E1I1/L1        2E1I1/L1
    -----------------------------------------------------------------------

      1344000000    32256000000  1032192000000   516096000000
    -----------------------------------------------------------------------

      RIGIDITY         TOP          SHEAR         ELEMENT
        GIr          CONTACT        STRAIN         SHEAR
       (PSI)          AREA         (IN/IN)       DEFLECTION
                     (IN^2)                         (IN)
    -------------------------------------------

         2400000           4032   0.0000001033   0.0000049603

    -----------------------------------------------------------------------


    ELEMENT # 2    CONCRETE
                       DEPTH       TRANSVERSE                      HEIGHT
        E2              B2             H2            I2              L2
       (PSI)           (IN)           (IN)         (IN^4)           (IN)
    -----------------------------------------------------------------------

         4000000              42            48         387072               66

    -----------------------------------------------------------------------

    12E2I2/L2^3    6E2I2/L2^2     4E2I2/L2        2E2I2/L2
    -----------------------------------------------------------------------

     64625093.914   2132628099.2    93835636364    46917818182
    -----------------------------------------------------------------------

      RIGIDITY         TOP          SHEAR         ELEMENT
        GIr          CONTACT        STRAIN         SHEAR
       (PSI)          AREA         (IN/IN)       DEFLECTION
                     (IN^2)                         (IN)

  -------------------------------

       2400000           2016   0.0000002067   0.0000136409
```

```
-----------------------------------------------------------------------------

ELEMENT # 3    OAK
               DEPTH         TRANSVERSE                      HEIGHT
    E3          B3              H3            I3               L3
   (PSI)       (IN)            (IN)         (IN^4)            (IN)
-----------------------------------------------------------------------------

        335720           42            64        917504             30

-----------------------------------------------------------------------------

12E3I3/L3^3    6E3I3/L3^2    4E3I3/L3       2E3I3/L3
-----------------------------------------------------------------------------

   1.3690E+08    2.0535E+09    4.1070E+10    2.0535E+10
-----------------------------------------------------------------------------

   RIGIDITY       TOP          SHEAR         ELEMENT
     Glr        CONTACT        STRAIN         SHEAR
    (PSI)         AREA         (IN/IN)      DEFLECTION
                 (IN^2)                        (IN)
-------------------------------------------------------------

         23980          2688   0.0000155139   0.0004654176

-----------------------------------------------------------------------------


ELEMENT # 4    DOUGLAS FIR
               DEPTH         TRANSVERSE                      HEIGHT
    E4          B4              H4            I4               L3
   (PSI)       (IN)            (IN)         (IN^4)            (IN)
-----------------------------------------------------------------------------

         48629           42            26         61516              6

-----------------------------------------------------------------------------

12E4I4/L4^3    6E4I4/L4^2    4E4I4/L4       2E4I4/L4
-----------------------------------------------------------------------------

   1.6619E+08    4.9858E+08    1.9943E+09    9.9715E+08
-----------------------------------------------------------------------------

   RIGIDITY       TOP          SHEAR         ELEMENT
     Glr        CONTACT        STRAIN         SHEAR          TOTAL
    (PSI)         AREA         (IN/IN)      DEFLECTION        SHEAR
                 (IN^2)                        (IN)       DEFLECTION (IN)
-----------------------------------------------------------------------------

          3474         764.4   0.0003766275    0.002259765     2.7438E-03
```

```
F/                                          STIFFNESS MATRIX
M                                                                                                       D


Q1   1.3440E+09   3.2256E+10  -1.3440E+09   3.2256E+10   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 q1

M1   3.2256E+10   1.0322E+12  -3.2256E+10   5.1610E+11   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 th1

Q2  -1.3440E+09  -3.2256E+10   1.4086E+09  -3.0123E+10  -6.4625E+07   2.1326E+09   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 q2

M2   3.2256E+10   5.1610E+11  -3.0123E+10   1.1260E+12  -2.1326E+09   4.6918E+10   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 th2

Q3   0.0000E+00   0.0000E+00  -6.4625E+07  -2.1326E+09   2.0152E+08  -7.9132E+07  -1.3690E+08   2.0535E+09   0.0000E+00   0.0000E+00 q3

M3   0.0000E+00   0.0000E+00   2.1326E+09   4.6918E+10  -7.9132E+07   1.3491E+11  -2.0535E+09   2.0535E+10   0.0000E+00   0.0000E+00 th3

Q4   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  -1.3690E+08  -2.0535E+09   3.0309E+08  -1.5549E+09 -1.66192E+08  4.98577E+08 q4

M4   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   2.0535E+09   2.0535E+10  -1.5549E+09   4.3064E+10 -4.98577E+08  9.97154E+08 th4

Q5   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 -1.66192E+08 -4.98577E+08  1.66192E+08 -4.98577E+08 q5

M5   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  4.98577E+08  9.97154E+08 -4.98577E+08  1.99431E+09 th5

------------------------------------------------------------------------------------------------------------------------------------
```

```
KNOWN VALUES:                                          # OF SYSTEM BLOCKS =              60
QI =                                -1000 lbs

M1 = QI*(L1+L2+L3+L4) =            -150000 IN*LBS

Q2 = M2 = Q3 = M3 = M4 = Q4 = M5          0

Q5 =                                 1000 lbs

q1 = th1=                  0
-----------------------------------------------------------------------------------------

SOLVED UNKNOWNS:

q2=  0.0000124628 in

th2  0.0000004883 rad
                                                          -B1           -B2
q3   0.0001572266 in                                 -2846.7317806  -174396.69421

th3  0.0000034296 rad

q4   0.0002980984 in                                 -29566.937031  -499717.35324

th4  0.0000054749 rad


q5   0.0003550162 in                                 -53[illegible]

th5   0.000011492 rad

K (BEND HORIZ) FOR 1 KEEL BLOCK =  335[illegible]           335[illegible]
------------------------------------------------------------------------------------------

K (BEND HORIZ) ALL KEEL BLOCKS =   201275823.1 lbs/in          201275.8231 KIPS/IN
------------------------------------------------------------------------------------------

MATRIX CHECK:

  QI =              -1000.0000

  M1 =            -150000.0000

  Q2 =                  0.0000

  M2 =                  0.0000

  Q3 =                  0.0000

  M3 =                  0.0000

  Q4 =                 -0.0000

  M4 =                 -0.0000

  Q5 =               1000.0000

  M5 =                  0.0000
=========================================================================================


TOTAL KEEL BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION:
USS LEAHY CG-16 PLASTIC
-----------------------------------------------------------------------------------

Khk (SIDEBLOCK HORIZONTAL STIFFNESS) = P/(BENDING DISPL + SHEAR DISPLACEMENT)

Khk       =                 322.71 KIPS/IN        (PER BLOCK)

Khk       =               19362.33 KIPS/IN        (ENTIRE KEEL BLOCK SYSTEM)
-----------------------------------------
```

USS LEAHY
SIDE BLOCK
HORIZONTAL
PLASTIC
STIFFNESS
225112 kips/in

```
       27-Jan-88

HORIZONTAL STIFFNESS MATRIX FOR 4 LAYERS        ORIGINAL PER DOCKING DRAWING

USS LEAHY PLASTIC
THIS IS A SIDE BLOCK SYSTEM FOR USS LEAHY CG-16 WITH 12.5 FT BUILDUP
12 FOOT CENTERS

   ELEMENT # 1    CONCRETE
                       DEPTH         TRANSVERSE                      HEIGHT
         E1             B1              H1            I1               L1
       (PSI)           (IN)            (IN)         (IN^4)            (IN)
   ------------------------------------------------------------------------

          4000000             96             168     37933056              48

   ------------------------------------------------------------------------

   12E1I1/L1^3     6E1I1/L1^2     4E1I1/L1       2E1I1/L1
   ------------------------------------------------------------------------

      16464000000    395136000000 12644352000000  6322176000000
   ------------------------------------------------------------------------

     RIGIDITY         TOP           SHEAR          ELEMENT
       Glr          CONTACT         STRAIN          SHEAR
      (PSI)          AREA          (IN/IN)        DEFLECTION
                    (IN^2)                           (IN)
   ------------------------------------------------------------------------

         2400000         16128   0.0000000258   0.0000012401

   ------------------------------------------------------------------------


   ELEMENT # 2    CONCRETE
                       DEPTH         TRANSVERSE                      HEIGHT
         E2             B2              H2            I2               L2
       (PSI)           (IN)            (IN)         (IN^4)            (IN)
   ------------------------------------------------------------------------

          4000000             48             100      4000000              66

   ------------------------------------------------------------------------

   12E2I2/L2^3     6E2I2/L2^2     4E2I2/L2       2E2I2/L2
   ------------------------------------------------------------------------

     667835378.58    22038567493    969696969697    484848484848
   ------------------------------------------------------------------------

     RIGIDITY         TOP           SHEAR          ELEMENT
       Glr          CONTACT         STRAIN          SHEAR
      (PSI)          AREA          (IN/IN)        DEFLECTION
                    (IN^2)                           (IN)
------------------------------------------------------------------------

      2400000          3360    0.000000124   0.0000081845

------------------------------------------------------------------------
```

```
ELEMENT # 3    OAK
                 DEPTH      TRANSVERSE                  HEIGHT
     E3           B3            H3           I3           L3
    (PSI)        (IN)          (IN)        (IN^4)        (IN)
----------------------------------------------------------------------

      335720           50            93    3351487.5            57

----------------------------------------------------------------------

12E3I3/L3^3   6E3I3/L3^2    4E3I3/L3      2E3I3/L3
----------------------------------------------------------------------

   7.2907E+07    2.0779E+09    7.8959E+10    3.9479E+10
----------------------------------------------------------------------

  RIGIDITY        TOP          SHEAR        ELEMENT
    GIr         CONTACT        STRAIN        SHEAR
   (PSI)         AREA         (IN/IN)     DEFLECTION
                (IN^2)                       (IN)
----------------------------------------------------------------------

       23980           4650   0.000008968  0.0005111787

----------------------------------------------------------------------


ELEMENT # 4    DOUGLAS FIR
                 DEPTH      TRANSVERSE                  HEIGHT
     E4           B4            H4           I4           L3
    (PSI)        (IN)          (IN)        (IN^4)        (IN)
----------------------------------------------------------------------

       48629           28            18        13608             6

----------------------------------------------------------------------

12E4I4/L4^3   6E4I4/L4^2    4E4I4/L4      2E4I4/L4
----------------------------------------------------------------------

   3.6764E+07    1.1029E+08    4.4116E+08    2.2058E+08
----------------------------------------------------------------------

  RIGIDITY        TOP          SHEAR        ELEMENT
    GIr         CONTACT        STRAIN        SHEAR          TOTAL
   (PSI)         AREA         (IN/IN)     DEFLECTION        SHEAR
                (IN^2)                       (IN)      DEFLECTION (IN)
----------------------------------------------------------------------

        3474            504  0.0005712184  0.0034273102    3.9479E-03
```

```
F/                                         STIFFNESS MATRIX
M                                                                                                                     D


Q1   1.6464E+10   3.9514E+11  -1.6464E+10   3.9514E+11   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  0.0000E+00    0.0000E+00 q1

M1   3.9514E+11   1.2644E+13  -3.9514E+11   6.3222E+12   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  0.0000E+00    0.0000E+00 th1

Q2  -1.6464E+10  -3.9514E+11   1.7132E+10  -3.7310E+11  -6.6784E+08   2.2039E+10   0.0000E+00   0.0000E+00  0.0000E+00    0.0000E+00 q2

M2   3.9514E+11   6.3222E+12  -3.7310E+11   1.3614E+13  -2.2039E+10   4.8485E+11   0.0000E+00   0.0000E+00  0.0000E+00    0.0000E+00 th2

Q3   0.0000E+00   0.0000E+00  -6.6784E+08  -2.2039E+10   7.4074E+08  -1.9961E+10  -7.2907E+07   2.0779E+09  0.0000E+00    0.0000E+00 q3

M3   0.0000E+00   0.0000E+00   2.2039E+10   4.8485E+11  -1.9961E+10   1.0487E+12  -2.0779E+09   3.9479E+10  0.0000E+00    0.0000E+00 th3

Q4   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  -7.2907E+07  -2.0779E+09   1.0967E+08  -1.9676E+09 -3.67635E+07  1.10291E+08 q4

M4   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   2.0779E+09   3.9479E+10  -1.9676E+09   7.9400E+10 -1.10291E+08  2.20581E+08 th4

Q5   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 -3.67635E+07 -1.10291E+08  3.67635E+07 -1.10291E+08 q5

M5   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  1.10291E+08  2.20581E+08 -1.10291E+08  4.41162E+08 th5

--------------------------------------------------------------------------------------------------------------------------------------
```

```
KNOWN VALUES:                                       # OF SYSTEM BLOCKS =              14
Q1 =                                 -1000 lbs

M1 = Q1*(L1+L2+L3+L4) =            -177000 IN*LBS

Q2 = M2 = Q3 = M3 = M4 = Q4 = M5          0

Q5 =                                  1000 lbs

q1 = th1=                       0
-----------------------------------------------------------------------------------------

SOLVED UNKNOWNS:

q2=  0.0000012224 in

th2  0.0000000484 rad

                                                           -B1             -B2
q3   0.0000189822 in                                  -2883.0278465  -202873.50847

th3  0.0000004444 rad
q4      0.00010784 in                                 -3307.3464598  -137531.70582

th4  0.0000021922 rad


q5   0.0002297964 in                                  -5206.3503209  -18860.324477

th5   0.000029393 rad

K (BEND HORIZ) FOR 1 SIDE BLOCK =  9273000.8265 lbs/in          9273.0008265 KIPS/IN
-----------------------------------------------------------------------------------------

K (BEND HORIZ) ALL SIDE BLOCKS =  129822011.571 lbs/in        129822.011571 KIPS/IN
-----------------------------------------------------------------------------------------

MATRIX CHECK:

   Q1 =              -1000.0000

   M1 =            -177000.0000

   Q2 =                  0.0000

   M2 =                  0.0000

   Q3 =                 -0.0000

   M3 =                  0.0000

   Q4 =                 -0.0000

   M4 =                 -0.0000

   Q5 =               1000.0000

   M5 =                 -0.0000
=========================================================================================


TOTAL SIDE BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION:
USS LEAHY PLASTIC          -
-----------------------------------------------------------------------------------------

Khs (SIDEBLOCK HORIZONTAL STIFFNESS) = P/(BENDING DISPL + SHEAR DISPLACEMENT)

Khs       =              239.37 KIPS/IN         (PER BLOCK)

Khs       =             3351.12 KIPS/IN         (ENTIRE SIDE BLOCK SYSTEM)
-----------------------------------------------------------------------------------------
```

USS LEAHY
KEEL BLOCK
HORIZONTAL
ELASTIC
STIFFNESS
414 [illegible]

```
     27-Jan-88

HORIZONTAL STIFFNESS MATRIX FOR 4 LAYERS        ORIGINAL PER DOCKING DRAWING

USS LEAHY ELASTIC
THIS IS A KEEL SYSTEM FOR USS LEAHY CG-16 WITH 12 FT BUILDUP
12 FOOT CENTERS

  ELEMENT # 1    CONCRETE
                   DEPTH       TRANSVERSE                      HEIGHT
       E1           B1             H1            I1              L1
     (PSI)         (IN)           (IN)        (IN^4)            (IN)
  ----------------------------------------------------------------------

       4000000             42             96       3096576            48

  ----------------------------------------------------------------------

  12E1I1/L1^3    6E1I1/L1^2     4E1I1/L1       2E1I1/L1
  ----------------------------------------------------------------------

    1344000000    32256000000  1032192000000   516096000000
  ----------------------------------------------------------------------

    RIGIDITY        TOP          SHEAR         ELEMENT
      Glr         CONTACT        STRAIN         SHEAR
     (PSI)         AREA         (IN/IN)      DEFLECTION
                  (IN^2)                        (IN)
  ----------------------------------------------------------------------

       2400000          4032   0.0000001033   0.0000049603

  ----------------------------------------------------------------------


  ELEMENT # 2    CONCRETE
                   DEPTH       TRANSVERSE                      HEIGHT
       E2           B2             H2            I2              L2
     (PSI)         (IN)           (IN)        (IN^4)            (IN)
  ----------------------------------------------------------------------

       4000000             42             48        387072            66

  ----------------------------------------------------------------------

  12E2I2/L2^3    6E2I2/L2^2     4E2I2/L2       2E2I2/L2
  ----------------------------------------------------------------------

    64625093.914   2132628099.2   93835636364   46917818182
  ----------------------------------------------------------------------

    RIGIDITY        TOP          SHEAR         ELEMENT
      Glr         CONTACT        STRAIN         SHEAR
     (PSI)         AREA         (IN/IN)      DEFLECTION
                  (IN^2)                        (IN)
----------------------------------------------------------------------

     2400000           2016   0.0000002067   0.0000136409

----------------------------------------------------------------------
```

```
ELEMENT # 3   OAK
                   DEPTH       TRANSVERSE                    HEIGHT
      E3           B3             H3            I3             L3
     (PSI)        (IN)           (IN)         (IN^4)          (IN)
-----------------------------------------------------------------------

        335720            42            64      917504            30

-----------------------------------------------------------------------

12E3I3/L3^3   6E3I3/L3^2   4E3I3/L3      2E3I3/L3
-----------------------------------------------------------------------

    1.3690E+08    2.0535E+09    4.1070E+10    2.0535E+10
-----------------------------------------------------------------------

   RIGIDITY         TOP         SHEAR        ELEMENT
      Gir         CONTACT       STRAIN        SHEAR
     (PSI)          AREA       (IN/IN)      DEFLECTION
                  (IN^2)                       (IN)
------------------------------------------    --

         23980          2688  0.0000155139  0.0004654176

----------------------------------------------------------------------- --


ELEMENT # 4   DOUGLAS FIR
                   DEPTH       TRANSVERSE                    HEIGHT
      E4           B4             H4            I4             L3
     (PSI)        (IN)           (IN)         (IN^4)          (IN)
-----------------------------------------------------------------------

        175549            42            26       61516             6

-----------------------------------------------------------------------

12E4I4/L4^3   6E4I4/L4^2   4E4I4/L4      2E4I4/L4
-----------------------------------------------------------------------

    5.9995E+08    1.7998E+09    7.1994E+09    3.5997E+09
-----------------------------------------------------------------------

   RIGIDITY         TOP         SHEAR        ELEMENT
      Gir         CONTACT       STRAIN        SHEAR          TOTAL
     (PSI)          AREA       (IN/IN)      DEFLECTION       SHEAR
                  (IN^2)                       (IN)     DEFLECTION (IN)
---------------------------------------------------------------------- -

         12539         764.4  0.0001043299  0.0006259797    1.1100E-03
```

```
F/                                              STIFFNESS MATRIX
M                                                                                                                                    D

Q1   1.3440E+09   3.2256E+10  -1.3440E+09   3.2256E+10   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 q1

M1   3.2256E+10   1.0322E+12  -3.2256E+10   5.1610E+11   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 th1

Q2  -1.3440E+09  -3.2256E+10   1.4086E+09  -3.0123E+10  -6.4625E+07   2.1326E+09   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 q2

M2   3.2256E+10   5.1610E+11  -3.0123E+10   1.1260E+12  -2.1326E+09   4.6918E+10   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 th2

Q3   0.0000E+00   0.0000E+00  -6.4625E+07  -2.1326E+09   2.0152E+08  -7.9132E+07  -1.3690E+08   2.0535E+09   0.0000E+00   0.0000E+00 q3

M3   0.0000E+00   0.0000E+00   2.1326E+09   4.6918E+10  -7.9132E+07   1.3491E+11  -2.0535E+09   2.0535E+10   0.0000E+00   0.0000E+00 th3

Q4   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  -1.3690E+08  -2.0535E+09   7.3685E+08  -2.5365E+08 -5.99948E+08  1.79985E+09 q4

M4   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   2.0535E+09   2.0535E+10  -2.5365E+08   4.8269E+10 -1.79985E+09  3.59969E+09 th4

Q5   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  -5.99948E+08 -1.79985E+09  5.99948E+08 -1.79985E+09 q5

M5   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   1.79985E+09  3.59969E+09 -1.79985E+09  7.19938E+09 th5

------------------------------------------------------------------------------------------------------------------------------------------
```

```
KNOWN VALUES:                                              # OF SYSTEM BLOCKS =                 60
Q1 =                                   -1000 lbs

M1 = Q1*(L1+L2+L3+L4) =              -150000 IN*LBS

Q2 = M2 = Q3 = M3 = M4 = Q4 = M5           0

Q5 =                                    1000 lbs

q1 = th1=               0
------------------------------------------------------------------------------------------

SOLVED UNKNOWNS:

q2=  0.0000124628 in

th2  0.0000004883 rad

                                                                -B1             -B2
q3   0.0001572266 in                                   -2846.7317806  -174396.69421

th3  0.0000034296 rad

q4   0.0002980984 in                                   -29566.937031  -499717.355[illegible]

th4  0.0000054749 rad


q5    0.000337615 in                                    -1896[illegible]  -5819[illegible]317

th5  0.0000071417 rad

K (BEND HORIZ) FOR 1 KEEL BLOCK =  3354597.0517 lbs/in          3354.5970517 KIPS/IN
__________________________________________________________________________________________

K (BEND HORIZ) ALL KEEL BLOCKS =    20127[illegible] lbs/in          2012[illegible]
__________________________________________________________________________________________

MATRIX CHECK:

  Q1 =              -1000.0000

  M1 =            -150000.0000

  Q2 =                  0.0000

  M2 =                  0.0000

  Q3 =                  0.0000

  M3 =                  0.0000

  Q4 =                 -0.0000

  M4 =                 -0.0000

  Q5 =               1000.0000

  M5 =                  0.0000
==========================================================================


TOTAL KEEL BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION:
USS LEAHY CG-16 ELASTIC
------------------------------------------------------------------------------

Khk (SIDEBLOCK HORIZONTAL STIFFNESS) = P/(BENDING DISPL + SHEAR DISPLACEMENT)

Khk       =             690.79 KIPS/IN       (PER BLOCK)

Khk       =           41447.53 KIPS/IN       (ENTIRE KEEL BLOCK SYSTEM)
```

USS LEAHY
SIDE BLOCK
HORIZONTAL
[illegible]
[illegible]
862 [illegible] /IN

```
     27-Jan-88

HORIZONTAL STIFFNESS MATRIX FOR 4 LAYERS        ORIGINAL PER DOCKING DRAWING

USS LEAHY ELASTIC
THIS IS A SIDE BLOCK SYSTEM FOR USS LEAHY CG-16 WITH 12.5 FT BUILDUP
12 FOOT CENTERS

  ELEMENT # 1    CONCRETE
                   DEPTH       TRANSVERSE                 HEIGHT
       E1           B1             H1           I1           L1
      (PSI)        (IN)           (IN)       (IN^4)        (IN)
  ---------------------------------------------------------------------

       4000000            96           168    37933056              48

  ---------------------------------------------------------------------

  12E1I1/L1^3    6E1I1/L1^2    4E1I1/L1       2E1I1/L1
  ---------------------------------------------------------------------

    16464000000   395136000000 12644352000000  6322176000000
  ---------------------------------------------------------------------

    RIGIDITY         TOP          SHEAR       ELEMENT
      Glr          CONTACT        STRAIN       SHEAR
     (PSI)          AREA         (IN/IN)     DEFLECTION
                   (IN^2)                       (IN)
  ---------------------------------------------------------------------

       2400000          16128  0.0000000258  0.0000012401

  ---------------------------------------------------------------------


  ELEMENT # 2    CONCRETE
                   DEPTH       TRANSVERSE                 HEIGHT
       E2           B2             H2           I2           L2
      (PSI)        (IN)           (IN)       (IN^4)        (IN)
  ---------------------------------------------------------------------

       4000000            48           100     4000000              66

  ---------------------------------------------------------------------

  12E2I2/L2^3    6E2I2/L2^2    4E2I2/L2       2E2I2/L2
  ---------------------------------------------------------------------

    667835378.58    22038567493   96969696.97   484848484848
  ---------------------------------------------------------------------

    RIGIDITY         TOP          SHEAR       ELEMENT
      Glr          CONTACT        STRAIN       SHEAR
     (PSI)          AREA         (IN/IN)     DEFLECTION
                   (IN^2)                       (IN)
```

```
ELEMENT # 3     OAK
                    DEPTH         TRANSVERSE                      HEIGHT
     E3              B3              H3            I3              L3
    (PSI)           (IN)            (IN)         (IN^4)           (IN)
-----------------------------------------------------------------------

       335720              50              93    3351487.5              57

-----------------------------------------------------------------------

12E3I3/L3^3    6E3I3/L3^2     4E3I3/L3        2E3I3/L3
-----------------------------------------------------------------------

    7.2907E+07     2.0779E+09     7.8958E+10     3.947[illegible]
-----------------------------------------------------------------------

   RIGIDITY          TOP          SHEAR         ELEMENT
     GIr           CONTACT        STRAIN         SHEAR
    (PSI)           AREA         (IN/IN)       DEFLECTION
                   (IN^2)                         (IN)
-------------------------------------------- -

        23980            4650   0.000008968   0.0005111787

---------------------------------------------


ELEMENT # 4     DOUGLAS FIR
                    DEPTH         TRANSVERSE                      HEIGHT
     E4              B4              H4            I4              L3
    (PSI)           (IN)            (IN)         (IN^4)           (IN)
-----------------------------------------------------------------------

       175549              28              18        13608               6

-----------------------------------------------------------------------

12E4I4/L4^3    6E4I4/L4^2     4E4I4/L4        2E4I4/L4
-----------------------------------------------------------------------

    1.3271E+08     3.9814E+08     1.5926E+09     7.9629E+08
-----------------------------------------------------------------------

   RIGIDITY          TOP          SHEAR         ELEMENT
     GIr           CONTACT        STRAIN         SHEAR          TOTAL
    (PSI)           AREA         (IN/IN)       DEFLECTION        SHEAR
                   (IN^2)                         (IN)      DEFLECTION (IN)
------------------------------------------

        12539             504  0.0001582341   0.0009494048     1.4700E-03
```

```
F/                                    STIFFNESS MATRIX
M                                                                                                                       D


Q1   1.6464E+10   3.9514E+11  -1.6464E+10   3.9514E+11   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  0.0000E+00   0.0000E+00 q1

M1   3.9514E+11   1.2644E+13  -3.9514E+11   6.3222E+12   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  0.0000E+00   0.0000E+00 th1

Q2  -1.6464E+10  -3.9514E+11   1.7132E+10  -3.7310E+11  -6.6784E+08   2.2039E+10   0.0000E+00   0.0000E+00  0.0000E+00   0.0000E+00 q2

M2   3.9514E+11   6.3222E+12  -3.7310E+11   1.3614E+13  -2.2039E+10   4.8485E+11   0.0000E+00   0.0000E+00  0.0000E+00   0.0000E+00 th2

Q3   0.0000E+00   0.0000E+00  -6.6784E+08  -2.2039E+10   7.4074E+08  -1.9961E+10  -7.2907E+07   2.0779E+09  0.0000E+00   0.0000E+00 q3

M3   0.0000E+00   0.0000E+00   2.2039E+10   4.8485E+11  -1.9961E+10   1.0487E+12  -2.0779E+09   3.9479E+10  0.0000E+00   0.0000E+00 th3

Q4   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  -7.2907E+07  -2.0779E+09   2.0562E+08  -1.6797E+09 -1.32715E+08  3.98144E+08 q4

M4   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   2.0779E+09   3.9479E+10  -1.6797E+09   8.0551E+10 -3.98144E+08  7.96288E+08 th4

Q5   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 -1.32715E+08 -3.98144E+08  1.32715E+08 -3.98144E+08 q5

M5   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  3.98144E+08  7.96288E+08 -3.98144E+08  1.59258E+09 th5
```

```
KNOWN VALUES:                                              # OF SYSTEM BLOCKS =              14
Q1 =                                  -1000 lbs

M1 = Q1*(L1+L2+L3+L4) =             -177000 IN*LBS

Q2 = M2 = Q3 = M3 = M4 = Q4 = M5          0

Q5 =                                   1000 lbs

q1 = th1=                    0
------------------------------------------------------------------------------------------

SOLVED UNKNOWNS:

q2=  0.0000012224 in

th2  0.0000000484 rad

                                                           -B1           -B2
q3   0.0000189822 in                              -2883.0278465  -202873.50847

th3  0.0000004444 rad
q4     0.00010784 in                              -3307.3464598  -137531.70582

th4  0.0000021922 rad


q5   0.0001511327 in                             -16184.7430109   -52427.02098

th5  0.0000097271 rad

K (BEND HORIZ) FOR 1 SIDE BLOCK =  9273000.8265 lbs/in          9273.0008265 KIPS/IN
------------------------------------------------------------------------------------------

K (BEND HORIZ) ALL SIDE BLOCKS =  129822011.571 lbs/in       129822.011571 KIPS/IN
------------------------------------------------------------------------------------------

MATRIX CHECK:

  Q1 =              -1000.0000

  M1 =            -177000.0000

  Q2 =                  0.0000

  M2 =                  0.0000

  Q3 =                 -0.0000

  M3 =                  0.0000

  Q4 =                  0.0000

  M4 =                  0.0000

  Q5 =               1000.0000

  M5 =                 -0.0000
==========================================================================================


TOTAL SIDE BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION:
USS LEAHY ELASTIC
------------------------------------------------------------------------------

Khs (SIDEBLOCK HORIZONTAL STIFFNESS) = P/(BENDING DISPL + SHEAR DISPLACEMENT)

Khs       =           .     616.85 KIPS/IN        (PER BLOCK

Khs       =                8635.89 KIPS/IN        (ENTIRE SIDE BLOCK SYSTEM)
```

USS LEAHY
KEEL BLOCK
VERTICAL
ELASTIC
STIFFNESS

(65590.62 KIPS/IN)

```
VERTICAL STIFFNESS CALCULATIONS FOR DRYDOCK BLOCKS

HULL TYPE       16 DOCKING PLAN # =    194787417 REV 1

SYSTEM # USS LEAHY           KEEL BLOCKS          ORIGINAL PER DOCKING DRAWING

BLOCK SPA    12.00 FEET

VERTICAL STIFFNESS:
------------------------------------------------------------------------------------------
                                                                                   PIER
LEVEL  MATERIAL      E       LENGTH     WIDTH      HEIGHT        K          1/K     TOTAL K
  #                (PSI)      (IN)       (IN)       (IN)     (KIPS/IN)            (KIPS/IN)
------------------------------------------------------------------------------------------
                            (DEPTH)  (TRANSVERSE)
                              (B)        (H)        (L)


  1      D.FUR    12539.19   42.00      26.00       6.00     2282.13    0.0004382   1093.18
  2       OAK     23980.00   42.00      64.00      30.00     2148.61    0.0004654
  3    CONCRETE 4000000.00   42.00      48.00      66.00   122181.82    0.0000082
  4    CONCRETE 4000000.00   42.00      96.00      48.00   336000.00    0.0000030
                                                  150.00
                   1845.83                         12.50
                                                     #                             TOTAL STIFF
                                                  BLOCKS          60               OF BLOCK SY
                                                                                   (KIPS/IN):

                                                                                    65590.62
```

USS LEAHY
SIDE BLOCK
VERTICAL
STIFFNESS
ELASTIC
9557.85 KIPS/IN

```
VERTICAL STIFFNESS CALCULATIONS

HULL TYPE      16 DOCKING PLAN # =     1948741 REV 1

SYSTEM # 1 ELASTIC            SIDE BLOCKS          ORIGINAL PER DOCKING DRAWING

BLOCK SPACING =         12.00 FEET

VERTICAL STIFFNESS:
-----------------------------------------------------------------------------------------------
                                                                                          PIER
LEVEL  MATERIAL       E       LENGTH      WIDTH       HEIGHT        K             1/K     TOTAL K
  #                 (PSI)      (IN)        (IN)        (IN)      (KIPS/IN)              (KIPS/IN)
-----------------------------------------------------------------------------------------------
                             (DEPTH)  (TRANSVERSE)
                               (B)         (H)         (L)


  1      D.FIR     12539.19   28.00       18.00        6.00      1053.29      0.0009494   682.70
  2       OAK      23980.00   50.00       93.00       57.00      1956.26      0.0005112
  3    CONCRETE  4000000.00   48.00      100.00       66.00    290909.09      0.0000034
  4    CONCRETE  4000000.00   96.00      168.00       48.00   1344000.00      0.0000007
                                                      177.00
                                                      177.00
                    850.00                              #                                TOTAL STIFF
                                                      BLOCKS            14               OF BLOCK SY
                                                                                         (KIPS/IN):

                                                                                           9557.85
```

USS LEAHY
SIDE BLOCK
VERTICAL
PLASTIC
STIFFNESS
[illegible]

```
VERTICAL STIFFNESS CALCULATIONS

HULL TYPE      16 DOCKING PLAN # =     1948741 REV 1

SYSTEM # 1 PLASTIC            SIDE BLOCKS          ORIGINAL PER DOCKING DRAWING

BLOCK SPACING =         12.00 FEET

VERTICAL STIFFNESS:
-----------------------------------------------------------------------------------------------
                                                                                          PIER
LEVEL  MATERIAL       E       LENGTH      WIDTH       HEIGHT        K             1/K     TOTAL K
  #                 (PSI)      (IN)        (IN)        (IN)      (KIPS/IN)              (KIPS/IN)
-----------------------------------------------------------------------------------------------
                             (DEPTH)  (TRANSVERSE)
                               (B)         (H)         (L)


  1      D.FIR      3473.50   28.00       18.00        6.00       291.[illegible]      0.[illegible]   231.[illegible]
  2       OAK      23980.00   42.00       64.00       57.00      1130.85      0.0008843
  3    CONCRETE  4000000.00   48.00      100.00       66.00    290909.09      0.0000034
  4    CONCRETE  4000000.00   96.00      168.00       48.00   1344000.00      0.0000007
                                                      177.00
                                                      177.00
                    850.00                              #                                TOTAL STIFF
                                                      BLOCKS            14               OF BLOCK SY
                                                                                         (KIPS/IN):

                                                                                           3243.91
```

System 1-11 and *USS Leahy* Stiffness Table . . . . .

TOTAL KEEL AND SIDE PIER STIFFNESS KIPS/IN
BILINEAR SYSTEMS (1-11) PER DOCKING DRAWINGS & USS LEAHY CG-16

SYSTEM	KVK	KVS	KVSP	KHK	KKHP	KHS	KSHP
1	46808.74	10113.39	4025.64	59223.08	38434.86	5825.13	2212.17
2	46808.74	5231.06	2082.23	59223.08	38434.86	3013.00	1144.23
3	31919.89	6178.56	3211.52	28875.45	22849.71	4055.29	1897.66
4	31919.89	3195.81	1661.13	28875.45	22849.71	2097.56	981.55
5	46808.74	3195.81	1661.13	59223.08	38434.86	2097.56	981.55
6	83270.20	43011.07	22269.52	79683.44	53718.39	28797.14	13345.17
7	83270.20	28512.95	14762.94	79683.44	53718.39	19090.24	8846.80
8	83270.20	21747.17	11259.87	79683.44	53718.39	14560.35	6747.56
9	24375.19	8629.57	4065.53	22050.35	17448.87	5842.63	2409.17
10	19442.11	6808.09	3188.10	17587.78	13917.55	4625.36	1890.63
11	19442.11	5236.99	2452.39	17587.78	13917.55	3557.97	1454.33
LEAHY	65590.62	9557.85	3243.91	41447.53	19362.33	8635.89	3351.12

Leahy XEL, QD, KU, and KD Values for Bilinear Douglas Fir Caps .

QD VALUES:
1 = KEEL HORIZONTAL STIFFNESS
2 = SIDE BLOCK HORIZONTAL STIFFNESS
3 = SIDE BLOCK VERTICAL STIFFNESS

SYSTEM #	KEEL CONT. AREA (IN^2)	SHEAR DF PROP LIMI (PSI)	KHK (KIPS/IN)	XEL1 (IN)	KU1-KD1 (KIPS/IN)	QD1 (KIPS)	SB CAP AREA (IN^2)	SHEAR DF PROP LIMI (PSI)	KHS (KIPS/IN)	XEL2 (IN)	KU2-KD2 (KIPS/IN)	QD2 (KIPS)	CAPAREA (IN^2)	D.FIR PROP LIMI (PSI)	KVS (KIPS/IN)	YEL1 (IN)	KU3-KD3 (KIPS/IN)	QD3 (KIPS)
1	55440.00	930.0	59223.1	0.8706	20788.22	18098.07	8352.00	930.0	5825.13	1.3334	3612.96	4817.602	8352.00	450.0	10113.39	0.3716	6087.75	2262.366
2	55440.00	930.0	59223.1	0.8706	20788.22	18098.07	4320.00	930.0	3013.00	1.3334	1868.77	2491.858	4320.00	450.0	5231.06	0.3716	3148.83	1170.188
3	55440.00	930.0	28875.5	1.7856	6025.74	10759.39	8352.00	930.0	4055.29	1.9154	2157.63	4132.640	8352.00	450.0	6178.56	0.6083	2967.04	1804.841
4	55440.00	930.0	28875.5	1.7856	6025.74	10759.39	5220.00	930.0	2097.56	2.3144	1116.01	2582.897	5220.00	450.0	3195.81	0.7350	1534.68	1128.028
5	55440.00	930.0	59223.1	0.8706	20788.22	18098.07	5220.00	930.0	2097.56	2.3144	1116.01	2582.897	5220.00	450.0	3195.81	0.7350	1534.68	1128.028
6	108864.00	930.0	79683.4	1.2706	25965.05	32990.45	57672.00	930.0	28797.14	1.8625	15451.97	28779.44	57672.00	450.0	43011.07	0.6034	20741.55	12515.21
7	108864.00	930.0	79683.4	1.2706	25965.05	32990.45	38232.00	930.0	19090.24	1.8625	10243.44	19078.50	38232.00	450.0	28512.95	0.6034	13750.01	8296.604
8	108864.00	930.0	79683.4	1.2706	25965.05	32990.45	29160.00	930.0	14560.35	1.8625	7812.79	14551.40	29160.00	450.0	21747.17	0.6034	10487.3	6327.919
9	42336.00	930.0	22050.4	1.7856	4601.48	8216.272	9600.00	930.0	5842.63	1.5281	3433.46	5246.590	9600.00	450.0	8629.57	0.5006	4564.04	2284.778
10	33768.00	930.0	17587.8	1.7856	3670.23	6553.458	7488.00	930.0	4625.36	1.5056	2734.73	4117.349	7488.00	450.0	6808.09	0.4949	3619.99	1791.679
11	33768.00	930.0	17587.8	1.7856	3670.23	6553.458	5760.00	930.0	3557.97	1.5056	2103.64	3167.190	5760.00	450.0	5236.99	0.4949	2784.6	1378.212
LEAHY	60480.00	930.0	41447.5	1.3571	22085.2	29970.73	7056.00	930.0	8635.89	0.7599	5284.77	4015.693	7056.00	450.0	9557.85	0.3322	6313.94	2097.545

Rotational Moment of Inertia Calculation for *USS Leahy*.

```
ROTATIONAL MOMENT OF INERTIA CALCULATOR ABOUT THE KEEL:

SHIP NAME:         USS LEAHY CG-16

Ikeel = Ixx + T^2*W/g

T = ship's calculative draft =         15.25 FT =          183 IN

Ikeel =  2537275. KIPS*SEC^2*IN

Ixx = (W/g)*kxx^2 = mass moment of inertia about the roll axis

Ixx =    1449223. KIPS*SEC^2*IN

W = ship displacement =        5600 TONS =      12544 KIPS

g = accel. of gravity =      386.09 IN/SEC^2

kxx = 0.64 * B/2     Radius of gyration about the roll axis
                      from Introduction to Naval Architecture Page 272
                           for Destroyer type ships

B = ship's beam =       55 FT =          660 IN

kxx =                211.2 IN
```

"3DOFRUB" *USS Leahy* Input Data File

```
***SHIP/SUB DRYDOCK BLOCKING SYSTEM***  DATA FILE: B:LEAHTRUE.DAT

        ***INPUT FILE DATA***


SHIP NAME:   USS LEAHY CG-16
DISCRIPTION OF ISOLATORS IF USED: NO ISOLATOR ALL BILINEAR
DISCRIPTION OF BUILDUP: 12 SPACING COMPOSITE
DISCRIPTION OF WALE SHORES USED: NO WALE SHORES
DISCRIPTION OF DAMPING: 5 % DAMPING
LOCATION OF DRYDOCK BEING STUDIED: LONG BEACH NAVAL SHIPYARD DD # 3
NAVSEA DOCKING DRAWING NUMBER: BUSHIPS 1948741 REV.1
REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: LEAHKHEL.WK1 LEAHKVEL.WK1 ETC.
MISC. COMMENTS: LEAHTRUE.DAT  1318 28 JAN 88
SHIP WEIGHT  (KIPS)                                         W= 12544
HEIGHT OF KG (IN)                                           H= ~~288~~ 264
MOMENT OF INERTIA  (KIPS*IN*SEC^2)                         IK= 2537275
SIDE PIER VERTICAL STIFFNESS (KIPS/IN)                    Kvs= 9557.849
SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)           Kvsp= 3243.91
KEEL PIER VERTICAL STIFFNESS (KIPS/IN)                    KVK= 65590.62
HEIGHT OF WALE SHORES  (IN)                               AAA= 0
WALE SHORE STIFFNESS (KIPS/IN)                             KS= 0
SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN)                  KHS= 8635.889
KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN)                  KHK= 41447.53
SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN)  KSHP= 3351.12
KEEL PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN)  KKHP= 19362.33
RESTORING FORCE AT 0 DEFLECT KEEL HORIZ    (KIPS) QD1= 29970.73
RESTORING FORCE AT 0 DEFLECT SIDE HORIZ    (KIPS) QD2= 4015.69
RESTORING FORCE AT 0 DEFLECT SIDE VERT     (KIPS) QD3= 2097.55
GRAVITATIONAL CONSTANT (IN/SEC 2)                       GRAV= 386.09

SIDE BLOCK WIDTH  (IN)                                    SBW= 126
KEEL BLOCK WIDTH  (IN)                                    KBW= 108
SIDE BLOCK HEIGHT (IN)                                    SBH= 181
KEEL BLOCK HEIGHT (IN)                                    KBH= 150
BLOCK ON BLOCK FRICTION COEFFICIENT                        U1= .3
HULL ON BLOCK FRICTION COEFFICIENT                         U2= .5
SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN)            BR= 289
SIDE PIER CAP PROPORTIONAL LIMIT                         SCPL= .7
KEEL PIER CAP PROPORTIONAL LIMIT                         KCPL= .45
TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN 2) SAREA= 7056
TOTAL KEEL PIER CONTACT AREA   (IN 2)                   KAREA= 60480
PERCENT CRITICAL DAMPING                                 ZETA= .05
HULL NUMBER (XXXX)                                       HULL= 16
SYSTEM NUMBER (XXX)                                      NSYS= 1
CAP ANGLE (RAD)                                          BETA= .485
```

Leahy Cap Angle Regression Analysis

```
CAP ANGLE ANALYSIS                              ** PAGE 1 **                                    ** 14-Mar-88  **


USS LEAHY CG-16 ANALYSIS
DURING THE 1 OCT 87 WHITTIER EARTHQUAKE
EXCITED BY THE DRY DOCK # 2 ACCELERATION TIME HISTORY

CAP ANGLE ANALYSIS:

TRANSVERSE DISTANCE BETWEEN B AND C HEIGHTS =      18 IN

-----------------------------------------------------------------------------------------------------------

  BLOCK      CAP      CAP                 B                B                C                C    FAILURE
    #       ANGLE    ANGLE             HEIGHT            TOTAL            HEIGHT            TOTAL    MODE
            (RAD)    (DEG)     (FT)      IN    (EIGHTHS)  (IN)      (FT)    (IN)   (EIGHTHS)  (IN)
-----------------------------------------------------------------------------------------------------------


      15    0.583    33.4         2       6         6    30.75         3       4         2    40.25 SBSLIDE
      14    0.485    27.8         2       3         1    27.13         2      11         2    35.25 SBSLIDE
      13    0.426    24.4         1      11         5    23.63         2       6         7    30.88 SBSLIDE
       7    0.386    22.1         1      11         7    23.88         2       6         4    30.50 SBSLIDE
      12    0.386    22.1         1       9         0    21.00         2       3         5    27.63 SBSLIDE
       6    0.378    21.6         2       0         6    24.75         2       7         2    31.25 SBSLIDE
       1    0.370    21.2         3       9         6    45.75         4       4         1    52.13 SBSLIDE
       4    0.370    21.2         2       6         0    30.00         3       0         3    36.38 SBSLIDE
       3    0.362    20.7         2      10         2    34.25         3       4         4    40.50 SBLIFTOFF
       2    0.362    20.7         3       3         3    39.38         3       9         5    45.63 SBLIFTOFF
       5    0.362    20.7         2       3         1    27.13         2       9         3    33.38 SBLIFTOFF
      10    0.315    18.1         1       5         0    17.00         1      10         4    22.50 SBLIFTOFF
       9    0.300    17.2         1       3         4    15.50         1       8         6    20.75 SBLIFTOFF
       8    0.293    16.8         1       3         1    15.13         1       8         2    20.25 SBLIFTOFF
      11    0.285    16.3         1       7         0    19.00         2       0         0    24.00 SBLIFTOFF

-----------------------------------------------------------------------------------------------


   CAP    FAILED   REGRESS MEASURED
  ANGLE   SLIDING   DATA   BLOCK DISPLACEMENT
  (DEG     (%)               (IN)
-----------------------------------
   33.40     47.1%    45.4%  1.500          Regression Output:
   27.79     78.6%    77.0%  1.500 Constant                      2.331953
   24.54     90.1%    84.7%        Std Err of Y Est              0.058128
   24.41     92.0%    85.9%          R Squared                   0.962758
   22.19    116.5%   109.0%  0.750 No. of Observations                 12          Y = -0.05622 * X + 2.33195
   21.64    116.6%   111.5%  0.656 Degrees of Freedom                  10
   21.19    116.6%   114.1%  0.375
   20.73    125.5%   116.6%  0.375 X Coefficient(s)  -0.05622
   19.07    134.6%   131.6%        Std Err of Coef.  0.003496
   17.20    134.6%   136.5%
   16.77    134.6%   138.9%  0.375
   16.74    174.6%   141.3%  0.125
```

"3DOFRUB" *USS Leahy* Output File

```
                           **** System  1 ****

                             ** Hull  16 **


                           * Ship Parameters *

    Weight        Moment of Inertia         K.G.
  15232.0 kips   3038013.0 kips-in-sec2    180.0 ins


                         * Drydock Parameters *

Side Block Height   Side Block Width   Keel Block Height   Keel Block Width
  131.0 ins            168.0 ins            150.0 ins          108.0 ins

Side-to-Side Pier Distance   Wale Shore Ht.   Wale Shore Stiffness  Cap Angle
      239.0 ins                     .0 ins              .0 kips/in  .426 rad

1Side Side Pier Contact Area   Total Keel Pier Contact Area      kkhp
             7056.0 in2                  60480.0 in2          19362.3 kips/in

B/B Friction Coeff   H/B Friction Coeff     kshp          kvsp
        .300                .500        3351.1 kips/in  3243.9 kips/in

Side Pier Fail Stress Limit    Keel Pier Fail Stress Limit      QD1
             .700 kips/in2                .450 kips/in2      29970.7 kips

Side Pier Vertical Stiffness   Side Pier Horizontal Stiffness   QD2
        9557.9 kips/in                8635.9 kips/in           4015.7 kips

Keel Pier Vertical Stiffness   Keel Pier Horizontal Stiffness   QD3
       65590.6 kips/in               41447.5 kips/in           2097.6 kips


                   * System Parameters and Inputs *

Earthquake Used is 1 OCT 87  WHITTIER CA

Horizontal acceleration input is LBNSY DD2 TRANSVERSE COMPONENT

Vertical acceleration input is LBNSY DD2 VERTICAL COMPONENT
                     Earthquake Acceleration Time History.

Vertical/Horizontal Ground Acceleration Ratio   Data Time Increment
           1.000                                       .010 sec

Gravitational Constant   % System Damping
       386.09 in/sec2            5.00 %

                        Mass Matrix

        39.4519               .0000           7101.3494
          .0000             39.4519               .0000
      7101.3494               .0000        3038013.0000

                        Damping Matrix

       131.3605               .0000           7408.0983
          .0000            132.3067               .0000
      7408.0983               .0000        3426523.9438
```

```
                     Stiffness Matrix


       58719.3100               .0000          535425.1800
           .0000           84706.3200                .0000
      535425.1800               .0000       388054529.8468


Undamped Natural Frequencies      Mode #1         Mode #2         Mode #3
                               11.266 rad/sec  50.533 rad/sec  46.337 rad/sec
Damped Natural Frequencies        Mode #1         Mode #2         Mode #3
                               11.251 rad/sec  50.469 rad/sec  46.279 rad/sec


For Earthquake Acceleration of 100.00 % of the 1 OCT 87  WHITTIER CA


Maximums/Failures        X (ins)    Y (ins)        Theta (rads)  Time (sec)
-----------------       --------   --------       ------------- -----------
 Maximum X             -.013138                                   13.77
 Maximum Y                        -.005077                         6.16
 Maximum Rotation                                 .000945          9.11
Side block sliding      .011768    .000990        .000856          9.07


For Earthquake Acceleration of  90.00 % of the 1 OCT 87  WHITTIER CA


Maximums/Failures        X (ins)    Y (ins)        Theta (rads)  Time (sec)
-----------------       --------   --------       ------------- -----------
 Maximum X             -.011824                                   13.77
 Maximum Y                        -.004570                         6.16
 Maximum Rotation                                 .000851          9.11

No failures occurred.


For Earthquake Acceleration of  99.00 % of the 1 OCT 87  WHITTIER CA


Maximums/Failures        X (ins)    Y (ins)        Theta (rads)  Time (sec)
-----------------       --------   --------       ------------- -----------
 Maximum X             -.013007                                   13.77
 Maximum Y                        -.005027                         6.16
 Maximum Rotation                                 .000936          9.11
Side block sliding      .011650    .000981        .000848          9.07


For Earthquake Acceleration of  98.00 % of the 1 OCT 87  WHITTIER CA


Maximums/Failures        X (ins)    Y (ins)        Theta (rads)  Time (sec)
-----------------       --------   --------       ------------- -----------
 Maximum X             -.012876                                   13.77
 Maximum Y                        -.004976                         6.16
 Maximum Rotation                                 .000926          9.11
Side block sliding      .011532    .000971        .000839          9.07
```

```
 For Earthquake Acceleration of  97.00 % of the 1 OCT 87  WHITTIER CA


 Maximums/Failures          X (ins)   Y (ins)          Theta (rads)  Time (sec)

-----------------         --------  --------        -------------  -----------
 Maximum X               -.012744                                     13.77
 Maximum Y                          -.004925                           6.16
 Maximum Rotation                                   .000917            9.11
Side block sliding         .011415   .000961        .000830            9.07


For Earthquake Acceleration of  96.00 % of the 1 OCT 87  WHITTIER CA

Maximums/Failures          X (ins)   Y (ins)          Theta (rads)  Time (sec)
-----------------         --------  --------        -------------  -----------
 Maximum X               -.012613                                     13.77
 Maximum Y                          -.004874                           6.16
 Maximum Rotation                                   .000907            9.11
Side block sliding         .011507   .001823        .000856            9.08


For Earthquake Acceleration of  95.00 % of the 1 OCT 87  WHITTIER CA

Maximums/Failures          X (ins)   Y (ins)          Theta (rads)  Time (sec)
-----------------         --------  --------        -
 Maximum X               -.012481                                     13.77
 Maximum Y                          -.004824                           6.16
 Maximum Rotation                                   .000898            9.11
Side block sliding         .011387   .001804        .000847            9.08


For Earthquake Acceleration of  94.00 % of the 1 OCT 87  WHITTIER CA

Maximums/Failures          X (ins)   Y (ins)          Theta (rads)  Time (sec)
-----------------         --------  --------        -------------  -----------
 Maximum X               -.012350                                     13.77
 Maximum Y                          -.004773                           6.16
 Maximum Rotation                                   .000889            9.11
Side block sliding         .011267   .001785        .000838            9.08


For Earthquake Acceleration of  93.00 % of the 1 OCT 87  WHITTIER CA

Maximums/Failures          X (ins)   Y (ins)          Theta (rads)  Time (sec)
-----------------         --------  --------        -
 Maximum X               -.012219                                     13.77
 Maximum Y                          -.004722                           6.16
 Maximum Rotation                                   .000879            9.11
Side block sliding         .011091   .002500        .000854            9.09
```

```
For Earthquake Acceleration of  92.00 % of the 1 OCT 87  WHITTIER CA

Maximums/Failures        X (ins)    Y (ins)          Theta (rads)  Time (sec)
-----------------        --------   --------         ------------- -----------
 Maximum X               -.012087                                     13.77
 Maximum Y                          -.004671                           6.16
 Maximum Rotation                                      .000870         9.11
Side block sliding         .010972   .002473           .000845         9.09


For Earthquake Acceleration of  91.00 % of the 1 OCT 87  WHITTIER CA

Maximums/Failures        X (ins)    Y (ins)          Theta (rads)  Time (sec)
-----------------        --------   --------         ------------- -----------
 Maximum X               -.011956                                     13.77
 Maximum Y                          -.004630                           6.16
 Maximum Rotation                                      .000860         9.11

No failures occurred.
```

APPENDIX 4

1. California Division of Mines and Geology Report on 1 October 1987 Whittier
2. Survivability Comparison Spreadsheets

California Division of Mines and Geology Report on 1 October 1987 Whittier Earthquake . . . . . .

Middlefield Menlo Park, Ca 94025 (415)

STATE OF CALIFORNIA—THE RESOURCES AGENCY GEORGE DEUKMEJIAN Governor

DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY
OFFICE OF STRONG MOTION STUDIES
630 BERCUT DRIVE
SACRAMENTO, CA 95814
(PHONE 916-322 3105)

digitized
Prof Mihr Trifunac
USC / Civil Eng
LA, CA
213-741-2987

October 3, 1987

To : Strong Motion Data Users

From : Tony Shakal and Staff Tony Shakal
California Strong Motion Instrumentation Program (CSMIP)
Division of Mines and Geology/Department of Conservation

Subject: CSMIP Records from Whittier Earthquake of October 1, 1987

Accelerograms of particular interest recorded at CSMIP stations during the October 1 earthquake near Whittier, 15 km east of downtown Los Angeles, are attached. Over 35 records have been recovered at this time; record recovery from outlying stations is still underway. We estimate that over 100 CSMIP stations have recorded the earthquake.

The map in Figure 1 shows the locations of the stations for which records are included here and described below. The map also shows the locations of some of the other CSMIP stations from which records are being recovered. Table 1 lists preliminary station epicentral distances and, when available, peak acceleration values.

Ground-Response Stations:
- o Alhambra - Closest CSMIP station to the epicenter (7 km); instrument in a 1-story school.
- o Obregon Park - Largest CSMIP ground acceleration, 45% g horizontal, was recorded at this station approximately 10 km from the epicenter. The instrument is in a small building.
- o San Marino - Closest station to northwest, relatively low amplitude (20% g).
- o Downey, Inglewood, 116th St. School - These records from close-in freefield stations to th west of the epicenter are also included for reference.

Structures:
- o Admin. Bldg. - Cal State Univ LA. Nine-story reinforced concrete building about 10 km fro the epicenter with a "soft first-story" design very similar to the Imperial County Service Building in El Centro. Maximum acceleration of about 40% g at the base, and 50% g at the roof. For comparison, the 1979 Imperial County Services Building record had a peak value of about 35% g at the base, and 60% g at the roof. The CSULA record is shorter in duration, and has less long period energy than the 1979 record. This CSULA building is near the parking structure where the news reported a fatality from a falling concrete slab
- o Los Angeles - Sears Warehouse. Large 5-story reinforced-concrete frame building about 14 km from the epicenter. Peak acceleration was 18% g at the base and 24% g at the roof.
- o Burbank - Records from two buildings in the Burbank area, 25 km northwest of the epicenter are included. A 6-story steel frame building had a base acceleration of about 25% g, and roof acceleration of 30% g. A nearby 10-story reinforced concrete building had a roof acceleration of 55%.

Although definitive patterns await further data, it appears that San Marino, south of Pasadena, had relatively low shaking (20% g) though only 10 km from the epicenter. Many mo distant stations have greater amplitudes. Pomona, 30 km east of the epicenter, had only 5% ground acceleration (record not shown here), much lower than stations at a similar distance to the West. A low acceleration record (5% g) was recorded at the base-isolated County building in Rancho Cucamonga. Some of the buildings from which records were recovered suffered damage during the earthquake; damage information is incomplete at this time.

A standard data report on all CSMIP records will be completed in several weeks. To allow rapid distribution of these records, copies are being sent to only a subset of our normal mailing list. You may wish to make more copies to distribute to your colleagues.

TABLE 1

CALIFORNIA STRONG-MOTION INSTRUMENTATION PROGRAM (CSMIP)
DATA RECOVERED FROM RECENT EARTHQUAKES
(File last updated: 3 October 1987, 12:00 PDT)

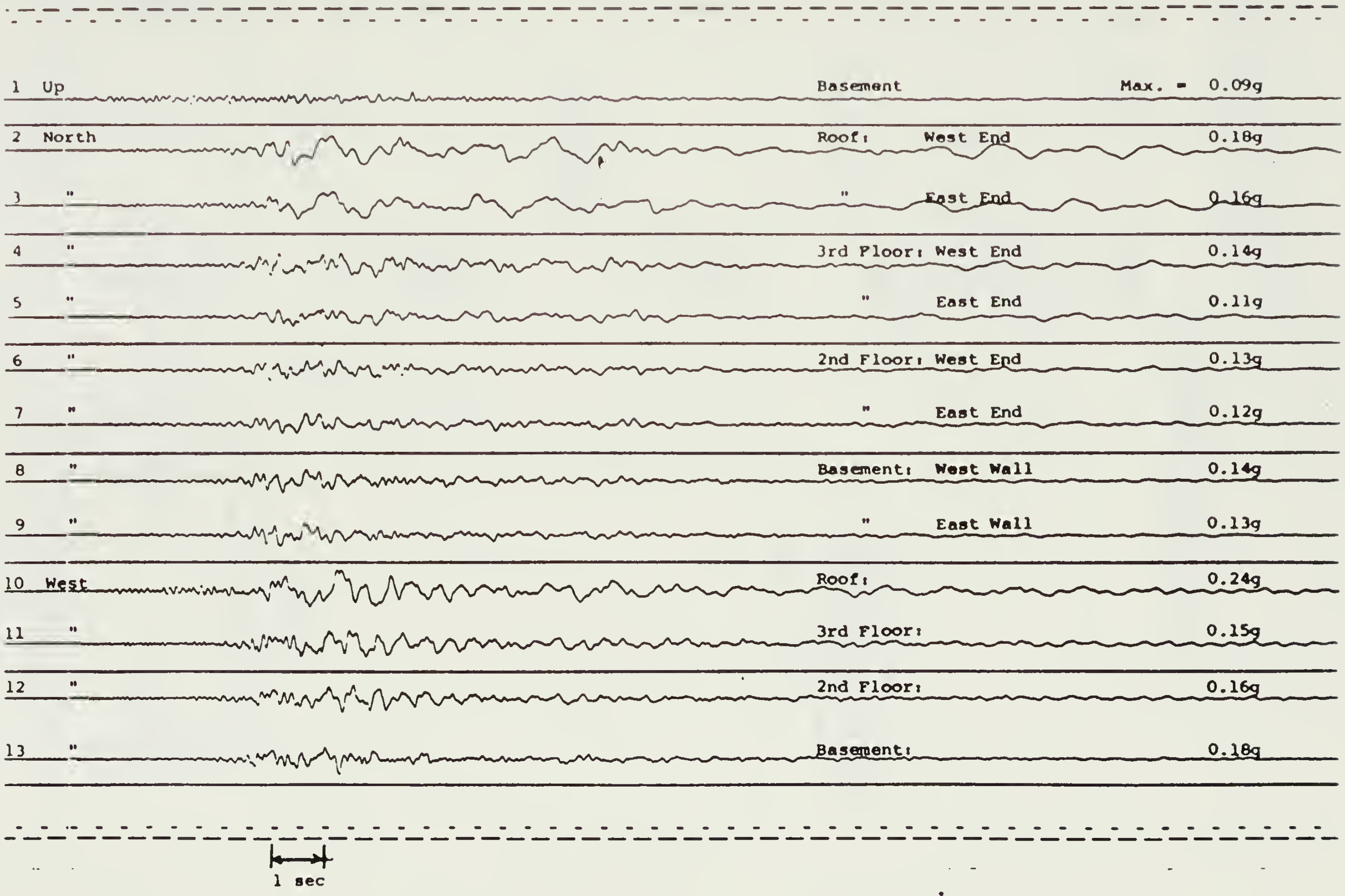
Earthquake in Whittier area, east of Los Angeles
1 October 1987, ~07:42 PDT ~5.8 ML (BRK)
Epicenter (Preliminary): 34.06N, 118.08W (CIT)

No.	Station Name	N.Lat	W.Long	Epicentral Dist(km)	Az*	Max. Acceleration
24461	Alhambra - Fremont School	34.070	118.150	7	(281)	0.40g Horiz., 0.20g Vert.
24401	San Marino - SW Academy	34.115	118.130	8	(321)	0.20g H, 0.14g V
24468	L.A. - CSULA Admin. Building	34.067	118.168	9	(277)	Ground: 0.39g H, 0.14g V Structure: 0.48g H, 0.53g V
24400	L.A. - Obregon Park	34.037	118.178	10	(256)	0.45g H, 0.15g V
24402	Altadena - Eaton Canyon Park	34.177	118.096	13	(352)	
24463	L.A. - Store Warehouse	34.028	118.223	14	(256)	Ground: 0.18g H, 0.09g V Structure: 0.24g V
14368	Downey	33.924	118.167	17	(210)	0.20g H, 0.17g V
24399	Mt. Wilson	34.224	118.057	19	(5)	
14403	L.A. - 116th St. School	33.929	118.260	22	(230)	0.40g H, 0.11g V
23210	Cogswell Dam	34.245	117.964	23	(26)	
24236	L.A. - Hollywood Storage Bldg.	34.090	118.338	25	(278)	Ground: 0.12g H, 0.04g V Structure: 0.22g H
24303	L.A -Hollywood Stor Bldg. FF	34.090	118.339	25	(278)	0.21g H, 0.08g V
23328	Puddingstone Dam	34.091	117.808	25	(81)	Ground: 0.07g H, 0.04g V Structure: 0.18g H, 0.09g V
14196	Inglewood-Union Oil	33 905	118.279	25	(228)	0.28g H, 0.08g V
24370	Burbank - Calif. Fed. Savings	34.185	118.308	26	(303)	Ground: 0.22g H, 0.10g V Structure: 0.30g H
24385	Burbank - Pacific Manor	34.187	118.311	26	(303)	Ground: 0.26g H, 0.06g V Structure: 0.54g H
24464	L.A. - North Hollywood Sheraton Hotel	34.138	118.359	28	(289)	Ground: 0.11g H, 0.08g V Structure: 0.16g H
25511	Pomona - First Fed. Savings	34.056	117.748	30	(90)	Ground: 0.05g H, 0.04g V Structure: 0.16g H
25525	Pomona - 4th & Locust FF	34.056	117.748	30	(90)	Ground: 0.07g H, 0.06g V
14311	Long Beach - State Univ. Engineering Bldg.	33.783	118.112	31	(186)	Triggered
14241	Long Beach - Recreation Park	33.778	118.133	32	(190)	Triggered
24231	L A.-UCLA Math.-Science Bldg.	34.069	118.442	34	(272)	Triggered
14533	Long Beach - City Hall	33.768	118.195	34	(199)	Triggered
14323	Long Beach-Harbor Admin. Bldg.	33.755	118.200	36	(199)	Triggered
14395	Long Beach-Harbor Admin. FF	33.754	118.200	36	(199)	Triggered
24322	Sherman Oaks-Union Bank Bldg.	34.154	118.465	38	(287)	Triggered
14406	L A. - Vincent Thomas Bridge	33.750	118.271	39	(208)	
24087	Arleta - San Fernando	34.236	118.439	39	(301)	0.09g H, 0.09g V
13122	Featherly Park	33.869	117.709	40	(122)	
24386	Van Nuys - Holiday Inn	34 221	118.471	41	(296)	Triggered
24207	Pacoima Dam	34.334	118.396	43	(316)	
24436	Tarzana-Cedar Hill Nursery A	34.160	118.534	44	(285)	Triggered
24514	Sylmar-Olive View Med. Cntr.	34.326	118.444	45	(311)	
23497	Rancho Cucamonga - Law & Just. Center	34.104	117.574	47	(84)	Ground: 0.03g H Structure: 0.06g H

---

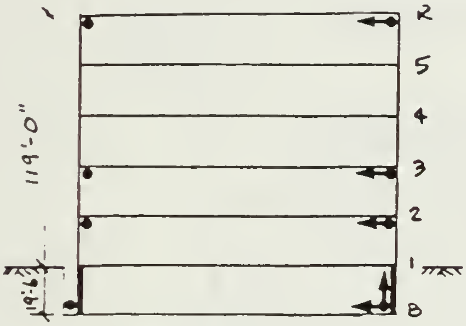
* Azimuth from earthquake epicenter to station, CW from N, 0-360 deg.

Los Angeles - Sears Warehouse
(CSMIP Station No. 24463)



Los Angeles - Sears Warehouse
(CSMIP Station No. 24463)

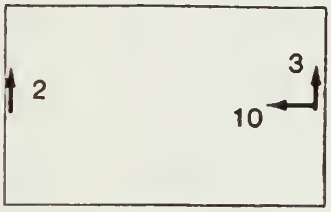
INSTRUMENTATION LAYOUT



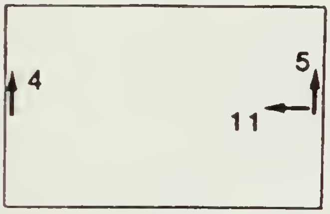
W/E Elevation

Ductile Reinforced Concrete
Perimeter Frame Designed in
Accordance with the 1970 Los
Angeles Building Code

Designed in 1970

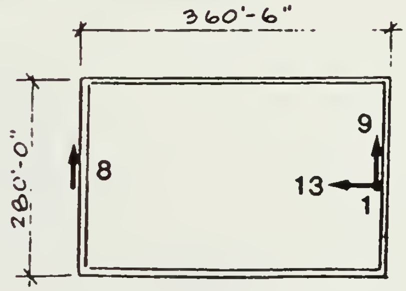


Roof Level



3rd Floor

2nd Floor



Basement

Survivability Comparison Spreadsheets. . . . . . .

COMPARISON OF SYSTEMS (1-11)

SYSTEM #	SIGMAN'S % SURVIVED	MODE #1 FREQ (RAD/S)	MODE #1 FREQ (HZ)	FAILURE MODE	BILINEAR 3DOFALL % SURVIVED	MODE #1 FREQ (RAD/S)	MODE #1 FREQ (HZ)	FAILURE MODE	LINEAR 3DOFALL % SURVIVED	MODE #1 FREQ (RAD/S)	MODE #1 FREQ (HZ)	FAILURE MODE	1" RUB 3DOFALL % SURVIVED	MODE #1 FREQ (RAD/S)	MODE #1 FREQ (HZ)	FAILURE MODE	NORMALIZED WHITTIER BILINEAR 3DOFALL % SURVIVED	MODE #1 FREQ (RAD/S)	MODE #1 FREQ (HZ)	REGRESS FREQ^2	FAILURE MODE
1	24%	5.454	0.868031	SBLIFT	15%	6.425	1.022570	SBLIFT	19%	6.425	1.022570	SBLIFT	32%	4.215	0.670838	SBLIFT	4.9%	6.425	1.022570	1.045650	SBLIFT
2	23%	3.883	0.617998	SBLIFT	22%	4.557	0.725269	SBLIFT	33%	4.557	0.725269	SBLIFT	29%	2.934	0.466960	SBCRUSH	6.6%	4.557	0.725269	0.526015	SBLIFT
3	39%	4.013	0.638686	SBLIFT	29%	4.973	0.791477	SBLIFT	33%	4.973	0.791477	SBLIFT	42%	3.917	0.623409	KBOVER	7.8%	4.973	0.791477	0.626436	SBLIFT
4	21%	2.819	0.448657	SBLIFT	26%	3.491	0.555609	SBLIFT	29%	3.491	0.555609	SBLIFT	39%	2.711	0.431469	SBLIFT	12.3%	3.491	0.555609	0.308702	SBLIFT
5	13%	2.848	0.453273	SBLIFT	21%	3.492	0.555769	SBLIFT	21%	3.492	0.555769	SBLIFT	28%	2.712	0.431628	SBLIFT	9.8%	3.492	0.555769	0.308879	SBLIFT
6	26%	9.69	1.542211	SBLIFT	30%	9.193	1.463111	SBLIFT	30%	9.193	1.463111	SBLIFT	27%	7.001	1.114243	KBOVER	13.9%	9.193	1.463111	2.140694	SBLIFT
7	27%	7.953	1.265759	SBLIFT	24%	7.469	1.188728	SBLIFT	24%	7.469	1.188728	SBLIFT	26%	5.687	0.905114	KBOVER	9.0%	7.469	1.188728	1.413074	SBLIFT
8	23%	6.976	1.110264	SBLIFT	23%	6.508	1.035780	SBLIFT	23%	6.508	1.035780	SBLIFT	32%	4.951	0.787976	KBOVER	8.0%	6.508	1.035780	1.072840	SBLIFT
9	33%	5.863	0.933125	SBLIFT	22%	6.213	0.988829	SBLIFT	27%	6.213	0.988829	SBLIFT	28%	4.697	0.747550	KBOVER	5.4%	6.213	0.988829	0.977784	SBLIFT
10	28%	6.857	1.091325	SBLIFT	24%	7.184	1.143369	SBLIFT	26%	7.184	1.143369	SBLIFT	24%	5.36	0.853070	KBOVER	8.0%	7.184	1.143369	1.307292	SBLIFT
11	29%	6.177	0.983100	SBLIFT	20%	6.278	0.999174	SBLIFT	24%	6.278	0.999174	SBLIFT	28%	4.675	0.744049	KBOVER	5.2%	6.278	0.999174	0.998350	SBLIFT
TOT AVG =	26%				23%				26%				30%								
616 AVG =	24%				23%				27%				34%								
726 AVG =	25%				26%				26%				28%								
688 AVG =	33%				22%				27%				28%								
637 AVG =	28%				22%				25%				26%								

```
HULL    TYPE                            REGRESS
 #      SYSTEM                           CURVE
                                         DATA
------------------------------------------------
 616   COMP 8 FT                        0.063153
 616   COMP 16 FT                       0.076323
 616   TIMBER 8 FT                      0.068653
 616   TIMBER 16 FT                     0.108367
 616   TIMB SIDE COMP KEEL 16 FT        0.108329
 726   COMP 8 FT                        0.144275
 726   COMP 12 FT                       0.079635
 726   COMP 16 FT                       0.063838
 633   COMP SIDE TIMB KEEL 12 FT        0.061895
 637   COMP SIDE TIMB KEEL 12 FT        0.073439
 637   COMP SIDE TIMB KEEL 16 FT        0.062206

MODE#1  SIGMAN  BILINEAR LINEAR   1*RUB    LINE    REGRESS
 FREQ     %        %        %       %      TOTAL    LINE
 (HZ)  SURVIVED SURVIVED SURVIVED SURVIVED
-------------------------------------------------------------
  1.37     24%                               24%     25%         Regression Output:
  0.62     23%                               23%     25%Constant                    0.249848
  0.64     29%                               29%     25%Std Err of Y Est            0.053504
  0.45     21%                               21%     25%R Squared                   0.000064
  0.45     13%                               13%     25%No. of Observations               44
  1.54     26%                               26%     25%Degrees of Freedom                42
  1.27     27%                               27%     25%
  1.11     23%                               23%     25%X Coefficient(s)  0.001465
  0.93     33%                               33%     25%Std Err of Coef.  0.028153
  1.09     28%                               28%     25%
  0.95     29%                               29%     25%
  1.02              15%                      15%     25%
  0.73              22%                      22%     25%
  0.79              29%                      29%     25%
  0.56              26%                      26%     25%
  0.56              21%                      21%     25%
  1.46              30%                      30%     25%
  1.19              24%                      24%     25%
  1.04              23%                      33%     25%
  0.99              22%                      22%     25%
  1.14              24%                      24%     25%
  1.00              20%                      20%     25%
  1.02                       19%             19%     25%
  0.73                       33%             33%     25%
  0.79                       30%             30%     25%
  0.56                       29%             29%     25%
  0.56                       31%             31%     25%
  1.46                       30%             30%     25%
  1.19                       24%             24%     25%
  1.04                       23%             23%     25%
  0.99                       27%             27%     25%
  1.14                       26%             26%     25%
  1.00                       24%             24%     25%
  0.67                                32%    32%     25%
  0.47                                29%    29%     25%
  0.62                                42%    42%     25%
  0.43                                39%    39%     25%
  0.43                                28%    28%     25%
  1.11                                27%    27%     25%
  0.91                                26%    26%     25%
  0.79                                32%    32%     25%
  0.75                                28%    28%     25%
  0.35                                34%    34%     25%
  0.74                                28%    28%     25%
```

APPENDIX 5

1. "3DOFRUB" Isolator (EL Centro) Input Data File
2. "3DOFRUB" Isolator (EL Centro) Output File
3. "3DOFRUB" Isolator (NORM DD2) Input Data File
4. "3DOFRUB" Isolator (NORM DD2) Output File
5. Isolator Equivalent Modulus Stiffness Spreadsheets
6. Required Isolator Characteristics Spreadsheet

"3DOFRUB" Isolator (EL Centro)
Input Data File . . . .

```
***SHIP/SUB DRYDOCK BLOCKING SYSTEM***  DATA FILE: B:S891GOOD.DAT

         ***INPUT FILE DATA***

SHIP NAME:   LAFAYETTE SSBN 616
DISCRIPTION OF ISOLATORS IF USED: 6" RUBBER CAP W/ ISOLATORS
DISCRIPTION OF BUILDUP: 8 SPACING COMPOSITE
DISCRIPTION OF WALE SHORES USED: NO WALE SHORES
DISCRIPTION OF DAMPING: 8% DAMPING
LOCATION OF DRYDOCK BEING STUDIED: NO SPECIFIC LOCATION
NAVSEA DOCKING DRAWING NUMBER: 845-[illegible]
REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: S15KVE1.WK1  ETC.
MISC. COMMENTS: S891RISO.DAT  1245 15 FEB 88


PRESS ANY KEY TO CONTINUE...








SHIP WEIGHT  (KIPS)                                       W= 16369.9
HEIGHT OF KG (IN)                                         H= 193
MOMENT OF INERTIA  (KIPS*IN*SEC^2)                       IK= 2410451
SIDE PIER VERTICAL STIFFNESS (KIPS/IN)                  Kvs= 1303.23
SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)         Kvsp= 4093.1
KEEL PIER VERTICAL STIFFNESS (KIPS/IN)                  KVK= 8062.08
KEEL PIER VERTICAL PLASTIC STIFFNESS(KIPS/IN)          KVKP= 22101.31
HEIGHT OF WALE SHORES  (IN)                             AAA= 0
WALE SHORE STIFFNESS (KIPS/IN)                           KS= 0
SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN)                KHS= 55
KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN)                KHK= 271.91
SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KSHP= 11.12
KEEL PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KKHP= 42.02
RESTORING FORCE AT 0 DEFLECT KEEL HORIZ    (KIPS) QD1= 135.08
RESTORING FORCE AT 0 DEFLECT SIDE HORIZ    (KIPS) QD2= 18.4
RESTORING FORCE AT 0 DEFLECT SIDE VERT     (KIPS) QD3=-1773.63
RESTORING FORCE AT 0 DEFLECT KEEL VERT     (KIPS) QD4=-9577.08
GRAVITATIONAL CONSTANT (IN/SEC^2)                    GRAV= 386.09

PRESS ANY KEY TO CONTINUE...





  SIDE BLOCK WIDTH  (IN)                                 SBW= 999
  KEEL BLOCK WIDTH  (IN)                                 KBW= 999
  SIDE BLOCK HEIGHT (IN)                                 SBH= 75
  KEEL BLOCK HEIGHT (IN)                                 KBH= 61
  BLOCK ON BLOCK FRICTION COEFFICIENT                     U1= 9
  HULL ON BLOCK FRICTION COEFFICIENT                      U2= .75
  SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN)         BR= 144
  SIDE PIER CAP PROPORTIONAL LIMIT                      SCPL= .7
  KEEL PIER CAP PROPORTIONAL LIMIT                      KCPL= .7
  TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN^2) SAREA= 8352
  TOTAL KEEL PIER CONTACT AREA   (IN^2)             KAREA= 55440
  PERCENT CRITICAL DAMPING                              ZETA= .08
  HULL NUMBER (XXXX)                                    HULL= 616
  SYSTEM NUMBER (YYY)                                   NSYS= 891
  CAP ANGLE (RAD)                                       BETA= .377

  PRESS ANY KEY TO CONTINUE...
```

"3DOFRUB" Isolator (EL Centro) Output File . . . .

```
                        ** Hull 616 **


                    * Ship Parameters *

   Weight          Moment of Inertia          K.G.
 16369.9 kips   2410451.0 kips-in-sec2    193.0 ins


                   * Drydock Parameters *

Side Block Height   Side Block Width   Keel Block Height   Keel Block Width
   75.0 ins            999.0 ins             61.0 ins           999.0 ins

Side-to-Side Pier Distance   Wale Shore Ht.   Wale Shore Stiffness  Cap Angle
      144.0 ins                   .0 ins                .0 kips/in   .377 rad

1Side Side Pier Contact Area   Total Keel Pier Contact Area      kkhp
          8352.0 in2                    55440.0 in2              42.0 kips/in

B/B Friction Coeff   H/B Friction Coeff      kshp           kvsp
      9.000                .750          11.1 kips/in  4098.1 kips/in

Side Pier Fail Stress Limit    Keel Pier Fail Stress Limit      kvkp
         .700 kips/in2                  .700 kips/in2       22101.3 kips/in

Side Pier Vertical Stiffness   Side Pier Horizontal Stiffness
      1303.2 kips/in                   55.0 kips/in

Keel Pier Vertical Stiffness   Keel Pier Horizontal Stiffness
      3062.1 kips/in                  271.9 kips/in

     QD1                QD2                QD3                QD4
   135.1 kips         13.4 kips       -1773.6 kips       -9577.0 kips


               * System Parameters and Inputs *

Earthquake Used is 1940 EL CENTRO

Horizontal acceleration input is HORIZONTAL

Vertical acceleration input is
                    Earthquake Acceleration Time History.

Vertical/Horizontal Ground Acceleration Ratio   Data Time Increment
         1.000                                        .010 sec

Gravitational Constant   % System Damping
      386.09 in/sec2           8.00 %

                       Mass Matrix      .

           42.3992             .0000           8183.0420
             .0000           42.3992               .0000
         8183.0420             .0000        2410451.0000

                      Damping Matrix

           17.2698             .0000           1823.2557
             .0000          107.6096               .0000
         1823.2557             .0000         726995.2543
```

```
                    Stiffness Matrix

      381.9100              .0000           1540.0000
         .0000          10668.5400              .0000
     1540.0000              .0000       10105627.1325


Undamped Natural Frequencies      Mode #1        Mode #2        Mode #3
                                1.784 rad/sec  5.864 rad/sec  15.863 rad/sec
Damped Natural Frequencies        Mode #1        Mode #2        Mode #3
                                1.778 rad/sec  5.845 rad/sec  15.812 rad/sec


For Earthquake Acceleration of 100.00 % of the 1940 EL CENTRO

Maximums/Failures          X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------         --------  --------        ------------- -----------
 Maximum X                8.683955                                   8.25
 Maximum Y                          -.516443                         5.63
 Maximum Rotation                                   -.009067         6.47
Side block crushing        .848398  -.303353         .008030         5.86


For Earthquake Acceleration of  90.00 % of the 1940 EL CENTRO

Maximums/Failures          X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------         --------  --------        ------------- -----------
 Maximum X               -6.332777                                   6.97
 Maximum Y                          -.398401                         5.61
 Maximum Rotation                                   -.012778         7.34
Side block liftoff       -1.519886   .095785        -.012452         7.30
Side block crushing      -2.340034  -.101646        -.010844         7.24


For Earthquake Acceleration of  80.00 % of the 1940 EL CENTRO

Maximums/Failures          X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------         --------  --------        ------------- -----------
 Maximum X               -5.730834                                   6.96
 Maximum Y                          -.357898                         5.60
 Maximum Rotation                                   -.011979         7.32
Side block liftoff       -1.161818   .124231        -.011965         7.31
Side block crushing      -1.933861  -.103703        -.010878         7.24


For Earthquake Acceleration of  70.00 % of the 1940 EL CENTRO

Maximums/Failures          X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------         --------  --------        ------------- -----------
 Maximum X               -5.133748                                   6.95
 Maximum Y                          -.313161                         5.60
 Maximum Rotation                                   -.010912         7.31

No failures occurred.
```

```
For Earthquake Acceleration of  79.00 % of the 1940 EL CENTRO

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)  Time (sec)
-----------------         --------   --------        ------------- -----------
 Maximum X                -5.666482                                  6.96
 Maximum Y                           -.358425                        5.60
 Maximum Rotation                                    -.011854        7.32
Side block liftoff        -1.062687   .158909        -.011854        7.32
Side block crushing       -1.322698  -.102559        -.010792        7.24


For Earthquake Acceleration of  78.00 % of the 1940 EL CENTRO

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)  Time (sec)
-----------------         --------   --------        ------------- -----------
 Maximum X                -5.614749                                  6.95
 Maximum Y                           -.348951                        5.60
 Maximum Rotation                                    -.011776        7.32
Side block liftoff        -1.036571   .152184        -.011776        7.32


For Earthquake Acceleration of  77.00 % of the 1940 EL CENTRO

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)  Time (sec)
-----------------         --------   --------        ------------- -----------
 Maximum X                -5.542802                                  6.95
 Maximum Y                           -.344477                        5.60
 Maximum Rotation                                    -.011750        7.31
Side block liftoff         -.996025   .150506        -.011749        7.32


For Earthquake Acceleration of  76.00 % of the 1940 EL CENTRO

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)  Time (sec)
-----------------         --------   --------        ------------- -----------
 Maximum X                -5.484800                                  6.95
 Maximum Y                           -.340008                        5.60
 Maximum Rotation                                    -.011522        7.31
Side block liftoff         -.929225   .171991        -.011477        7.33


For Earthquake Acceleration of  75.00 % of the 1940 EL CENTRO

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)  Time (sec)
-----------------         --------   --------        ------------- -----------
 Maximum X                -5.415882                                  6.95
 Maximum Y                           -.335530                        5.60
 Maximum Rotation                                    -.011375        7.31
Side block liftoff         -.917368   .169728        -.011331        7.33


For Earthquake Acceleration of  74.00 % of the 1940 EL CENTRO

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)  Time (sec)
```

```
-----------------      --------  --------       ------------- -----------
 Maximum X             -5.395319                                6.95
 Maximum Y                        -.331056                      5.60
 Maximum Rotation                                -.011318       7.31
Side block liftoff      -.318169   .183618       -.011208       7.34


For Earthquake Acceleration of  73.00 % of the 1940 EL CENTRO

Maximums/Failures       X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------      --------  --------       ------------- -----------
 Maximum X             -5.337773                                6.95
 Maximum Y                        -.326582                      5.60
 Maximum Rotation                                -.011196       7.31
Side block sliding      -.726184   .190748       -.010986       7.35
Side block overturning  -.726184   .190748       -.010986       7.35


For Earthquake Acceleration of  72.00 % of the 1940 EL CENTRO

Maximums/Failures       X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------      --------  --------       ------------- -----------
 Maximum X             -5.269186                                6.95
 Maximum Y                        -.322108                      5.60
 Maximum Rotation                                -.011063       7.31

No failures occurred.
```

"3DOFRUB" Isolator (NORM DD2)
Input Data File . . . .

```
***SHIP/SUB DRYDOCK BLOCKING SYSTEM***  DATA FILE: B:S893DD11.DAT

          ***INPUT FILE DATA***
                                                         FULL [illegible]


SHIP NAME:   LAFAYETTE SSBN 616
DISCRIPTION OF ISOLATORS IF USED: 6" RUBBER CAP W/ ISOLATORS
DISCRIPTION OF BUILDUP: 8 SPACING COMPOSITE
DISCRIPTION OF WALE SHORES USED: NO WALE SHORES
DISCRIPTION OF DAMPING: 8% DAMPING
LOCATION OF DRYDOCK BEING STUDIED: DD2 LBNSY
NAVSEA DOCKING DRAWING NUMBER: 845-2006640
REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: S15KVE1.WK1  ETC.
MISC. COMMENTS: S893DD11.DAT  1255 17 FEB 88


PRESS ANY KEY TO CONTINUE...
```

```
SHIP WEIGHT  (KIPS)                                         W= 16369.9
HEIGHT OF KG (IN)                                           H= 193
MOMENT OF INERTIA  (KIPS*IN*SEC^2)                         IK= 2410451
SIDE PIER VERTICAL STIFFNESS (KIPS/IN)                    Kvs= 1303.23
SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)  Kvsp= 4093.1
KEEL PIER VERTICAL STIFFNESS (KIPS/IN)                    KVK= 8062.08
KEEL PIER VERTICAL PLASTIC STIFFNESS(KIPS/IN)   KVKP= 22101.31
HEIGHT OF WALE SHORES  (IN)                               AAA= 0
WALE SHORE STIFFNESS (KIPS/IN)                             KS= 0
SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN)                  KHS= 44
KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN)                  KHK= 217.59
SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KSHP= 8.899999
KEEL PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KKHP= 33.62
RESTORING FORCE AT 0 DEFLECT KEEL HORIZ   (KIPS) QD1= 108.06
RESTORING FORCE AT 0 DEFLECT SIDE HORIZ   (KIPS) QD2= 14.72
RESTORING FORCE AT 0 DEFLECT SIDE VERT    (KIPS) QD3=-1773.63
RESTORING FORCE AT 0 DEFLECT KEEL VERT    (KIPS) QD4=-9577.03
GRAVITATIONAL CONSTANT (IN/SEC^2)               GRAV= 386.09

PRESS ANY KEY TO CONTINUE...
```

```
  SIDE BLOCK WIDTH  (IN)                                   SBW= 999
  KEEL BLOCK WIDTH  (IN)                                   KBW
  SIDE BLOCK HEIGHT (IN)                                   SBH= 75
  KEEL BLOCK HEIGHT (IN)                                   KBH= 61
  BLOCK ON BLOCK FRICTION COEFFICIENT                       U1= 9
  HULL ON BLOCK FRICTION COEFFICIENT                        U2= .75
  SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN)           BR= 144
  SIDE PIER CAP PROPORTIONAL LIMIT                       SCPL= .7
  KEEL PIER CAP PROPORTIONAL LIMIT                       KCPL= .7
  TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN^2) SAREA= 8352
  TOTAL KEEL PIER CONTACT AREA   (IN^2)             KAREA= 55440
  PERCENT CRITICAL DAMPING                               ZETA= .08
  HULL NUMBER (XXXX)                                     HULL= 616
  SYSTEM NUMBER (XXX)                                    NSYS= 893
  CAP ANGLE (RAD)                                        BETA= .377

  PRESS ANY KEY TO CONTINUE...
```

"3DOFRUB" Isolator (NORM DD2) Output File . . . .

```
                            ** Hull 616 **


                       * Ship Parameters *

     Weight           Moment of Inertia          K.G.
  16369.9 kips    2410451.0 kips-in-sec2      193.0 ins


                      * Drydock Parameters *

Side Block Height   Side Block Width   Keel Block Height   Keel Block Width
   75.0 ins             999.0 ins              61.0 ins           999.0 ins

Side-to-Side Pier Distance   Wale Shore Ht.   Wale Shore Stiffness  Cap Angle
      144.0 ins                    .0 ins                .0 kips/in  .377 rad

1Side Side Pier Contact Area   Total Keel Pier Contact Area       kkhp
          8352.0 in2                    55440.0 in2               33.6 kips/in

B/B Friction Coeff   H/B Friction Coeff      kshp            kvsp
      9.000                 .750            8.9 kips/in  4093.1 kips/in

Side Pier Fail Stress Limit     Keel Pier Fail Stress Limit      kvkp
          .700 kips/in2                   .700 kips/in2      22101.3 kips/in

Side Pier Vertical Stiffness   Side Pier Horizontal Stiffness
      1303.2 kips/in                   44.0 kips/in

Keel Pier Vertical Stiffness   Keel Pier Horizontal Stiffness
      8062.1 kips/in                 217.5 kips/in

     QD1                  QD2                   QD3                  QD4
   103.1 kips           14.7 kips          -1773.6 kips         -9577.0 kips


                   * System Parameters and Inputs *

Earthquake Used is 1 OCT 87 WHITTIER * 10.94

Horizontal acceleration input is LBNSY DD2 TRANSVERSE COMPONENT

Vertical acceleration input is LBNSY DD2 VERTICAL COMPONENT
                         Earthquake Acceleration Time History.

Vertical/Horizontal Ground Acceleration Ratio   Data Time Increment
          1.000                                             .010 sec

Gravitational Constant   % System Damping
      386.09 in/sec2           8.00 %

                          Mass Matrix

      42.3992                  .0000               8183.0420
        .0000                42.3992                   .0000
    8183.0420                  .0000            2410451.0000

                         Damping Matrix

      15.7037                  .0000               1739.8344
        .0000               107.6096                   .0000
    1739.8344                  .0000             730840.6480
```

```
                         Stiffness Matrix

      305.5300              .0000          1232.0000
         .0000         10668.5400              .0000
     1232.0000              .0000      10105319.1325


Undamped Natural Frequencies      Mode #1          Mode #2           Mode #3
                              1.722 rad/sec   5.438 rad/sec    15.[illegible] rad/sec
Damped Natural Frequencies        Mode #1          Mode #2           Mode #3
                              1.717 rad/sec   5.416 rad/sec    15.812 rad/sec


For Earthquake Acceleration of 100.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures         X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------        --------  --------        ------------- -----------
 Maximum X               6.429004                                   16.72
 Maximum Y                          .293265                          5.72
 Maximum Rotation                                   -.019115        14.50
Side block liftoff       2.744572   .043471          .013135        13.86
Side block crushing      2.744572   .043471          .013135        13.86


For Earthquake Acceleration of  90.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures         X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------        --------  --------        ------------- -----------
 Maximum X               5.717000                                   13.73
 Maximum Y                          .262813                          5.72
 Maximum Rotation                                    .015841        17.17
Side block sliding     -1.967609    .006875          .013540        16.18
Side block overturning -1.967609    .006875          .013540        16.18
Side block liftoff     -1.962900    .025600          .013302        16.19
Side block crushing     -.720489  -.055832         -.011755        14.45


For Earthquake Acceleration of  80.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures         X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------        --------  --------        ------------- -----------
 Maximum X               5.310249                                   13.72
 Maximum Y                          .232091                          5.72
 Maximum Rotation                                    .015249        17.17
Side block liftoff        .615975   .005610          .013596        17.08
Side block crushing      -.065472  -.047853         -.011683        14.45


For Earthquake Acceleration of  70.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures         X (ins)   Y (ins)         Theta (rads)  Time (sec)
-----------------        --------  --------        ------------- -----------
 Maximum X              -4.878304                                    9.09
 Maximum Y                          .200566                          5.72
 Maximum Rotation                                    .013879        17.16
Side block sliding        .036986  -.013022          .013815        17.18
```

```
---- ----- ------ -       --------  --------          --------      -----
Side block overturning     .036986  -.013022           .018[illegible]       17.16
Side block liftoff         .154749   .005155           .018670       17.13
Side block crushing       2.330717  -.020748          -.011920       15.[illegible]


For Earthquake Acceleration of  60.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)   Y (ins)          Theta (rads)  Time (sec)
-----------------        --------  --------         ------------- -----------
 Maximum X                5.014680                                   13.77
 Maximum Y                           .167810                          5.72
 Maximum Rotation                                     -.007604       12.17

No failures occurred.


For Earthquake Acceleration of  69.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)   Y (ins)          Theta (rads)  Time (sec)
-----------------        --------  --------         ------------- -----------
 Maximum X               -4.793266                                    9.09
 Maximum Y                           .195318                          5.72
 Maximum Rotation                                      .018709       17.16
Side block sliding         -.002265  -.005044           .018709       17.16
Side block overturning     -.002265  -.005044           .018709       17.16
Side block liftoff          .048491   .002218           .018686       17.14
Side block crushing        2.436910  -.023426          -.011937       15.60


For Earthquake Acceleration of  68.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)   Y (ins)          Theta (rads)  Time (sec)
-----------------        --------  --------         ------------- -----------
 Maximum X               -4.852107                                    9.09
 Maximum Y                           .192487                          5.72
 Maximum Rotation                                      .018540       17.16
Side block crushing      -1.663434  -.049468           .011728       16.09


For Earthquake Acceleration of  67.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)   Y (ins)          Theta (rads)  Time (sec)
-----------------        --------  --------         ------------- -----------
 Maximum X               -4.829379                                    9.09
 Maximum Y                           .189656                          5.72
 Maximum Rotation                                      .018499       17.16
Side block crushing      -1.664699  -.048735           .011693       16.09


For Earthquake Acceleration of  66.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)   Y (ins)          Theta (rads)  Time (sec)
-----------------        --------  --------         ------------- -----------
 Maximum X                5.723670                                   13.73
 Maximum Y                           .185186                          5.72
 Maximum Rotation                                      .01[illegible]       17.16
```

```
Side block liftoff        .594215   .00[illegible]       .01[illegible]      17.1[illegible]
Side block crushing      1.252601  -.013856       -.012157      15.57


For Earthquake Acceleration of  65.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)    Y (ins)        Theta (rads)  Time (sec)
-----------------         --------   --------       ------------- -----------
 Maximum X                5.876296                                  13.75
 Maximum Y                           .18[illegible]                           5.7[illegible]
 Maximum Rotation                                   .012521       17.15
Side block crushing        .866109   .006230        .012813       17.12


For Earthquake Acceleration of  64.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)    Y (ins)        Theta (rads)  Time (sec)
-----------------         --------   --------       ------------- -----------
 Maximum X                5.787844                                  13.75
 Maximum Y                           .178997                        5.72
 Maximum Rotation                                   .012185       17.15
Side block crushing        .798469  -.004347        .012171       17.16


For Earthquake Acceleration of  63.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)    Y (ins)        Theta (rads)  Time (sec)
-----------------         --------   --------       ------------- -----------
 Maximum X                5.725950                                  13.75
 Maximum Y                           .176201                        5.72
 Maximum Rotation                                   .011489       17.11

No failures occurred.
```

Isolator Equivalent Modulus Stiffness Spreadsheets. . .

```
17-Feb-8[illegible]

HORIZONTAL STIFFNESS MATRIX FOR 4 LAYERS        ORIGINAL DOCKING DRAWING WITH RUBBER CAP
                                                AND ISOLATORS
SYSTEM 86
THIS IS A KEEL SYSTEM FOR HULL 616 WITH 4 FT BUILDUP
8 FOOT CENTERS


  ELEMENT # 1    CONCRETE
                   DEPTH       TRANSVERSE                     HEIGHT
      E1            B1            H1           I1               L1
     (PSI)          IN           (IN)        (IN^4)            (IN)
  ------------------------------------------------------------------------

      4000000          42            48         387072              27

  ------------------------------------------------------------------------

  12E1I1/L1^3    6E1I1/L1^2    4E1I1/L1      2E1I1/L1
  ------------------------------------------------------------------------

   943934156.38  12743111111.1  229376000000  114688000000
  ------------------------------------------------------------------------

    RIGIDITY        TOP          SHEAR        ELEMENT
     G1r          CONTACT        STRAIN        SHEAR
     (PSI         AREA         (IN/IN)      DEFLECTION
                  (IN^2)                       (IN)
  ------------------------------------------------------------------------

     24[illegible]            2016    [illegible]0002667   0.0000055904

  ------------------------------------------------------------------------


  ELEMENT # 2    [illegible] ISOLATORS
                   DEPTH       TRANSVERSE                     HEIGHT
      E2            B2            H2           I2               L2
     (PSI)         (IN)          (IN)        (IN^4)            (IN)
  ------------------------------------------------------------------------

         699           42            48         387072              27

  ------------------------------------------------------------------------

  12E2I2/L2^3    6E2I2/L2^2    4E2I2/L2      2E2I2/L2
  ------------------------------------------------------------------------

   164952.49280   2226858.6667     40083456      20041728
  ------------------------------------------------------------------------

    RIGIDITY        TOP          SHEAR        ELEMENT
     G2r          CONTACT        STRAIN        SHEAR
     (PSI)         AREA         (IN/IN)      DEFLECTION
                  (IN^2)                       (IN)
  ------------------------------------------------------------------------

         7[illegible]         2016   0.0[illegible]958154  0.0191[illegible]2452

  ------------------------------------------------------------------------
```

```
ELEMENT # 3    DOUGLAS FIR
                   DEPTH        TRANSVERSE                    HEIGHT
     E3             B3             H3            I3             L3
    (PSI            (IN)           (IN)         (IN 4)          (IN)
--------------------------------------------------------------------------------

       175549            42            48        387072              1

--------------------------------------------------------------------------------

12E3I3/L3^3    6E3I3/L3^2     4E3I3/L3       2E3I3/L3
--------------------------------------------------------------------------------

    8.1540E+11     4.0770E+11     2.7180E+11     1.3590E+11
--------------------------------------------------------------------------------

   RIGIDITY          TOP           SHEAR         ELEMENT
     G3-           CONTACT        STRAIN          SHEAR
    PSI)            AREA          (IN/IN)      DEFLECTION
                   (IN^2)                         (IN)
----------------------------------------------------------------

        12539          2016   0.0000395584   0.0000395584

--------------------------------------------------------------------------------


ELEMENT # 4    RUBBER
                   DEPTH        TRANSVERSE                    HEIGHT
     E4             B4             H4            I4             L3
    (PSI)           (IN)           (IN)         (IN^4)          (IN)
--------------------------------------------------------------------------------

          992            42            48        387072              6

--------------------------------------------------------------------------------

12E4I4/L4^3    6E4I4/L4^2     4E4I4/L4       2E4I4/L4
--------------------------------------------------------------------------------

    2.1332E+07     6.3996E+07     2.5598E+08     1.2799E+08
--------------------------------------------------------------------------------

   RIGIDITY          TOP           SHEAR         ELEMENT
     G4-           CONTACT        STRAIN          SHEAR          TOTAL
    (PSI)           AREA          (IN/IN)      DEFLECTION        SHEAR
                   (IN^2)                         (IN)       DEFLECTION (IN)
--------------------------------------------------------------------------------

          335        1411.2   0.0021134066   0.0126804396     2.0433E-01
```

```
F/                                          STIFFNESS MATRIX
M                                                                                                                             D


Q1    9.4393E+08    1.2743E+10   -9.4393E+08    1.2743E+10    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00     0.0000E+00    0.0000E+00 q1

M1    1.2743E+10    2.2938E+11   -1.2743E+10    1.1469E+11    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00     0.0000E+00    0.0000E+00 th1

Q2   -9.4393E+08   -1.2743E+10    9.4410E+08   -1.2741E+10   -1.6495E+05    2.2269E+06    0.0000E+00    0.0000E+00     0.0000E+00    0.0000E+00 q2

M2    1.2743E+10    1.1469E+11   -1.2741E+10    2.2942E+11   -2.2269E+06    2.0042E+07    0.0000E+00    0.0000E+00     0.0000E+00    0.0000E+00 th2

Q3    0.0000E+00    0.0000E+00   -1.6495E+05   -2.2269E+06    8.1540E+11    4.0770E+11   -8.1540E+11    4.0770E+11     0.0000E+00    0.0000E+00 q3

M3    0.0000E+00    0.0000E+00    2.2269E+06    2.0042E+07    4.0770E+11    2.7184E+11   -4.0770E+11    1.3590E+11     0.0000E+00    0.0000E+00 th3

Q4    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00   -8.1540E+11   -4.0770E+11    8.1542E+11   -4.0764E+11   -2.13320E+07   6.39959E+07 q4

M4    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00    4.0770E+11    1.3590E+11   -4.0764E+11    2.7206E+11   -6.39959E+07   1.27992E+08 th4

Q5    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00  -2.13320E+07  -6.39959E+07    2.13320E+07  -6.39959E+07 q5

M5    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00   6.39959E+07   1.27992E+08   -6.39959E+07   2.55984E+08 th5
```

```
KNOWN VALUES:                                          # OF SYSTEM BLOCKS =              55
Q1 =                                   -1000 lbs

M1 = Q1*(L1+L2+L3+L4) =               -61000 IN*LBS

Q2 = M2 = Q3 = M3 = M4 = Q4 = M5           0

Q5 =                                    1000 lbs

q1 = th1=                  0
-----------------------------------------------------------------------------------------

SOLVED UNKNOWNS:

q2=  0.0000122419 in

th2  0.0000008283 rad

                                                           -B1            -B2
q3   0.0337143375 in                                  -1003.86391667   -34060.4635

th3  0.0020465601 rad

q4   [illegible] in                                   [illegible] [illegible]

th4  0.0020466558 rad


q5   0.0482283934 in                                   -894528.95774  -2318464.4599

th5  0.0020935378 rad

 K (BEND HORIZ) FOR 1 KEEL BLOCK =  27963.465505 lbs/in          27.963465505 KIPS/IN
-----------------------------------------------------------------------------------------

 K (BEND HORIZ) ALL KEEL BLOCKS =   1537990.6028 lbs/in          1537.9906028 KIPS/IN
-----------------------------------------------------------------------------------------

 MATRIX CHECK:

   Q1 =               -1000.0000

   M1 =              -61000.0000

   Q2 =                    0.0000

   M2 =                    0.0000

   Q3 =                    0.0000

   M3 =                    0.0000

   Q4 =                    0.0000

   M4 =                    0.0000

   Q5 =                 1000.0000

   M5 =                    0.0000
  TOTAL KEEL BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION:
  SYSTEM 86 1" RUBBER CAP W/ ISOLATORS
  ---------------------------------------------------------------------------------------

  Khk (SIDEBLOCK HORIZONTAL STIFFNESS) = P/(BENDING DISPL + SHEAR DISPLACEMENT)

  Khk       =                 3.96 KIPS/IN        (PER BLOCK)
                            217.53
  Khk       =               217.78 KIPS/IN        (ENTIRE KEEL BLOCK SYSTEM)
```

```
      17-Feb-88

HORIZONTAL STIFFNESS MATRIX FOR 4 LAYERS        ORIGINAL DOCKING DRAWING WITH RUBBER CAP
                                                AND ISOLATORS
SYSTEM 8b
THIS IS A KEEL SYSTEM FOR HULL 616 WITH 4 FT BUILDUP
9 FOOT CENTERS


   ELEMENT # 1    CONCRETE
                   DEPTH       TRANSVERSE                    HEIGHT
       E1            B1            H1           I1             L1
      (PSI)         (IN)          (IN)        (IN^4)          (IN)
 ---------------------------------------------------------------------

       1.00E+50            42            48        387072            27

 ---------------------------------------------------------------------

 12E1I1/L1^3    6E1I1/L1^2     4E1I1/L1       2E1I1/L1
 ---------------------------------------------------------------------

  2.3598354E+52  3.1857778E+53  5.7344000E+54  2.8672000E+54
 ---------------------------------------------------------------------

    RIGIDITY         TOP         SHEAR        ELEMENT
      GIr          CONTACT       STRAIN        SHEAR
     (PSI)          AREA        (IN/IN)      DEFLECTION
                   (IN^2)                       (IN)
 ---------------------------------------------------------------------

 ***************         2016  8.2671958E-51  2.2321429E-49

 ---------------------------------------------------------------------


   ELEMENT # 2    OAK
                   DEPTH       TRANSVERSE                    HEIGHT
       E2            B2            H2           I2             L2
      (PSI)         (IN)          (IN)        (IN^4)          (IN)
 ---------------------------------------------------------------------

       1.00E+50            42            48        387072             6

 ---------------------------------------------------------------------

 12E2I2/L2^3    6E2I2/L2^2     4E2I2/L2       2E2I2/L2
 ---------------------------------------------------------------------

  2.1504000E+54  6.4512000E+54  2.5804800E+55  1.2902400E+55
 ---------------------------------------------------------------------

    RIGIDITY         TOP         SHEAR        ELEMENT
      GIr          CONTACT       STRAIN        SHEAR
     (PSI)          AREA        (IN/IN)      DEFLECTION
                   (IN^2)                       (IN)
 --------------------------------------------------------------------

     1.00E+49          2016  4.9603175E-50  2.9761905E-49

 --------------------------------------------------------------------
```

```
ELEMENT # 3    DOUGLAS FIR
                DEPTH       TRANSVERSE                      HEIGHT
     E3          B3            H3            I3              L3
    (PSI)       (IN)          (IN)         (IN^4)           (IN)
----------------------------------------------------------------------

     1.00E+50           42           48        387072              1

----------------------------------------------------------------------

12E3I3/L3^3   6E3I3/L3^2    4E3I3/L3      2E3I3/L3
----------------------------------------------------------------------

   4.6449E+55    2.3224E+56    1.5483E+56    7.7414E+55
----------------------------------------------------------------------

   RIGIDITY        TOP          SHEAR        ELEMENT
     GIr         CONTACT        STRAIN        SHEAR
    (PSI)         AREA         (IN/IN)      DEFLECTION
                 (IN^2)                        (IN)
--------------------------------------------------------

     1.00E+49          2016  4.9603175E-50  4.9603175E-50

----------------------------------------------------------------------


ELEMENT # 4    DIS ISOLATOR
                DEPTH       TRANSVERSE                      HEIGHT
     E4          B4            H4            I4              L3
    (PSI)       (IN)          (IN)         (IN^4)           (IN)
----------------------------------------------------------------------

          699           42           48        387072             27

----------------------------------------------------------------------

12E4I4/L4^3   6E4I4/L4^2    4E4I4/L4      2E4I4/L4
----------------------------------------------------------------------

   1.6495E+05    2.2269E+06    4.0083E+07    2.0042E+07
----------------------------------------------------------------------

   RIGIDITY        TOP          SHEAR        ELEMENT
     GIr         CONTACT        STRAIN        SHEAR          TOTAL
    (PSI)         AREA         (IN/IN)      DEFLECTION       SHEAR
                 (IN^2)                        (IN)      DEFLECTION (IN)
----------------------------------------------------------------------

     6.99E+01        1411.2   0.0101375791   0.2737146361     2.7371E-01
```

```
F                                   STIFFNESS MATRIX
M                                                                                                                  D


Q1   2.3598E+52   3.1858E+53   2.3598E+52   3.1858E+53   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 q1

M1   3.1858E+53   5.7344E+54  -3.1858E+53   2.8672E+54   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 th1

Q2  -2.3598E+52  -3.1858E+53   2.1740E+54   6.1326E+54   2.1504E+54   6.4512E+54   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 q2

M2   3.1858E+53   2.8672E+54   6.1326E+54   3.1539E+55  -6.4512E+54   1.2902E+55   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 th2

Q3   0.0000E+00   0.0000E+00  -2.1504E+54  -6.4512E+54   4.6664E+56   2.2579E+56   4.6449E+56   2.3224E+56   0.0000E+00   0.0000E+00 q3

M3   0.0000E+00   0.0000E+00   6.4512E+54   1.2902E+55   2.2579E+56   1.8063E+56  -2.3224E+56   7.7414E+55   0.0000E+00   0.0000E+00 th3

Q4   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  -4.6449E+56  -2.3224E+56   4.6449E+56  -2.3224E+56 -1.64952E+05   2.22686E+06 q4

M4   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   2.3224E+56   7.7414E+55  -2.3224E+56   1.5483E+56 -2.22686E+06   2.00417E+07 th4

Q5   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 -1.64952E+05 -2.22686E+06  1.64952E+05  -2.22686E+06 q5

M5   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  2.22686E+06  2.00417E+07 -2.22686E+06   4.00835E+07 th5
```

```
KNOWN VALUES:                                        # OF SYSTEM BLOCKS =             55
Q1 =                              -1000 lbs

M1 = Q1*(L1+L2+L3+L4) =          -61000 IN*LBS

Q2 = M2 = Q3 = M3 = M4 = Q4 = M5      0

Q5 =                               1000 lbs

q1 = th1=  -                 0
------------------------------------------------------------------------------------------

SOLVED UNKNOWNS:

q2= 4.8967634E-49 in

th2 3.3133371E-50 rad
                                                          -B1            -B2
q3  7.0335751E-49 in                                      -1267750       -4048000

th3 3.7938678E-50 rad
q4  7.4165358E-49 in                                      -335512000     -169252000

th4 3.5649148E-50 rad


q5   0.024249406 in                                       -999.99999997        -27000

th5  0.0017471692 rad

K (BEND HORIZ) FOR 1 KEEL BLOCK = 1.3483384E+51 lbs/in      1.3483384E+48 KIPS/IN
------------------------------------------------------------------------------------------

K (BEND HORIZ) ALL KEEL BLOCKS =  7.4158612E+50 lbs/in      7.4158612E+49 KIPS/IN
------------------------------------------------------------------------------------------

MATRIX CHECK:

   Q1 =              -1000.0000

   M1 =             -61000.0000

   Q2 =                  0.0000

   M2 =                  0.0000

   Q3 =                  0.0000

   M3 =                  0.0000

   Q4 =                  0.0000

   M4 =                  0.0000

   Q5 =               1000.0000

   M5 =                  0.0000
TOTAL KEEL BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION:
SYSTEM 86 1" RUBBER CAP w/ ISOLATORS
------------------------------------------------------------------------------------------

Khk (SIDEBLOCK HORIZONTAL STIFFNESS) = P/(BENDING DISPL + SHEAR DISPLACEMENT)

Khk       =            3.36 KIPS/IN       (PER BLOCK)
                     183.00
Khk       =          184.59 KIPS/IN       (ENTIRE KEEL BLOCK SYSTEM)
```

```
       17-Feb-88

HORIZONTAL STIFFNESS MATRIX FOR 4 LAYERS        1" RUBBER CAP E1
                                                WITH ISOLATORS
SYSTEM 3b KU
THIS IS A SIDE BLOCK SYSTEM FOR HULL 616 WITH 5 FT BUILDUP
16 FOOT CENTERS


  ELEMENT # 1    CONCRETE
                    DEPTH       TRANSVERSE                   HEIGHT
     E1              B1            H1           I1             L1
    (PSI)           (IN)          (IN)        (IN^4)          (IN)
------------------------------------------------------------------------

     4000000           48            42        296352            48

------------------------------------------------------------------------

12EI1/L1^3    6EI1/L1^2    4EI1/L1      2EI1/L1
------------------------------------------------------------------------

   128625000    3087000000   98784000000   49392000000
------------------------------------------------------------------------

   RIGIDITY        TOP          SHEAR        ELEMENT
     G1r         CONTACT        STRAIN        SHEAR
     PSI          AREA         (IN/IN)      DEFLECTION
                 (IN^2)                        (IN)
------------------------------------------------------------------------

     2400000          2016   0.0000002067   0.0000099206

------------------------------------------------------------------------


  ELEMENT # 2    DIS ISOLATOR
                    DEPTH       TRANSVERSE                   HEIGHT
     E2              B2            H2           I2             L2
    (PSI)           (IN)          (IN)        (IN^4)          (IN)
------------------------------------------------------------------------

         875          23.4          29.7   51086.24235            19

------------------------------------------------------------------------

12EI2/L2^3    6EI2/L2^2    4EI2/L2      2EI2/L2
------------------------------------------------------------------------

  78204.628178  742943.96769  9410623.5908  4705311.7954
------------------------------------------------------------------------

   RIGIDITY        TOP          SHEAR        ELEMENT
     G1r         CONTACT        STRAIN        SHEAR
    (PSI)         AREA         (IN/IN)      DEFLECTION
                 (IN^2)                        (IN)

   ---------- ------------------------------------ ---------------------

         93      456.436   0.023492087   0.4463496527

------------------------------------------------------------------------
```

```
ELEMENT # 3    DOUGLAS FIR
                  DEPTH        TRANSVERSE                      HEIGHT
     E3             B3             H3             I3             L3
   (PSI)           (IN)           (IN)         (IN^4)           (IN)
---------------------------------------------------------------------------

         95297            12             24         13824              2

---------------------------------------------------------------------------

12E3I3/L3^3    6E3I3/L3^2     4E3I3/L3       2E3I3/L3
---------------------------------------------------------------------------

    1.9761E+09     1.9761E+09     2.6348E+09     1.3174E+09
---------------------------------------------------------------------------

   RIGIDITY         TOP          SHEAR         ELEMENT
     GIr          CONTACT        STRAIN         SHEAR
    (PSI)          AREA         (IN/IN)      DEFLECTION
                  (IN^2)                        (IN)
-------------------------------------------------------------

          6807           288   0.0005101012   0.0010202023

---------------------------------------------------------------------------


ELEMENT # 4    RUBBER
                  DEPTH        TRANSVERSE                      HEIGHT
     E4             B4             H4             I4             L3
   (PSI)           (IN)           (IN)         (IN^4)           (IN)
---------------------------------------------------------------------------

           992            12             24         13824              6

---------------------------------------------------------------------------

12E4I4/L4^3    6E4I4/L4^2     4E4I4/L4       2E4I4/L4
---------------------------------------------------------------------------

    7.6196E+05     2.2856E+06     9.1423E+06     4.5711E+06
---------------------------------------------------------------------------

   RIGIDITY         TOP          SHEAR         ELEMENT
     GIr          CONTACT        STRAIN         SHEAR          TOTAL
    (PSI)          AREA         (IN/IN)      DEFLECTION        SHEAR
                  (IN^2)                        (IN)      DEFLECTION (IN)
---------------------------------------------------------------------------

           335           288   0.0103556924   0.0621341541     5.0951E-01
```

```
F/                                           STIFFNESS MATRIX
M                                                                                                                      D


Q1   1.2867E+08   3.0670E+09  -1.2863E+08   3.0670E+09   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 q1

M1   3.0870E+09   9.8784E+10  -3.0970E+09   4.9392E+10   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 th1

Q2  -1.2863E+08  -3.0870E+09   1.2870E+08  -3.0863E+09  -7.8205E+04   7.4294E+05   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 q2

M2   3.0870E+09   4.9392E+10  -3.0863E+09   9.8793E+10  -7.4294E+05   4.7053E+06   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 th2

Q3   0.0000E+00   0.0000E+00  -7.8205E+04  -7.4294E+05   1.9762E+09   1.9753E+09  -1.9761E+09   1.9761E+09   0.0000E+00   0.0000E+00 q3

M3   0.0000E+00   0.0000E+00   7.4294E+05   4.7053E+06   1.9753E+09   2.6442E+09  -1.9761E+09   1.3174E+09   0.0000E+00   0.0000E+00 th3

Q4   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  -1.9761E+09  -1.9761E+09   1.9766E+09  -1.9738E+09 -7.61856E+05  2.28557E+06 q4

M4   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   1.9761E+09   1.3174E+09  -1.9738E+09   2.6439E+09 -2.28557E+06  4.57114E+06 th4

Q5   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00 -7.61856E+05 -2.28557E+06  7.61856E+05 -2.28557E+06 q5

M5   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00  2.28557E+06  4.57114E+06 -2.28557E+06  9.14227E+06 th5
```

```
KNOWN VALUES:                                          # OF SYSTEM BLOCKS =            29
Q1 =                                  -1000 lbs

M1 = Q1*(L1+L2+L3+L4) =              -75000 IN*LBS

Q2 = M2 = Q3 = M3 = M4 = Q4 = M5          0

Q5 =                                   1000 lbs

q1 = th1=                     0
--------------------------------------------------------------------------------

SOLVED UNKNOWNS:

q2=  0.0000573372 in

th2  0.0000020651 rad
                                                            -B1           -B2
q3    0.083548359 in                                 -1006.01829834  -27062.032332

th3   0.007440467 rad
q4    [illegible]                                    -1993 2071.1    -184710053.6

th4  0.[illegible] rad
          .

q5   0.1487973266 in                                 -93027.411451   -299112.21654

th5  0.0087636791 rad

K (BEND HORIZ) FOR 1 SIDE BLOCK = 10158.4281953 lbs/in        10.1584281953 KIPS/IN
--------------------------------------------------------------------------------

K (BEND HORIZ) ALL SIDE BLOCKS =   294594.41766 lbs/in         294.59441766 KIPS/IN
--------------------------------------------------------------------------------

MATRIX CHECK:

  Q1 =            -1000.0000

  M1 =           -75000.0000

  Q2 =                0.0000

  M2 =                0.0000

  Q3 =                0.0000

  M3 =                0.0000

  Q4 =                0.0000

  M4 =                0.0000

  Q5 =             1000.0000

  M5 =                0.0000
TOTAL SIDE BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION:
SYSTEM 8b 1"RUBBER CAP w/ ISOLATORS  KU
--------------------------------------------------------------------------------

Khs (SIDEBLOCK HORIZONTAL STIFFNESS) = P/(BENDING DISPL + SHEAR DISPLACEMENT)

khs      =             1.52 KIPS/IN      (PER BLOCK)
                      44.00
Khs      =            44.08 KIPS/IN      (ENTIRE SIDE BLOCK SYSTEM)
```

Required Isolator Characteristics Spreadsheet . . . .

```
ISOLATOR REQUIREMENTS FOR SYSTEM 2b:


TOTAL FOR KEEL ISOLATORS (55 BLOCKS):

              Xel =     0.58736 IN

              KHK =         190 KIPS/IN

              KKHP =         26 KIPS/IN

              QD1 =       92.25 KIPS

              MAX R1 =      195 KIPS

       DIMENSIONS:       42x48x29 INCHES

       EQUIVALENT REQ D ISOLATOR KHK TOTAL=  144.72 KIPS/IN

       EQUIVALENT KHK PER ISOLATOR =           2.63 KIPS/IN

       EQUIVALENT REQ D ISOLATOR KKHP TOT=     20.4 KIPS/IN

       EQUIVALENT KKHP PER ISOLATOR =          0.37 KIPS/IN

              KVK =    25296.68 KIPS/IN

              MAX R5 =    15200 KIPS

       EQUIVALENT REQ D ISOLATOR KVK TOTAL=    1169 KIPS/IN

       EQUIVALENT KVK PER ISOLATOR =          21.25 KIPS/IN

TOTAL FOR ONE SIDE OF SIDE BLOCK ISOLATORS (29 BLOCKS):

              Xel =     0.41939 IN

              KHS =          37 KIPS/IN

              KSHP =          6 KIPS/IN

              QD2 =       92.25 KIPS

              MAX R2 =       36 KIPS

       DIMENSIONS:       24x30x20 INCHES

       EQUIVALENT REQ'D ISOLATOR KHS TOTAL=   59.71 KIPS/IN

       EQUIVALENT KHS PER ISOLATOR =           2.06 KIPS/IN

       EQUIVALENT REQ D ISOLATOR KSHP TOT=     9.38 KIPS/IN

       EQUIVALENT KSHP PER ISOLATOR =          0.32 KIPS/IN

              KVS =     4554.23 KIPS/IN

         MAX R3,4=    4200 KIPS

  EQUIVALENT REQ D ISOLATOR KVS TOTAL=   833.2 KIPS IN

  EQUIVALENT KVS PER ISOLATOR =          28.73 KIPS/IN
```

APPENDIX 6

1. "3DOFRUB" Wale Shore (EL Centro) Input Data File
2. "3DOFRUB" Wale Shore (EL Centro) Output File
3. "3DOFRUB" Wale Shore (NORM DD2) Output File
4. Wale Shore Design Spreadsheet

"3DOFRUB" Wale Shore (EL Centro)
Input Data File . . . .

```
     ***SHIP SIDE DRYDOCK BLOCKING SYSTEM***   DATA FILE: B:551WS.DAT

            ***INPUT FILE DATA***


 SHIP NAME:   LAFAYETTE SSBN 616
 DISCRIPTION OF ISOLATORS IF USED: 1" RUBBER CAP
 DISCRIPTION OF BUILDUP:
8 FT SPACING COMPOSITE CAP AND PIERS RIGIDLY ATTACHED TO GROUND
 DISCRIPTION OF WALE SHORES USED: WALE SHORE DESIGN
 DISCRIPTION OF DAMPING: 5 % DAMPING
 LOCATION OF DRYDOCK BEING STUDIED: NO SPECIFIC LOCATION
 NAVSEA DOCKING DRAWING NUMBER: 845-2006640
 REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: SYSTEM 12
 MISC. COMMENTS: 551WS.DAT  1955 15 FEB 88

SHIP WEIGHT  (KIPS)                                      W= 16369.9
HEIGHT OF KG (IN)                                        H= 193
MOMENT OF INERTIA  (KIPS*IN*SEC 2)                      IK= 2410451
SIDE PIER VERTICAL STIFFNESS (KIPS/IN)                 Kvs= 4554.23
SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)        Kvsp= 7552.4
KEEL PIER VERTICAL STIFFNESS (KIPS/IN)                 KVK= 25286.68
KEEL PIER VERTICAL PLASTIC STIFFNESS(KIPS/IN)         KVKP= 37857.79
HEIGHT OF WALE SHORES  (IN)                            AAA= 193
WALE SHORE STIFFNESS (KIPS/IN)                          KS= 6000
SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN)               KHS= 4583.79
KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN)               KHK= 18215.1
SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KSHP= 4583.79
KEEL PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KKHP= 18215.1
RESTORING FORCE AT 0 DEFLECT KEEL HORIZ   (KIPS) QD1= 0
RESTORING FORCE AT 0 DEFLECT SIDE HORIZ   (KIPS) QD2= 0
RESTORING FORCE AT 0 DEFLECT SIDE VERT    (KIPS) QD3=-545.44
RESTORING FORCE AT 0 DEFLECT KEEL VERT    (KIPS) QD4=-2734.11
GRAVITATIONAL CONSTANT (IN/SEC 2)                     GRAV= 386.09


SIDE BLOCK WIDTH   (IN)                                SBW= 999
KEEL BLOCK WIDTH   (IN)                                KBW= 999
SIDE BLOCK HEIGHT  (IN)                                SBH= 75
KEEL BLOCK HEIGHT  (IN)                                KBH= 61
BLOCK ON BLOCK FRICTION COEFFICIENT                     U1= 9
HULL ON BLOCK FRICTION COEFFICIENT                      U2= .75
SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN)         BR= 144
SIDE PIER CAP PROPORTIONAL LIMIT                      SCPL= .7
KEEL PIER CAP PROPORTIONAL LIMIT                      KCPL= .7
TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN 2) SAREA= 8352
TOTAL KEEL PIER CONTACT AREA   (IN 2)             KAREA= 55440
PERCENT CRITICAL DAMPING                              ZETA= .05
HULL NUMBER (XXXX)                                    HULL= 616
SYSTEM NUMBER (XXX)                                   NSYS= 01
CAP ANGLE (RAD)                                       BETA= .377
```

"3DOFRUB" Wale Shore (EL Centro) Output File . . . .

```
                         **** System 51 ****

                           ** Hull 616 **


                       * Ship Parameters *

   Weight          Moment of Inertia          K.G.
 16369.9 kips   2410451.0 kips-in-sec2    193.0 ins


                     * Drydock Parameters *

Side Block Height   Side Block Width   Keel Block Height   Keel Block Width
   75.0 ins            999.0 ins            61.0 ins            999.0 ins

Side-to-Side Pier Distance   Wale Shore Ht.   Wale Shore Stiffness  Cap Angle
      144.0 ins                 193.0 ins          6000.0 kips/in   .377 rad

1Side Side Pier Contact Area   Total Keel Pier Contact Area      kkhp
          8352.0 in2                    55440.0 in2          18215.1 kips/in

B/B Friction Coeff   H/B Friction Coeff     kshp            kvsp
      9.000                .750         4583.8 kips/in  7552.4 kips/in

Side Pier Fail Stress Limit    Keel Pier Fail Stress Limit      kvkp
         .700 kips/in2                   .700 kips/in2       37857.8 kips/in

Side Pier Vertical Stiffness   Side Pier Horizontal Stiffness
      4554.2 kips/in                4583.8 kips/in

Keel Pier Vertical Stiffness   Keel Pier Horizontal Stiffness
      25236.7 kips/in               18215.1 kips/in

     QD1                  QD2                   QD3                  QD4
      .0 kips              .0 kips            -545.4 kips          -2734.1 kips


                   * System Parameters and Inputs *

Earthquake Used is 1940 EL CENTRO

Horizontal acceleration input is HORIZONTAL

Vertical acceleration input is
                    Earthquake Acceleration Time History.

Vertical/Horizontal Ground Acceleration Ratio   Data Time Increment
         1.000                                         .010 sec

Gravitational Constant   % System Damping
      386.09 in/sec2            5.00 %

                      Mass Matrix

         42.3992                .0000             8183.0420
           .0000              42.3992                 .0000
       8183.0420                .0000          2410451.0000

                      Damping Matrix

        112.6209                .0000            12864.9077
           .0000             120.7612                 .0000
      12864.9077                .0000          3394384.9143
```

```
                        Stiffness Matrix

     39332.6800             .0000        2444346.1200
          .0000        34395.1400               .0000
   2444346.1200             .0000      490307122.3111


Undamped Natural Frequencies      Mode #1         Mode #2         Mode #3
                              13.912 rad/sec  44.216 rad/sec  28.482 rad/sec
Damped Natural Frequencies        Mode #1         Mode #2         Mode #3
                              13.895 rad/sec  44.161 rad/sec  28.446 rad/sec


For Earthquake Acceleration of 100.00 % of the 1940 EL CENTRO

Maximums/Failures           X (ins)    Y (ins)         Theta (rads)  Time (sec)
-----------------          --------   --------        -------------  ----------
 Maximum X                 -.190291                                     5.59
 Maximum Y                            -.252994                          5.34
 Maximum Rotation                                      -.004427         5.42
Side block sliding           .185743   .084169         -.004133         5.40
Side block overturning       .185743   .084169         -.004133         5.40
Side block liftoff         -.030776    .141339          .003411         5.22


For Earthquake Acceleration of  90.00 % of the 1940 EL CENTRO

Maximums/Failures           X (ins)    Y (ins)         Theta (rads)  Time (sec)
-----------------          --------   --------        -------------  ----------
 Maximum X                 -.170186                                     5.59
 Maximum Y                            -.227695                          5.34
 Maximum Rotation                                      -.003984         5.42
Side block liftoff           .164073    .131310        -.003910         5.41


For Earthquake Acceleration of  80.00 % of the 1940 EL CENTRO

Maximums/Failures           X (ins)    Y (ins)         Theta (rads)  Time (sec)
-----------------          --------   --------        -------------  ----------
 Maximum X                 -.150553                                     5.59
 Maximum Y                            -.203158                          5.34
 Maximum Rotation                                      -.003528         5.42
Side block liftoff           .130779    .153106        -.003528         5.42


For Earthquake Acceleration of  70.00 % of the 1940 EL CENTRO

Maximums/Failures           X (ins)    Y (ins)         Theta (rads)  Time (sec)
-----------------          --------   --------        -------------  ----------
 Maximum X                 -.128083                                     5.59
 Maximum Y                            -.181906                          5.34
 Maximum Rotation                                      -.002984         5.42

No failures occurred.
```

```
For Earthquake Acceleration of  79.00 % of the 1940 EL CENTRO

Maximums/Failures        X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------       --------  --------       ------------- -----------
 Maximum X              -.148659                                  5.59
 Maximum Y                        -.200619                        5.34
 Maximum Rotation                                 -.003483        5.42
Side block liftoff        .129136   .151192       -.003483        5.42


For Earthquake Acceleration of  78.00 % of the 1940 EL CENTRO

Maximums/Failures        X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------       --------  --------       ------------- -----------
 Maximum X              -.146360                                  5.59   ←
 Maximum Y                        -.198222                        5.34
 Maximum Rotation                                 -.003433        5.42
Side block liftoff        .127544   .149438       -.003433        5.42


For Earthquake Acceleration of  77.00 % of the 1940 EL CENTRO

Maximums/Failures        X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------       --------  --------       ------------- -----------
 Maximum X              -.144471                                  5.59
 Maximum Y                        -.195681                        5.34
 Maximum Rotation                                 -.003389        5.42
Side block liftoff        .125900   .147522       -.003389        5.42


For Earthquake Acceleration of  76.00 % of the 1940 EL CENTRO

Maximums/Failures        X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------       --------  --------       ------------- -----------
 Maximum X              -.141425                                  5.59
 Maximum Y                        -.193812                        5.34
 Maximum Rotation                                 -.003332        5.42
Side block liftoff        .124888   .146568       -.003332        5.42


For Earthquake Acceleration of  75.00 % of the 1940 EL CENTRO

Maximums/Failures        X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------       --------  --------       ------------- -----------
 Maximum X              -.139552                                  5.59
 Maximum Y                        -.191262                        5.34
 Maximum Rotation                                 -.003288        5.42
Side block sliding        .123237   .144640       -.003288        5.42
Side block overturning    .123237   .144640       -.003288        5.42
Side block liftoff        .102642   .161626       -.003261        5.43
```

```
For Earthquake Acceleration of  74.00 % of the 1940 EL CENTRO

-----------------      --------  --------       ------------- -----------
 Maximum X              -.135798                                  5.59
 Maximum Y                        -.139456                        5.34
 Maximum Rotation                                -.003212         5.42
Side block sliding       .078937   .160034       -.003086         5.44
Side block overturning   .078937   .160034       -.003086         5.44
Side block liftoff       .101108   .160146       -.003186         5.43


For Earthquake Acceleration of  73.00 % of the 1940 EL CENTRO

Maximums/Failures       X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------      --------  --------       ------------- -----------
 Maximum X              -.134148                                  5.59
 Maximum Y                        -.137440                        5.34
 Maximum Rotation                                -.003136         5.42
Side block sliding       .097464   .157809       -.003107         5.43
Side block overturning   .097464   .157809       -.003107         5.43


For Earthquake Acceleration of  72.00 % of the 1940 EL CENTRO

Maximums/Failures       X (ins)   Y (ins)        Theta (rads)  Time (sec)
-----------------      --------  --------       ------------- -----------
 Maximum X              -.131683                                  5.59
 Maximum Y                        -.136486                        5.34
 Maximum Rotation                                -.003082         5.42

No failures occurred.
```

"3DOFRUB" Wale Shore (NORM DD2) Output File . . . .

```
                              **** System 51 ****

                                ** Hull 616 **


                             * Ship Parameters *

    Weight           Moment of Inertia         K.G.
  16369.9 kips    2410451.0 kips-in-sec2    193.0 ins


                           * Drydock Parameters *

Side Block Height    Side Block Width    Keel Block Height    Keel Block Width
   75.0 ins              999.0 ins             61.0 ins             999.0 ins

Side-to-Side Pier Distance    Wale Shore Ht.   Wale Shore Stiffness  Cap Angle
      144.0 ins                  193.0 ins          6000.0 kips/in   .377 rad

1Side Side Pier Contact Area   Total Keel Pier Contact Area      kkhp
            8352.0 in2                   55440.0 in2          18215.1 kips/in

B/B Friction Coeff   H/B Friction Coeff      kshp           kvsp
       9.000                 .750        4583.8 kips/in  7552.4 kips/in

Side Pier Fail Stress Limit    Keel Pier Fail Stress Limit      kvkp
           .700 kips/in2               .700 kips/in2       37857.8 kips/in

Side Pier Vertical Stiffness   Side Pier Horizontal Stiffne
     4554.2 kips/in                  4583.8 kips/in

Keel Pier Vertical Stiffness   Keel Pier Horizontal Stiffness
    25236.7 kips/in                 18215.1 kips/in

     OD1                    OD2                    OD3                   OD4
      .0 kips                .0 kips           -545.4 kips          -2734.1 kips


                       * System Parameters and Inputs *

Earthquake Used is 1 OCT 87 WHITTIER * 10.94

Horizontal acceleration input is LBNSY DD2 TRANSVERSE COMPONENT

Vertical acceleration input is LBNSY DD2 VERTICAL COMPONENT
                    Earthquake Acceleration Time History.

Vertical/Horizontal Ground Acceleration Ratio   Data Time Increment
          1.000                                            .010 sec

Gravitational Constant   % System Damping
      386.09 in/sec2            5.00 %

                         Mass Matrix

        42.3992                .0000           8183.0420
          .0000              42.3992               .0000
      8183.0420                .0000        2410451.0000

                        Damping Matrix

       112.6209                .0000          12864.9077
          .0000             120.7612               .0000
     12864.9077                .0000        3394384.8143
```

```
                    Stiffness Matri

    39382.6800              .0000         24[illegible].12[illegible]
        .0000          34395.1400              .0000
  2444346.1200              .0000         49[illegible]1[illegible].6111


Undamped Natural Frequencies      Mode #1         Mode #2         Mode #3
                              13.912 rad/sec  44.216 rad/s    28.4[illegible] rad/[illegible]
Damped Natural Frequencies        Mode #1         Mode #2         Mode #3
                              13.895 rad/sec  44.161 rad/s    28.446 rad/sec


For Earthquake Acceleration of 100.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)  Time (sec)
-----------------         --------   --------        ------------- -----------
 Maximum X                 .146279                                     4.21
 Maximum Y                            .141489                          4.44
 Maximum Rotation                                      .006770         7.85
Side block sliding        -.106816    .018661          .005081         8.37
Side block overturning    -.106816    .018661          .005081         8.37
Side block liftoff         .101835    .008066         -.005242         7.57
Side block crushing       -.126764    .018346          .006770         7.85


For Earthquake Acceleration of  90.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)  Time (sec)
-----------------         --------   --------        ------------- -----------
 Maximum X                 .132140                                     4.21
 Maximum Y                            .127431                          4.44
 Maximum Rotation                                      .006075         7.85
Side block sliding         .110379    .017975         -.005054         7.59
Side block overturning     .110379    .017975         -.005054         7.59
Side block liftoff         .109161    .021440         -.005097         7.60


For Earthquake Acceleration of  80.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)  Time (sec)
-----------------         --------   --------        --   --
 Maximum X                 .118111                                     4.21
 Maximum Y                            .113385                          4.44
 Maximum Rotation                                      .005349         7.85
Side block sliding        -.099814    .024784          .004983         7.82
Side block overturning    -.099814    .024784          .004983         7.82
Side block liftoff        -.102703    .023521          .005192         7.83

For Earthquake Acceleration of  70.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)  Time (sec)
-----------------         --------   --------        ------------- -----------
 Maximum X                 .103739                                     4.21
 Maximum Y                            .099230                          4.44

No failures occurred.
```

```
For Earthquake Acceleration of  79.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)   Time (sec)
-----------------         --------   --------       -------------   -----------
 Maximum X                 .116810                                      4.21
 Maximum Y                            .111976                           4.44
 Maximum Rotation                                      .005283          7.85
Side block sliding        -.099938    .007420          .005234          7.86
Side block overturning    -.099938    .007420          .005234          7.86
Side block liftoff        -.101425    .02[illegible]7          .0051[illegible]7          7.8[illegible]
```

```
For Earthquake Acceleration of  78.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)   Time (sec)
-----------------         --------   --------       -------------   -----------
 Maximum X                 .115422                                      4.21
 Maximum Y                            .110565                           4.44
 Maximum Rotation                                      .005216          7.85
Side block liftoff        -.100145    .022933          .005062          7.83
```

```
For Earthquake Acceleration of  77.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)   Time (sec)
-----------------         --------   --------       -------------   -----------
 Maximum X                 .114073                                      4.21
 Maximum Y                            .109152                           4.44
 Maximum Rotation                                      .005150          7.85
Side block sliding        -.098869    .022639          .004997          7.83
Side block overturning    -.098869    .022639          .004997          7.83
Side block liftoff        -.099086    .019273          .005115          7.84
```

```
For Earthquake Acceleration of  76.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)   Time (sec)
-----------------         --------   --------       -------------   -----------
 Maximum X                 .112592                                      4.21
 Maximum Y                            .107735                           4.44
 Maximum Rotation                                      .00508[illegible]          7.85
Side block sliding        -.097927    .019054          .005051          7.84
Side block overturning    -.097927    .019054          .005051          7.84
```

```
For Earthquake Acceleration of  75.00 % of the 1 OCT 87 WHITTIER * 10.94

Maximums/Failures          X (ins)    Y (ins)         Theta (rads)   Time (sec)
-----------------         --------   --------       -------------   -----------
 Maximum X                 .111111                                      4.21
 Maximum Y                            .106817                           4.44

  No failures occurred.
```

Wale Shore Design Spreadsheet

```
VERTICAL STIFFNESS CALCULATIONS FOR WALE SHORES

HULL TYPE  [illegible]   DOCKING PLAN # =   845-[illegible]

SYSTEM #        51          WALE SHORES         ORIGINAL DOCKING DRAWING
                                                RUBBER CAP E2
BLOCK SPA     8.00 FEET                         LENSY DD2
                                                27X14 WF 42.68
VERTICAL STIFFNESS:

-----------------------------------------------------------------------------------------------------
                                                                                    PIER
  LEVEL  MATERIAL     E      LENGTH     WIDTH      HEIGHT        K           I/K      TOTAL K
    #               (PSI)     (IN)      (IN)        (IN)     (KIPS/IN)              (KIPS/IN)

--------------------------------------------------------------------------------------------------------
                            (DEPTH) (TRANSVERSE)
                              (B)        (H)         (L)


    1     RUBBER      3571    29.00      17.00        1.00      1760.50     0.0005680    437.51
    2     RUBBER      3571    29.00      17.00        2.50       704.20     0.0014200
    3     STEEL   30000000    29.00      17.00        0.50   29580000.00    0.0000000
    4     STEEL   30000000     1.00      42.68      381.00      3360.63     0.0002976
                                                  385.00

                                                    #                                TOTAL STIFFNESS
                                             WALE SHORES            14               OF BLOCK SYSTEM
                PLATE AREA =            493.00    IN^2                               (KIPS/IN):

                WT PER FT =            145.00 LBS         SHORE WT (TNS)=        2.06    6125.13

                MAX I =             0.1316930 INS         E1 STIFFNESS =       134.15 KIPS/IN

                MAX THETA =         0.0070820 RADS        XEL FORCE=            48.91 KIPS =              21.83

                HT WS =                190.50 INS             XEL =              0.36 INS

                X PRIME =                0.57 INS          JACK DISPL =          0.57 INS

        QUAKE   FORCE =                249.38 KIPS        JACK FORCE =         138.79 KIPS =              61.96

        TOTAL   FORCE =                388.17 KIPS

        SHIP    STRESS =               787.36 PSI

          BEAM  STRESS =              9094.85 PSI

         SIGMA    YIELD =            33000.00 PSI         MILD STEEL

                      =                227.53 MPa

                  RHO =                  3.09 INS

                  Le =                 381.00 INS         SIMPLY SUPPORTED POPOV P 557,531

                Le/RHO =               123.30

         SIGMA  ULT =                   93.00 MPa         FIG 11.13 SHIP STRUCTURAL DESIGN P 338

                      =              13488.51 PSI
```

Thesis
L89135 Luchs
c.1 Earthquake resistant
submarine drydock block
system design.