"DYNAMIC ANALYSIS OF A POSTULATED MAIN OR FEEDWATER LINE PIPE BREAK OUTSIDE CONTAINMENT"

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CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.

Indian Point Station, Unit No. 2

Docket No. 50-247

~~MAY~~ June 8, 1973

3835

Dynamic Analysis of a Postulated Main Steam or Feed Line Pipe Break Outside Containment.

In accordance with the requirements of the Regulatory Staff at a meeting held on April 12, 1973, Con Edison of New York, Inc. has undertaken to complete the following analysis:

1. Dynamic analyses of a typical (worst) case break in a main steam or feedwater line to determine the response of the restraints and the margin of conservatism in the original static analysis.
2. Analysis of the impact of a main feed line on the slab at Elevation 32'6" in the shield wall area as a result of a postulated guillotine break in one of these lines. This analysis should consider the potential for penetration (using modified Petrie formula) as well as gross structural response.
3. Analysis of the pressure/temperature history of the room at Elevation 32'6" as a result of a feed line break considering blowdown of the section of pipe from the break to the feed regulator valve in addition to steady-state flow through the regulator valve.
4. An analysis to account for the effects of potential spurious operation of the control panels for the power-operated relief valves as a result of a high temperature environment in the shield wall area at EL 43'0".

This report sets forth the results of the requested analyses. Discussion is by item number as above.

Item 1: Dynamic Analysis of Main Steam Line Break

A. Break Selection

Break locations identified in Part 1 of the report entitled "Analysis of High Energy Lines" Dated April 9, 1973 were reviewed in the field to select a failure which would either be the worst case or, alternatively, most clearly show the response of the restraint system. Of the postulated failures that could affect the seismic Class I steel or piping the break main steam line 24, at the inlet to the first elbow outside containment, was selected.

Thrust load is a direct functionof steam generator pressure. Though 100% power would be the most likely power level at the time of failure, the hot standby condition could be more severe due to the higher steam generator pressure. Accordingly, an initial steam generator pressure of 1020 psia was assumed; this pressure corresponds to hot standby reactor coolant temperature of 547°F.

The postulated failure could result in limited separation of the pipe due to the restraints. The blowdown thrust from the steam generator could be directed toward the penetration while the elbow and whip restraints could be loaded due to blowdown of the piping downstream of the penetration. The jet impinement load could be partially directed axial to the piping and partially in a 360° fan. Thrust load due to steam generator blowdown could continue at the same rate until the steam generator is dry, but the load due to blowdown of the downstream piping could end rather quickly due to closure of the main steam check valves. To provide further conservatism in the analysis, we have elected to apply the thrust load due to full sustained blowdown of the steam generator, directly to the elbow and thus to the restraints. The whip restraints are therefore loaded more severely than could be the case in an actual pipe failure.

B. Forcing Function

The blowdown forcing function was determined by use of the Steam computer code applied to the piping layout which is shown in simplified form as figure 1. Figures 2 and 3 show the force and line pressure at the break for time 0 to 0.5 seconds respectively.

Pressure are given in psia while the force is normalized to P_oA or approximately 549 kips for a steam generator pressure of 1020 psia. The initial depressurization is followed by a surge to 373 kips as full flow develops. At approximately 0.17 seconds the force begins to decrease due to the effect of the venturi with a temporary leveling off at ca 275 kips at 0.4 seconds. At 2 seconds after the break, water carryover begins with a decrease in steam quality from 100% to 20%. The effect on the forcing function at the break is shown in figure 4. The peak force due to water carryover is 329 kips compared with 373 kips during the early part of the transient. The conclusion is that entrainment, when it occurs, has no significant effect on the forcing function.

C. Analytical Procedure

Protection against pipe whip effects requires the consideration of the thrust resulting from the postulated break acting on the pipe, the pipe whip restraints, and the supporting structure. The piping system responds to the break by moving in the direction of the applied blowdown force. After the formation of a plastic hinge mechanism, the pipe accelerates through the gap between the pipe and the restraint which increases the energy to be absorbed by the restraint.

A dynamic time history analysis was performed to evaluate the dynamic response of the piping and associated structural components. The dynamic response to the applied forcing function at the break was determined using a computational algorithm which has the ability to model in time the effects of gaps and the nonlinear behavior of the piping and the support structures into the plastic range. The MARC-CDC computer program was used to evaluate the piping/restraint system. MARC-CDC is a general purpose finite element program designed for the non-linear analysis of structural components using the large displacement theory. The elastic-plastic and large displacement analysis is effected in a series of piecewise linear increments.

The dynamic behavior in MARC-CDC is defined by dynamic equations which include the acceleration terms. These terms are obtained by means of D'Alembert's principle and the dfinition of equivalent forces by the principle of virtual work. This operation results in the formulation of a consitent mass matrix. The dynamic equations are solved by a step-by step numerical integration.

A total of five different elements were used to characterized the stiffness and mass characteristics of the piping/support system. The triangular plate element was used only in the main feedwater line problem to model the properities of the floor slab.

The pipe element was used to represent the stiffness and mass properties of the piping. This element consists of a straight beam of arbitrary cross-section with two nodes, one at each end of the beam. The position of the beam is defined at each end point by the three coordinates x,y, z axes of the global cartesian coordinate system. Each node is allowed six degress-of-freedom, the displacements u,v, w along the x, y, z axes and three rotations θ_x, θ_y, θ_z, about the x, y, z axes. the element has resistance in both bending (about any axis in the plane normal to the axis in the plane normal to the axis of the beam) and transverse shear.

The input data define the position of the beam, the geometry of the cross-section, poissons ratio, mass density, and the constitutive relation; i.e. elastic-perfectly plastic, or work hardening (isotropic or kinematic). The output data consists of nodal displacements, velocities, accelerations, and stresses in the element, The total equivalent, J_2 stress which is used in determining the plastic behavior of the element is also printed.

The stress output is given at the centroid of sixteen subsections (Figure 5) in the cross-section of the element. This feature allows the user to monitor the spread of plasticity through the various cross-sections of the piping/support system.

Beam elements were used to model the piping restraint system. The WF structural shapes were represented using I-beam elements (Figure 5) which also contain sixteen subsections. The characteristics of the I-beam element are exactly the same as those described for the pipe element, except that the cross-sectional geometry is that of an I-beam.

The truss element is a simple straight truss with a constant cross-section. The position of the truss is defined by the three coordinates x, y, z (global cartesian coordinate system) at each node. Each node is allowed three degrees-of-freedom, the displacements u, v, w along the local x, y, z axis. The truss resists either axial compression or tension. The input data is the same as for the pipe element. The computer program output consists of nodal displacements, velocities, accelerations and axial stresses.

The gap element is identical to the truss element except that the constitutive relation is defined (Figure 5) so that the element models the behavior of a gap. The simplest way to describe the constitutive relation for the gap element is to represent the clearance between the pipe and the restraint as perfectly plastic, and upon contact, to account for the elastic deformation of the pipe by a linear elastic relationship.

D. Mathematical Model

Bounds of the model as shown in Figure 6 extended from the circumferential break location just outside of the containment to a location approximately 52 feet past the second valve. Because of the existence of four pipe whip restraints along the pipe and the as installed, are adequate. Results are summarized below:

a) Pipe

Yield hinge located in the vicinity of node 12

Maximum strain level (in/in) = 0.045

Percent of ultimate strain = 25%
(E_u = 0.18 in/in)

b) Restraint

Equivalent static design load = 340 kips
(design stress at or below yield)

Maximum dynamic load applied at node 13 (t = 0.0155 sec.) = 429 kips

Maximum strain level (in/in) = remains elastic

Percent of ultimate strain = less than 1%
(E_u = 0.18 in/in)

Item 2: Impact of a Main Feed Line on the Slab at Elevation 32'6"

A. Initial Results:

The evaluation of the effects of a guillotine break of a main feedwater line and subsequent impact of the floor slab included consideration of local penetration and gross structural loading of the slab. These initial results showed that gross structural response was satisfied and that no penetration occurred. However, it was our opinion that significant spalling might occur under these conditions. To preclude this, a three-foot length of 16WF71 beam was installed in Unit No. 2 beneath each of the feed lines.

Similar modifications are being made for Unit No. 3. All further discussions for this item consider these beams in place.

B. Break Selection:

The failure selected was a circumferential break at the outlet of the upturning elbow to main feed line 21 just above the slab at Elevation 32'6". This is shown schematically in Figure 12. Selection of line 21 was made on the basis of the highest bending load that could be placed on the slab due to a failure in this area of one of the feed lines.

C. Forcing Function:

The forcing function used in the analysis is shown as a solid line in Figure 13. The actual forcing function expected to physically occur at the failure is shown as a dashed line. Due to the near proximity of the break to both the elbow - at which the load is applied - and the downstream check valve, the duration of the depressurization effect is very short, less than 5 milli-

The forcing function used in the program and given earlier in Figures 2 and 3 was characterized as shown in Figure 9 for use in the code.

The blowdown force was applied at node 1 (Figure 7). The theoretical basis describing the development of this forcing function was given in an earlier section of this report.

E. Results

Figures 9, 10 and 11 summarize the significant results. The displacement time-history of the main steam line piping for several time increments is indicated in Figure 9. The application of the blowdown force develops a plastic hinge in the vicinity of the second pipe whip restraint. The gap between the bumper and column (first restraint) is initially closed and the resulting force-time history in the column is given by Figure 10. The force-time history for the second pipe ship restraint upon closure of the clearance at this location is indicated in Figure 11.

F. Conclusions

Design criteria were discussed and set forth in the report entitled "Analysis of High Energy Lines" dated April 9, 1973, submitted earlier and need not be repeated. Essentially though, the design was based on loads statically applied at the most disadvantageous locations with the resulting stresses limited well below those levels allowed for more rigorous analysis techniques. For a coupled nonlinear dynamic analysis of the pipe-restraint system - which explicitly takes into account the elastic-plastic deformation of the pipe-restraint system and the impact effects due to the clearance between the restraint and pipe - the maximum allowable strain in the pipe and the restraint is limited to 50 percent of their ultimate values.

The results of such an analysis performed for which is effectively a random break location shows that the equivalent static analysis originally performed was in fact very conservative and the restraints long run of pipe past the second valve, the terminal boundary was considered fixed.

The main steam line piping was modeled using the pipe elements. The masses of the isolation and relief valves were accounted in the pipe elements by increasing appropriately the density of the elements which contained these discrete masses.

The first two pipe whip restraints were modeled in great detail. The first restraint was a column and was represented by a truss element extending between nodes 3-4 (Figure 7). The clearance between the bumper attached to the pipe and this column is 0.697 inches in the hot position. This clearance was modeled by a gap element nodes 2-3 (Figure 7).

The second pipe whip restraint which consists of a configuration of WF beams (Section A-A Figure 6) was modeled using the beam elements. A comparison of Section A-A in Figure 6 with the equivalent mathematical model representation in Figure 7 indicates the accurate representation of this restraint. The clearance between the pipe and the restraint is accounted for by gap elements nodes 12-13 and 12-18 (Figure 7). The application of the blowdown forces is in the direction to close the clearance between nodes 12 and 13.

It was anticipated that the load resulting from the blowdown force and subsequent impact would be completely carried by the first two pipe whip restraints. As a result, the structural members of the third and fourth restraints were not included in the model. However, the clearances between the pipe and the restraint at these two locations were modeled using gap elements. The results of the analysis indicate that the clearance at the third restraint (nodes 28-29 and 28-30) and at the fourth restraint (nodes 34-35 and 34-36) did not close completely during the dynamic event and that this characterization was valid.

seconds and the system does not have time to respond. Consequently, the analysis can be justifiably simplified and the single step function shown the solid line was used.

D. Analytical Procedure:

The analytical procedure is the same as used for the main steam line break with the addition of a triangular plate element which was used to model the floor slab at Elevation 32'6". This element possesses nine degress of freedom.

E. Mathematical Model

A nonlinear dynamic analysis of main feedwater line 21 was performed to establish the design margins. The postulated circumferential break location is indicated in the schematic representation of the line and concrete floor slab (Fig. 12).

The feedwater piping was modeled using pipe elements. The 3-inch clearance between the pipe and the 16WF71 beam was represented by a gap element nodes 22-23 (Fig. 14). The 16WF71 encompasses nodes 23, 24 and 25. The pipe support is a truss element connecting nodes 16 and 27. The floor slab was modeled using triangular plate elements. The number of plate elements in the vicinity of the impact area was increased to account for the localized nature of the impact loading. Triangular boundary nodes 30, 37, and 49 are fixed, while nodes 25, 46, ane 48 are simply supported.

The blowdown force resulting from the circumferential break was applied at node 1. The forcing function used in the analysis is given in Figure 13.

F. Results:

Figures 15 and 16 summarize the significant results of the analysis. The displacement time-history of the feedwater line for several time increments is given in Fig. 15. The force-time history of the floor slab at the point of impact is presented in Figure 16.

G. Conclusions:

A summary of the results of this analysis considering the beams in place is given below.

a) Pipe

Yield hinge located in the vicinity of node 16.

Maximum strain level (in/in) = 0.001.

Percent of ultimate strain = 0.6%.
(ε_u = 0.18 in/in)

b) Floor Slab

Maximum dynamic load applied at impact location (t - 0.0225 sec.) = 562 kips

Maximum displacement of slab at node 26 = 0.13 inches

Rebar stress at yield = 60.0 ksi

Maximum calculated rebar stress = 47.7 ksi

Allowable concrete shear in slab = 186 psi

Maximum calculated concrete shear in slab = 167 psi

Item 3: Pressure/Temperature History of Room at El 32'6"

In order to determine the maximum pressure in the room at El 32'6" considering blowdown of the section of pipe from the break to the feedwater regulator, an absolute upper limit was established by assuming that the entire contents of the pipe between the regulating valve, FCV-417, and the check valve, BFD-6, discharged into the room in the time required for the pressure drop vave to travel from the break location to the regulating valve. This is quite conservative.

There are 935 gallons of water in the length of pipe and 0.018 seconds are required for the pressure drop wave to travel back to the regulating valve. The rate of discharge is therefore 52,000 gpm (6100 #/sec.) of which 1410 #/sec. is flashed steam and 4690 #/sec. is water at 212°F. This flow rate occurs for .018 seconds and then decreases to the 17,000 gpm limit imposed by the feed regulator valve.

Using a formula for steam flow when back pressure exceeds critical pressure and the same vent area as previously used, we calculate the maximum pressure in the room to be 1.6 psig.

The pressure load combined with the break load on the floor slab has been compared with the strength of the slab; rebar stress within the slab is less than yield, punching shear in the slab is less than allowable.

Item 4: Failure of Control Panels for Atmospheric Dump Valves

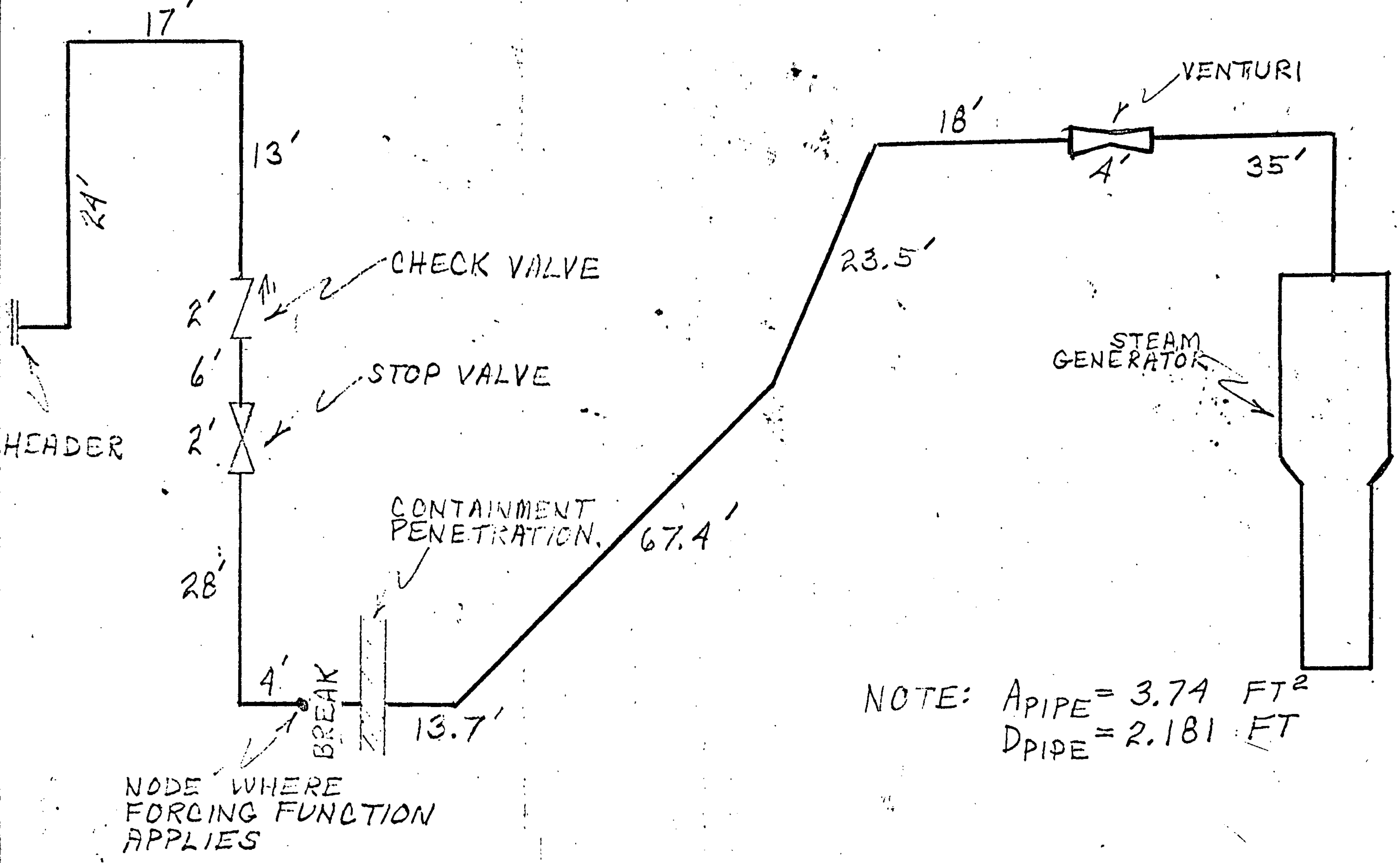
As temperature exceeds 150°F, the I/P transducer is expected to decrease in accuracy with eventual failure of the coil at high temperatures. Failure of this coildwill result in a low milliamp signal and the atmospheric dump valves will either remain closed or close if open.

If the cause of high temperature were failure of a main steam line, operation of the atmospheric dump valves would not be required for some time after blowdown of the affected steam generator. Following blowdown, the area would gradually become accessible to personnel at which time the atmospheric dump valves could be operated either manually or by local control using air or the standby N_2 supply.

Prior to the area becoming accessible, decay heat removal will be accomplished by periodic lifting of the main steam relief valves with steam generator level maintained using the auxiliary feed system.

FIGURE 1

PIPING LAYOUT MODEL FOR IPP STEAM BREAK



NOTE: $A_{PIPE} = 3.74 \ FT^2$
$D_{PIPE} = 2.181 \ FT$

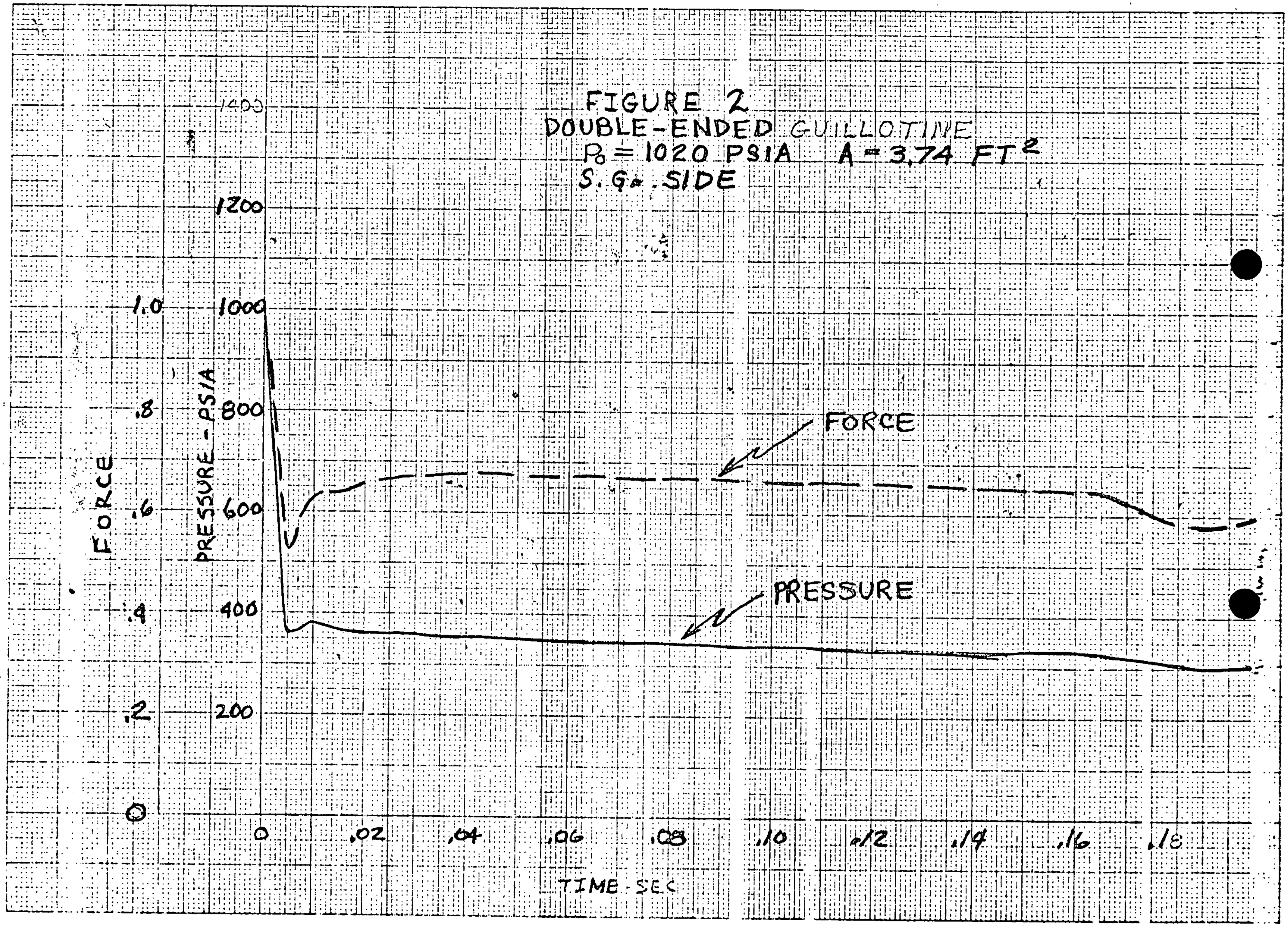


FIGURE 2
DOUBLE-ENDED GUILLOTINE
P_0 = 1020 PSIA A = 3.74 FT^2
S.G. SIDE

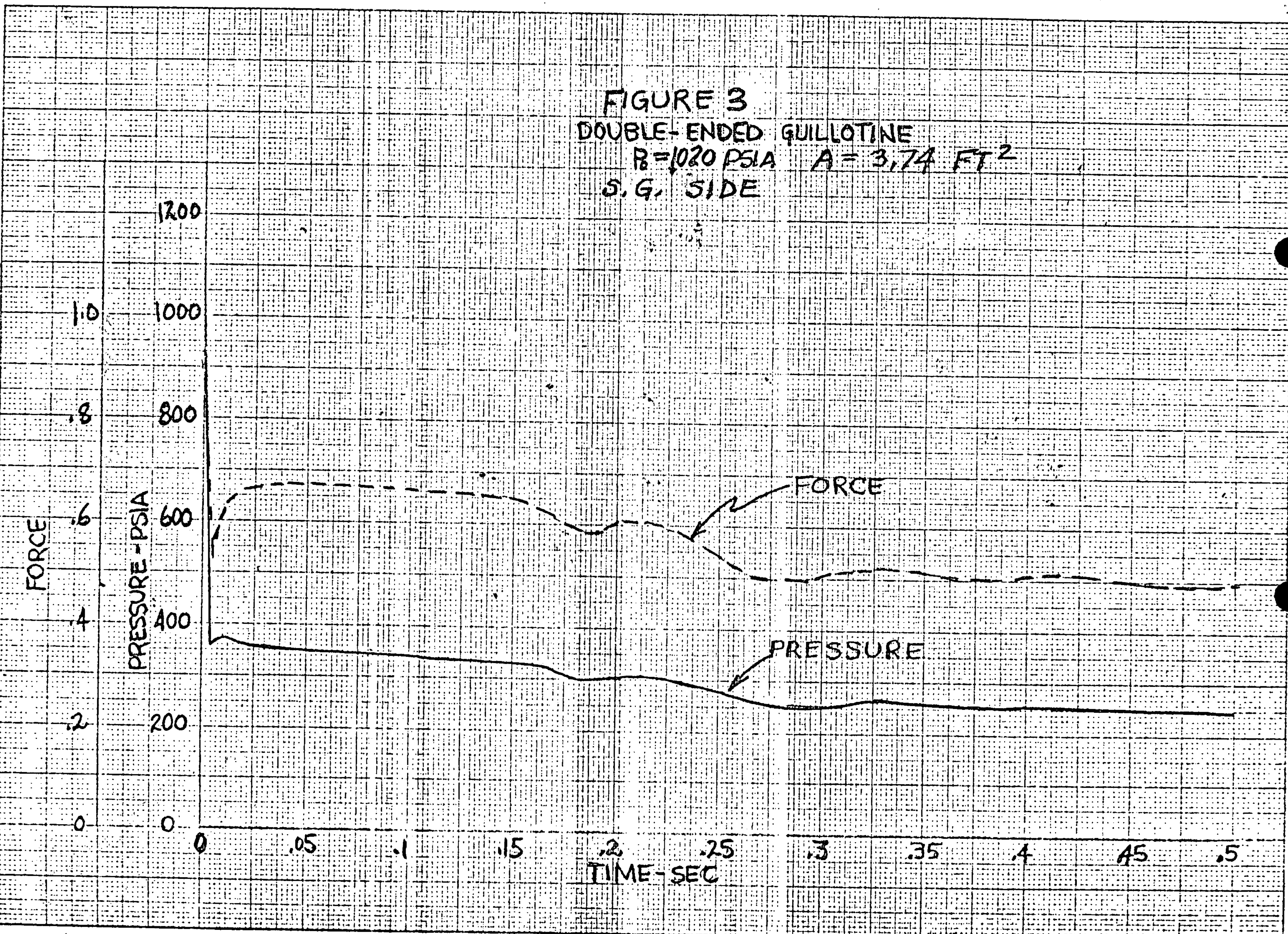


FIGURE 3
DOUBLE-ENDED GUILLOTINE
P_0 = 1020 PSIA A = 3.74 FT^2
S.G. SIDE

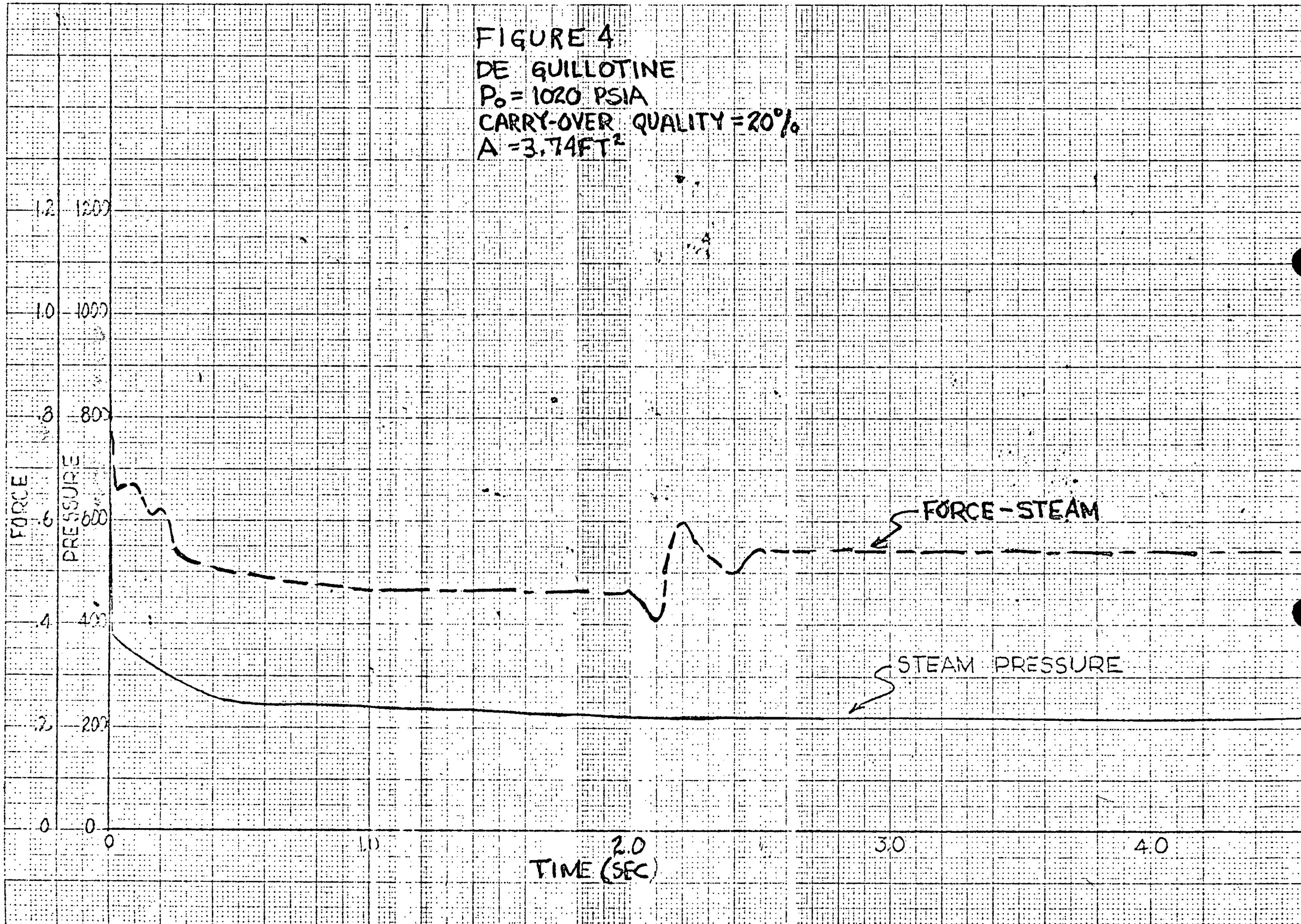


FIGURE 4
DE GUILLOTINE
P₀ = 1020 PSIA
CARRY-OVER QUALITY = 20%
A = 3.74 FT²
FORCE
PRESSURE
1.2
1200
1.0
1000
.8
800
.6
600
.4
400
.2
200
0
0
FORCE-STEAM
STEAM PRESSURE
0
1.0
2.0
3.0
4.0
TIME (SEC)

STRESSES CALCULATED AT CENTROID OF EACH SUBSECTION

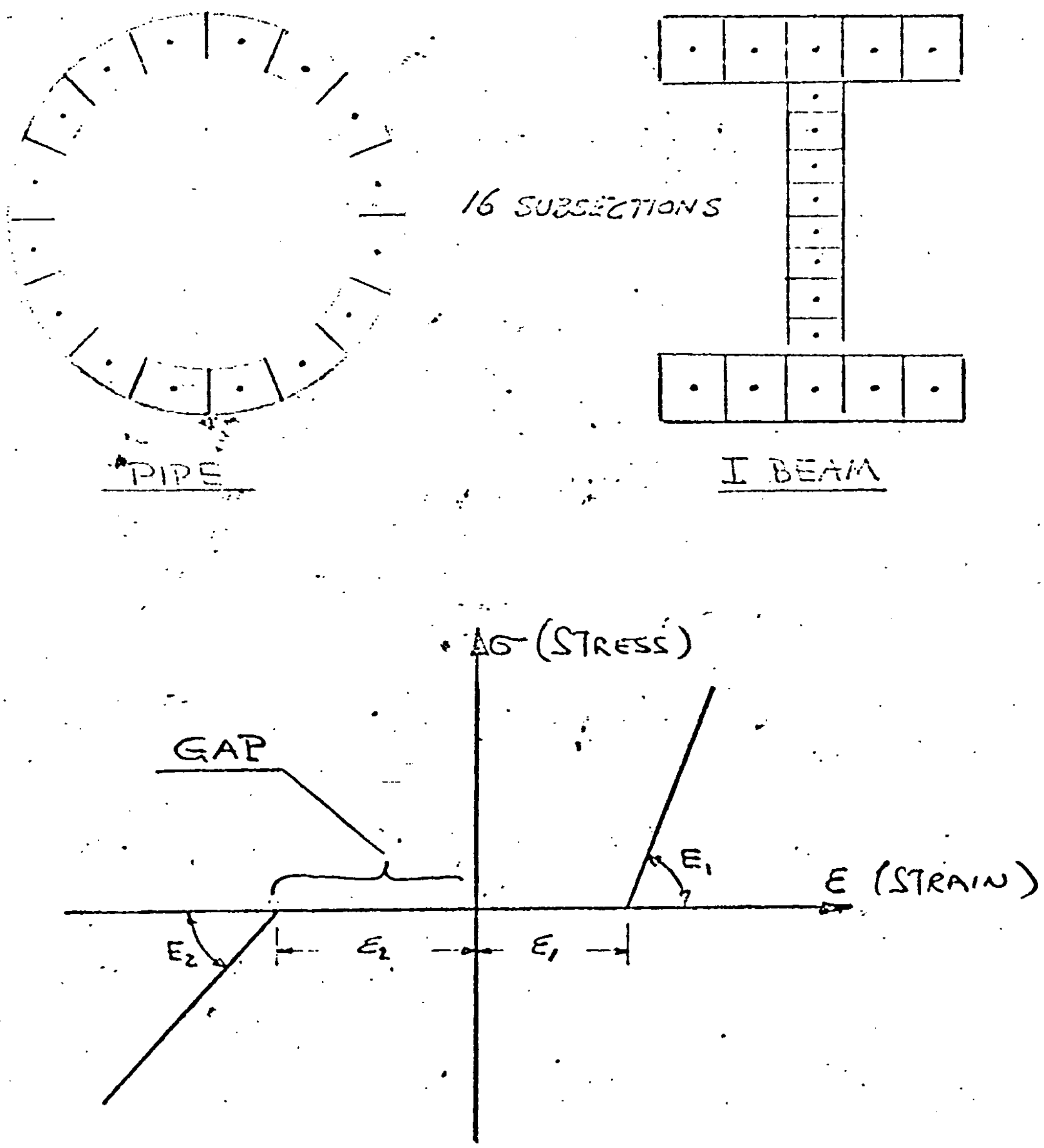


FIG. 5. PIPE / SUPPORT - SYSTEM FINITE ELEMENT REPRESENTATION

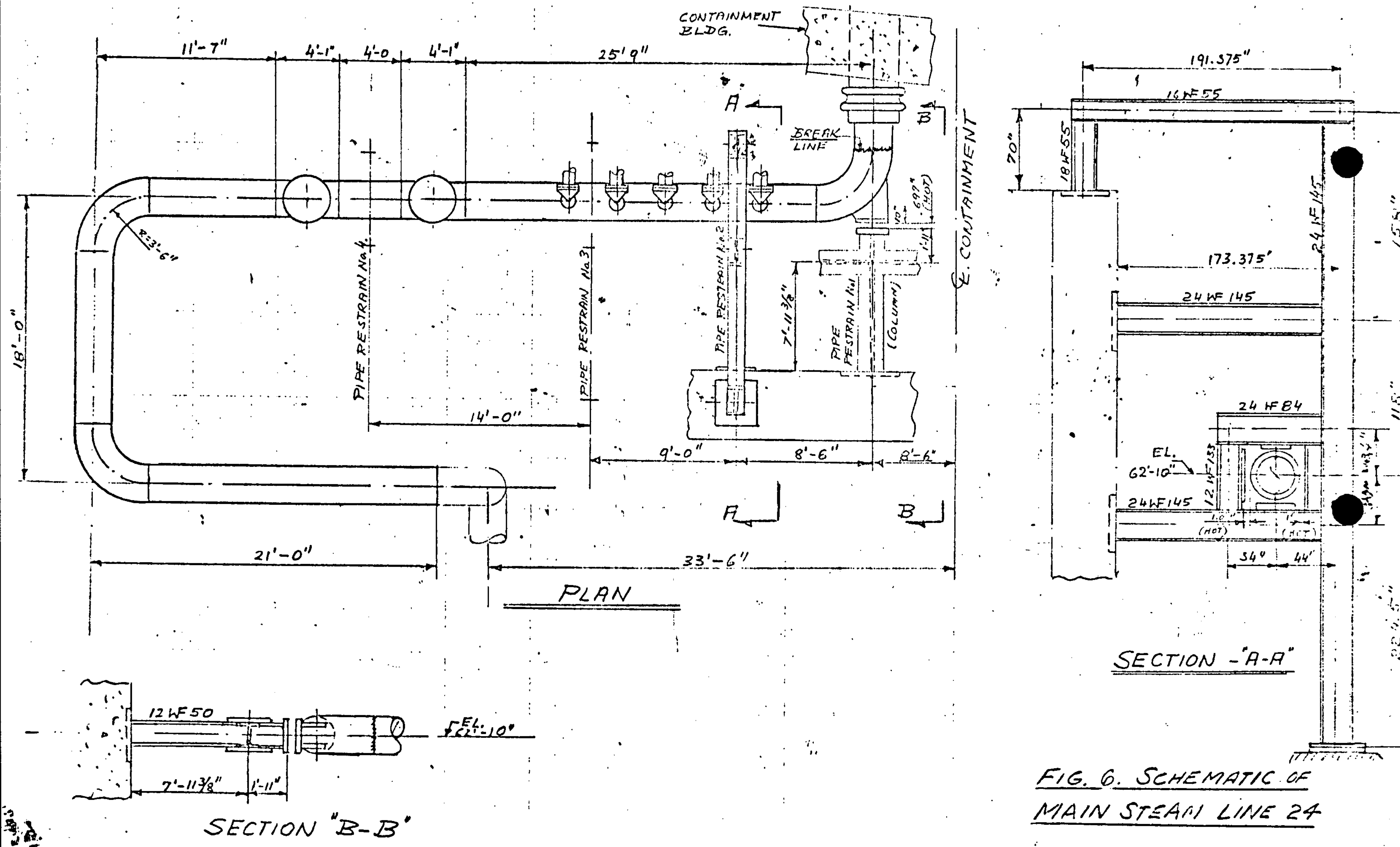


FIG. 6. SCHEMATIC OF MAIN STEAM LINE 24

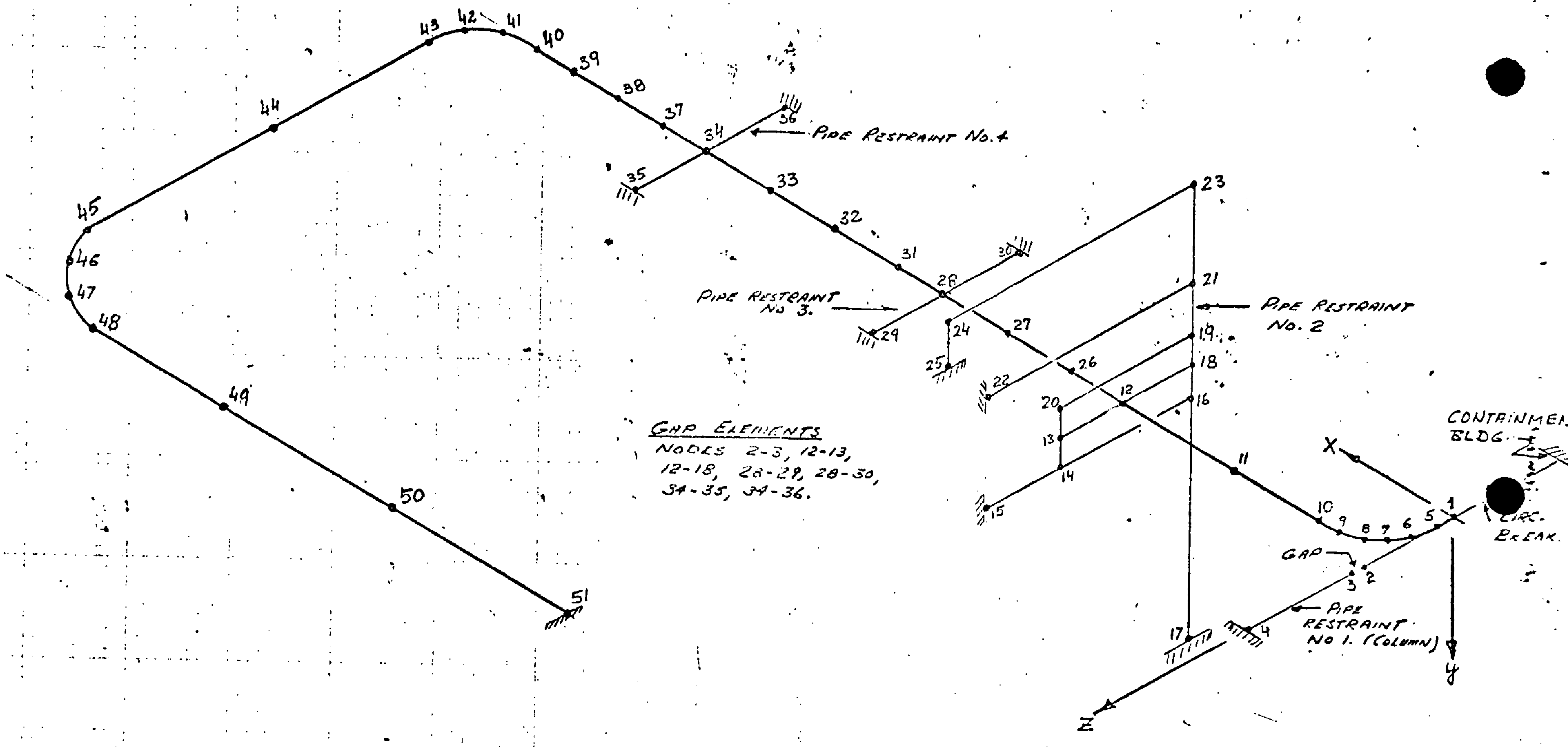


FIG. 7. MATHEMATICAL MODEL OF MAIN STEAM LINE 24

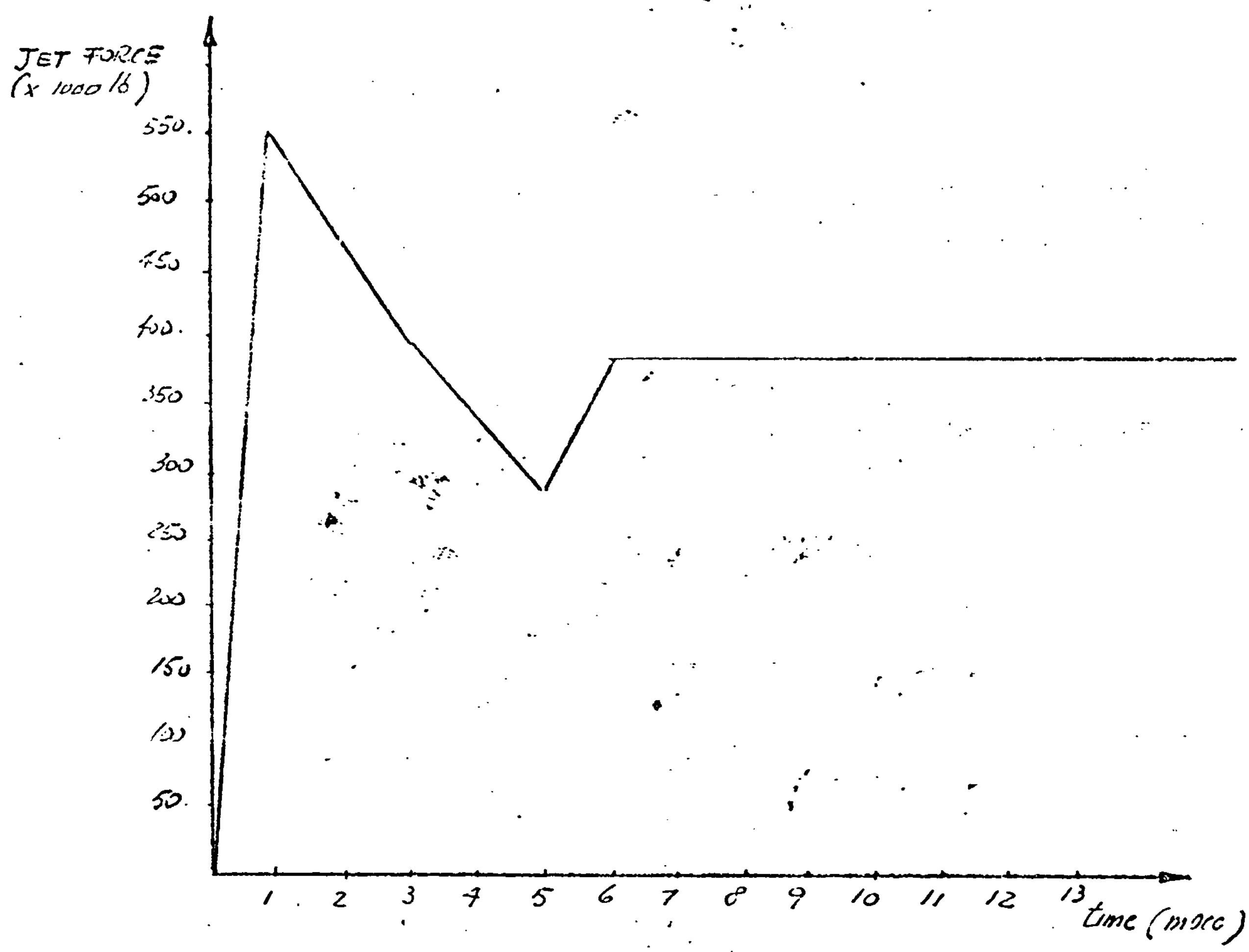


FIG 8. MAIN STEAM LINE CIRCUMFERENTIAL BREAK FORCING FUNCTION USED IN COMPUTER PROGRAM

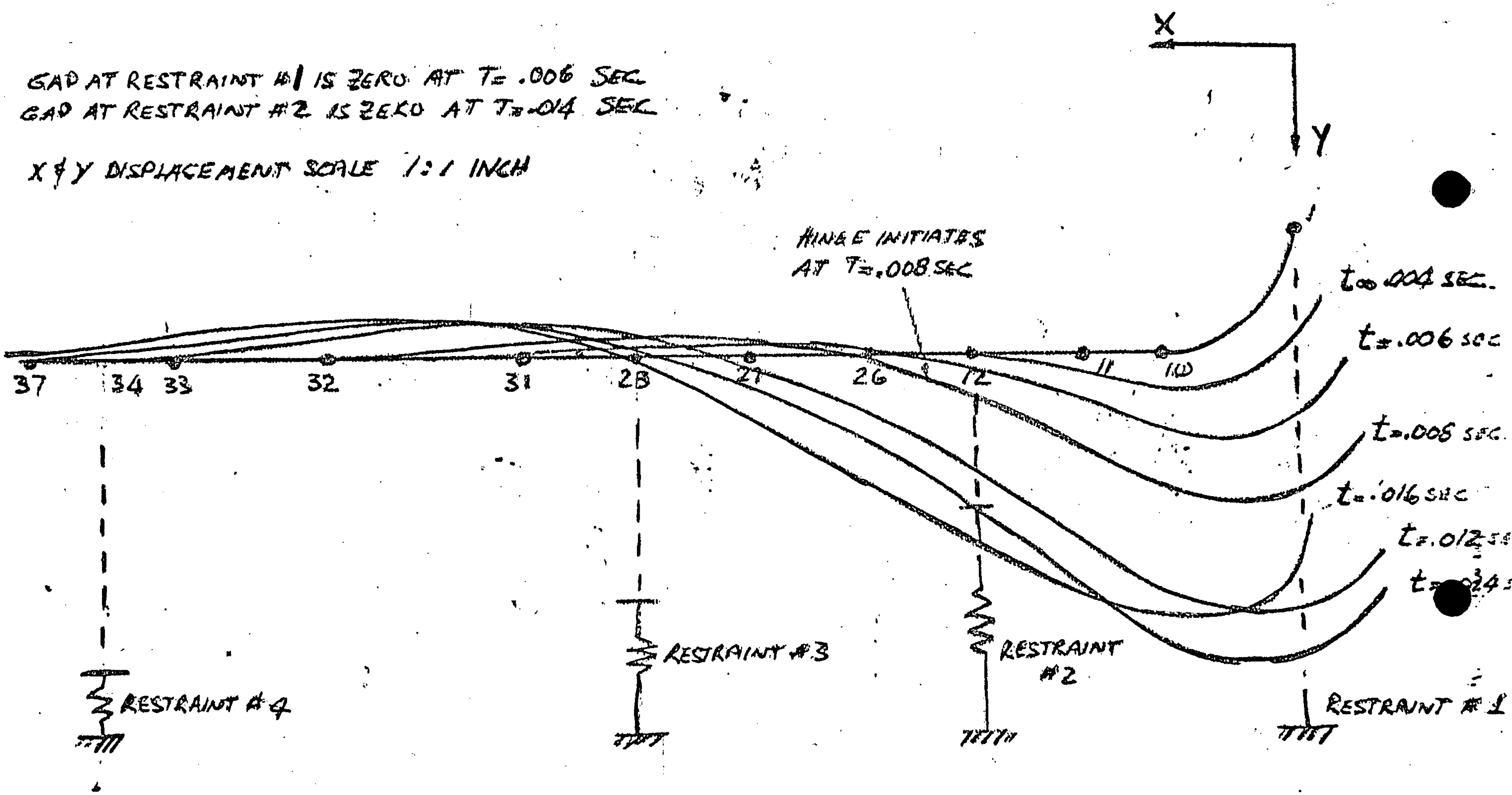


FIG. 9: DISPLACEMENT TIME-HISTORY OF MAIN STEAM LINE

T/C #3522

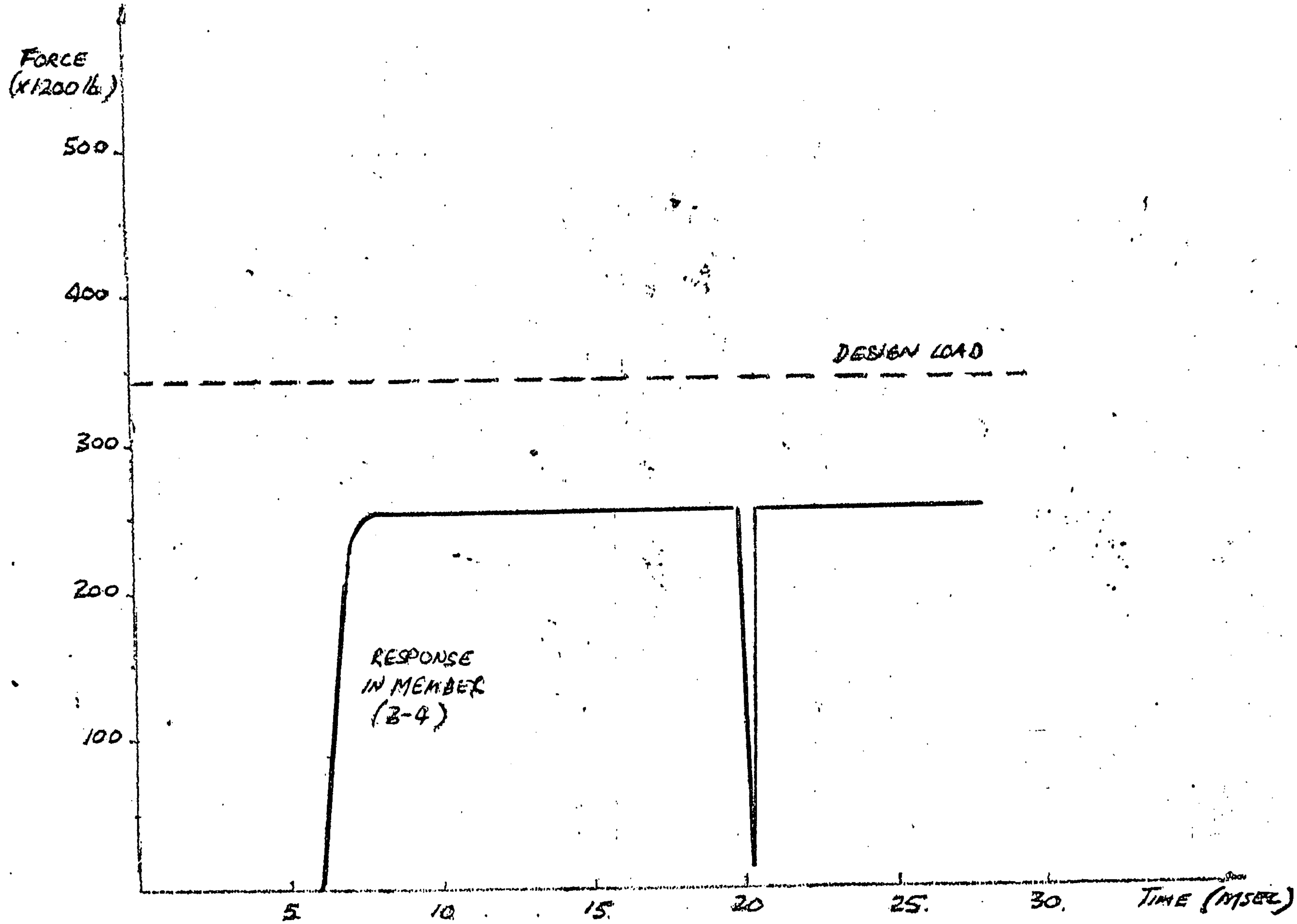


FIG.10. FORCE TIME-HISTORY OF PIPE RESTRAINT No. 1 (COLUMN)

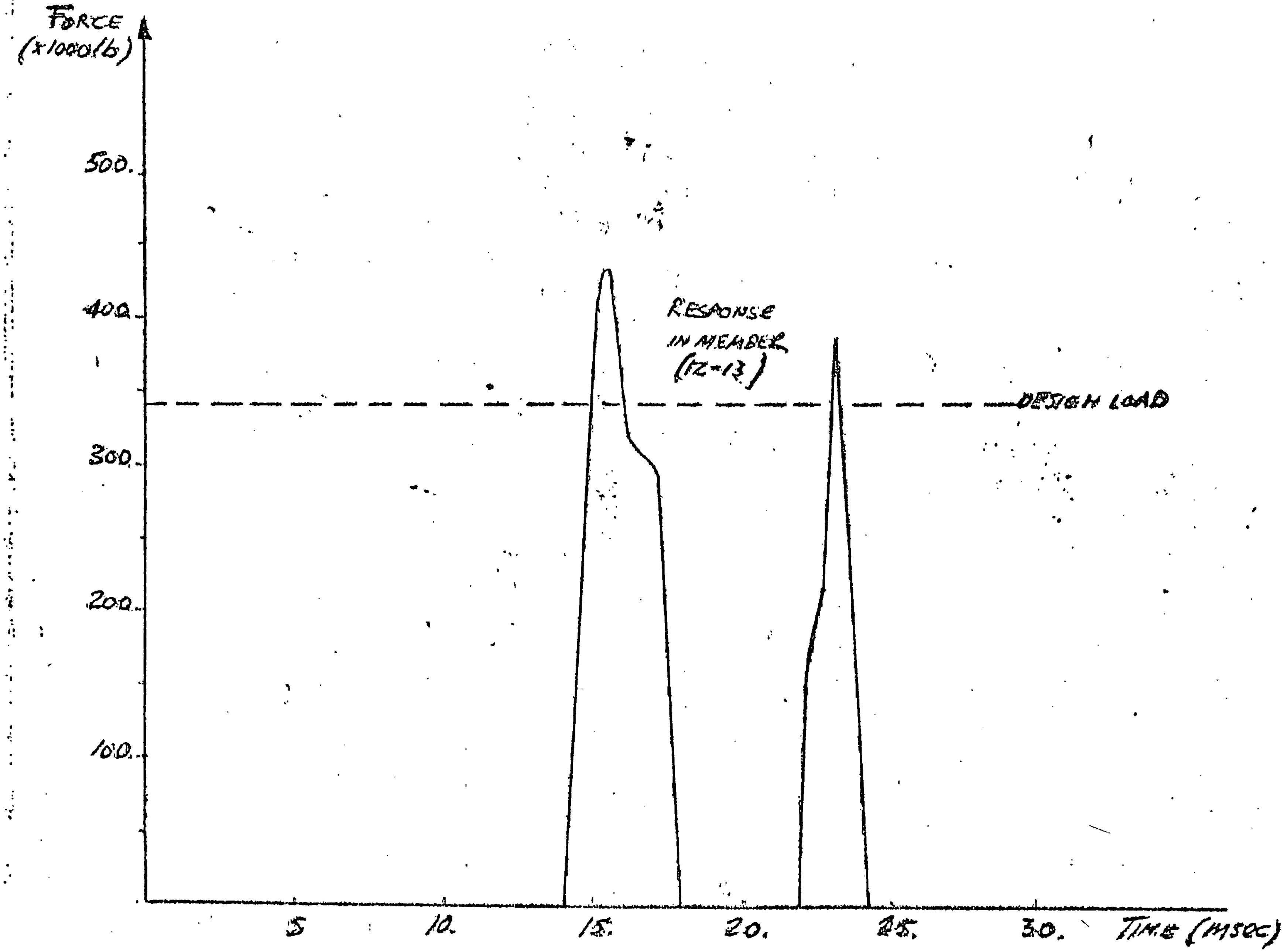


FIG. 21 FORCE TIME-HISTORY OF RPE RESTRAINT NO. 2

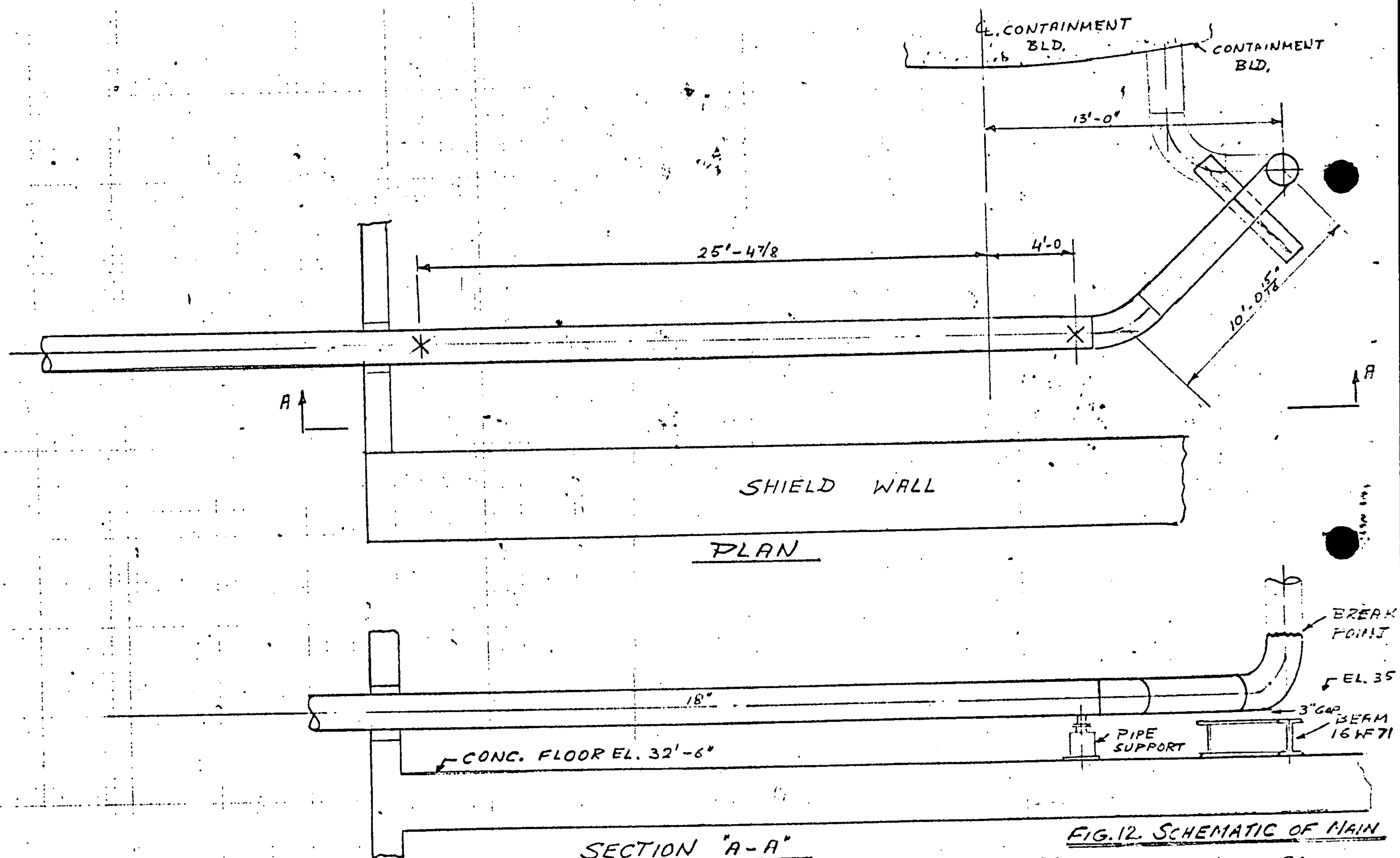


FIG. 12. SCHEMATIC OF MAIN FEEDWATER LINE 21

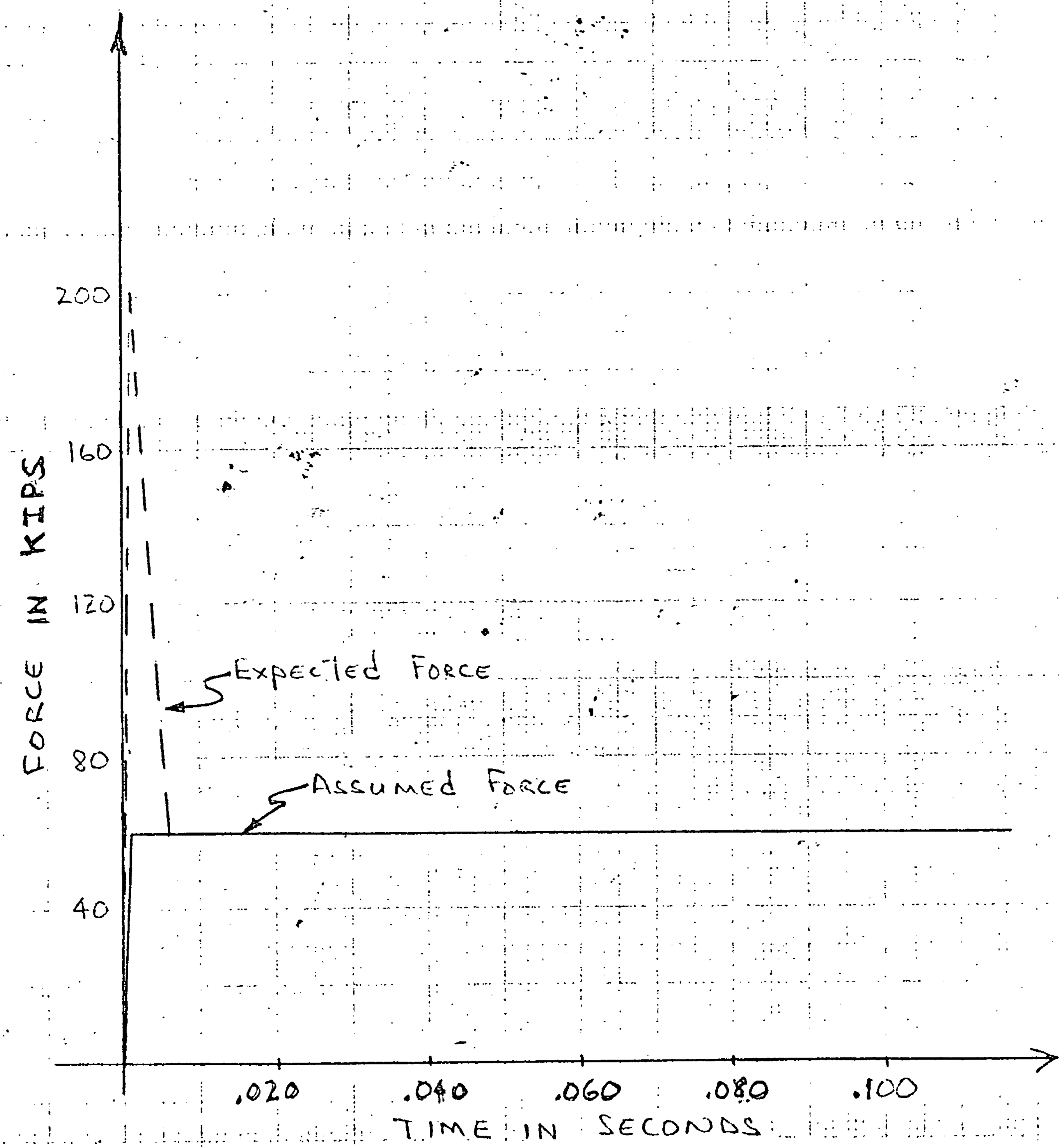


FIG. 13: MAIN FEEDWATER LINE CIRCUMFERENTIAL BREAK FORCING FUNCTION.

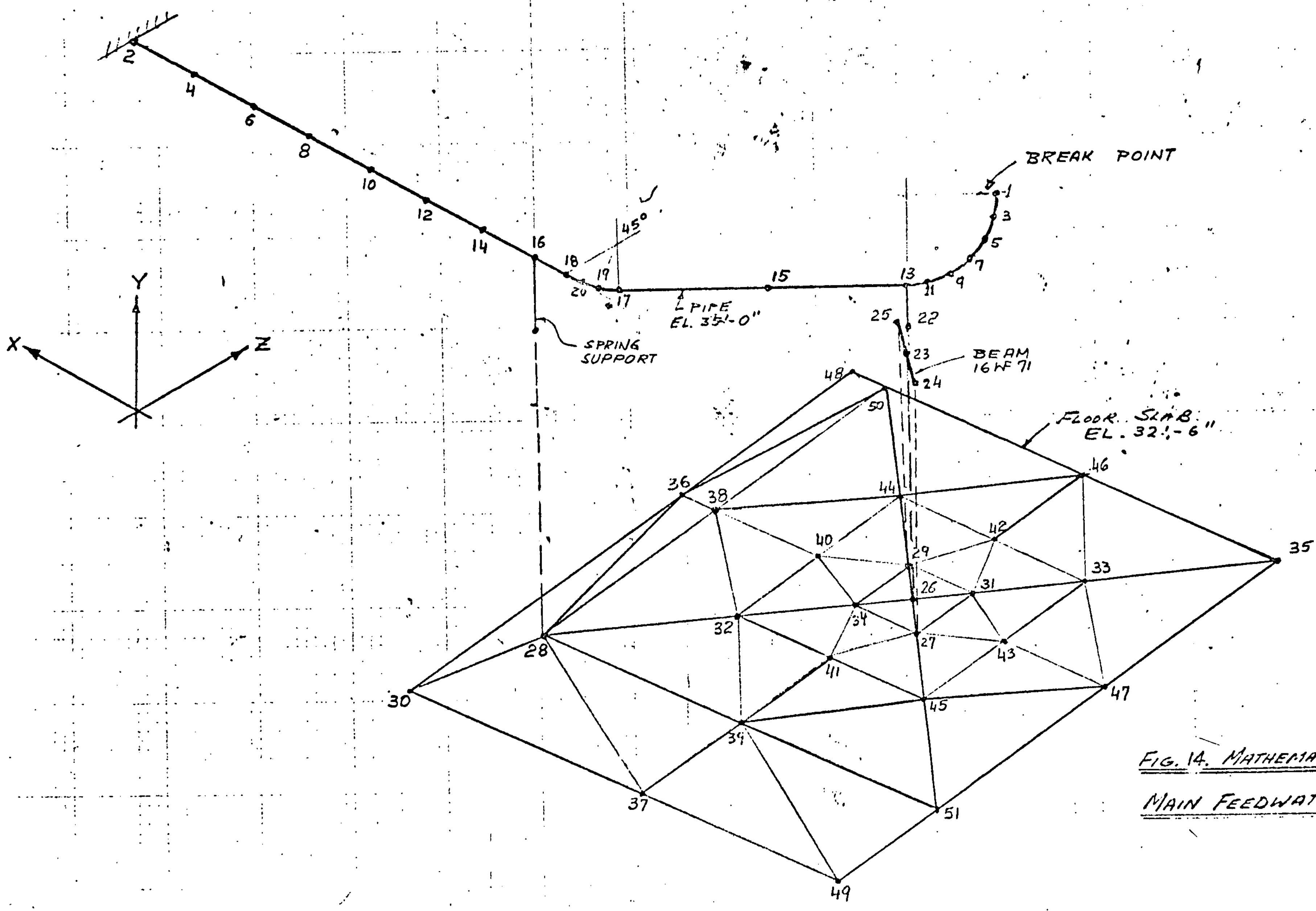


Fig. 14. Mathematical Model of Main Feedwater Line 21

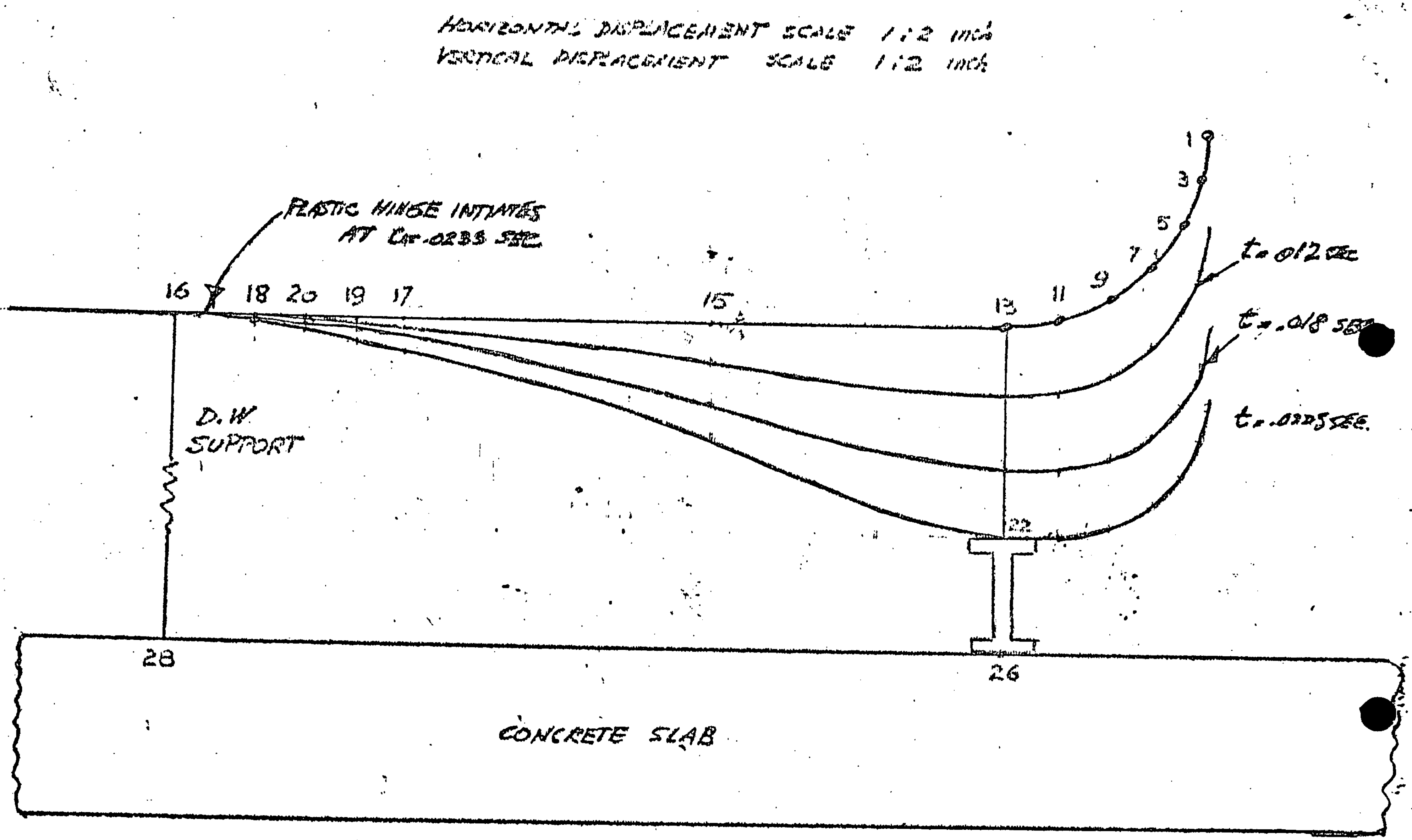


FIG. 15 DISPLACEMENT TIME-HISTORY OF MAIN FEEDWATER LINE

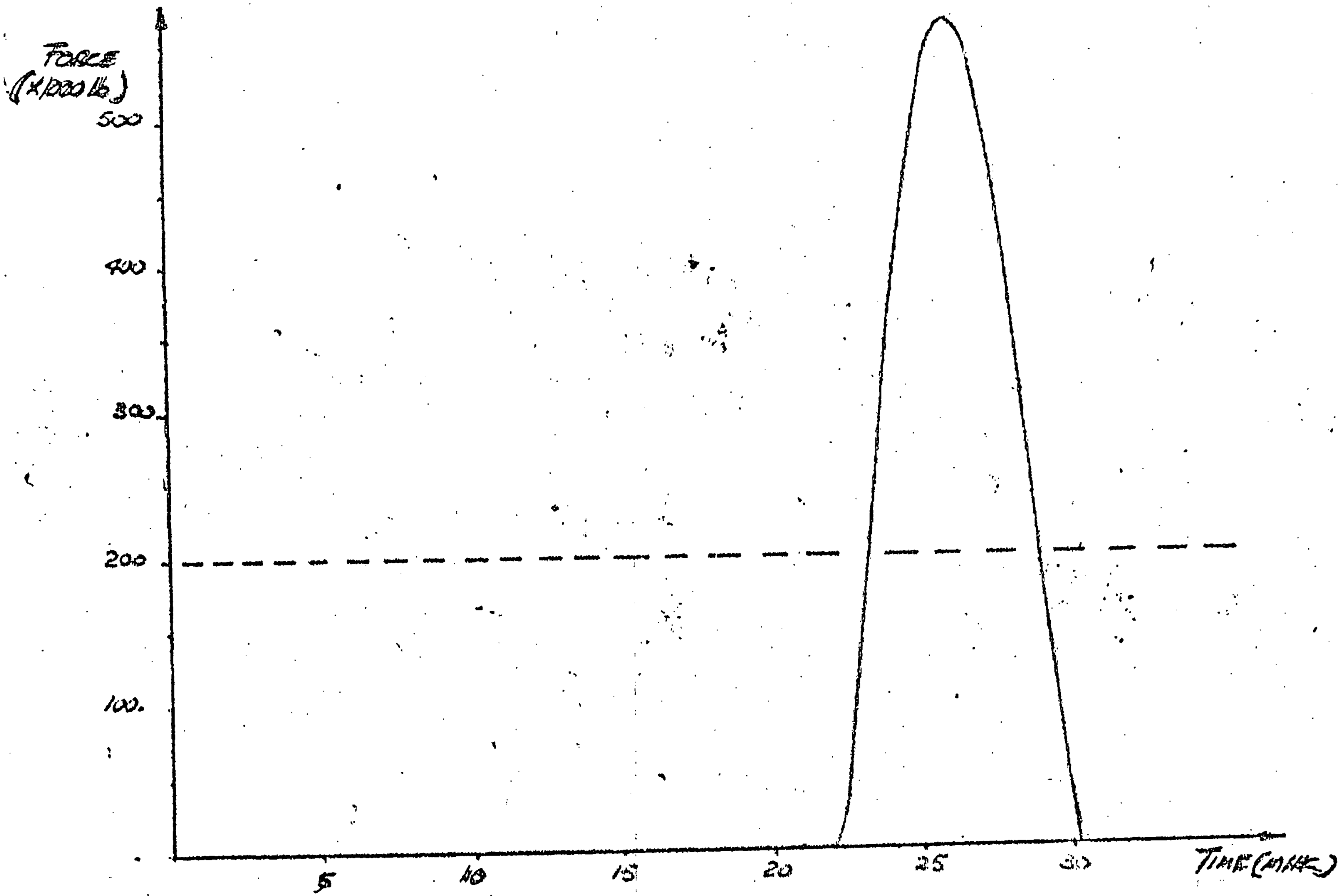


FIG. 16 FORCE TIME-HISTORY OF FLOOR SLAB AT POINTS OF IMPACT

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