UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
TEXAS UTILITIES ELECTRIC COMPANY, ET AL.	)	Docket Nos. 50-445 50-446
	)	
(Comanche Peak Steam Electric Station, Units 1 and 2)	)	(Application for Operating Licenses)

AFFIDAVIT OF ROBERT C. IOTTI AND JOHN C. FINNERAN, JR. REGARDING CONSIDERATION OF FORCE DISTRIBUTION IN AXIAL RESTRAINTS

We, Robert C. Iotti and John C. Finneran, Jr., being first duly sworn, hereby depose and state as follows:

(Iotti) I am employed by Ebasco Services, Inc. as Chief Engineer of Applied Physics. In this position, I am responsible for directing various analytical and design projects in diverse technical areas, including analyses of the response of piping and support systems for dynamic events, including earthquakes. I have been engaged by TUEC to coordinate and oversee the technical activities performed to respond to the Board's Memorandum and Order of December 28, 1983. A statement of my educational and professional qualifications is attached to Applicants' letter of May 16, 1984, to the Licensing Board.

(Finneran) I am the Pipe Support Engineer for the Pipe Support Engineering Group at Comanche Peak Steam Electric Station. In this position, I oversee the design work of all pipe design organizations for Comanche Peak. A statement of my educational and professional qualifications was received into evidence as Applicants' Exhibit 142B.

Q. What is the purpose of this affidavit?

A. The purpose of this affidavit is to address CASE's concerns with Applicants' method of determining the load distribution to axial restraints. CASE's concerns regarding Applicants' analyses of axial restraints are set forth in Sections XII and XVII of their Proposed Findings.

Q. What are axial restraint supports?

A. There are two types of axial restraints. The first type employs trunnions which distribute the axial load to the remainder of the restraint which is configured as a trapeze. The second type distributes the axial load to a frame support via lugs welded to the pipe. The purpose of both types is to provide an axial restraint for the pipe. Both types employ welded attachments to the pipe being restrained. (See Figure 1.)[1]

There are different configurations for both types. For the first type, which will hereinafter be referred to as welded attachments to trapeze supports, there are two basic configurations employed for both horizontal and vertical supports. One configuration employs a single trunnion welded to the pipe and also welded to a beam or tube steel cross piece which is then connected to the two legs of the

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1 Figures and Tables are appended at the end of the Affidavit.

trapeze (see Figure 1, type 1). These legs are either sway struts or snubbers. The other configuration employs double trunnions (on either side of the pipe, which may run either vertically or horizontally) which are attached to the two legs of the trapeze (see Figure 1, types 2 and 3).

The second type of axial restraint will hereinafter be referred to as lug-type and exists in two configurations: four lugs and two lugs.

1. Welded Attachments to Trapezes (Trunnions)

Q. What is CASE's concern with the welded attachment to trapeze supports?

A. CASE alleges that Applicants' design method for this type of restraint (modelling the support as a single support acting in the axial direction) is incorrect in that it ignores the rotational resistance of the restraint and, thus, does not account for certain effects on the piping and supports. (See CASE Proposed Findings at Sections XII and XVII)

Q. What is your evaluation of CASE's concerns?

A. First, we do not agree that modelling of these supports as unidirectional supports, i.e., as a single support acting in the axial direction, is incorrect. As CYGNA has stated[2], and we agree, the modelling assumption employed by Gibbs & Hill in their pipe stress analysis is generally appropriate. This is so because the rotations are very small and

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2 See Tr. 13081-83; 13105-10 and 13124-25. See also Board April 1984 Exhibit No. 1 (Testimony of Nancy H. Williams), Response to Doyle Question 12, at 27.

accommodated by the play in the two legs of the support. Moreover, when seismic analyses are performed using the response spectrum method, as is the case at CPSES, the resulting support loads are not dependent on the relative phase between the response motions, i.e., the axial and rotational motion. In fact, modelling of the rotational constraint of the support using a response spectrum analysis would always add the peak of the response load resulting from the axial motion to the peak of the response load resulting from the rotation. Therefore, this modelling technique would be very conservative and not necessarily a more realistic modelling technique. Consequently, Applicants' believe that modelling the restraints in question as purely axial restraints is adequate. As already noted, this view is shared by Cygna. Even though we do not believe the modelling technique proposed by CASE is either more appropriate or necessary, we have evaluated the impact on piping stresses and support loads which could be calculated by modelling the supports as CASE would wish.

In order to assess the effect on piping stresses from modelling the rotational constraints, Gibbs & Hill performed a reanalyses of several stress problems for lines ranging in size from 4" to the 32". Table 1 (attached) shows a comparison of the results obtained for the pipe stresses under the two different modelling assumptions, i.e., with and without modelling of the rotational constraint, for the

32" main steam line. As shown therein, the pipe stresses are negligibly affected by the modelling assumptions. Analyses of the other lines indicate identical results with respect to pipe stresses. Thus, these analyses demonstrate that excluding the rotational constraint of the trapeze supports has virtually no effect on the pipe stresses.

Q. What is the impact on the loads computed for the supports themselves when the rotational constraint is modelled?

A. There is a change in loads on the supports themselves when the trapeze supports are modelled with the rotational constraint. However, that change occurs only for the trapeze supports themselves. The remaining supports are not significantly affected. Table 2 compares the loads computed for all supports other than the trapeze supports under the two modelling approaches for the main steam lines. As is evident from the table, the change in support loads is negligible. The same result was obtained for the other lines reanalyzed.

For the trapeze supports themselves, however, the change in calculated loads can be much greater. This change would be expected when one models the rotational constraint of the trapeze support using a response spectrum analysis. Under this circumstance there will be an additional load acting on the component in each side of the trapeze due to the rotational constraint since it is assumed that the peak load due to trunnion rotation is always coincident with the peak load to due axial movement. This effect is illustrated in Table 3 for the trapeze supports included in the same stress problems from which Tables 1 and 2 have been taken. However, a completely bounding conclusion cannot be made as to the magnitude of the load increase resulting from the inclusion of the rotational constraint. This is so because in addition to the analytical technique, (i.e., response spectrum vs. time history linear analysis vs. nonlinear), differences in loads are generally a function of piping flexibility, support rotational stiffness, and the free angle of rotation of the pipe as calculated from the non-rotational constraint analysis.

Q. Have you performed any additional analyses to assess the potential load increases and their consequences which may result from employing the modelling assumption suggested by CASE?

A. Yes. Every double trunnion support employed in Comanche Peak Unit 1 and common has been evaluated against the loads which would be computed either from computer stress analysis or manual methods (discussed below), employing the rotational constraint.

For all of these supports the "free" rotation of the pipe (computed in the absence of rotational constraint) at the location of the support is very small, i.e., less than 0.94 degrees. Accordingly, it is appropriate when evaluating the loads resulting from this modelling technique, i.e., including the rotational constraint of the support, to consider the rotation which produces the increased load into either side of the trapeze to be self-limiting. In other words, that rotation cannot exceed the value which would occur if there were no rotational constraint. Loads resulting from such rotation are, therefore, also self-limiting and may be characterized as loads resulting from the constraint of free end displacement. Section NF, Article NF-3231.1, of the ASME Code permits evaluation of such loads against an allowable equal to three times the normal allowable. Further, that Article requires no evaluation of such loads for emergency or faulted conditions. The total load experienced by the support can thus be characterized as being composed of the axial load, which gives rise to primary stresses in the pipe and supports, and the rotational load which is self-limiting and gives rise to secondary stresses in the pipe and supports.

Q. What are the results of your analyses of these supports?

A. The stresses resulting from the axial load have been previously evaluated in the normal design process and were found acceptable. The total stresses resulting from the combined axial and rotational loads calculated in our reanalysis have been evaluated for each of the double trunnions in Unit 1 and common against the allowable limits permitted by Section NF-3231.1. The total loads imposed on each side of the trapeze from modelling the rotational constraint have been found to be acceptable, i.e., in no case have Code allowables been exceeded, when the increased loads have been factored in the support design.

Q. What is the manual method used as an alternate to the computer analysis?

A. This manual method conservatively predicts the effect of the self-limiting pipe rotation on the distribution of loads to each side of the trapeze. It provides an appropriate method to readily calculate the change in load resulting from inclusion of the rotational constraint. To illustrate the appropriateness of this manual method we present in Table 4 a comparison of the additional loads[3] (due to rotation constraint) computed by response spectrum analysis and by the manual method for the 32" main steam problems of Tables 1, 2 and 3. This table also shows the "free" rotation angle at the trapeze support points. As is evident from the results, the manual method always calculates additional loads which are higher than predicted by computer analysis. This conclusion was further confirmed by comparison of the results from computer analyses and the manual method for other piping systems.

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3 Additional loads here refers to the increment of load due to modelling of the rotational constraint of the support, which is over and above the load computed by the original analysis performed with no rotational constraint in the model.

Q. What is your conclusion regarding the validity of CASE's concerns with respect to the modelling of rotational constraint for trapeze supports?

A. CASE's assertion that Applicants employed incorrect modelling assumptions for these supports is unfounded. As we previously indicated, modelling the trapeze restraint as a single axial restraint is common practice in the industry, and no basis exists to conclude that this practice is not appropriate or that another analytical model is more realistic or better than the conventional analysis. As demonstrated above, even if the trapeze restraints are modelled as CASE suggests, the resulting support loads and pipe stresses are within Code allowable values. Hence, CASE's concern that Applicants' modelling approach for these supports could have adverse consequences for the supports and piping is not valid.

2. Lug-Type Restraints

Q. With respect to the lug-type axial restraints, do you agree with CASE's assertions that the method employed by ITT Grinnell to determine the loading distribution in axial restraints is inadequate?

A. No, we do not. CASE presents two concerns which can be summarized, as follows:

(a) Construction cannot achieve perfect planes in the installation of the four lugs on the pipe. Therefore, distribution of load according to stiffness of the support structure is not valid (_see_ CASE Proposed Findings at XII-6), and

(b) Angularity of the pipe (due to thermal expansion at the point of support) will preclude four point contact. Consequently, the structure should be analyzed assuming single point contact at the extreme point of the structure (_see_ CASE Findings at XII-6).

We will address the two concerns separately, below.

Q. Have you performed any analyses to assess the validity of CASE's concerns?

A. Yes. With respect to CASE's first concern, we concur with CASE's premise that perfection in construction is not achievable. On the other hand, it is neither necessary nor reasonable to expect that the four lugs can be installed in a _perfect_ circumferential plane with "zero" tolerance. Nonetheless, we expect the lugs to be installed within "reasonable" limits and, indeed, have found that this is the case.

Construction practices in the installation of pipe lugs ensure that the maximum deviation in alignment of the lugs with their mating surfaces will be very small. We surveyed twenty-nine supports which have lugs welded to the pipe on both sides of the support frame (_see_ Figure 1). In only one instance was the measured maximum deviation (difference in distance between any of the lugs and the frame, on their respective sides of the frame) in excess of 1/16 inch. In this instance, the deviation was 5/64 inch on one side of the support. In five other instances, the deviation on one side was 1/16 inch. Twelve supports had essentially no deviation.

More importantly, we found that in most instances at least two lugs on either side of the frame are equidistant from the frame, and that the maximum deviation between two lugs on any one side of the frame nowhere exceeds 1/32 of an inch. In fact, 19 out of the 29 supports reviewed had at least the two closest lugs located equidistant from the frame on both sides of the frame.

Q. What do these findings regarding the location of the lugs demonstrate?

A. With maximum deviations at 1/16 inch, any overstress condition which may occur in the pipe, in the lug or in the frame will only be localized and self-limiting. If a local overstress condition does occur at a single lug, resulting local deformations will readily redistribute the load to other lugs. Because Applicants designed each lug to carry half the maximum load which could occur, even if some local deformation occurs the entire load will be fully resisted upon engaging one other lug.

Q. What have you found in your analysis of CASE's second concern regarding the distribution of loads between the lugs?

A. We first considered the situation which CASE claims should be addressed. Specifically, CASE argues that the load should be assumed to be taken by the lug furthest from the support anchors (see Figure 1) on the support structure (see CASE Proposed Findings at XII-6,7). Under Applicants' original design assumption that two opposite lugs carry the load, the load on the frame is assumed to act through the point where imaginary lines connecting all four lugs intersect. This loading condition will result in a given deflection of the frame. If, however, the load is applied further out via the extreme outboard lug (as CASE argues should be assumed), the frame deflection can be larger, since the moment lever arm between the frame embedments and the point of load application is longer. Therefore, the frame may experience larger stresses than would otherwise be computed on the basis of two lugs sharing the load. On the other hand, frame deflection will tend to close the gaps to the other lugs.

Consequently, two cases are possible, if the load is initially not shared by at least two opposite or adjacent lugs. One case corresponds to the instance whereby the lugs are much stronger than the frame. In that instance the entire frame will either deflect sufficiently to bring additional lugs in contact (if it is sufficiently flexible) or it will deflect or yield locally to accomplish the same thing. The second case corresponds to the instance in which the frame is stronger than the lugs, and the loaded lug deforms inelastically until an opposite or adjacent lug shares the load. Applicants have investigated both cases.

To illustrate the case of the frame being weaker than the lugs, Applicants have performed a study of idealized frames loaded axially via a four lug arrangement. The typical frame used is shown in Figure 2. Two different cases were analyzed. One case utilized a M4 x 13 frame members with a 4" diameter pipe and the other case used W6x15.5 frame members with an 8" diameter pipe. For each case, four load combinations have been analyzed. The load combinations that have been chosen are, as follows:

1. Total load P, applied to the outboard lug (joint 6 of STRUDL Model)
2. Total load shared equally, P/4, amongst all lugs (joints 3, 5, 6, 9)
3. Total load shared equally by the horizontal lugs only, P/2 (joints 3 and 9)
4. Total load, P, applied to the inboard lug (joint 5)

The results of these analyses are tabulated in Table 5 for each loading case and each configuration analyzed.

Q. Have you analyzed the effect of frame deflection on the capability of the support frame to engage additional lugs?

A. The two cases were chosen to simulate frames that are relatively rigid, so that their deflection under these loads would not exceed the 1/16-inch guideline used at CPSES to design supports. One case was chosen to represent a frame the deflection of which would be small, while the other represents the instance in which the frame deflection would approach the maximum 1/16-inch. Therefore, these frames represent the range of frame deflections that would be encountered at Comanche Peak and, thus, provide an indication of the ability of those frames to deflect so as to permit engagement of additional lugs.

If the frame is sufficiently stiff to deflect a minimal amount (as in CASE I) it will either carry the load having engaged a single lug or will deflect further until another lug is engaged. That additional deflection, however, is not likely to significantly exceed 1/16". Alternatively, if the frame does deflect approximately 1/16" (as in CASE II), depending on the relative distribution of the lugs, a second lug may be engaged before the final deflection is achieved or the final deflection may slightly exceed 1/16". Again, any excess loads would be self-limiting in that as soon as the required small deflection is achieved, the load will be shared by at least two lugs, and hence, the deflection no longer increases for a given load.

We note that for the frames associated with the twenty-nine supports which were reviewed for lug spacing, the combination of pipe rotation, local yieldings of lugs, and frame motion will only have to result in a displacement of less than 1/32 of an inch for a second (or third) lug to become engaged. In most instances, frame displacement alone will result in this displacement. When this is not the case, minimal yielding of the lug or the frame will bring a second lug in contact with the frame.

Q. Have you analyzed the effects of localized yielding of the pipe or lugs?

A. Yes. We have analyzed the effect of localized yielding in the lug and pipe surface which would be necessary to bring additional lugs in contact with the frame. This analysis, which has been performed using a non-linear finite element technique and the computer program, NASTRAN, is presented in Attachment 1.

Q. What are the results of your analysis?

A. The results show that minimal plastic strains, entirely localized at the surface of the pipe and lug welds permit 1/16" deflection of the lugs. These minimal strains are of no consequence to the integrity of the pipe or the lug.

In addition, Gibbs and Hill has verified that the additional bending stresses on the pipe, which would occur if the two loaded lugs were adjacent rather than opposite, are acceptable. Attachment 2 summarizes the results of Gibbs and Hill's calculations of these additional stresses for pipe sizes ranging from 3 inch to 24 inches in diameter.

Q. What are your conclusions regarding CASE's concerns with respect to force distribution in axial restraints.

A. We conclude that although the consideration of rotational constraint in modelling axial restraints could result in the calculation of higher loads in these supports, such a modelling assumption is no more appropriate than the conventional assumption of modelling the restraint as a single axial restraint. This is particularly so given Applicants' use of response spectra analyses. Moreover, even if the rotational constraint was included, the analyses discussed above demonstrate that the supports are capable of accommodating whatever load increases may be calculated by that technique. With regard to the CASE's second concern, (modelling of lugs), we believe it is premised on unrealistic assumptions. Nonetheless, even taking those assumptions as given, we have shown that a very small deflection or local yielding of either the frame or the initially contacted lug, will bring at least one other lug in contact with the frame. This fact is consistent with Applicants' design approach of assuming at least two lugs will share the load. In sum, CASE's assertions present no concern for the adequacy of the design of these supports or accompanying piping.

Robert C. Iotti

Subscribed and sworn to before me this 9th day of July, 1984.

Notary Public

STELLA GITZ
NOTARY PUBLIC, STATE OF NEW YORK
No. 31-1444786
Qualified in New York County
Commission Expires Mar. 30, 1985

John C. Finneran, Jr.

Subscribed and sworn to before me this 9TH day of July, 1984.

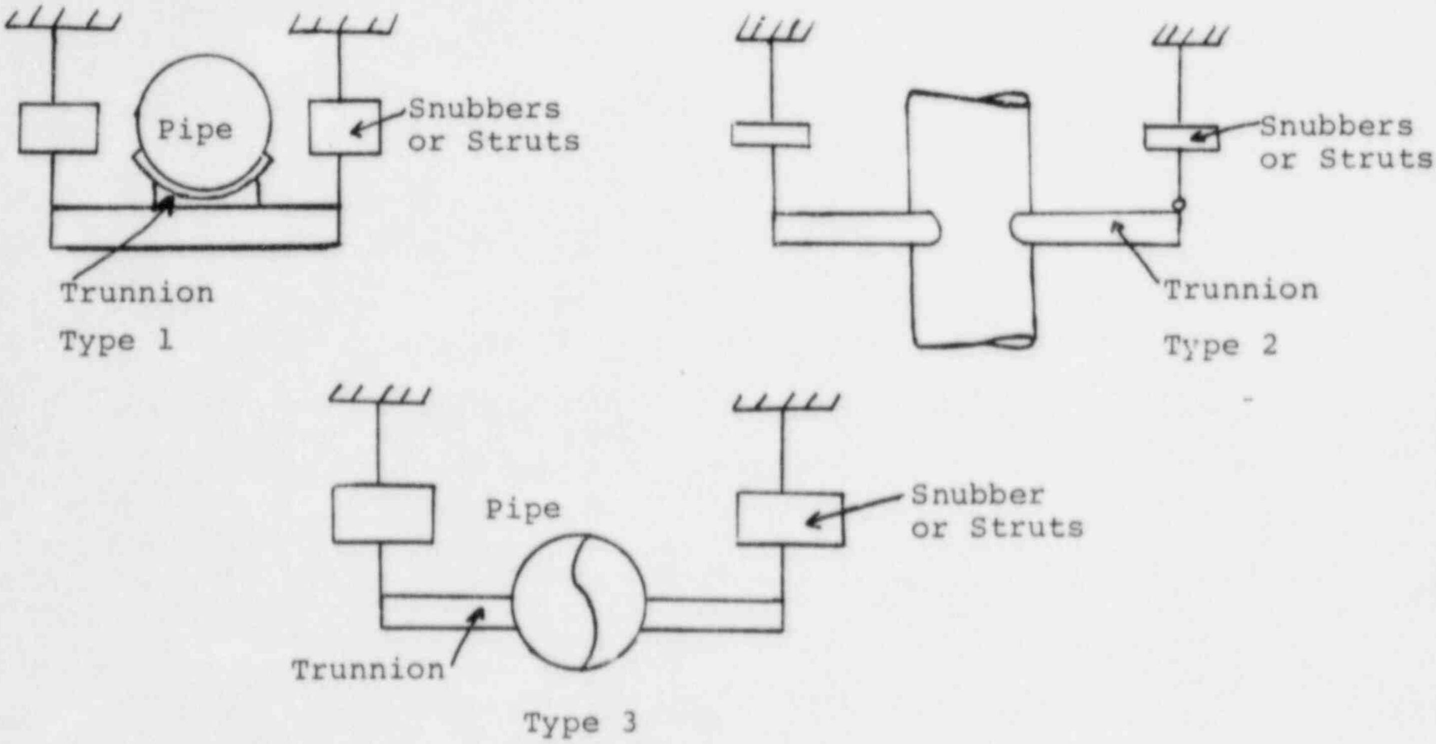
Notary Public

This is a telecopy facsimile. The original will be sent under separate cover.

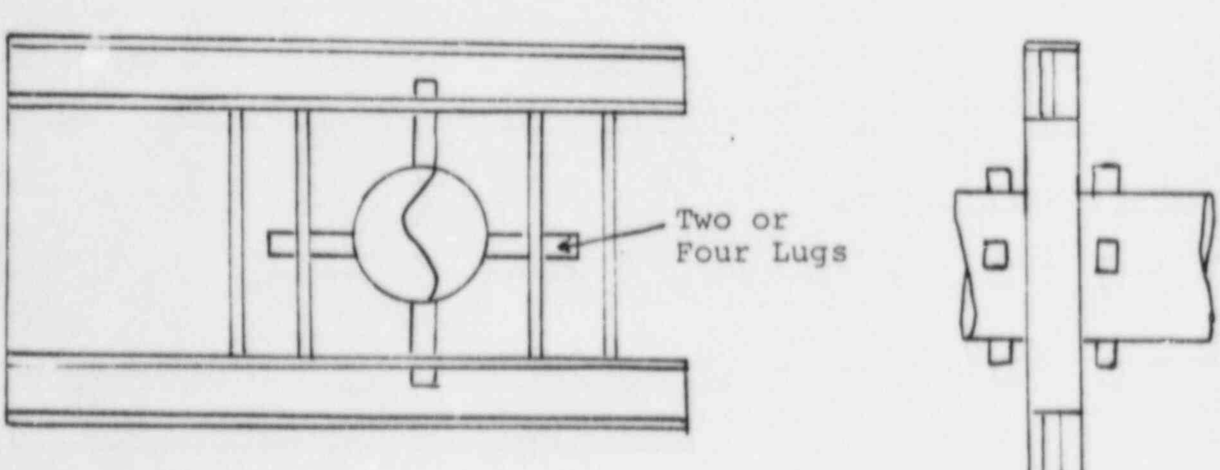
FIGURE 1

TYPICAL TRUNNIONS & LUG SUPPORTS

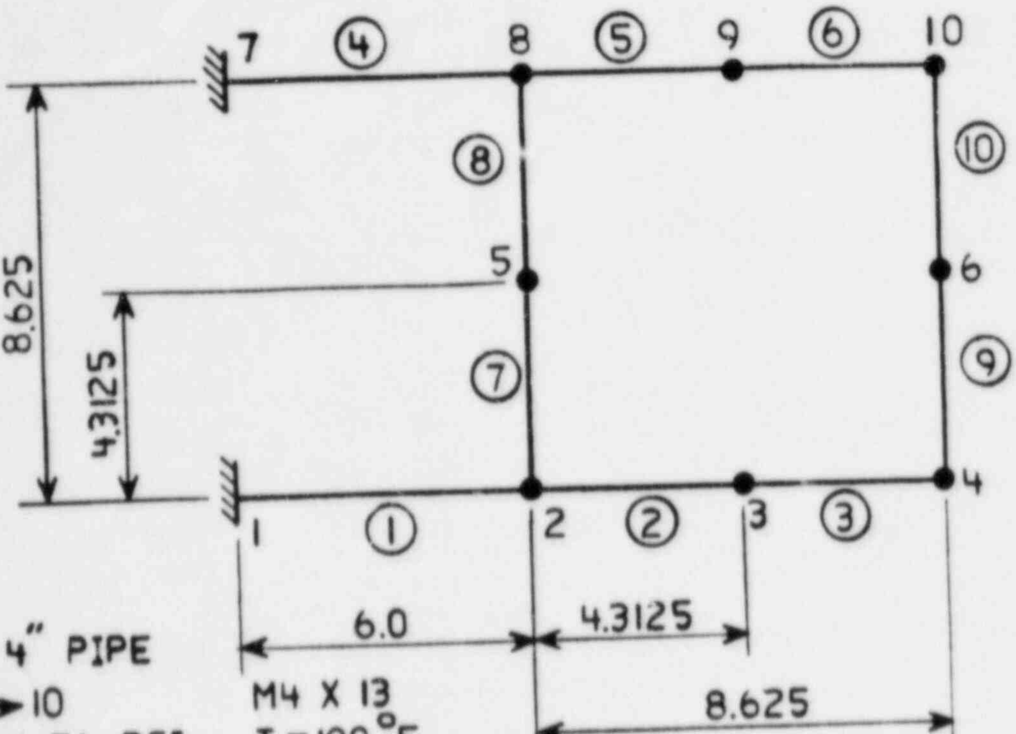
Trunnions



Lugs



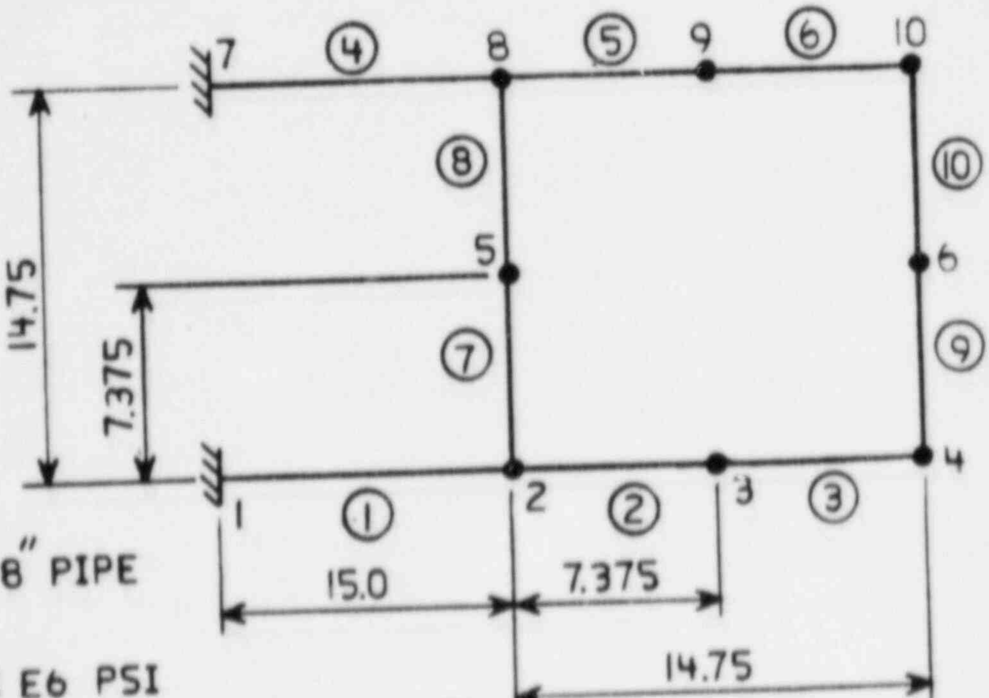
CASE I



CASE I: 4" PIPE
MEM. 1 → 10
E = 27.85 X E6 PSI
G = 10.71 X E6 PSI

M4 X 13
T = 100°F
S_Y = 36,000 PSI

CASE II



CASE II: 8" PIPE
T = 100°F
E = 27.85 X E6 PSI
G = 10.71 X E6 PSI
MEM. 1 → 10

S_Y = 36,000 PSI
W6 X 15.5

TABLE 1
MAXIMUM PIPE STRESS COMPARISON*

Prob. No.	Node No.	EQ 9. Upset	EQ.9 Upset (Trapeze)	EQ. 9 Emerg.	EQ.9 Emerg. (Trapeze)	EQ.10	EQ.10 (Trapeze)
1-1	15	9152	9140	9844	9826	3190	3149
	20	9969	9963	10816	10792	15218	15202
	9	9690	9676	10499	10942	13457	13545
	130	10259	10252	11307	11360	1992	2040
1-4	30	11475	11081	12167	11692	2179	2034
	106	10965	10796	11554	11348	2830	3118
	304	8421	8205	8616	8360	5240	5110
	85	8819	8693	9933	9020	13981	14692

* Equations (9) and (10) are the equations of the ASME Code Section III which are used to compute stresses in the piping system for comparison to allowable values. (Trapeze) refers to results which are obtained by the analysis which models the rotational constraint of the support.

TABLE 2
CHANGE OF ADJACENT SUPPORT LOADS FOR ROTATIONAL CONSTRAINT AND NON-ROTATIONAL CONSTRAINT ANALYSIS

Hanger No.	Rotational Constraint Analysis (Kips)			No-Rotational Constraint Analysis (Kips)		
	Fx	Fy	Fz	Fx	Fy	Fz
MS-1-04-004-C72K		33.63			32.37	
MS-1-01-004-C72K			44.3			42.87
MS-1-01-005-C72K		28.52	2.75		28.71	2.76
MS-1-01-006-C72K	70.87	12.52		70.86	12.52	
MS-1-01-007-C72K		33.27			33.83	
MS-1-04-006-C72K		36.21			37.14	

TABLE 3

COMPARISON OF TRAPEZE LOADS FOR ROTATIONAL CONSTRAINT AND NON-RATIONAL CONSTRAINT ANALYSIS

Hanger No.	A. Rotational Constraint Analysis (Kips)			B. Non-Rotational Constraint Analysis (Kips)		
	Fx	Fy	Fz	Fx	Fy	Fz
MS-1-01-003-C72K			53.59			27.77
MS-1-04-005-C72K			102			52.59
MS-1-04-007-C72K	86.4			63.43		
MS-1-04-008-C72K			36.87			22.2
MS-1-04-009-C72K		70.66			41.23	

TABLE 4

COMPARISON OF UNBALANCED LOADS IN TRAPEZE SUPPORTS FOR MANUAL AND COMPUTER ANALYSIS - SSE & FSAM

Hanger No.	Free Rotation θ (deg.)	Rotational Stiffness k_o	Loads From Manual Method $= \frac{k_o \theta}{L}$ (Kips)	Computer Load (Kips) M/L
MS-1-01-003-C72K	.111	4.6×10^8	16.02	11.80
MS-1-04-005-C72K	.206	8.52×10^8	51.05	24.73
MS-1-04-007-C72K	.054	9.84×10^8	16.56	10.76
MS-1-04-008-C72K	.048	8.52×10^8	11.90	7.28
MS-1-04-009-C72K	.139	8.62×10^8	40.22	15.26

TABLE 5

RESULTS OF FRAME ANALYSES
(Figure 2 Frames)

CASE I

Loading Case/ Deflection Inches		Joint 3	Joint 5	Joint 6	Joint 9	Max. T Members 1 & 4
I.	All loads on outboard lug	.0114424	.0046689	.0201173	.0114194	14.79
II.	Loads shared 4-ways	.0086715	.0041157	.0140854	.0086628	12.07
III.	Loads shared 2-ways	.0087955	.0039680	.0139015	.0087955	12.06
IV.	Loads on Lug Inboard	.0056525	.0038580	.0084212	.0056409	9.37

CASE II

Loading Case/ Deflection Inches		Joint 3	Joint 5	Joint 6	Joint 9	Max. T Members 1 & 4
I.	All loads on outboard lug	.0378060	.0194758	.0595369	.0378060	16.56
II.	Loads shared 4-ways	.0294855	.0163781	.0440817	.0294855	13.85
III.	Loads shared 2-ways	.0296730	.0161213	.0436851	.0296730	13.85
IV.	Loads on Lug Inboard	.0207901	.0137941	.0294179	.0207901	11.15

ATTACHMENT 1

PIPE LUG ELASTO-PLASTIC ANALYSIS

I. INTRODUCTION

Typical pipe axial supports at CPSES consist of four lugs which are welded to the pipe on both sides of the support frame. The design assumes that at least two of the four lugs function to transfer load to the frame. CASE has alleged that it is possible for only one lug to be functional due to the fact that installation tolerance may result in only one lug making contact with the frame. This study investigates the local stress and strain conditions in the lug and the pipe which might occur if a single lug carries all of the load, contrary to the design assumption that at least two opposite lugs would share the load.

Inspection of several supports selected randomly have shown that a maximum deviation of 1/32 of an inch separates adjacent lugs. Thus, any loaded lug displacing more than 1/32 inches will cause the load to be shared by at least another lug. The same inspection identified 1/16 of an inch as the maximum gap between the frames and any lug. To account for a possible maximum deviation between lugs of 1/16 of an inch, this study assesses the effects at a maximum deformation of a lug equal to 1/16 of an inch.

The analysis has been performed using elasto-plastic behavior of the lug and pipe material to closely follow the distribution in plastic strain in the pipe and the lug that might occur before another lug closes the gap to the frame and begins to share load.

II. MODELLING

A finite element model of the pipe and lug has been constructed utilizing the MSC/NASTRAN finite element computer program. The pipe is modelled with sufficient length so that the local deformations are not affected by the model boundaries. Since the load is applied to one lug, symmetry is employed so that only half of the pipe with the lug at center is included in the model as shown in Fig. 1. As will be demonstrated, the strain effects are so localized that the use of a symmetric model is appropriate.

The half pipe is modelled with two sides fixed and two ends with symmetric boundary conditions. Since the objective of this analysis is to obtain the local strain distribution in the pipe and lug when the lug displaces 1/16 of an inch at its load center, these boundary conditions are appropriate.

The lug and its welds to the pipe are modelled with hexahedron elements (CHEXA). The pipe wall is modelled with shell elements (CQUAD4). Figs. 2-5 show different parts of the model. The pipe and the lugs are both assumed to be made of SA36 steel. The stress-strain curve of the material employed in the model is shown in Fig. 6. For modelling purposes, the curve has been approximated by a bi-linear curve. The slope of the elastic portion of the bi-linear curve is 29,000,000 psi and that of the plastic portion, 140,000 psi. Yield stress is assumed to be 36,000 psi.

III. ANALYSIS

In an elasto-plastic analysis, the material behavior determines the stress-displacement pattern. Within the elastic limit (yield point), a linear relationship holds. Beyond yield, material strains in accordance to certain observed rules. Several criteria have been proposed that establish when and how a material yields. The most widely followed criteria are those established by Von Mises and Tresca.

As stresses exceed the yield strain, the stress-strain is no longer linear but changes with the increasing strain level. In a load-unload-reload loading pattern, it is observed that the new 'yield points' occur at different stress levels. This behavior is called strain hardening. Two of the most widely followed assumptions to account for strain hardening are the kinematic hardening and isotropic hardening assumptions. The choices of yield criterion and strain hardening assumption depend on the characteristics of the material. For this model we chose the kinematic hardening assumption because steel has been shown to behave closer to this rule. For the yield surface, we have chosen to adopt Von Mises.

The analysis is performed by applying incremental loads at the lug surface. Before the elasto-plastic analysis a linear analysis was done to estimate the initial load and subsequent incremental loads that should be applied to the lug.

The elasto-plastic analysis was begun with a load of 12,000 lbs applied to the lug. Subsequently, incremental loads of 2000 lbs were applied to the lug until the load reached 52,000 lbs, at which point a lug deflection totaling 1/16 of an inch was reached. The MSC/NASTRAN Solution #66 (nonlinear analysis) was utilized for this purpose. The solution provides element stresses and strains and grid point displacements at each load increment.

IV. RESULTS

Utilizing the computer output results, strain maps of the pipe and lug at selected load steps are plotted in Figs. 7-10. A load displacement curve of the grid point 148 (outer periphery of the lug) is presented in Fig. 11.

The strain maps show that the plastic strain is highly localized. This confirms that the model chosen is valid, since boundary condition effects are considerably removed from the local plastic strain area. The strain maps also provide the patterns of progressive yield as the load increases. The load-displacement curve can serve as a guide to determine the deformation of lug under the applied loads.

V. CONCLUSION

The results of this study show that the plastic strains of the pipe and the lug are limited to the local area immediately adjacent to the lug. The strain levels are very low. At 1/16 inch lug deflection, the maximum strain in the lug is only .0009 in/in and in the pipe shell, .007 in/in. At such low levels of plastic strains, the pipe and the lug can carry the applied load without adverse effects until the load begins to be shared by the other lug(s).

The small amount of permanent deformation in the pipe shell would only occur in the first cycle of applied load, since subsequent cycles would be reacted by at least two lugs which have been aligned by the deformation of the first lugs.

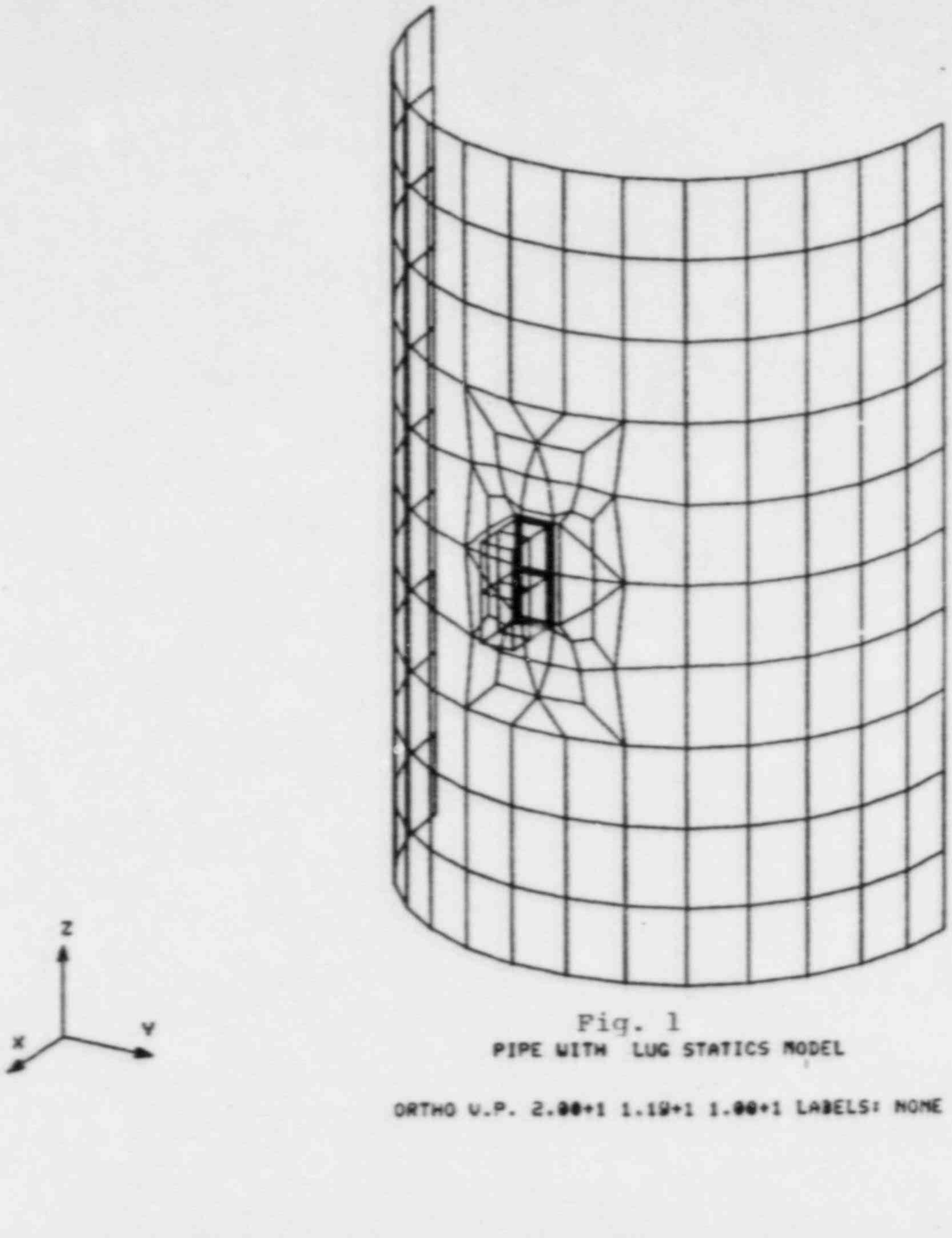


Fig. 1

PIPE WITH LUG STATICS MODEL

ORTHO V.P. 2.00+1 1.10+1 1.00+1 LABELS: NONE

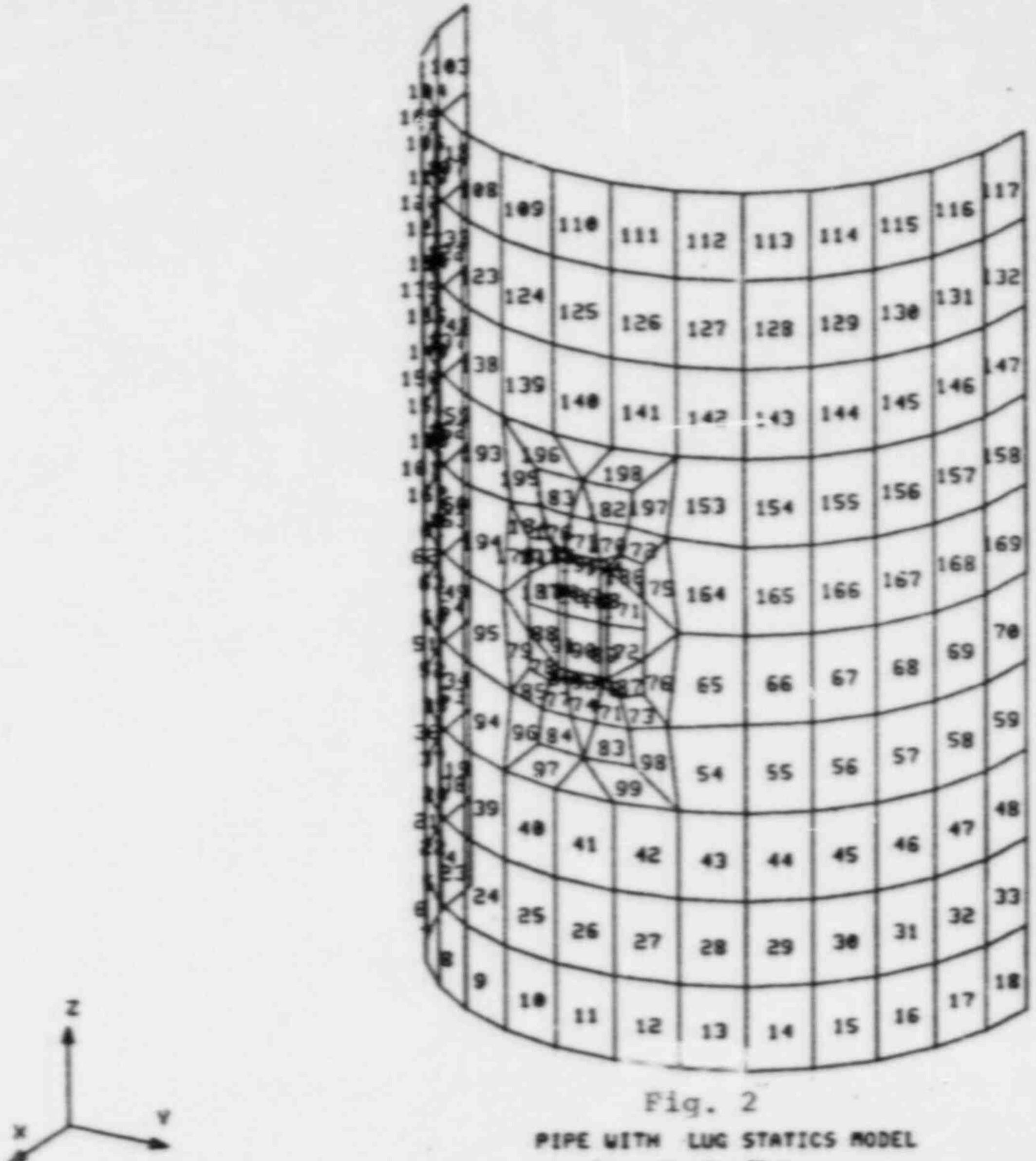


Fig. 2

PIPE WITH LUG STATICS MODEL

HALF PIPE

ORTHO V.P. 2.00+1 1.10+1 1.00+1 LABELS: ELEMENTS

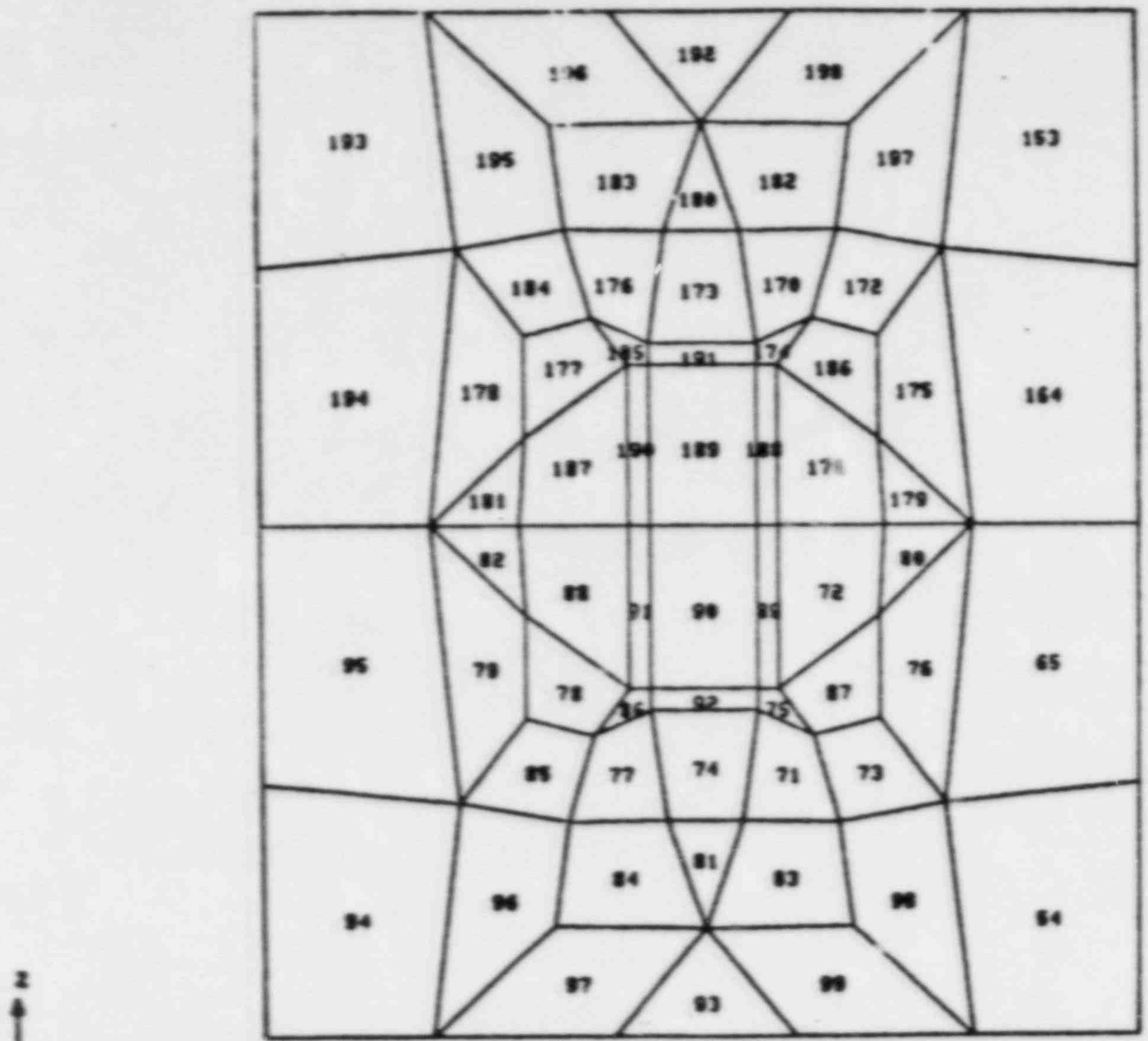


Fig. 3

PIPE WITH LUG STATICS MODEL

ORTHO V.P. 1.0000 0.0 0.0 LABELS: ELEMENTS

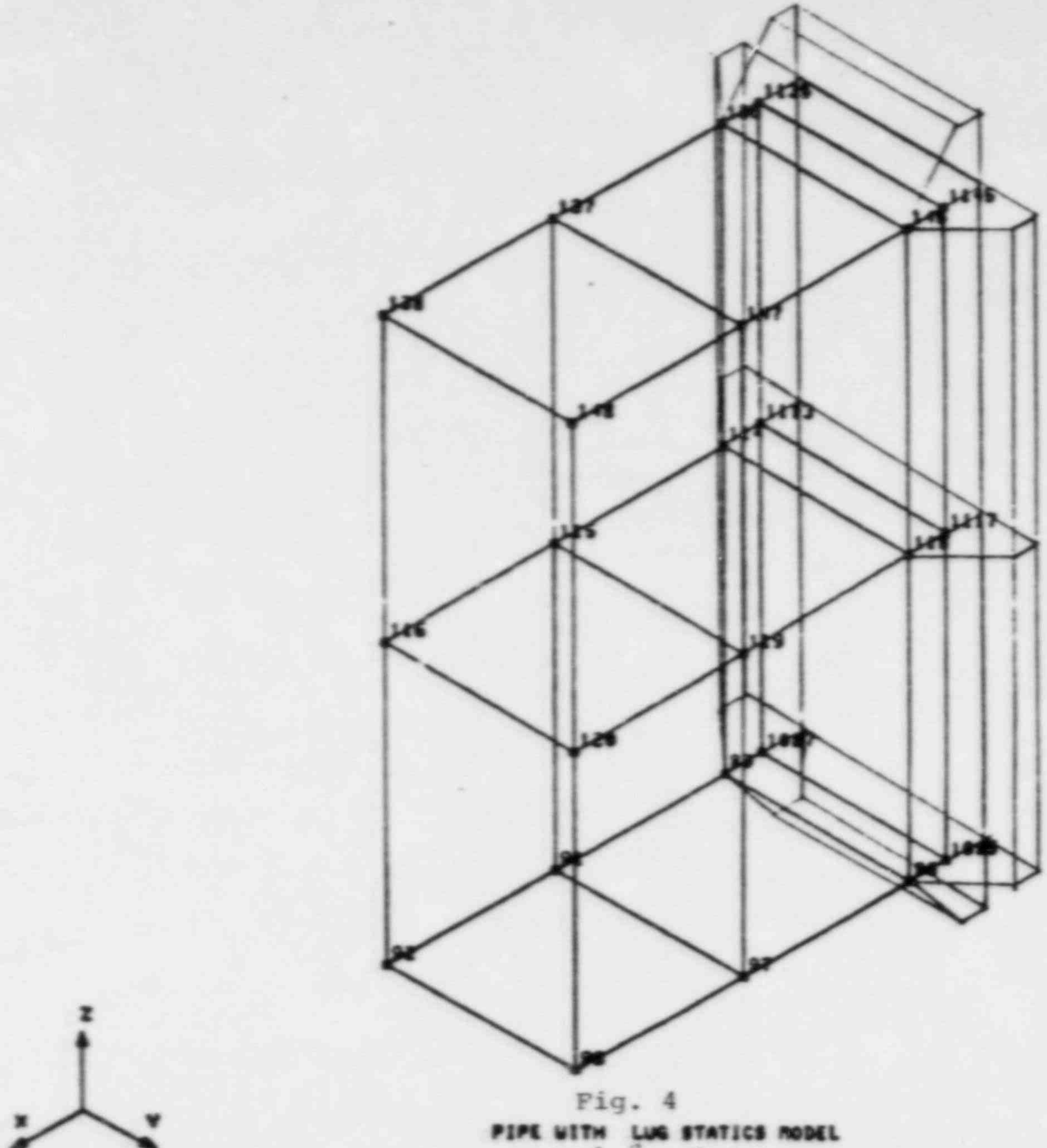


Fig. 4

PIPE WITH LUG STATICS MODEL

LUG & WELDS

ORTHO V.P. 1.0000 1.0000 1.0000 LABELS: GRIDIDS

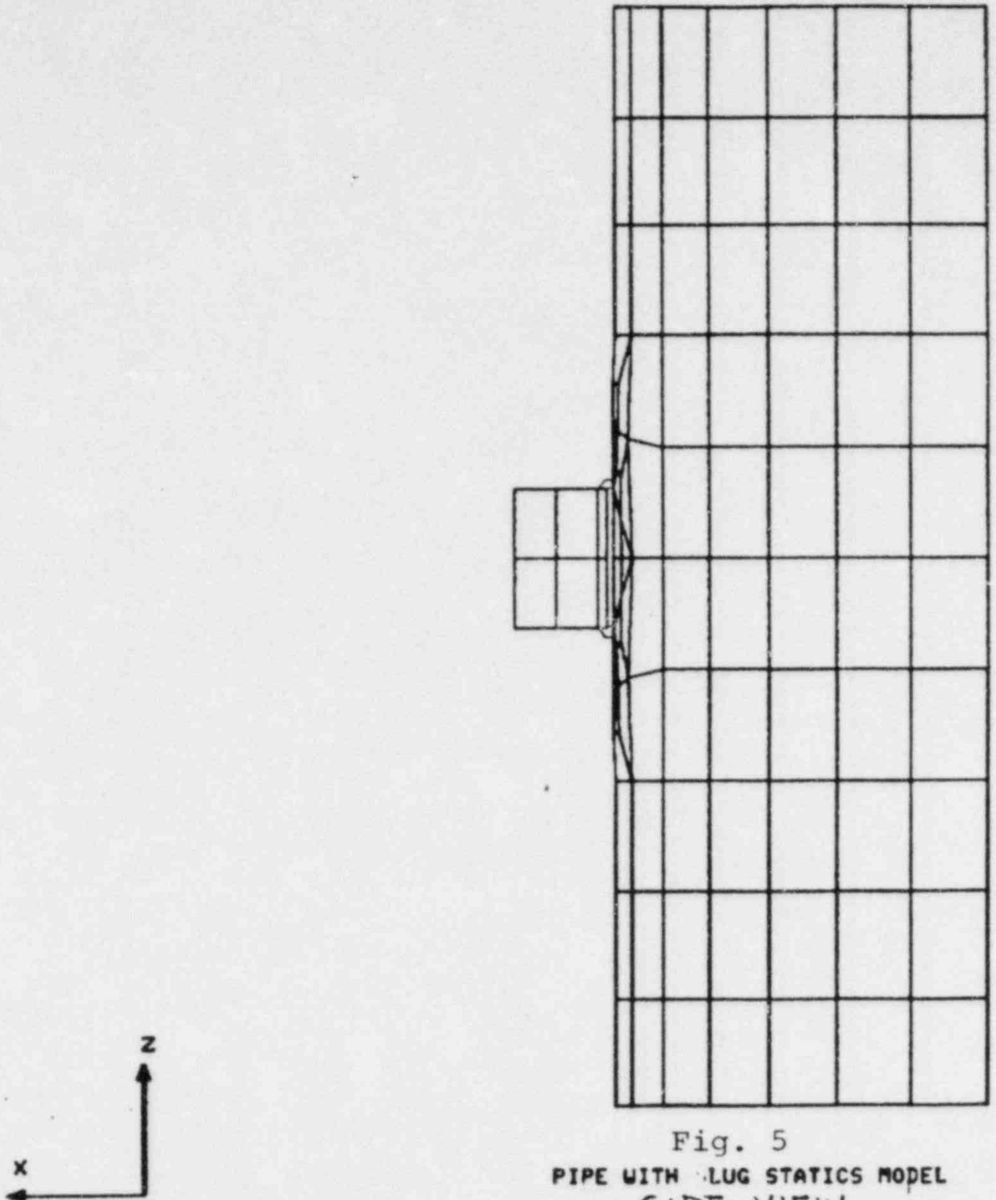


Fig. 5

PIPE WITH LUG STATICS MODEL

SIDE VIEW

ORTHO V.P. 0.0 1.0000 0.0 LABELS: NONE

Stress-Strain Curves For Specified Minimum Strength Properties

The curves presented herein represent the minimum values that are guaranteed for the steels indicated. The curves are indicative of the minimum stress-strain patterns which may be expected from actual testing of specimens.

In general, tensile test results exceed the specified minimum values for each steel. Many factors influence a test such as the composition of the heat of steel, location of the coupon, speed of testing, accuracy of testing equipment, individual performing the test, use of different testing machines, etc. Therefore, every test coupon will not produce identical results, even though all tests follow the procedure outlined by "Tentative Methods and Definitions for Mechanical Testing of Steel Products," ASTM Designation A 370.

The curves plotted are for the following steels: USS "T-1" (ASTM A 514, Grade F)*, USS "T-1" type A (ASTM A 514, Grade B)*, USS "T-1" type B, USS CON-PAC**, USS EX-TEN 60, USS COR-TEN (ASTM A 242), USS MAN-TEN (ASTM A 440), USS TRI-TEN (ASTM A 441), USS EX-TEN 50, USS EX-TEN 42, and ASTM A 36.

The minimum yield points, or yield strengths, and minimum tensile strengths are indicated for the steels plotted.

*These steels are available in plates, bars, and selected structurals; however, the ASTM specifications apply to plates only.
**Available in plates only.

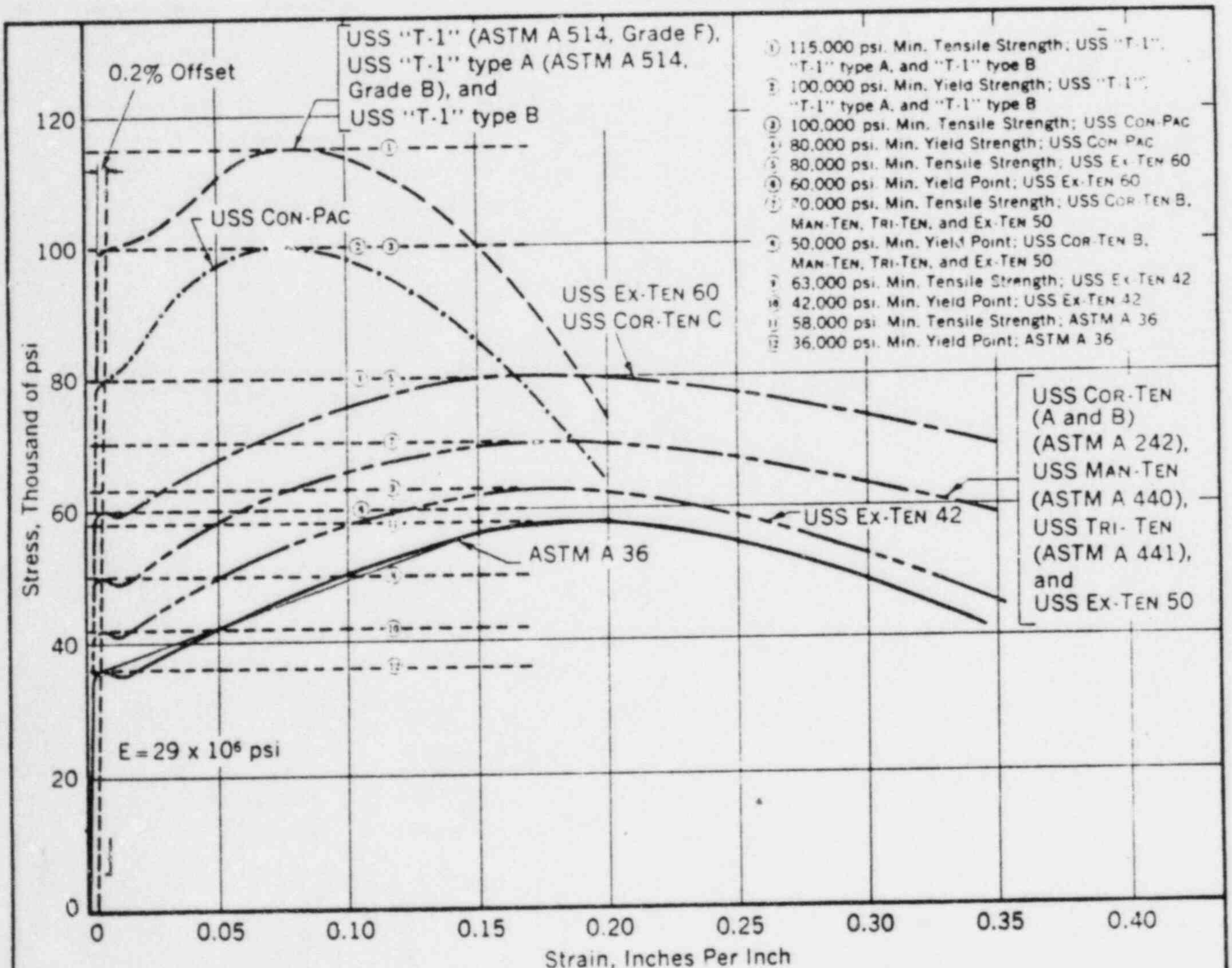


Fig. 6 Stress-Strain Curves For Specified Minimum Values

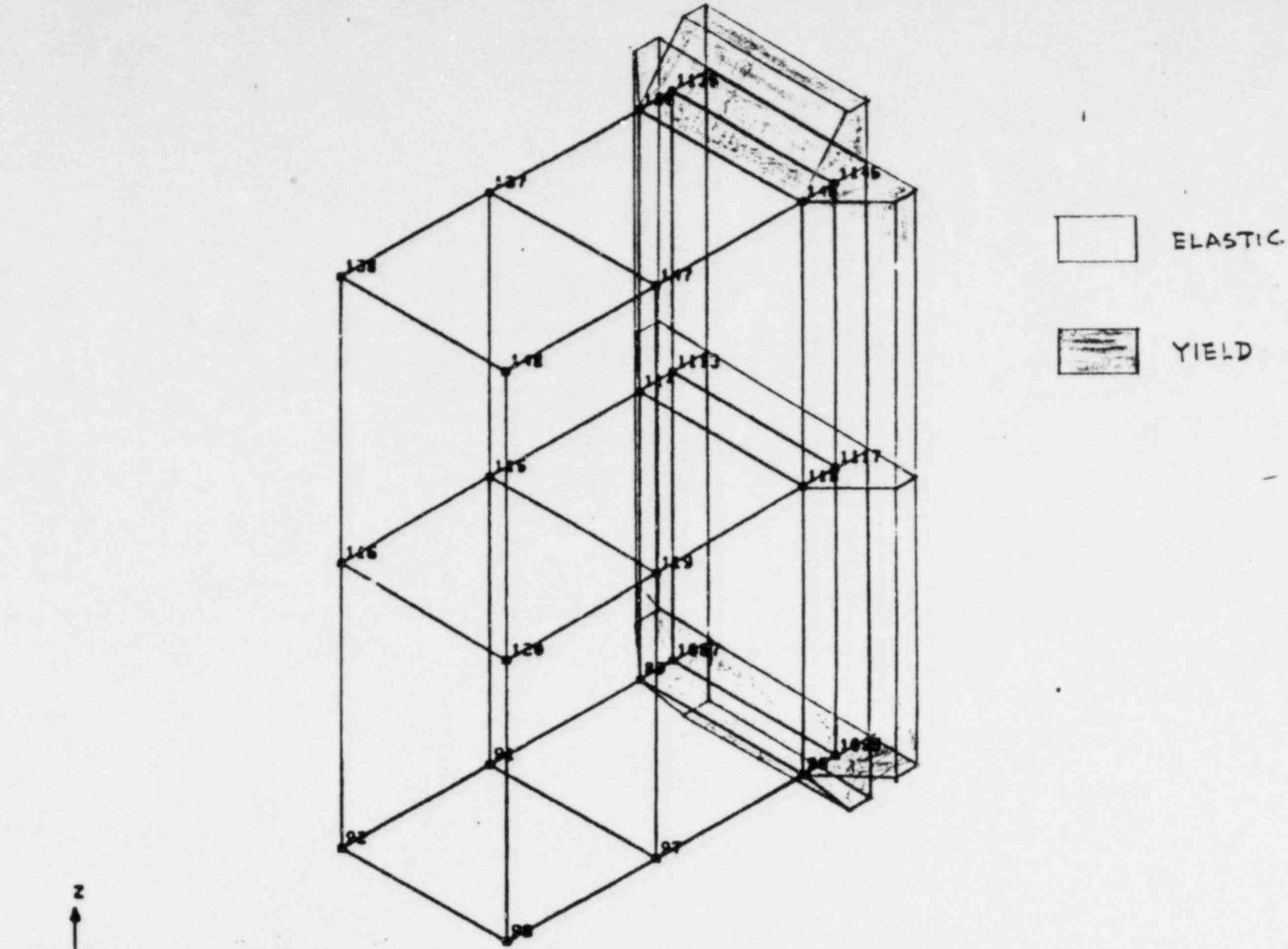


Fig. 7
PIPE WITH SLUG STATICS MODEL

YIELD MAP

LUG DEFORMATION = 1/32"

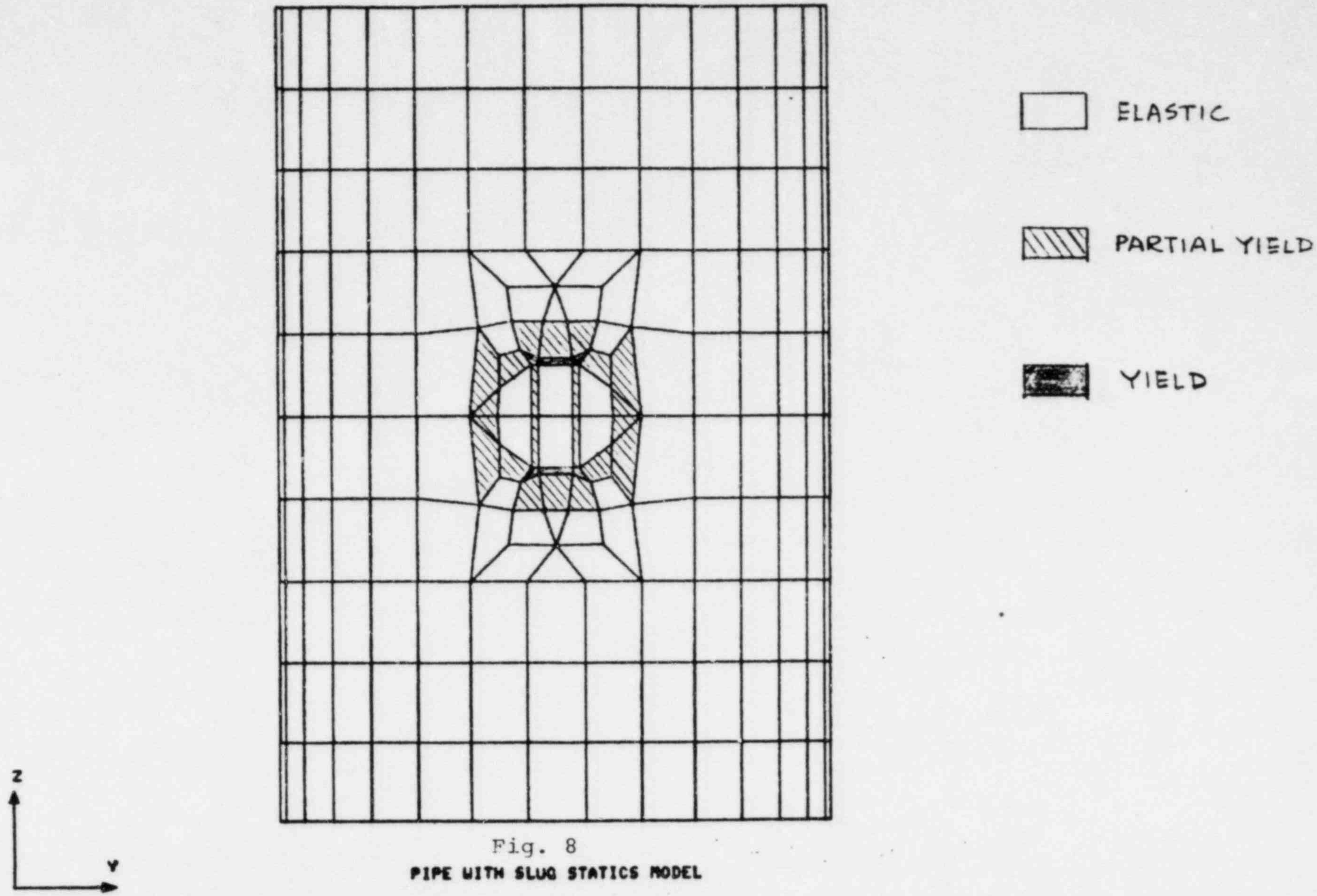
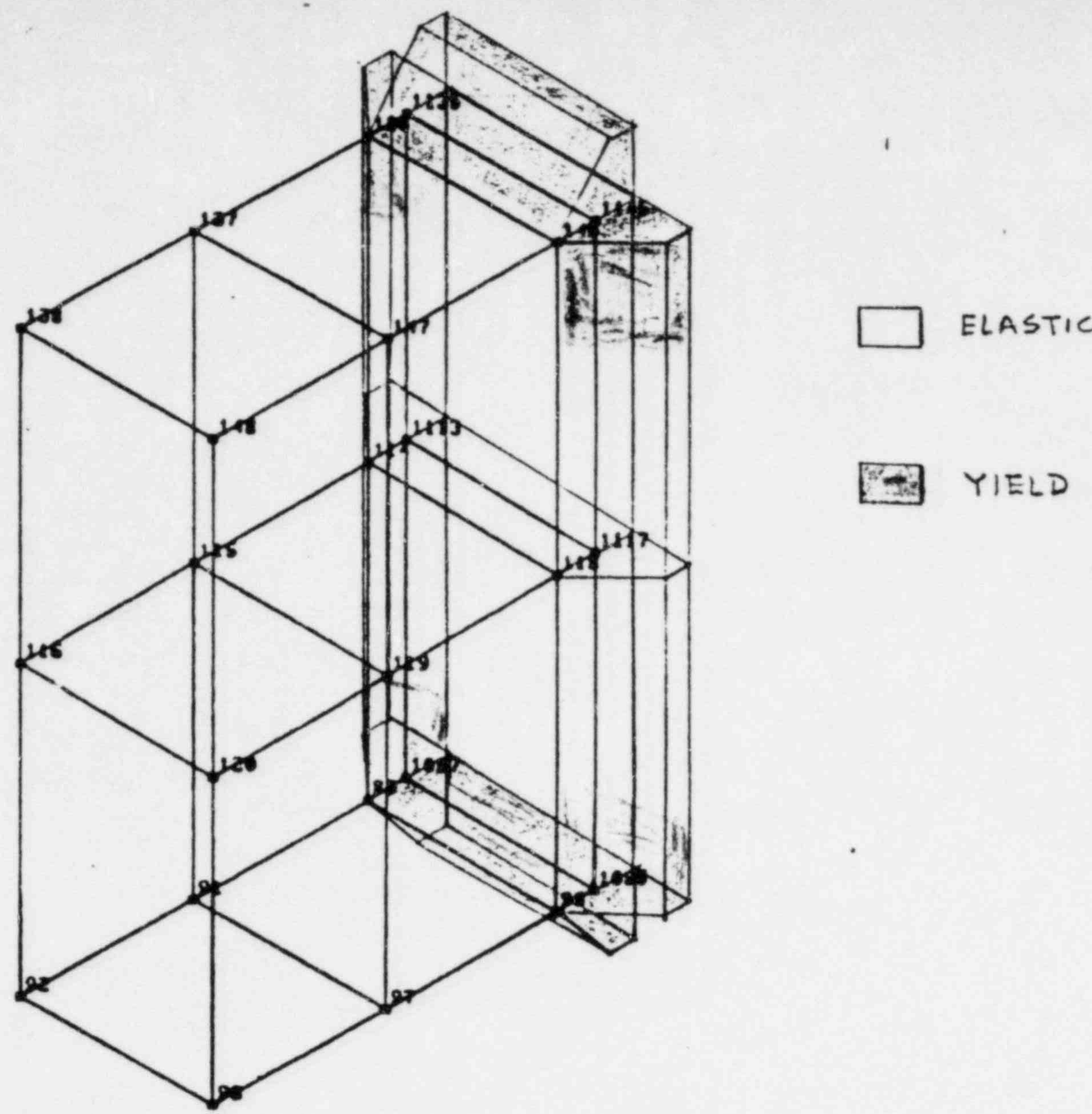


Fig. 8
PIPE WITH SLUG STATICS MODEL

YIELD MAP

LUG DEFORMATION = 1/32"



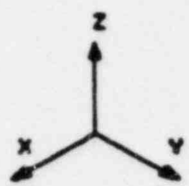


Fig. 9
PIPE WITH SLUG STATICS MODEL

YIELD MAP

LUG DEFORMATION = 1/16"

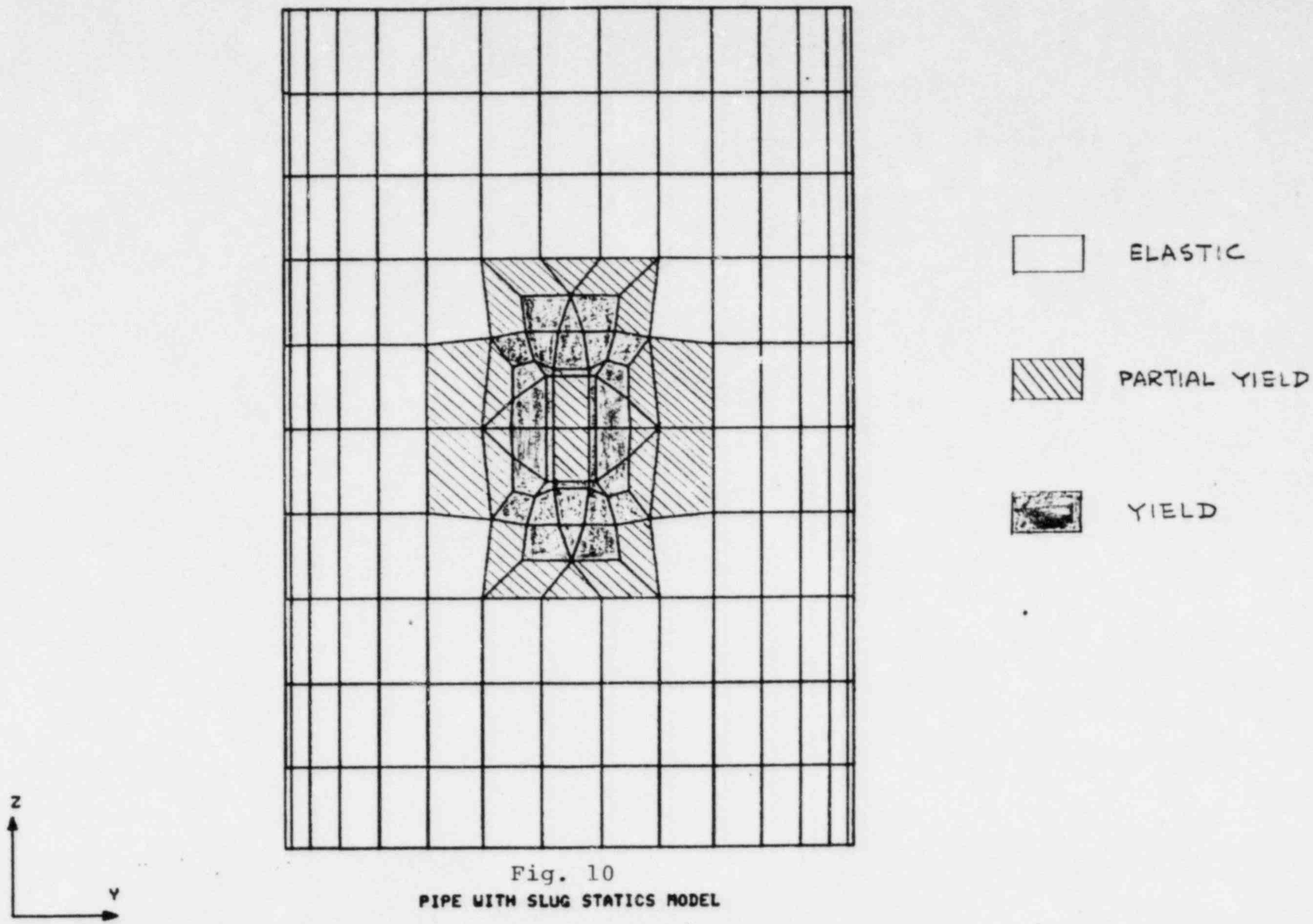


Fig. 10
PIPE WITH SLUG STATICS MODEL

YIELD MAP

LUG DEFORMATION = 1/16"

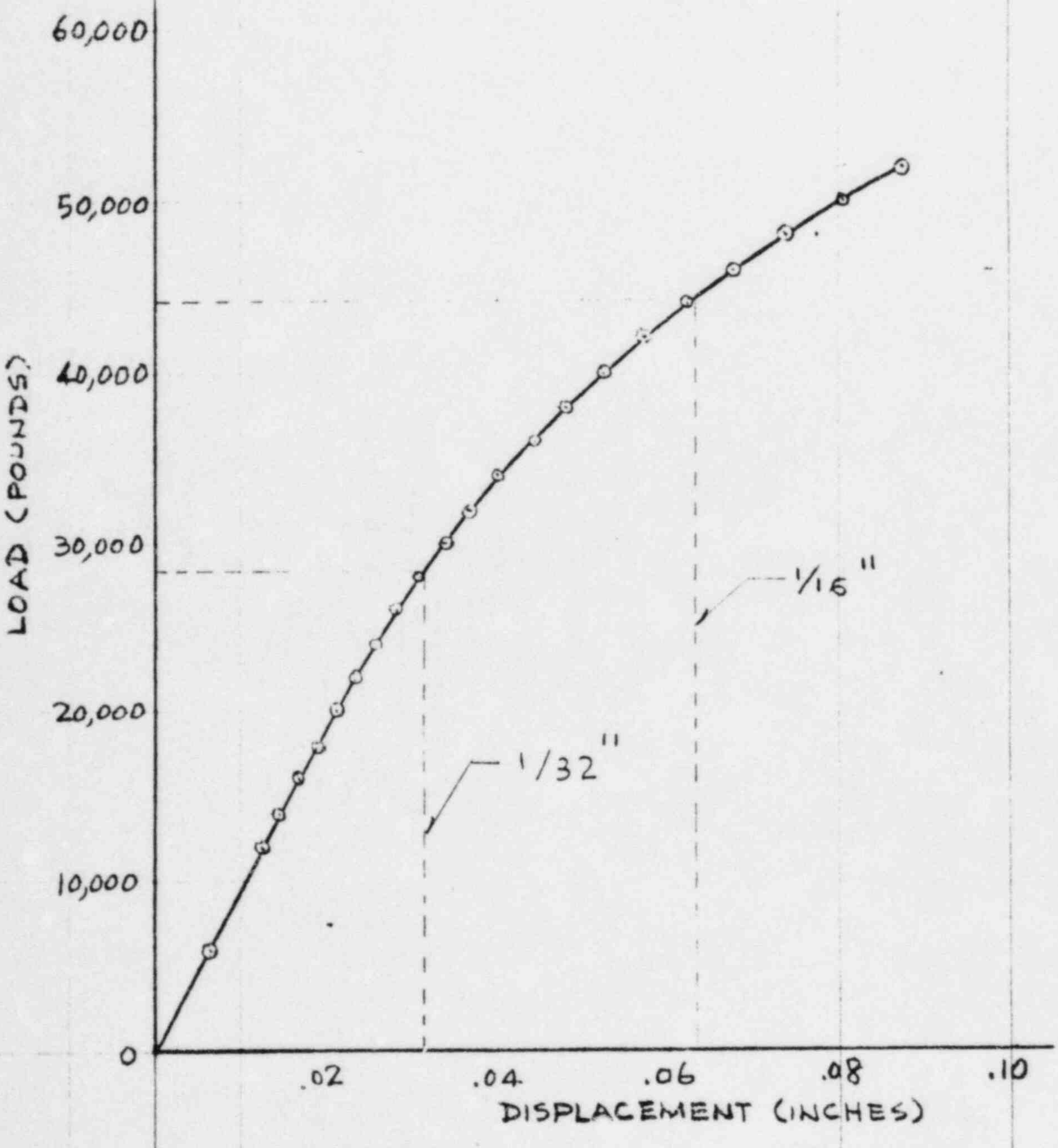


Fig. 11 LOAD-DISPLACEMENT CURVE OF GRID POINT 148

Gibbs & Hill, Inc. Job No. 00-2323-046 Client TUGCO.

Subject BENDING EFFECTS OF UNEVENLY LOADED SHEAR LUGS (2 LUGS ENGAGE)

Calculation Number Sheet No. 1 of 2

Revision	Original Issue	Date	Rev.	Date	Rev.	Date	Rev.	Date	Rev.	Date	
Checking Method #	1										
Preparer	ARu	2/15/84									
Checker	SHR	2/28/84									

BENDING EFFECTS DUE TO UNEVENLY LOADED SHEAR LUGS
(2 lugs are engaged)

The total of 774 welded attachments and anchors, analyzed by G & H, were categorized in accordance with the type of attachment (one trunion, double trunion and shear lugs), and the pipe size. Appendix A provides the overview of the distribution pattern for different attachment types and pipe sizes.

To perform the evaluation of bending effects due to unevenly loaded shear-lugs, 2 (two) such attachments were selected from each of 5 (five) different pipe sizes: 3" OD, 6" O.D, 10" OD, 16" OD and 24" OD, giving the total of 10 samples for evaluation.
The lug attachments selected, were the ones with the longest shear-lugs, ~~thus~~ the axial force for which they were designed has the longest value and the bending effects are the most significant.

The bending stress due to unevenly loaded lugs was added directly to general and local stress values at the welded attachment. The inspection of attached

Gibbs & Hill, Inc. JOB No. 00-2323-046 Client TUCO.

Subject BENDING EFFECTS OF UNEVENLY LOADED SHEAR LUGS (2 lugs engage)

Calculation Number Sheet No. 1 of 2

Revision	Original Issue	Date	Rev.	Date	Rev.	Date	Rev.	Date	Rev.	Date	
Checking Method #	1										
Preparer	ARu	2/15/84									
Checker	Sge	2/24/84									

calculation sheets 1 thru 5 shows clearly that in all cases the total stress is below the allowable.

There are several conservative assumptions which increase the safety factor of this evaluation

1. The force F (Fig 1) acts at the end of the lug. Actually the F force will act closer to ℄ of the lug thus reducing the bending moment.
2. It is assumed that max. bending stress due to F coincides with max. local stress. As shown in Fig. 1 the 70% of max. bending stress exists at welded attachment.
3. The pipe stress and the bending stress due to F are added as absolute sum. The normally used combination of SRSS of bending moments will produce the lower stress value.

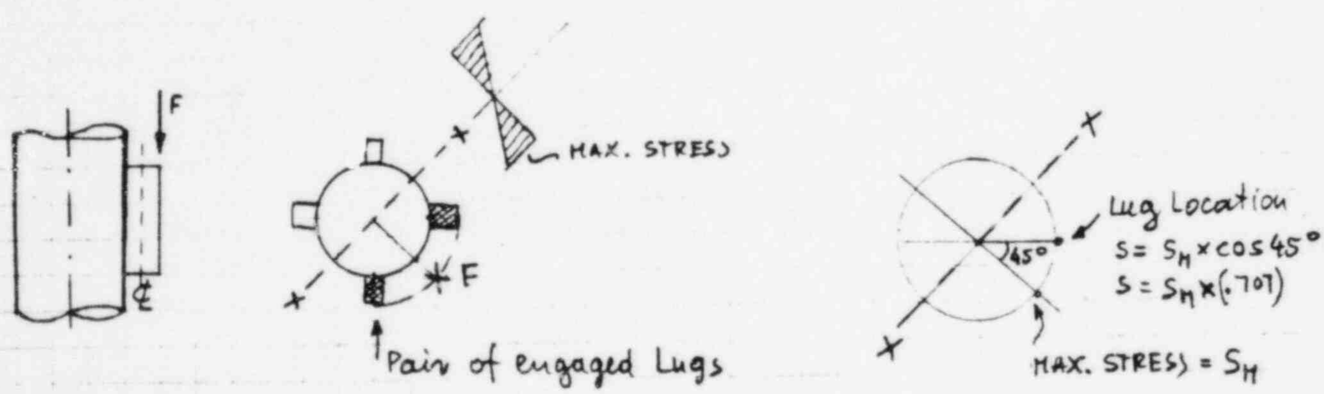


FIG. 1

Checking Method #
1. Line-by-line checking
2. Alternative Calculation Results compared
3. Identical Calculation Results compared
4. Compare inputs and results of computer with corresponding inputs and results of similar codes

F-166, 7-82

PIPE OD.: 3"

Gibbs & Hill, Inc. Job No. Client

Subject BENDING EFFECTS OF UNEVENLY LOADED SHEAR LUGS (2 LUGS ENGAGE)

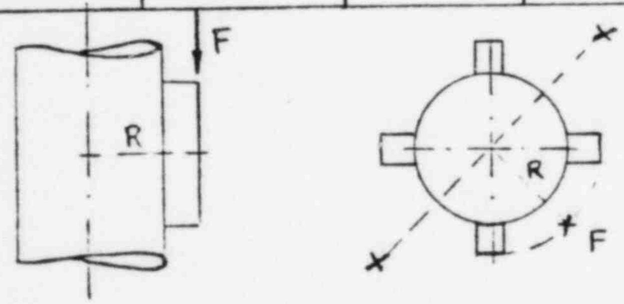
Calculation Number Sheet No. 1 of 5

Revision	Original Issue	Date	Rev.	Date	Rev.	Date	Rev.	Date	Rev.	Date
Checking Method #	1									
Preparer	ARM	2/15/84								
Checker	SAC	2/28/84								

PROB. NO.: AB-1-55C, BRH: CC-1-208-011-C53R, LUG SIZE (WIDTH, HEIGHT, LENGTH): 3/4, 3/4, 1 1/2

PIPE OD.: 3.5", SCHED: 40, MOMENT ARM.: 2.5", SECT. MODUL. Z: 1.724

CONDITION	LOAD F	BEND. MOMENT (LBS-IN)	BENDING STRESS	GEN + LOCAL STRESS	TOTAL STRESS	ALLOWABLE STRESS	REMARKS
Eq. 8	5	12.5	7.3	1194	1,201	S_h= 15,000	
Eq. 9 (½SSE)	151	377.5	219	2270	2,489	$1.5S_h$= 22,500	
Eq. 9 (½SSE)	151	377.5	219	2510	2,729	$1.8S_h$= 27,000	
Eq. 11	20	50	29	1721	1,750	(S_A+S_h)= 37,500	
Eq. 9 (SSE)	229	572	332	2767	3,099	$2.16S_h$= 32,400	



XX - NEUTRAL AXIS OF BENDING DUE TO THE FORCE F.

PROB. NO.: AB-1-55C, BRH.: CC-1-211-004-C53R, LUG SIZE (WIDTH, HEIGHT, LENGTH): 1/2, 1/2, 1

PIPE O.D.: 3.5", SCHED.: 40, MOMENT ARM.: 2.25", SECT. MODUL. Z: 1.724

CONDITION	LOAD F	BEND. MOMENT (LBS-IN)	BENDING STRESS	GEN + LOCAL STRESS	TOTAL STRESS	ALLOWABLE STRESS	REMARKS
Eq. 8	1	2.25	1	1,007	1008	S_h= 15,000	
Eq. 9 (½SSE)	174	391.5	227	1,970	2,197	$1.5S_h$= 22,500	
Eq. 9 (½SSE)	174	391.5	227	2,083	2,310	$1.8S_h$= 27,000	
Eq. 11	137	308.2	179	1,950	2,129	(S_A+S_h)=37,500	
Eq. 9 (SSE)	197	443.2	257	2,272	2,529	$2.16S_h$=32,400	

Checking Method #
1 Line-by-line checking
2 Alternative Calculation Results compared
3 Identical Calculation Results compared
4 Compare inputs and results of computer with corresponding inputs and results of similar codes

PIPE OD.: 6"

Gibbs & Hill, Inc. Job No. Client

Subject BENDING EFFECTS OF UNEVENLY LOADED SHEAR LUGS (2 LUGS ENGAGE)

Calculation Number Sheet No. 2 of 5

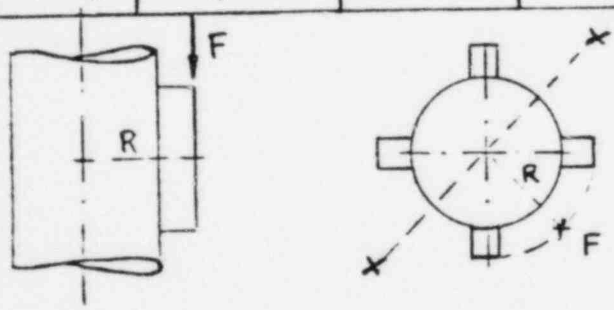
Revision	Original Issue	Date	Rev.	Date	Rev.	Date	Rev.	Date	Rev.	Date	Rev.	Date
Checking Method #	1											
Preparer	ARU	2/15/84										
Checker	SMR	2/28/84										

WIDTH, HEIGHT, LENGTH

PROB. NO.: AB-1-035A, BRH: CT-1-077-407-C72K, LUG SIZE.: 3/4, 3/4, 3

PIPE OD.: 6.625", SCHED: 40S, MOMENT ARM.: 4.063", SECT. MODUL. Z: 8.5

CONDITION	LOAD F	BEND. MOMENT (LBS-IN)	BENDING STRESS	GEN + LOCAL STRESS	TOTAL STRESS	ALLOWABLE STRESS	REMARKS
Eq. 8	0	0	0	1,931	1,931	S_h = 16,600	
Eq. 9 (1/2 SSE)	3508	14,253	1,676	8,755	10,431	$1.5S_h$ = 24,900	
Eq. 9 (1/2 SSE)	3508	14,253	1,676	11,691	13,367	$1.8S_h$ = 29,880	
Eq. 11	135	548	64	4,688	4,752	(S_A+S_h) = 44,250	
Eq. 9 (SSE)	4669	18,970	2,232	11,103	13,335	$2.16S_h$ = 35,856	



XX - NEUTRAL AXIS OF BENDING DUE TO THE FORCE F.

WIDTH, HEIGHT, LENGTH

PROB. NO.: AB-1-035A, BRH.: CT-1-036-405-C72R, LUG SIZE: 1, 1, 3

PIPE O.D.: 6.625", SCHED.: 40S, MOMENT ARM.: 4.313", SECT. MODUL. Z: 8.5

CONDITION	LOAD F	BEND. MOMENT (LBS-IN)	BENDING STRESS	GEN + LOCAL STRESS	TOTAL STRESS	ALLOWABLE STRESS	REMARKS
Eq. 8	17	73	8.6	2154	2,163	S_h = 16,600	
Eq. 9 (1/2 SSE)	1990	8,583	1010	5,439	6,449	$1.5S_h$ = 24,900	
Eq. 9 (1/2 SSE)	1990	8,583	1010	5,862	6,872	$1.8S_h$ = 29,880	
Eq. 11	2053	8,855	1042	13,895	14,937	(S_A+S_h) = 44,250	
Eq. 9 (SSE)	2519	10,864	1278	6,634	7,912	$2.16S_h$ = 35,856	

Checking Method #
1 Line-by-line checking
2 Alternative Calculation Results compared
3 Identical Calculation Results compared
4 Compare inputs and results of computer with corresponding inputs and results of similar codes.

PIPE OD.: 10"

Gibbs & Hill, Inc. Job No. Client

Subject BENDING EFFECTS OF UNEVENLY LOADED SHEAR LUGS (2 LUGS ENGAGE)

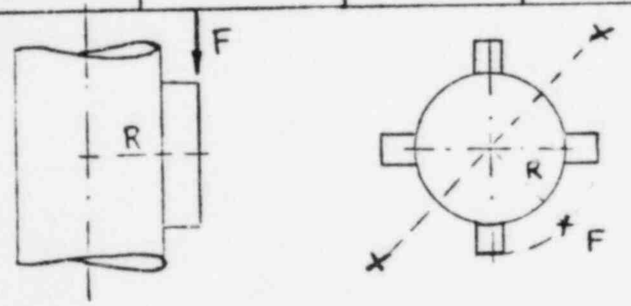
Calculation Number Sheet No. 3 of 5

Revision	Original Issue	Date	Rev.	Date	Rev.	Date	Rev.	Date	Rev.	Date	
Checking Method #	1										
Preparer	ARU	2/15/84									
Checker	SNR	2/28/84									

PROB. NO.: AB-1-180, BRH: YA-1-006-011-C52R, LUG SIZE.: 2, 1, 4 (WIDTH, HEIGHT, LENGTH)

PIPE OD.: 10.75", SCHED: 40, MOMENT ARM.: 6.375, SECT. MODUL. Z: 29.9

CONDITION	LOAD F	BEND. MOMENT (LBS-IN)	BENDING STRESS	GEN + LOCAL STRESS	TOTAL STRESS	ALLOWABLE STRESS	REMARKS
Eq. 8	10	64	2	491	493	S_h = 16,600	
Eq. 9 (½SSE)	1773	11,303	378	4,536	4914	$1.5S_h$ = 24,900	
Eq. 9 (½SSE)	1773	11,303	378	5,258	5636	$1.8S_h$ = 29,880	
Eq. 11	3393	21,630	723	5,361	6084	(S_A+S_h) = 44,250	
Eq. 9 (SSE)	1995	12,718	425	4,949	5374	$2.16S_h$ = 35,856	



xx - NEUTRAL AXIS OF BENDING DUE TO THE FORCE F.

PROB. NO.: AB-1-86B, BRH.: SF-X-005-030-F53R, LUG SIZE: 1, 3, 6 (WIDTH, HEIGHT, LENGTH)

PIPE O.D.: 10.75", SCHED.: 40, MOMENT ARM.: 8.375, SECT. MODUL. Z: 29.9

CONDITION	LOAD F	BEND. MOMENT (LBS-IN)	BENDING STRESS	GEN + LOCAL STRESS	TOTAL STRESS	ALLOWABLE STRESS	REMARKS
Eq. 8	2131	17,847	597	2767	3364	S_h = 18,000	
Eq. 9 (½SSE)	2395	20,058	671	3225	3896	$1.5S_h$ = 27,000	
Eq. 9 (½SSE)	2395	20,058	671	6765	7,436	$1.8S_h$ = 32,000	
Eq. 11	5280	42,220	1,412	15,422	16,834	(S_A+S_h) = 46,000	
Eq. 9 (SSE)	2533	21,214	709	3,458	4,167	$2.16S_h$ = 38,880	

Checking Method #
1 Line-by-line checking
2 Alternative Calculation Results compared
3 Identical Calculation Results compared
4 Compare inputs and results of computer with corresponding inputs and results of similar codes

Gibbs & Hill, Inc. Job No. Client

Subject: BENDING EFFECTS OF UNEVENLY LOADED SHEAR LUGS (2 LUGS ENGAGE)

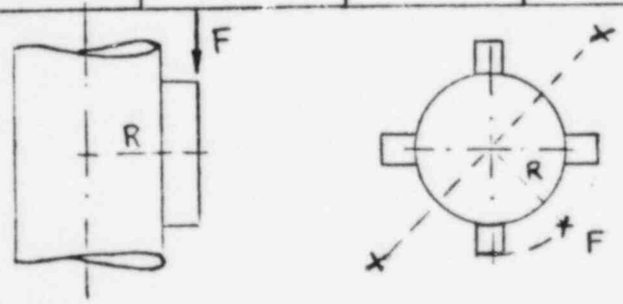
Calculation Number

Revision	Original Issue	Date	Rev.	Date	Rev.	Date	Rev.	Date	Rev.	Date
Checking Method #	1									
Preparer	ARU	2/15/84								
Checker	SK	2/28/84								

PROB. NO.: AB-1-035A, BRH.: CT-1-013-414-C82K, LUG SIZE (WIDTH, HEIGHT, LENGTH): 1½, 1½, 3

PIPE OD.: 16", SCHED.: 30 ST, MOMENT ARM.: 9.5", SECT. MODUL. Z: 70.3

CONDITION	LOAD F	BEND. MOMENT (LBS-IN)	BENDING STRESS	GEN + LOCAL STRESS	TOTAL STRESS	ALLOWABLE STRESS	REMARKS
Eq. 8	0	0	0	3497	3,497	S_h = 16,600	
Eq. 9 (½ SSE)	3,747	35,597	506	6550	7,522	$1.5S_h$ = 24,900	
Eq. 9 (½ SSE)	3747	35,597	506	8397	8,903	$1.8S_h$ = 29,880	
Eq. 11	5	47.5	.7	6508	6,509	(S_A+S_h) = 44,250	
Eq. 9 (SSE)	3745	35,577	506	8350	8,856	$2.16S_h$ = 35,856	



XX - NEUTRAL AXIS OF BENDING DUE TO THE FORCE F.

PROB. NO.: AB-1-035A, BRH.: CT-1-013-415-C62K, LUG SIZE (WIDTH, HEIGHT, LENGTH): 1½, 1½, 4

PIPE O.D.: 16", SCHED.: 30 ST, MOMENT ARM.: 9.5", SECT. MODUL. Z: 70.3

CONDITION	LOAD F	BEND. MOMENT (LBS-IN)	BENDING STRESS	GEN + LOCAL STRESS	TOTAL STRESS	ALLOWABLE STRESS	REMARKS
Eq. 8	0	0	0	3,474	3474	S_h = 16,600	
Eq. 9 (½ SSE)	9821	93,300	1,327	6,995	8,322	$1.5S_h$ = 24,900	
Eq. 9 (½ SSE)	9821	93,300	1,327	9,519	10,846	$1.8S_h$ = 29,880	
Eq. 11	871	8,275	118	4,819	4,937	(S_A+S_h) = 44,250	
Eq. 9 (SSE)	13881	131,870	1,876	8,360	10,236	$2.16S_h$ = 35,856	

Gibbs & Hill, Inc. Job No. Client

Subject BENDING EFFECTS OF UNEVENLY LOADED SHEAR LUGS (2 LUGS ENGAGE)

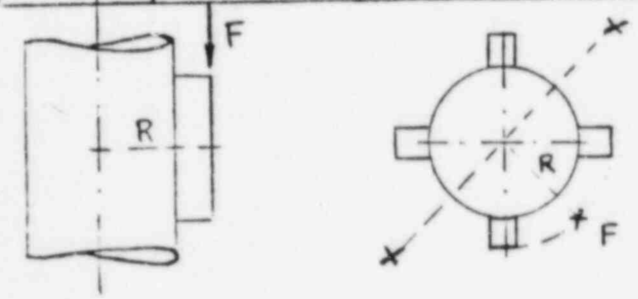
Calculation Number Sheet No. 5 of 5

Revision	Original Issue	Date	Rev.	Date	Rev.	Date	Rev.	Date	Rev.	Date	
Checking Method #	1										
Preparer	ARM	2/15/84									
Checker	4HR	4/28/84									

PROB. NO.: AB-1-60, BRH: CC-2-050-001-A435, LUG SIZE: 4, 1 3/4, 5 (WIDTH, HEIGHT, LENGTH)

PIPE OD.: 24", SCHED: 20 STD, MOMENT ARM: 13.75", SECT. MODUL. Z: 161.9

CONDITION	LOAD F	BEND. MOMENT (LBS-IN)	BENDING STRESS	GEN + LOCAL STRESS	TOTAL STRESS	ALLOWABLE STRESS	REMARKS
Eq. 8	3,157	43,409	268	3538	3,806	S_h = 15,000	DEAD WGT. SUPPORT ON A VERTICAL PIPE
Eq. 9 (½ SSE)	NA	NA	NA	4212	4,212	1.5 S_h = 22,500	
Eq. 9 (½ SSE)	NA	NA	NA	4638	4,638	1.8 S_h = 27,000	
Eq. 11	NA	NA	NA	5190	5,190	(S_A+S_h) = 37,500	
Eq. 9 (SSE)	NA	NA	NA	4645	6,945	2.16 S_h = 32,400	



XX - NEUTRAL AXIS OF BENDING DUE TO THE FORCE F.

PROB. NO.: AB-1-61B, BRH.: CC-1-070-002-A33R, LUG SIZE: 2, 2½, 5 (WIDTH, HEIGHT, LENGTH)

PIPE O.D.: 24", SCHED.: 20 ST, MOMENT ARM.: 14.5", SECT. MODUL. Z: 161.9

CONDITION	LOAD F	BEND. MOMENT (LBS-IN)	BENDING STRESS	GEN + LOCAL STRESS	TOTAL STRESS	ALLOWABLE STRESS	REMARKS
Eq. 8	9056	131,312	811	5115	5,926	S_h = 15,000	
Eq. 9 (½ SSE)	11844	171,738	1,061	6110	7,171	1.5 S_h = 22,500	
Eq. 9 (½ SSE)	11844	171,738	1,061	13607	14,668	1.8 S_h = 27,000	
Eq. 11	31214	452,603	2,796	34,319	37,115	(S_A+S_h) = 37,500	
Eq. 9 (SSE)	13458	195,141	1,205	6,686	7,891	2.16 S_h = 32,400	

Checking Method #
1 Line-by-line checking
2 Alternative Calculation Results compared
3 Identical Calculation Results compared
4 Compare inputs and results of computer with corresponding inputs and results of similar codes

F-166, 7-82

Appendix. A.

Date . . . .

Calc By . . . .

Chk'd/Appd. By . . . .

Gibbs & Hill, Inc

ENGINEERS, DESIGNERS, CONSTRUCTORS

NEW YORK

Filing Code . . . .

Sheet No. . . . . . Of . . . .

G & H Job No. . . . .

Subject . . . . Ref. Dwg./Spec. No. . . . .