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the southern electric system

June 6, 1979

Docket Nos. 50-348
50-364
NRC IE Bulletin No. 79-02

Mr. James P. O'Reilly
U. S. Nuclear Regulatory Commission
Region II
101 Marietta Street, N. W.
Suite 3100
Atlanta, Georgia 30303

Dear Mr. O'Reilly:

In response to IE Bulletin 79-02, Pipe Support Base Plate Design Using Concrete Expansion Anchor Bolts, dated March 8, 1979, Alabama Power Company submits the following response for Farley Units 1 and 2.

Yours very truly,

F. L. Clayton, Jr.

FLCJr/KAP/mmb

Enclosure

cc: Mr. R. A. Thomas
Mr. G. F. Trowbridge

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July 6, 1979

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This report is in response to I.E. Bulletin No. 79-02 concerning pipe support base plate designs using concrete expansion anchor bolts. In response to this bulletin, Alabama Power has initiated a testing, verification, design review and repair program for concrete anchor bolts to ensure adequacy of installation. The specific responses to the bulletin are provided below:

Response to Item 1:

Originally, flexibility of the base plate was not specifically taken into account in determining the concrete anchor bolt loads. Alabama Power Company is in the process of performing a design review that takes base plate flexibility into account in determining the concrete anchor bolt loads. This design review is described below.

Grinnell, Southern Company Services, Inc. (SCS) and Bechtel Power Corporation (as appropriate) are utilizing the calculated Westinghouse/Bechtel piping system hanger/seismic restraint design loads and the ICES STRUDL Program to develop design loading conditions (forces and moments) at the centroid of each attachment to the hanger/seismic restraint base plates. For simple cases the forces and moments are obtained by hand calculations. Bechtel then utilizes this information in conjunction with the inspection and test data for analyses of all base plate anchor bolts to determine if the existing base plate anchorage is adequate to meet the design loads with the prescribed safety factor or if corrective action is necessary. This determination is performed in accordance with FNP-1-ETP-123 (a Farley Nuclear Plant Engineering Technical Procedure) which has been reviewed by NRC, I&E Region II Staff.

More specifically, a summary of the evaluation of base plate design by Bechtel is as follows:

1. The method of analysis is based on an empirical-analytic technique developed by Bechtel which takes into account design parameters such as flexibility of the base plate and concrete anchor stiffness (based on actual pre-loaded load-displacement curves furnished by the manufacturer). This method has been verified with appropriate finite element analytical solutions. Description of this empirical-analytic technique is provided in Attachment I.

   A computer program for the empirical-analytical technique has been implemented for determining the anchor bolt loads for the majority of applications. For other cases refer to Item 3 below. This program requires plate dimensions, number of bolts, bolt size, bolt spacing, bolt stiffness, the applied forces and the allowable bolt shear and tension loads as inputs.

   The allowable loads for a given bolt are determined based on the concrete edge distance, bolt spacing, embedment length, shear cone overlapping, manufacturer's ultimate capacity, and safety factor.

   The program computes the forces on the bolt and calculates a shear-tension interaction based on allowable loads. An interaction value greater than the allowable is accepted as failure of the bolt (safety factor less than required). Unit 1 shear-tension interaction analyses are computed utilizing a linear relation. Even though a subsequent squared interaction formula is acceptable and its use has been justified by Bechtel in representing the shear-tension interaction, Alabama Power has chosen to continue with the use of linear relationship recognizing that the results from this technique are more conservative.

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The empirical-analytic method does not consider prying action for the following reasons:

a. Where the anchorage system capacity is governed by the concrete shear cone, the prying action would result in an application of an external compressive load on the cone and would not affect the anchorage capacity.

b. Where the bolt pull out determines the anchorage capacity, the additional load carried by the bolt due to the prying action will be self-limiting since the bolt stiffness decreases with increasing load. At higher loads the bolt extensions will be such that the corners of the base plate will separate from the concrete and the prying action will be relieved. This phenomena has been found to occur even when the bolt stiffnesses in the finite element analysis were varied from a high to a low value corresponding to both typical initial stiffnesses and to values beyond the allowable design load.

2. Calculated bolt loads are used to check stresses in the support base plate to ensure they are less than the allowable stress as specified by the American Institute of Steel Construction (AISC) code.

3. For special cases where the design of the support plate does not lend itself to this method, standard engineering analytical techniques with conservative assumptions are being employed.

All anchor bolts within the scope of this program shall be evaluated by Bechtel in accordance with the bolt acceptance criteria, current "as built" drawings, and the bolt design loads to determine if corrective action is required.

If any bolt on a base plate fails the acceptance criteria described above, one or more of the following actions are being taken:

a. Re-analyze the base plate assuming that the bolt is failed (bolts carries zero load).

b. Re-analyze the base plate incorporating bolt replacement as corrective action.

c. In those instances where repair corrective actions result in a piping support modification, Bechtel/Westinghouse (as appropriate) will analyze the effect of such modifications on the analysis of the piping system.

Response to Item 2·

In general, the current industry approach concerning the use of safety factors for various design loading conditions are described below:

1. Factors of safety (i.e. ratio of bolt ultimate capacity to design load) of four for wedge type and shell type anchor bolts, for service (operating) load cases, are used.

2. For factored loadings (which include accident/extreme environmental loads) safety factors of 1.2 and 3.0 are used commensurate with the provisions of Section B.7.2 of the Proposed Addition to Code Requirements for Nuclear Safety Related Concrete Structures (ACI-349-76) August, 1978. The factors of safety are consistent with the ultimate strength design method. A factor of safety of 1.2 is used if the failure mechanism for the anchor is controlled by the bolt material. If the failure mechanism is controlled by concrete shear cone action, a factor of safety of 3.0 is used. The utilization of sampling and quality control methods used are integral to selecting the factor of safety of 3.0.

3. For general structural design in steel, the AISC Specification has an approximate factor of safety of 1.7 for services loading (for example, column buckling). For factored accident/extreme environmental loads, a factor of safety of 1.1 is used on nuclear structures for both ductile (yielding) and non-ductile (column buckling) failures. In concrete design for factored loads, a factor of safety of 1.1 is used for flexural and tension action and 1.2 for shear action. It can be observed that a higher factor of safety is assigned to the expansion anchor only if its capacity is governed by the shear cone.

Based on the above interaction of design parameters and on the following additional factors, Alabama Power Company has concluded that a safety factor of 2 is sufficient to ensure operability of Seismic Category I piping system in the event of a seismic event:

a. 100% verification testing program with total Quality Control coverage of scoped systems (described in question 4) which minimizes installation uncertainties (e.g. verification of torque, embedment depth, nut engagement, plate configuration, expansion of shell, etc.)

b. Verification that plates are not overstressed by bolt loadings (e.g. consideration of minimum edge distance and proper bolt spacing).

Response to Item 3:

In the original design of the piping systems Bechtel/Westinghouse considered deadweight, thermal stresses, seismic loads, and dynamic loads (e.g. certain rapid valve openings and closings) in the generation of the static equivalent pipe support design loads.

The safety factors used for concrete expansion anchors, installed on supports for safety related piping systems, were not increased for loads which are cyclic in nature. The use of the same safety factor for cyclic and static loads is based on the Fast Flux Test Facility (FFTF) Tests*. The test results indicate:

1. The expansion anchors successfully withstood two million cycles of long term fatigue loading at a maximum intensity of 0.20 of the static ultimate capacity. When the maximum load intensity was steadily increased beyond the aforementioned value and cycled for 2,000 times at each load step, the observed failure load was about the same as the static ultimate capacity.

2. The dynamic load capacity of the expansion anchors, under simulated seismic loading, was about the same as their corresponding static ultimate capacities.

*Drilled - In Expansion Bolts Under Static and Alternating Loads, Report No. BR-5853-C-4, Rev. 1, by Bechtel Power Corporation, October 1976.

Response to Item 4:

Since existing Q.C. documentation is not adequate to document the installation parameters associated with each anchor bolt, the following programs have been undertaken:

Test Program

Alabama Power Company initiated a program to randomly select and test a sample of anchor bolts installed in Seismic Category I, Safety Related, 2½ inch and greater piping systems. Initial results of that program revealed that statistical sampling would not be sufficient to provide a 95% confidence level in anchor bolt reliability. As a result, the anchor bolt testing program was expanded to include 100% verification of anchorages associated with pipe hangers for those systems or portions of systems required to meet design basis accidents and those required to bring the plant to cold shutdown condition. These piping systems included in the program are:

a. Seismic Category I; Safety Related 2½ inches and above.

b. Seismic Category I; Safety Related ASME Section III, Class 1 piping, under 2½ inch.

c. Seismic Category I; Safety Related of other classes for which the designer performed detailed analysis.

d. All piping through containment penetrations.

The scope of this program given above has been reviewed and approved by the NRC I&E Region II Staff.

The specific systems involved in this testing program are listed in LER 79-21/01T.

Anchor bolts on hangers within the scope of this program are tested for the following parameters:

a. embedment - Actual embedment depth is determined.

b. grout - The presence of grout and leveling nuts is determined to ensure proper torque test.

c. type of bolts - Verification is made that installed bolts are in accordance with design bill of material.

d. number of bolts - Verification is made that the installed number of bolts is in accordance with design bill of material.

e. bolt dimensional measurements - Dimensional measurements are taken to determine the degree of compliance with the manufacturers' recommended bolt installation requirements.

f. torque - Bolts are torqued to a level such that the resultant tensile load on the anchor is equal to ¼ of the manufacturers' published pull-out load. For shell type bolt torque tests to be considered valid, the shell shoulder must not touch the base plate.

NOTE: A torque/tension relationship was developed for Hilti wedge type anchors based on tests performed at Farley. Torque/tension relationships were developed for Phillips shell type anchors under the direction of Bechtel Corporation with technical consultation from ITT-Phillips Drill Division at Plant Hatch. Since these relationships were completed and the majority of anchor bolt field verification was performed prior to I&E Bulletin 79-02 Revision 1 issuance, no site specific testing for the shell type anchors was performed. Torque requirements for Wej-it wedge type anchors were obtained from vendor data.

g. base plate dimensional measurements - Dimensional measurements of base plate parameters which could affect bolt loading or capacity (e.g. bolt spacing, edge distance) are taken.

Based on the results of the test program and the empirical-analytic evaluation, anchors are being repaired according to the following criteria:

i. Repair individual base plate anchorages not having a safety factor of at least 2.0.

ii. Repairs are done so that all repaired bolts have a safety factor of at least 4.0 and all base plate anchorages have a safety factor of at least 2.0.

iii. All repairs are done in accordance with written procedures and quality control checks.

The failure to test inaccessible anchor bolts will be justified by analysis which substantiates operability of the affected systems without assuming integrity of the anchorages which are not tested.

Preloading

Available test data indicates that it is not necessary that the bolt preload should be equal to or greater than the bolt design load because pipe supports and anchors are subjected to both static and dynamic loads. The dynamic loads such as seismic loads are short duration cyclic loads and are not fatigue type loads, therefore the amount of preload on the bolts will not greatly affect the performance of the anchorage. The initial installation torque on the bolt accomplishes the purpose of setting the anchor, but the ultimate capacity of the bolt is not affected by the amount of preload present in the bolt at the time of cyclic loading. For vibratory loads, the expansion anchors have successfully withstood long term fatigue conditions as discussed in the previous section (FFTF tests).

Response to Item 5:

The Alabama Power Company testing, analysis, and repair program will not be completed by July 6, 1979; however, Farley Nuclear Plant Unit 1 is currently shutdown during the present critical power demand period to complete the above program. The testing, analysis and repair program described in Item 4 will be completed prior to return to power generation. Documentation of the program will be maintained on site.

Response to Item 6:

A similar program for the verification of Unit 2 anchorages will be developed as the result of experience gained from Unit 1 activities. A full description of this program will be transmitted to NRC by a supplement to this bulletin response. Such verification program will be completed prior to initial criticality. Currently, the construction activities associated with Unit 2 are temporarily suspended due to the Company's financial condition.

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ATTACHMENT I

DETERMINATION OF EXPANSION

ANCHOR BOLT LOADS IN PIPE

SUPPORT BASE PLATES

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Summary

This report deals with the determination of anchor bolt loads in steel base plates supporting Seismic Category I piping systems. The anchors in question are of the expansion type. The loads are applied to the base plate through some type of attachments, usually concentric with the base plate, and could comprise of moments and forces in three directions. A review of the typical base plates used in supporting the subject piping systems indicate that the majority of them have either a 4, 6 or 8 bolt connection. The plate thicknesses usually vary from 1/2" to 1 1/2" and are not generally stiffened. The present formulation will, therefore, be devoted to base plate anchorage systems with aforementioned physical characteristics.

From a purely analytical standpoint the load distribution in a base plate anchorage system is fairly complex and it is necessary, therefore, that certain simplifying assumptions be made to arrive at conservative yet practical solutions. However, such assumptions should take into consideration the following parameters which might affect the load distribution in the anchorage system.

a. Flexibility of the base plate: considering the bending effects.
b. Bolt stiffness: to be based on actual preloaded load displacement curves as furnished by the manufacturer.
c. Prying action

For expansion anchor bolts prying action will not be critical for the following reasons:

a. Where the anchorage system capacity is governed by the concrete shear cone, the prying action would result in an application of an external compressive load on the cone and would not therefore affect the anchorage capacity.
b. Where the bolt pull out determines the anchorage capacity, the additional load carried by the bolt due to the prying action will be self-limiting since the bolt stiffness decreases with increasing load. At higher loads the bolt extension will be such that the corners of the base plate will lift off and the prying action will be relieved. This phenomena has been found to occur when the bolt stiffnesses in the Finite Element Analysis were varied from a high to a low value.

Method of Analysis for Anchor Bolt Loads:

In general, the Finite Element Method of Analysis may be used to analyze the base plates under consideration. However, such an approach will be both time consuming and expensive considering the number of base plates involved. A quasi analytical approach has been formulated taking into account the base plate flexibility and the bolt stiffness. The results of the analytical solution have been verified with appropriate Finite Element solutions and have shown good correlation for the typical cases studied.

INTRODUCTION:

THE PURPOSE OF THIS STUDY WAS TO DEVELOP AN ANALYTICAL METHOD FOR DETERMINING TENSION LOADS ON EXPANSION ANCHORS USED AS ANCHORS FOR PIPE SUPPORT BASE PLATES. FINITE ELEMENT ANALYSES (REF-1) SERVED AS A DATA BASE FOR DEVELOPING LESS EXPENSIVE AND LESS TIME CONSUMING ANALYTICAL, METHODS. THE METHOD WHICH IS PRESENTED AS A RESULT OF THIS STUDY USES PLATE FLEXIBILITY AND BOLT STIFFNESS AS THE PRIMARY PARAMETERS. THIS METHOD WILL BE COMPUTERIZED FOR 4, 6 & 8-BOLT PATTERNS.

ANALYSIS:

IN THE QUASI ANALYTICAL MODEL PRESENTED HERE, THE PLATE IS PRIMARILY TREATED AS A BEAM ON ELASTIC SPRINGS. BASE PLATES WITH THREE DIFFERENT BOLT CONFIGURATIONS HAVE BEEN CONSIDERED.

ASSUMPTIONS:

(a) SYMMETRICAL BOLT PATTERNS
(b) CENTROIDAL LOADING
(c) ATTACHMENT DIMENSIONS SMALL COMPARED TO THE PLATE DIMENSIONS
(d) UNITS FOR ALL VARIABLES:
    FORCE = KIPS
    LENGTH = INCHES

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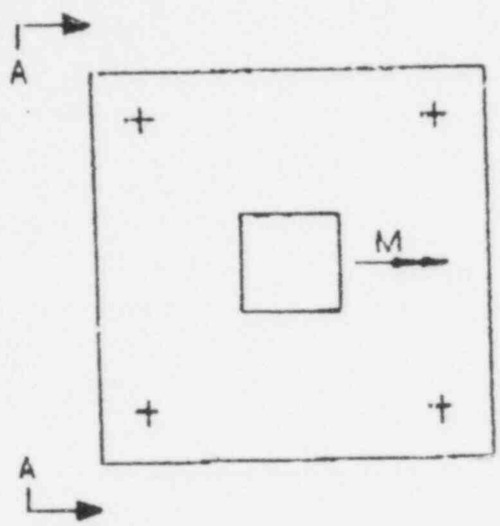
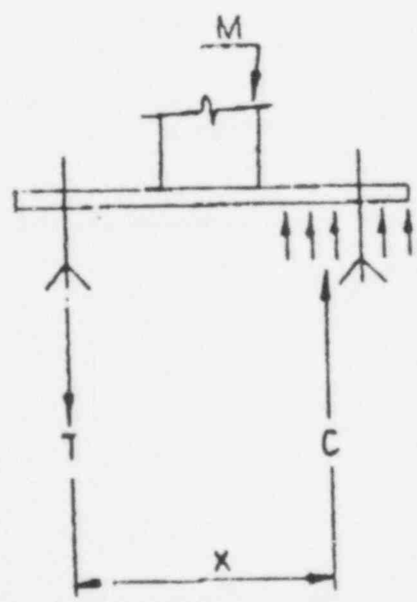
(I) 4-BOLT PATTERN - MOMENT AND TENSION LOADING CASES

GIVEN A PLATE WITH A 4-BOLT PATTERN AND A MOMENT ABOUT ONE AXIS: THIS PLATE WILL BE MODELED AS A BEAM



SECTION A-A



WHERE:

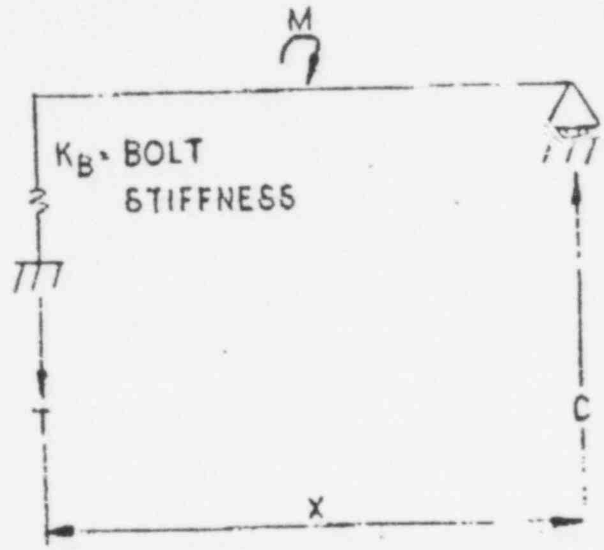
T: TOTAL TENSION (KIP)

C: RESULTANT OF COMPRESSIVE STRESS BLOCK (KIP)

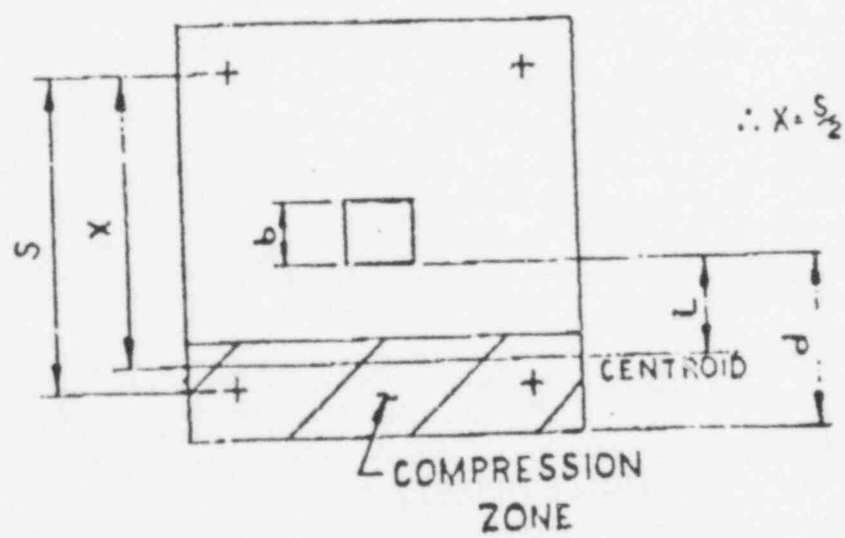
$T(X) + C(X) = M$

THE BEAM WILL BE IDEALIZED AS BEING SUPPORTED AT THE LOCATION OF THE COMPRESSIVE FORCE RESULTANT. THEREFORE, IF THE COMPRESSION CENTROID CAN BE LOCATED, "X" BECOMES KNOWN AND "T" CAN BE CALCULATED.

$T \cdot X = M$



FOR A 4-BOLT PATTERN LOADED CENTROIDALLY:



$\therefore X = \frac{S}{2} + \frac{b}{2} + L$

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CONCEPTUALLY,

$L = \text{FUNCTION}\ (t, d, K_b)$

WHERE,

L = DISTANCE FROM EDGE OF ATTACHMENT TO THE CENTER OF COMPRESSION (IN.)

t = PLATE THICKNESS (IN.)

d = DISTANCE FROM EDGE OF ATTACHMENT TO THE EDGE OF THE PLATE (IN)

K_b = BOLT STIFFNESS (K/IN.)

BASED ON A NUMBER OF FINITE ELEMENT ANALYSIS RESULTS (i.e. VARYING T, d & K_b), THE FOLLOWING EMPIRICAL RELATIONSHIP WAS DERIVED:

$$L = 3.5 \left[\left(\frac{t}{d}\right)^{\frac{2}{3}} \left(\frac{44}{K_b}\right)^{\frac{1}{3}} \right] (d) \qquad (1)$$

WHERE $L \leq d$

ONCE L IS CALCULATED, TOTAL TENSION (T) AND BOLT LOAD (F_T) CAN BE FOUND:

$$T = \frac{M}{\frac{s}{2} + \frac{b}{2} + L} \qquad (2)$$

$$F_T = \frac{T}{2} = \frac{M}{s + b + 2L} \qquad (3)$$

FOR CENTROIDALLY LOADED 4-BOLT PATTERNS ONLY

THIS METHOD CAN BE EXTRAPOLATED FOR USE WITH COMBINED LOADING CASES.

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FOR BIAXIAL BENDING:

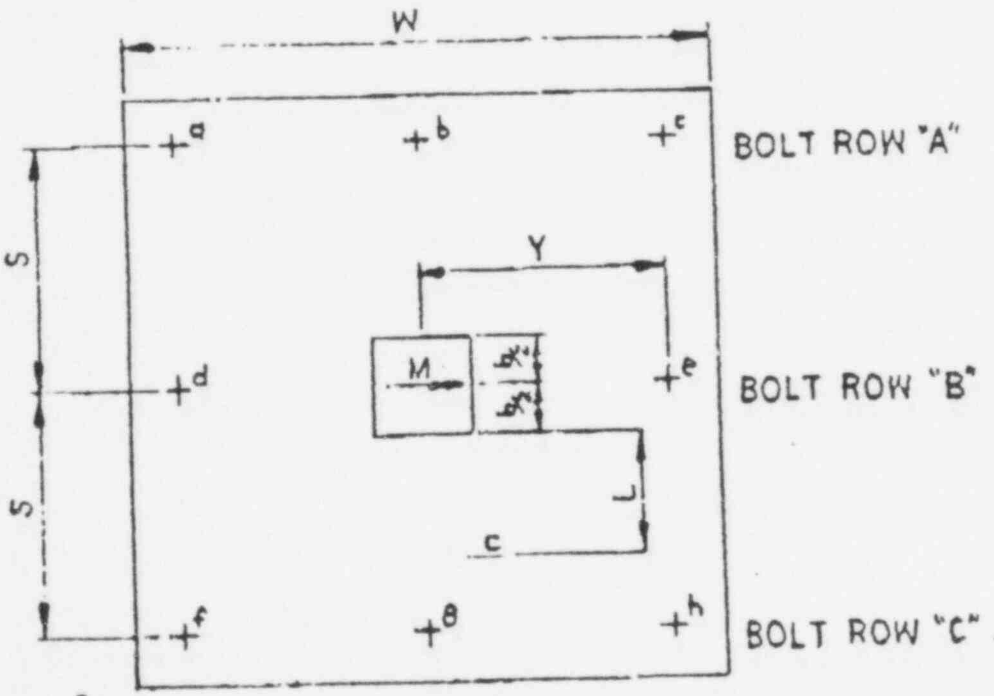
$$\text{CRITICAL } F_T = \frac{M}{S_x + b_x + 2L_x} + \frac{M_y}{S_y + b_y + 2L_y} \qquad (4)$$

FOR COMBINED BENDING AND TENSION:

$$\text{CRITICAL } F_T = \frac{M}{S + b + 2L} + \frac{T}{4} \qquad (5)$$

SINCE L VARIES WITH t, d & K, THE METHOD FOR FINDING L CAN BE USED FOR MANY PLATE AND BOLT PATTERNS. ONCE L IS KNOWN THE PLATE CAN BE MODELED AS A BEAM ON SPRINGS. THE BEAM CAN BE SOLVED BY VARIOUS METHODS AND THE TOTAL TENSION FORCE FOR ANY ROW OF BOLTS CAN BE CALCULATED. THIS WILL BE DEMONSTRATED FOR SIX AND EIGHT BOLT PATTERNS IN THE FOLLOWING DETAILS.

(II) 8-BOLT PATTERN - MOMENT LOADING CASE



BEAM MODEL:

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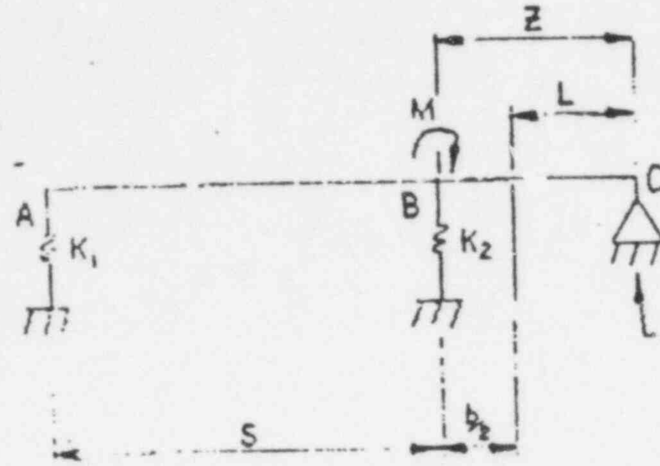

K_B = BOLT STIFFNESS

$I = \frac{Wt^3}{12}$

THE REACTIONS FOR THIS INDETERMINATE BEAM MODEL CAN BE SOLVED USING VIRTUAL WORK PRINCIPLE. THE FOLLOWING EQUATIONS WERE DERIVED FOR 8-BOLT PATTERNS:

$Z = \frac{b}{2} + L$ WHERE L IS DETERMINED FROM EQ (1)

$EI = .417Wt^3$ (KIP IN²)

IF REDUNDANTS ARE TAKEN AT "C":

$$EI\,\delta_{co} = \frac{EI\,M(K_1+K_2)}{S^2K_1K_2}\left[Z + \left(-\frac{K_1}{K_1K_2}\right)S\right] - \frac{MZS}{3} \qquad (6)$$

WHERE δ_{co} IS THE DEFLECTION AT "C" DUE ONLY TO "M":

$$EI\,\delta_{cc} = \frac{EI}{S^2K_1K_2}\left[K_1S^2 + 2K_1ZS + (K_1+K_2)Z^2\right] + \frac{Z^2}{3}\left[Z+S\right] \qquad (7)$$

WHERE δ_{cc} IS THE DEFLECTION DUE TO A 1^K FORCE APPLIED AT "C":

$$\text{REACTION AT } C = R_C = -\frac{EI\,\delta_{co}}{EI\,\delta_{cc}} \qquad (8)$$

$$\therefore R_A = \frac{[M - Z(R_C)]}{S}\;;\; R_B = R_C - R_A$$

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AS THE PLATE GETS WIDER AND Z BECOMES SMALL COMPARED TO Y, THE TWO MIDDLE BOLTS CANNOT BE LUMPED TOGETHER AS ONE SUPPORT WITH $K_2 = 2K_B$. K_2 WILL BE SOMETHING LESS THAN $2K_B$. THE FOLLOWING EXPRESSION FOR K_2 YIELDED RESULTS WHICH WERE IN GOOD AGREEMENT WITH FEM RESULTS:

$$K_2 = 2K_B\left(\frac{Z}{Y}\right)^2 \leq 2K_B \qquad (9)$$

FOR PLATE SIZES GENERALLY USED IN PIPE SUPPORTS, THIS WIDTH EFFECT WILL HAVE NEGLIGIBLE EFFECT ON ROW "A" i.e. THE STIFFNESSES OF THE THREE BOLTS CAN STILL BE LUMPED TOGETHER IN THE BEAM MODEL.

THE REACTIONS IN THE BEAM MODEL ARE NOW KNOWN. THE REACTION AT ANY ONE SUPPORT IS THE TOTAL TENSION IN THAT ROW OF BOLTS. TO DISTRIBUTE THE LOAD TO THE BOLTS:

FOR ROW "B" FROM SYMMETRY,

$$\text{TENSION PER BOLT} = F_{Td} = F_{Te} = \frac{R_B}{2} \qquad (10)$$

FOR ROW "A", THE RELATIVE STIFFNESS OF THE PLATE AND THE BOLTS AND THE BOLT DISTANCE FROM THE ATTACHMENT WILL AFFECT THE LOAD DISTRIBUTION BETWEEN THE MIDDLE AND THE CORNER BOLTS. EVIDENTLY THE BOLT CLOSEST TO THE ATTACHMENT WILL CARRY MORE LOAD AND IF THE ATTACHMENT SIZE IS SMALL, BOLT TO THE ATTACHMENT DISTANCE MAY BE SUBSTITUTED BY THE DISTANCE OF THE BOLT TO THE CENTER LINE OF THE PLATE. THUS TENSION IN THE MIDDLE BOLT "b":

$$F_{Tb} = \alpha\left[f\left(\frac{K_B}{EI/\ell_1^3}\right)\right]\left[\frac{1/L_m}{1/L_m + 2/L_c}\right](R_A) \qquad (11)$$

WHERE: L_m = DISTANCE FROM PLATE CENTER TO BOLT "b"

L_c = DISTANCE FROM PLATE CENTER TO BOLTS "a" & "c"

$\ell_1 = S + Z$

α = CONSTANT

BASED ON SEVERAL FEM ANALYSES THE FOLLOWING EXPRESSION OF F_{Tb} WAS ARRIVED AT:

$$F_{Tb} = \lambda (R_A) = \frac{2}{3}\left[\frac{K_b}{EI/\ell_1^3}\right]^{1/4}\left[\frac{1/L_m}{\frac{1}{L_m}+\frac{2}{L_c}}\right](R_A) \quad (12)$$

WITH THE LIMITS $0.333 < \lambda < 1.0$ CORRESPONDING TO VERY RIGID AND VERY FLEXIBLE PLATES.

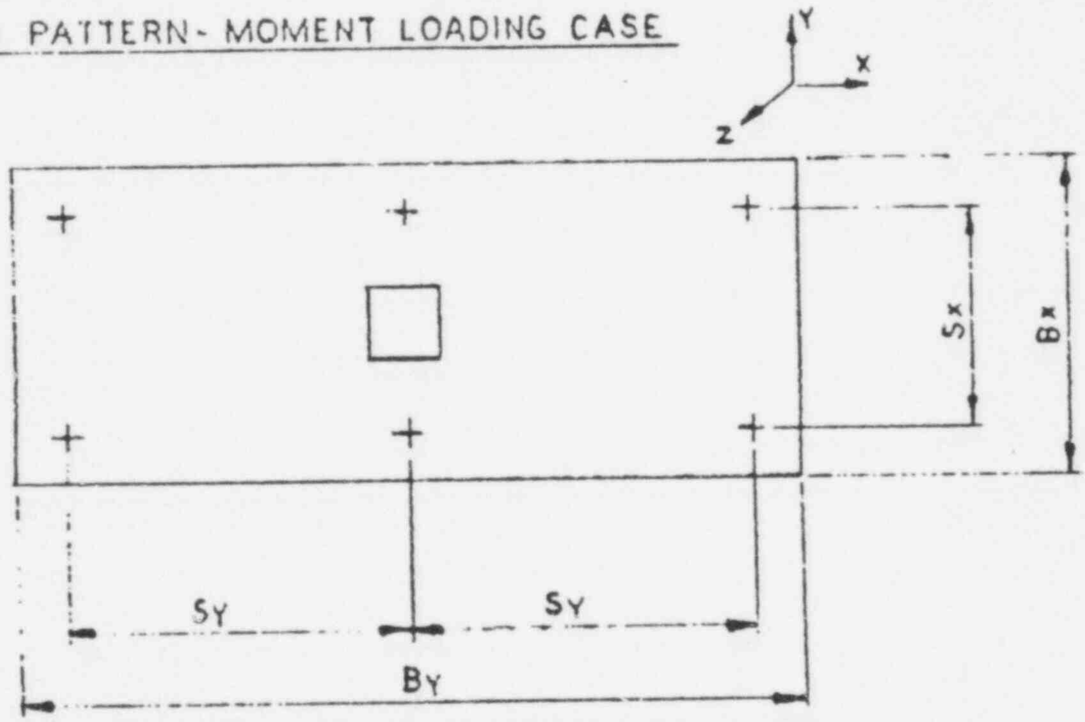
TENSION IN THE CORNER BOLTS IS GIVEN BY:

$$F_{Ta} = F_{Tc} = \frac{R_A - F_{Tb}}{2} \quad (13)$$

AND $F_{Tf} = F_{Tg} = F_{Th} = 0$ (14)

FOR BIAXIAL BENDING, THE RESULTANT BOLT FORCES WILL BE DETERMINED BY SUPERPOSITION.

(II) 6-BOLT PATTERN - MOMENT LOADING CASE



THE 6-BOLT PATTERN CAN BE SOLVED BY USING A COMBINATION OF THE EQUATIONS FOR 4-BOLT AND 8-BOLT PATTERNS.

FOR MOMENT ABOUT THE X-X AXIS:

(A) USE EQUATIONS (1) AND (2) TO SOLVE FOR TOTAL TENSION

(B) USE THE 8-BOLT DISTRIBUTION EQUATIONS (12) AND (13) FOR SOLVING THE BOLT LOADS WITH $\ell_1 = \frac{S_x}{2} + Z$ & $EI = 2417 B_y t^3$.

FOR MOMENT ABOUT THE Y-Y AXIS:

(A) USE EQUATIONS (6), (7) AND (8) TO SOLVE FOR REACTIONS WITH $K_Z = 2K_B\left(\frac{Z}{Y}\right)^2$; $S = S_Y$; $Y = \frac{S_X}{2}$; $EI = 2417 B_x t^3$

(B) DIVIDE THE REACTIONS CORRESPONDING TO EACH BOLT ROW BY 2 TO OBTAIN INDIVIDUAL BOLT LOADS.

(D) 6 AND 8-BOLT PATTERNS - TENSION LOADING CASES:

UNLIKE THE 4-BOLT PATTERN, FOR THE 6 & 8 BOLT CASES THE CENTRALLY APPLIED TENSION CANNOT BE DISTRIBUTED EQUALLY TO ALL THE BOLTS DUE TO THE INTERPLAY OF BOLT AND PLATE STIFFNESSES AND THE RELATIVE DISTANCES OF THE BOLTS FROM THE POINT OF APPLICATION OF THE LOAD.

BASED ON THE MOMENT CASE IT WILL BE ASSUMED THAT THE PARAMETRIC VARIABLES AFFECTING THE LOAD DISTRIBUTION WILL BE OF THE SAME FORM AS IN THE MOMENT CASE. THE CONSTANT $\frac{8}{9}$ FOR THE DISTRIBUTION FACTORS DFM_X AND DFM_Y WAS OBTAINED FROM FINITE ELEMENT ANALYSIS RESULTS.

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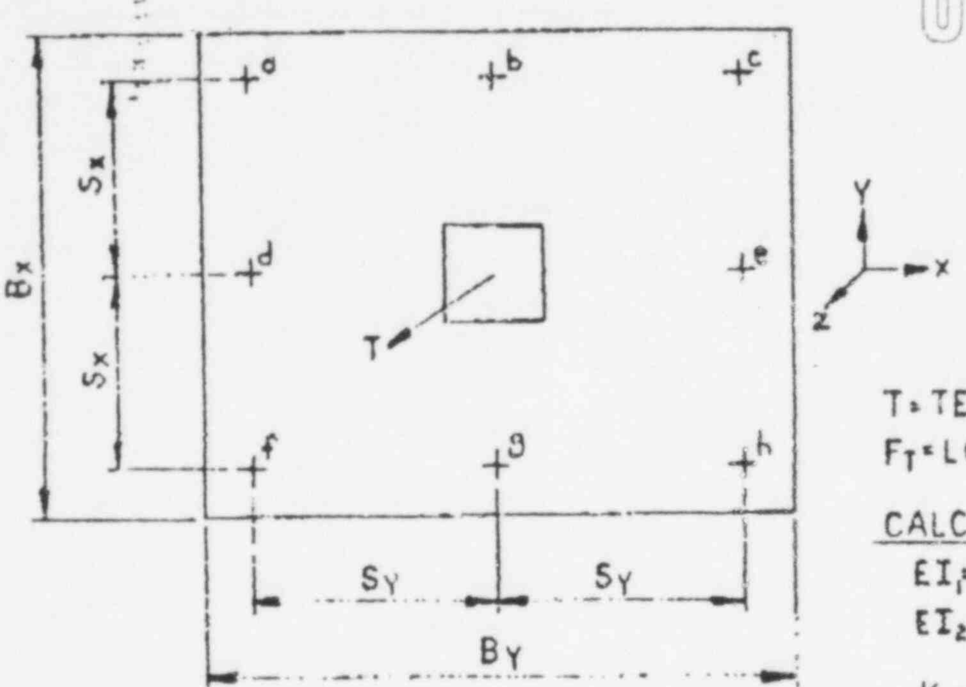
8-BOLT PATTERNS - TENSION LOADING CASE:



T = TENSION LOAD
F_T = LOAD PER BOLT

CALCULATE:

$EI_1 = 2417\, B_x t^3$

$EI_2 = 2417\, B_Y t^3$

$K_X = \frac{EI_1}{2S_Y}$

$K_Y = \frac{EI_2}{2S_X}$

$$T_X = \left[\frac{K_X}{K_X + K_Y}\right] T \quad ; \quad T_Y = T - T_X$$

$$L_c = \left[(S_X)^2 + (S_Y)^2\right]^{1/2}$$

$$DFM_X = \frac{8}{9}\left[\frac{K_B (2S_Y)^3}{EI_1}\right]^{1/4}\left[\frac{1/S_Y}{1/S_Y + 2/L_c}\right] \quad ; \quad 4/7 \le DFM_X \le 1.00$$

$$DFM_Y = \frac{8}{9}\left[\frac{K_B (2S_X)^3}{EI_2}\right]^{1/4}\left[\frac{1/S_X}{1/S_X + 2/L_c}\right] \quad ; \quad 4/7 \le DFM_Y \le 1.00$$

NOTE: FOR PLATE STIFFNESS VARYING FROM INFINITELY RIGID TO EXTREMELY FLEXIBLE:

$$\frac{4}{8} \le DFM \le 1$$

SINCE A "RIGID" PLATE DOES NOT EXIST, 4/7 WAS USED AS A LIMIT

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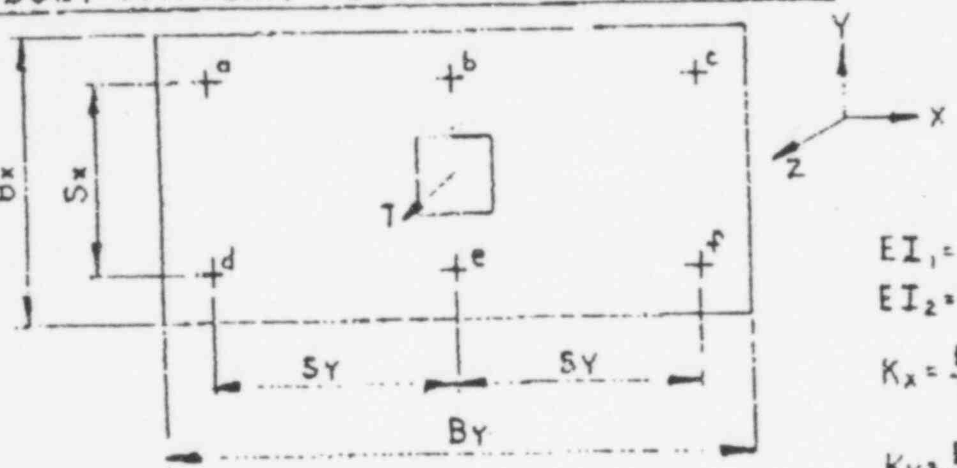
$F_{Tb} = F_{Tg} = [DFM_Y][\frac{T_Y}{2}]$

$F_{Td} = F_{Te} = [DFM_X][\frac{T_X}{2}]$

$F_{Ta} = F_{Tc} = F_{Tf} = F_{Th} = \left[\frac{T - 2(F_{Tb} + F_{Td})}{4}\right]$

IF BY ABOVE EQUATIONS $F_{Td} < F_{Ta}$ OR $F_{Tb} < F_{Ta}$, SET $F_{Td} = F_{Ta}$ OR $F_{Tb} = F_{Ta}$ AS LIMITING VALUES FOR RECTANGULAR PLATES

6-BOLT PATTERN-TENSION LOADING CASE:



$EI_1 = 2417 B_X t^3$

$EI_2 = 2417 B_Y t^3$

$K_X = \frac{EI_1}{2S_Y}$

$K_Y = \frac{EI_2}{S_X}$

$T_Y = \left[\frac{K_Y}{K_X + K_Y}\right] T$

$DFM_Y = \frac{8}{9}\left[\frac{K_B (S_X)^3}{EI_2}\right]^{1/4} \left[\frac{2/S_X}{2/S_X + 2/L_c}\right] \geq \frac{4}{7}$ AND ≤ 1.00

WHERE $L_c = \left[\left(\frac{S_X}{2}\right)^2 + \left(\frac{S_Y}{2}\right)^2\right]^{\frac{1}{2}}$

$F_{Tb} = F_{Te} = [DFM_Y][\frac{T_Y}{2}]$

$F_{Ta} = F_{Tc} = F_{Td} = F_{Tf} = \left[\frac{T - 2(F_{Tb})}{4}\right]$

BASED ON THE ABOVE EQUATION, IF $F_{Ta} (= F_{Tc} = F_{Td} = F_{Tf}) > F_{Tb} (= F_{Te})$, AS MAY BE THE CASE WHERE $S_X \geq 2S_Y$, THEN $F_{Ta} = F_{Tc} = F_{Td} = F_{Tf} = F_{Tb} = F_{Te} = \frac{T}{6}$

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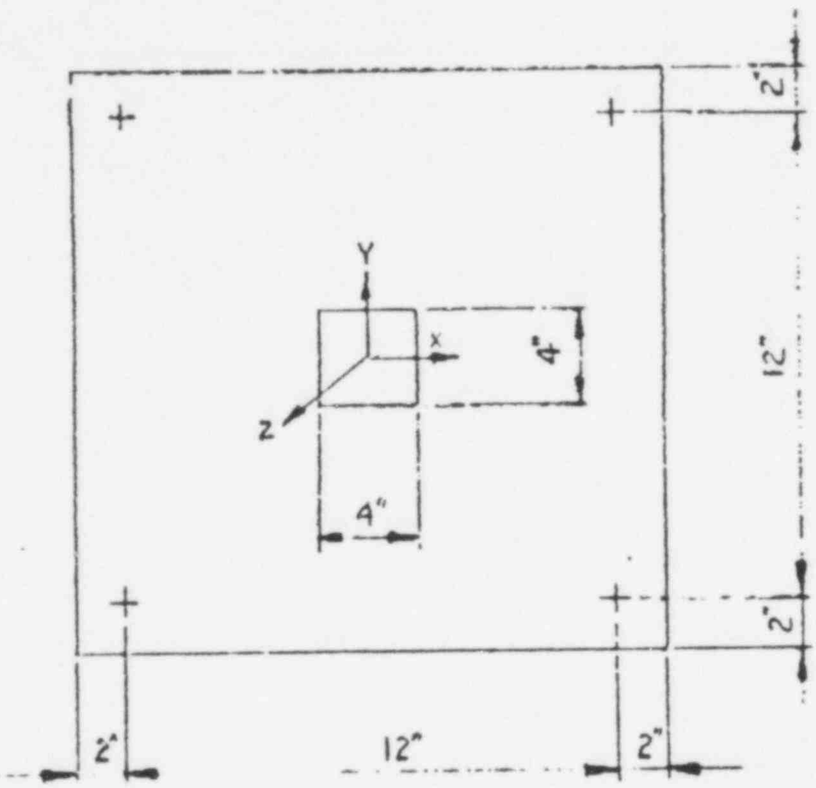
(IV) COMPARISON OF RESULTS:

FINITE ELEMENT METHOD VS BECHTEL MODEL

SKETCHES OF BASE PLATES ANALYSED:

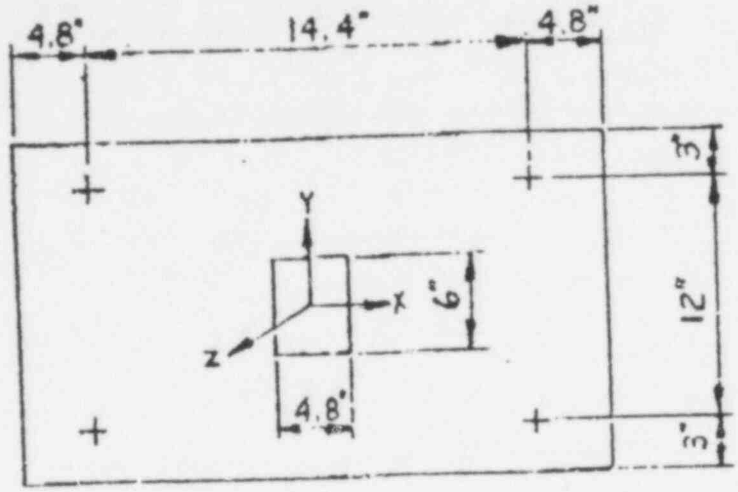
(A) 4-BOLT PATTERN



PL	t	K_B	LOADING
1	1/2"	44	M_X = 18K"
2	1/2"	44	M_X = 18K", M_Y = 36K"
3	1/2"	44	M_X = 18K", F_Z = 4K"
4	3/4"	44	M_Y = 18K"
5	3/4"	150	M_X = 18K"
6	3/4"	300	M_X = 18K"

K_B = BOLT STIFFNESS (K/IN)

t = PLATE THICKNESS



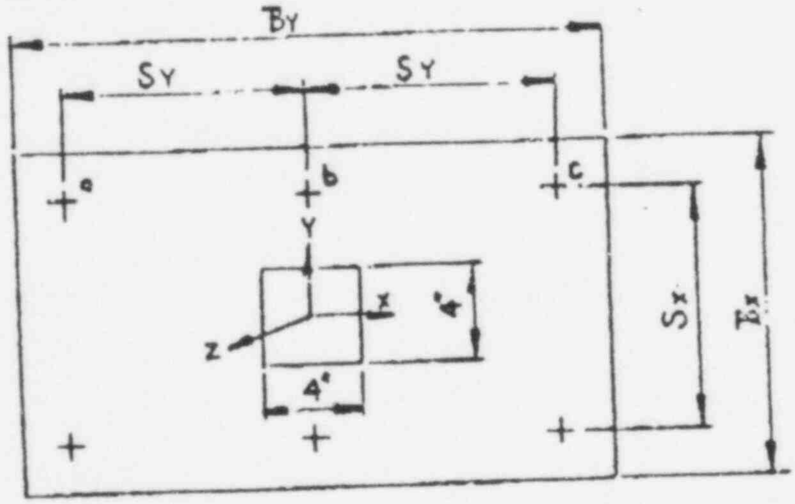
Pℓ	t	K_B	LOADING
7	3/8"	44	M_Y=247.5K"
8	2"	44	M_Y=247.5K"
9	1/2"	44	M_Y=247.5K" M_X=247.5K"

K_B = BOLT STIFFNESS (K/IN)

t = PLATE THICKNESS

FROM TELEDYNE ENGINEERING REPORT (REFERENCE 2)

(b) 6-BOLT PATTERN:



K_B = BOLT STIFFNESS (K/IN)

t = PLATE THICKNESS

Pℓ	t	K_B	S_X	S_Y	B_X	B_Y	LOADING
1	1/2"	44	12	8	16	20	M_X=36K"
2	1"	440	12	8	16	20	M_X=36K"
3	1"	44	22.5	4	25.5	12	F_Z=10K
4	2"	44	22.5	4	25.5	12	F_Z=10K
5	3/4	44	12	6	16	16	F_Z=10K
6	1"	44	12	6	16	16	F_Z=9K

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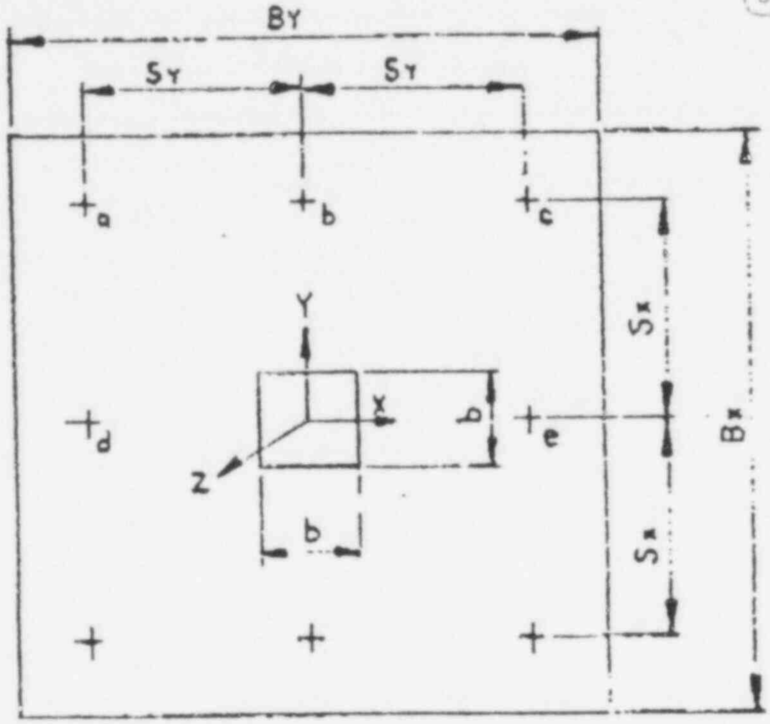
(C) 8-BOLT PATTERN:



℄	t	K_B	S_X	S_Y	B_X	B_Y	b	LOADING
1	1¼"	44	12	12	28	28	6	$M_x = 180^{K''}$
2	1½"	440	12	12	28	28	6	$M_x = 180^{K''}$
3	1"	300	8	8	20	20	4	$M_x = 90^{K''}$
4	1¼"	150	12	12	28	28	6	$F_z = 16^K$
5	1¼"	44	12	12	28	28	6	$F_x = 8^K$
6	1"	44	6	10	16	24		$F_z = 10^K$

K_B = BOLT STIFFNESS (KIP/IN)
t = PLATE THICKNESS

TABULATED RESULTS:

4-BOLT PATTERN:

ANALYSIS METHOD / PLATE	LOAD PER BOLT (K) FINITE ELEMENT	LOAD PER BOLT (K) BECHTEL ANALYTICAL MODEL	% DIFFERENCE
A (1)	0.75	0.75	0
A (2)	2.08	2.25	+8.2
A (3)	1.71	1.75	+2.3
A (4)	0.64	0.68	+6.3
A (5)	0.75	0.78	+4.0
A (6)	0.78	0.84	+7.7
A (7)	9.12	9.19	+0.8
A (8)	6.12	6.45	+5.4
A (9)	16.61	18.17	+9.4

6-BOLT PATTERN:

	TENSILE LOAD PER BOLT (K)				% DIFFERENCE	
	BOLTS a & c	BOLT b	BOLTS a & c	BOLT b		
ANALYSIS METHOD / PLATE	FINITE ELEMENT		BECHTEL ANALYTICAL MODEL		BOLTS a & c	BOLT b
B (1)	0.65	1.84	0.64	1.72	-1.5	-6.5
B (2)	0.61	1.96	0.72	1.86	+18.0	-5.1
B (3)	1.68	1.64	1.67	1.67	-0.7	+1.5
B (4)	1.67	1.66	1.67	1.67	0	+0.2
B (5)	1.55	1.89	1.67	1.67	+7.2	-13.5
B (6)	1.45	1.59	1.5	1.5	+3.2	-6.1

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POOR ORIGINAL

I-BOLT PATTERN:

PLATE / ANALYSIS METHOD	TENSILE LOAD PER BOLT (K) — FINITE ELEMENT — BOLT a	BOLT b	BOLT d	BECHTEL ANALYTICAL MODEL — BOLT a	BOLT b	BOLT d	% DIFFERENCE — BOLT a	BOLT b	BOLT d
((1)	1.89	2.64	0.75	1.94	2.70	0.92	+2.69	+2.5	+17.0
((2)	1.55	5.26	1.46	1.58	5.14	1.47	+1.9	-2.3	+0.7
((3)	1.22	3.32	0.88	1.32	3.23	0.85	+8.2	-2.6	-3.0
((4)	1.08	2.92	1.46	1.08	2.92	1.46	0	0	0
((5)	0.83	1.17	0.59	0.86	1.14	0.57	+3.6	-2.6	-3.5
((6)	0.99	1.95	1.06	0.96	2.04	1.01	-3.1	+4.4	-5.2

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REFERENCES

1. "ANSYS" ENGINEERING ANALYSIS SYSTEM, DEVELOPED BY SWANSON ANALYSIS SYSTEM, INC.

2. DILUNA, L.J. AND FLAHERTY, J.A., "AN ASSESSMENT OF THE AFFECT OF PLATE FLEXIBILITY ON THE DESIGN OF MOMENT-RESISTANT BASE PLATES", TELEDYNE ENGINEERING SERVICES (SUBMITTED TO ASME FOR PUBLICATION)

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