REPORT ON
PIPE SUPPORT BASE PLATE DESIGNS USING
CONCRETE EXPANSION ANCHOR BOLTS
(IN RESPONSE TO NRC BULLETIN 79-02, REVISION 1)
FOR THE
SNUPPS UNITS

Bechtel Power Corporation
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July, 1979

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Response to NRC Bulletin 79-02, Revision 1
For SNUPPS Units

1. Introduction

This report is submitted in response to the Nuclear Regulatory Commission (NRC) IE bulletin 79-02, Revision 1, requiring all licensees and permit holders for nuclear power plants to review the design and installation procedures for concrete expansion anchor bolts used for pipe support base plates in Seismic Category I systems. This report meets the requirements of the bulletin for all SNUPPS units at the following jobsites:

a. Callaway Unit 1 & 2; Owner - Union Electric Company; Docket Nos. 50-483 & 50-486.

b. Wolf Creek; Owners - Kansas Gas and Electric Company and Kansas City Power and Light Company; Docket No. 50-482.

c. Sterling; Owner - Rochester Gas and Electric Corporation; Docket No. 50-485.

d. Tyrone; Owner - Northern States Power Company; Docket No. 50-484.

Callaway Unit 1 and Wolf Creek are currently under construction. Construction of the remaining SNUPPS units has not yet begun.

2. General Discussion

The base plates for pipe supports for SNUPPS units mainly consist of plates with machine welded stud anchors that are embedded in concrete. When additional plates are required by design development after concrete is placed, surface mounted plates with expansion anchors or grouted anchor bolts are specified. Thus SNUPPS units make use of expansion anchors in pipe support base plates in limited applications.

SNUPPS units use the following surface mounted plates with concrete expansion anchors as replacements for embedded plates. The surface mounted plates are installed directly against the concrete surface without any grout or leveling nuts under the plate.

Plate Mark	Plate Size	No. of Anchors	Nominal Anchor Spacing	Anchor Diameter and Minimum Embedment Length
LP737	12"x1/2"x1'-0"	4	8" each way	5/8"x5"
LP737A	8"x3/4"x1'-0"	2	8"	1"x7"
LP837A	12"x1/2"x1'-0"	4	8" each way	3/4"x6 3/4", or 1"x5 1/2"*
LP837B	12"x1/2"x2'-4"	8	8" each way	3/4"x6 3/4", or 1"x5 1/2"*
LP137A	20"x7/8"x1'-8"	4	12" each way	1 1/4"x10 1/2"

* Alternate expansion anchors for use in shallow slabs.

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The aforementioned LP737 and LP837 plates were designed to carry relatively small loads, i.e., simultaneous application of four kips tension and four kips shear for LP737 and LP737A, and six kips tension and six kips shear for LP837A and LP837B. For design purposes the capacity of LP837B is considered the same as LP837A without taking credit for the additional anchors. This affords the flexibility of locating the attachment over a wider area of the plate without exceeding allowable loads on any single anchor. The design load on LP137A is 14 kips tension applied simultaneously with 14 kips shear.

The allowable design loads were determined by taking the plate flexibility into account. Therefore the load distribution to the anchors is dependent upon the relative locations of the anchors to the load, the plate thickness and edge distance, and the flexibility of the anchors. Future plates, if required, will be designed using the same criteria.

Although the effect of plate flexibility has been explicitly considered in the analysis, the impact of prying action on the anchor bolts was determined not to be critical for the following reasons:

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

b. Where bolt pull out determines the anchorage capacity, the additional load carried by the bolt due to 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.

3. Response to NRC Action Items

The following are the answers to the action items of NRC bulletin 79-02, Revision 1.

Item 1. Verify that pipe support base plate flexibility was accounted for in the calculation of anchor bolt loads. In lieu of supporting analysis justifying the assumption of rigidity, the base plates should be considered flexible if the unstiffened distance between the member welded to the plate and the edge of the base plate is greater than twice the thickness of the plate. It is recognized that this criterion is conservative. Less conservative acceptance criteria must be justified and the justification submitted as part of the response to the Bulletin. If the base plate is determined to be flexible, then recalculate the bolt loads using an appropriate analysis. If possible, this is to be done prior to testing of anchor bolts. These calculated bolt loads are referred to hereafter as the bolt design loads. A description of the analytical model used to verify that pipe support base plate flexibility is accounted for in the calculation of anchor bolt loads is to be submitted with your response to the Bulletin.

It has been noted that the schedule for analytical work on base plate flexibility for some facilities extends beyond the Bulletin reporting time frame of July 6, 1979. For those facilities for which an anchor bolt testing program is required (i.e., sufficient QC documentation does not exist), the anchor bolt testing program should not be delayed.

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Response: (a) All pipe support base plates were analyzed taking into account the plate flexibility, bolt stiffness, shear-tension interaction, minimum edge distance and proper bolt spacing. The allowable design loads for each plate were initially determined using a simplified beam model. A computer program based on a quasi analytical method was used to verify the results obtained by hand calculations. Appendix A describes the quasi analytical method and its verification. These results were compared to those obtained by finite element analyses (using "ANSYS Engineering Analysis System, Computer Program by Swanson Analysis System, Inc., Houston, Pa, Rev. 3 year 1978). The results indicate excellent correlation and that the simplified analytical method generally overpredicts the bolt loads compared to the finite element method. Appendix B describes the ANSYS model used in this verification.

(b) Tension-shear interaction in the anchor bolts was considered by the use of the following formula:

$$\left[\frac{P}{P'}\right]^{5/3} + \left[\frac{V}{V'}\right]^{5/3} \leqslant 1$$

Where: P is the calculated tension load
P' is the allowable tension load
V is the calculated shear load
V' is the allowable shear load

However, where the applied shear force is less than the frictional resistance developed in the shear plane between the steel and the concrete surface, then no additional provisions are required for shear.

Although a 5/3 power interaction was used in the SNUPPS design, a square interaction is considered adequate.

(c) Minimum edge distances for the steel plate were used per the AISC (American Institute of Steel Construction) "Specification for the Design, Fabrication and Erection of Structural Steel for Buildings", 7th Edition, adopted Feb. 12, 1969 with Supplements 1, 2 and 3.

Minimum edge distance for concrete was set at six inches, which, for the majority of the anchors with six inch embedment or less, would not reduce the shear cone area, therefore no reduction in strength need be taken into account. For the isolated cases that have an edge distance less than the anchor embedment, a review of actual loads on the anchor was made to ascertain that they do not exceed the reduced allowable load.

(d) For anchors spaced closer than twice the depth of embedment, a reduction in the allowable design load of anchors under tension, due to overlapping shear cones, was considered in accordance with the PCI (Prestressed Concrete Institute) "Manual on Design of Connections for Precast Prestressed Concrete", 1st Edition, 1973.

For plates resisting externally applied moment in conjunction with other direct forces, the strength reduction was applied only to the anchors under tension.

Item 2. Verify that the concrete expansion anchor bolts have the following minimum factor of safety between the bolt design load and the bolt ultimate capacity determined from static load tests (e.g. anchor bolt manufacturer's) which simulate the actual conditions of installation (i.e., type of concrete and its strength properties):

a. Four - For wedge and sleeve type anchor bolts,

b. Five - For shell type anchor bolts.

The bolt ultimate capacity should account for the effects of shear-tension interaction, minimum edge distance and proper bolt spacing.

If the minimum factor of safety of four for wedge type anchor bolts and five for shell type anchors can not be shown then justification must be provided.

Response: All expansion anchors used for seismic Category I pipe supports on the SNUPPS project are wedge type. They are designed using a factor of safety (i.e. ratio of bolt ultimate capacity to design load) of four for all loading combinations based upon data obtained from the different manufacturers.

Although a factor of safety of four is currently used for all loading combinations a factor of safety of three is considered adequate for factored loadings (which include accident/extreme environmental loads). This is 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. Further, where an effective program of 100% verification of acceptable anchor bolts is implemented, a factor of safety of two is also considered adequate for factored load combinations.

Item 3. Describe the design requirements, if applicable, for anchor bolts to withstand cyclic loads (e.g. seismic loads and high cycle operating loads).

Response: In the design of the piping systems deadweight, thermal stresses, seismic loads and dynamic loads (such as steam hammer in the main steam system) were considered in the generation of the static equivalent pipe support design loads. To the extent that these loads include cyclic considerations, these effects are included in the design of the hangers, base plates and anchorages.

The capacity of the expansion anchor bolts to withstand cyclic loads (seismic as well as high cyclic operating loads) have been evaluated in FFTF tests (Reference: "Drilled-in Expansion Bolts Under Static and Alternating Load." Report No. BR-5853-C-4, Revision 1 prepared by Bechtel Power Corporation, San Francisco, California for the U.S. Atomic Energy Commission, Hanford Engineering Development

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Laboratory, Richland, Washington, October, 1976). The test results indicate that:

(a) The expansion anchors successfully withstood two million cycles of long term fatigue loading at a maximum intensity of 0.2 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.

(b) The dynamic load capacities of the expansion anchors under simulated seismic loading, were about the same as their corresponding static ultimate capacities.

Based on the above data, the design requirements for expansion anchor bolts under cyclic loads are the same as for static loads.

Item 4. Verify from existing QC documentation that design requirements have been met for each anchor bolt in the following areas:

(a) Cyclic loads have been considered (e.g. anchor bolt preload is equal to or greater than bolt design load). In the case of the shell type, assure that it is not in contact with the back of the support plate prior to preload testing.

(b) Specified design size and type is correctly installed (e.g. proper embedment depth).

If sufficient documentation does not exist, then initiate a testing program that will assure that minimum design requirements have been met with respect to sub-items (a) and (b) above. A sampling technique is acceptable. One acceptable technique is to randomly select and test one anchor bolt in each base plate (i.e. some supports may have more than one base plate). The test should provide verification of sub-items (a) and (b) above. If the test fails, all other bolts on that base plate should be similarly tested. In any event, the test program should assure that each Seismic Category I system will perform its intended function.

Response: Design requirements of anchor bolts for cyclic loads have been discussed in the response to item 3.

Shell type anchors are not used for pipe support base plates in seismic Category I systems.

All expansion anchor bolts are designed, installed and verified in accordance with Bechtel Specification 10466-C103A. The installation, inspection and testing requirements along with acceptance criteria are given in section 5.3 and 6.0 of the named specification. Copies of the specification are available at the SNUPPS jobsites.

Specification 10466-C103A requires that:

a) Anchor bolts are torqued to specified minimum values that provide a preload greater than the bolt design load.

b) At least one bolt for each support, but not less than 10% of the total, are torque tested with a calibrated manually operated torque wrench to verify that the specified minimum torque has been provided.

c) The actual embedment equals or exceeds the embedment required by the design and shown on the drawings. The anchor bolts have their total length stamped on the exposed end to facilitate verification of the embedment length.

d) Visual inspection of all installed bolts is performed to verify compliance with the Specification and the drawings, including the following:

   1) Location of support.

   2) Type, size and number of expansion anchors and washers.

   3) Location and spacing of expansion anchors.

   4) Minimum edge distance of expansion anchors from edge of base plate and edge of concrete.

   5) Thread engagement of expansion anchors.

The Callaway and Wolf Creek job-sites have verified from existing QC documentation that the installation, inspection and testing of concrete expansion anchor bolts installed to date are in accordance with the design documents. Exceptions are reported as non-conformances in accordance with normal project procedures.

Inspection documentation is available at the Callaway and Wolf Creek jobsites. To-date construction has not commenced on the remaining SNUPPS units.

Bolt preload equal to or greater than bolt design load is not necessary to withstand dynamic loads even though current job specifications require such preloading. The dynamic loads are seismic loads (which are short duration cyclic loads) and vibratory loads. The seismic load is not a fatigue load, so the amount of preload on the bolts will not greatly affect the performance of the anchorage. For vibratory loads during plant operation, the expansion anchors have successfully withstood a long term fatigue environment as discussed [illegible] the response to item 3. Therefore, if the initial installatio[illegible]e on the bolt accomplishes the purpose of setting the wedge, then the ultimate capacity of the bolt is not affected by the amount of preload present in the bolt at the time of dynamic loading.

DETERMINATION OF EXPANSION ANCHOR BOLT LOADS IN PIPE SUPPORT BASE PLATES

Summary

This report describes a method for determining the anchor bolt loads in steel base places 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 attachment, usually concentric with the base plate, and could be comprised of moments and forces in three directions. A review of typical base plates indicates that the majority of them have either a 4, 6 or 8 bolt connection. The plate thicknesses usually vary from ½" to 1 ½" and are not generally stiffened.

From an 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. The following parameters, which might affect the load distribution in the anchor system, are considered:

a. Flexibility of the base plate.
b. Bolt stiffness.
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. With the bolt stiffness decreasing 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 has been found to occur when the bolt stiffnesses in the Finite Element Analysis were varied from a high to a low value to correspond typically to the initial stiffness and the stiffness beyond the allowable design load.

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 quasi analytical method 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:

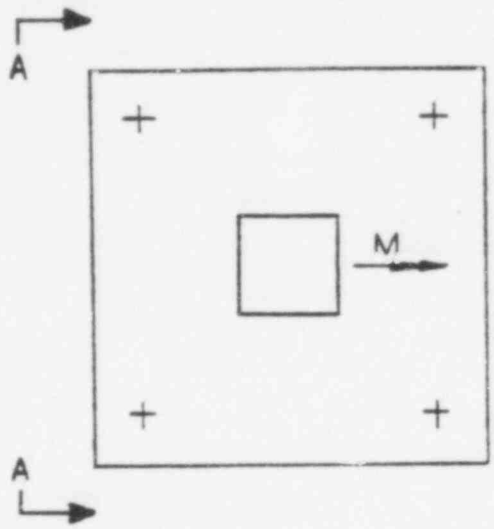
IN THE QUASI ANALYTICAL MODEL PRESENTED HERE, THE PLATE IS PRIMARILY TREATED AS A BEAM ON ELASTIC SPRINGS. BASE PLATES WITH THREE DIFFERENT BOLT CONFIGURATIONS HAVE BEEN CONSIDERED.

ASSUMPTIONS:

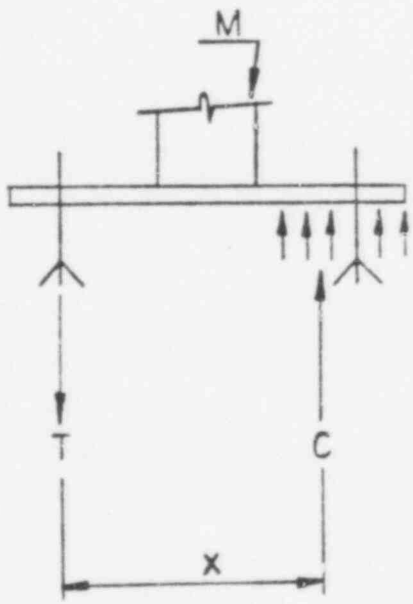
(a) SYMMETRICAL BOLT PATTERNS
(b) CENTROIDAL LOADING
(c) ATTACHMENT DIMENSIONS SMALL COMPARED TO THE PLATE DIMENSIONS
(d) UNITS FOR ALL VARIABLES:
    FORCE = KIPS
    LENGTH = INCHES

(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:

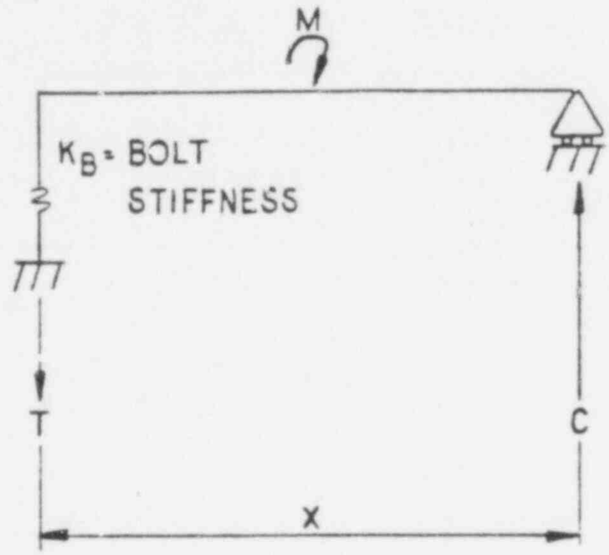
T = TOTAL TENSION (KIP)

C = RESULTANT OF COMPRESSIVE STRESS BLOCK (KIP)

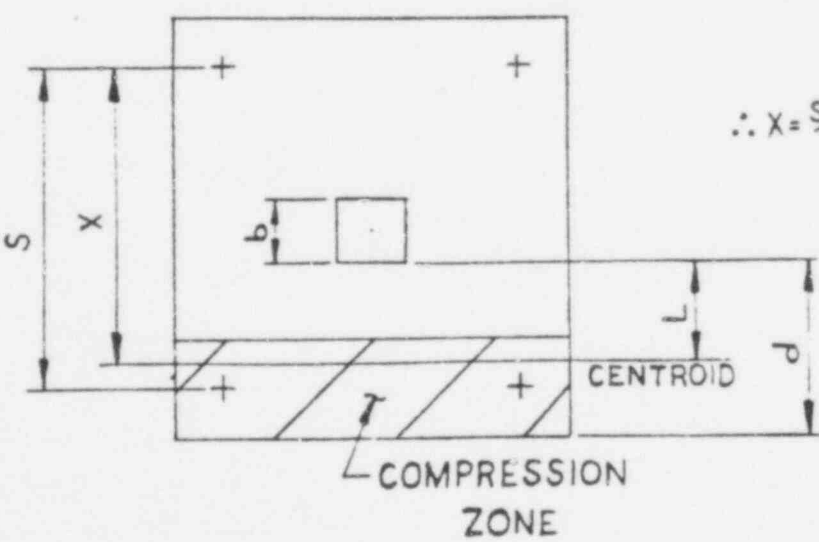
$T(X) = C(X) = M$

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 = 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:

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

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.

FOR BIAXIAL BENDING:

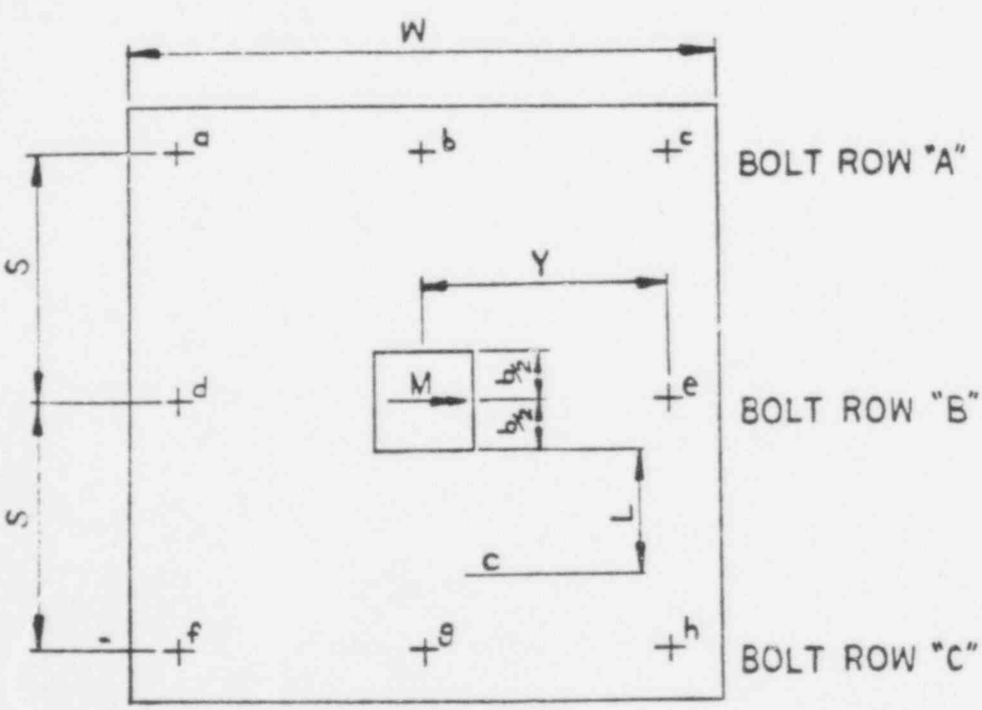
$$\text{CRITICAL } F_T = \frac{M}{\frac{S}{x}+\frac{b}{x}+2L_x} + \frac{M_y}{\frac{S}{y}+\frac{b}{y}+2L_y} \tag{4}$$

FOR COMBINED BENDING AND TENSION:

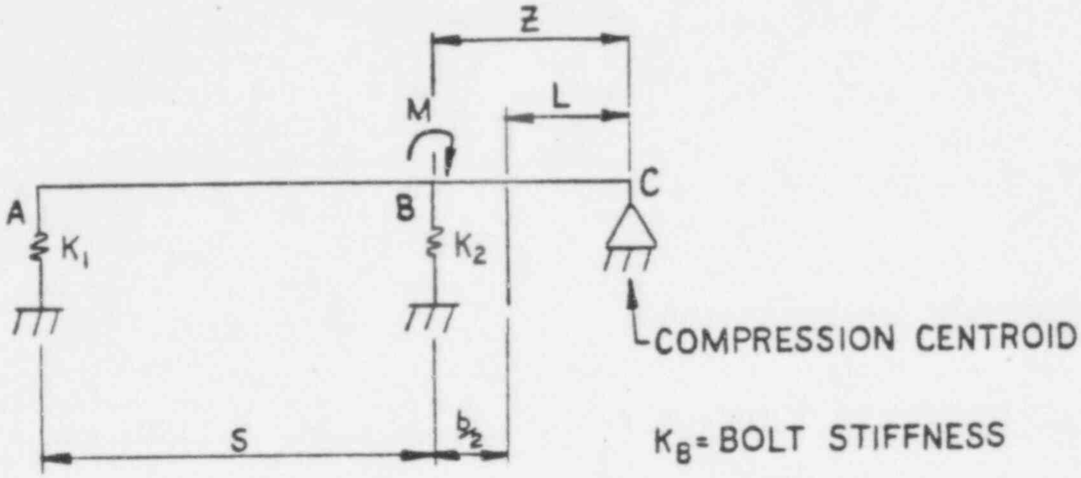
$$\text{CRITICAL } F_T = \frac{M}{S+b+2L} + \frac{T}{4} \tag{5}$$

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) <u>8-BOLT PATTERN - MOMENT LOADING CASE</u>



BEAM MODEL:



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)

$EI = 2417Wt^3$ (KIP IN^2)

IF REDUNDANTS ARE TAKEN AT "C":

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

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

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

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

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

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

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 STIFFNESS 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,
TENSION PER BOLT $= F_{Td} = F_{Te} = \frac{R_B}{2}$ (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. THE BOLT CLOSEST TO THE ATTACHMENT WILL CARRY MORE LOAD AND IF THE ATTACHMENT SIZE IS SMALL, THE DISTANCE OF THE BOLT TO THE CENTER LINE OF THE PLATE MAY BE SUBSTITUTED FOR THE DISTANCE OF THE BOLT TO THE ATTACHMENT. 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 DERIVED:

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

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

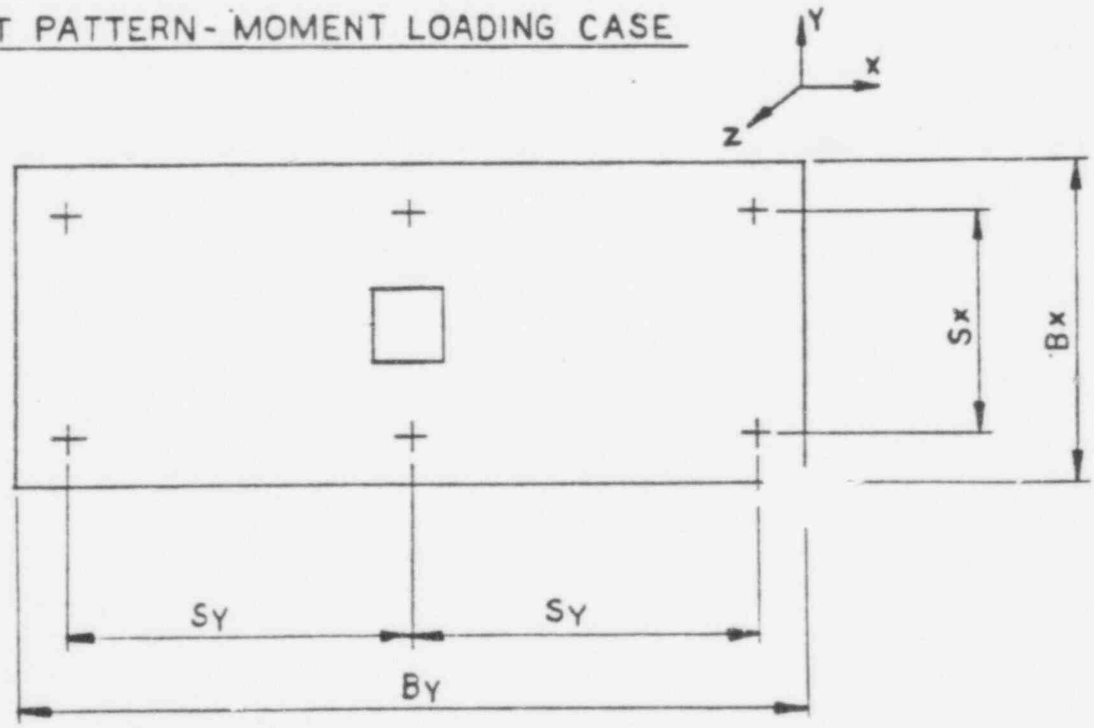
TENSION IN THE CORNER BOLTS IS GIVEN BY:

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

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

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

(III) 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 $K_Z = 2K_B\left(\frac{Z}{Y}\right)^2$; $S = S_Y$; $Y = \frac{S_X}{2}$; $EI = 2417 B_X t^3$

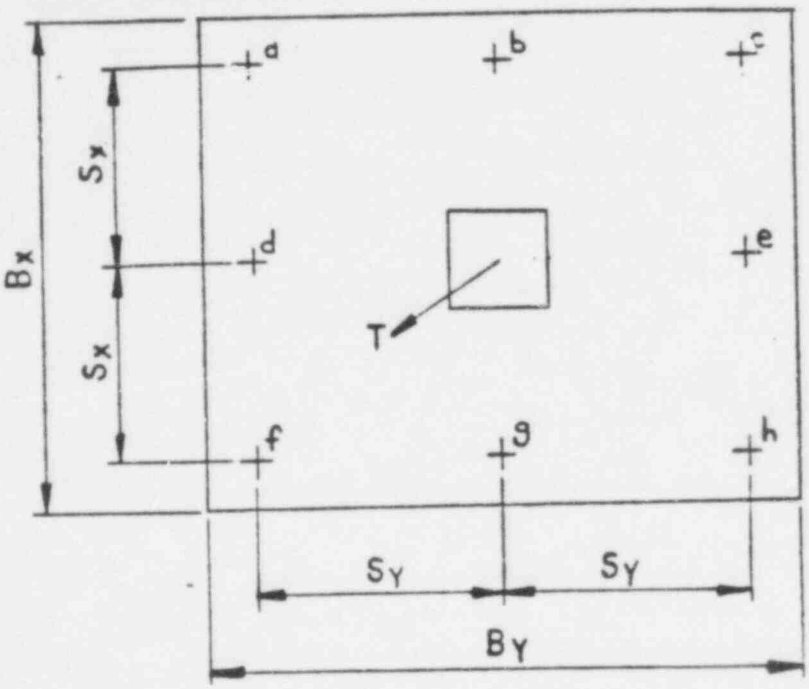
(B) DIVIDE THE REACTIONS CORRESPONDING TO EACH BOLT ROW BY 2 TO OBTAIN INDIVIDUAL BOLT LOADS.

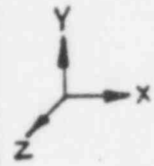
(D) 6 AND 8-BOLT PATTERNS - TENSION LOADING CASES:

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.

8-BOLT PATTERNS - TENSION LOADING CASE:





T = TENSION LOAD

F_T = LOAD PER BOLT

CALCULATE:

$EI_1 = 2417\, B_x t^3$

$EI_2 = 2417\, B_Y t^3$

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

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

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

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

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

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

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

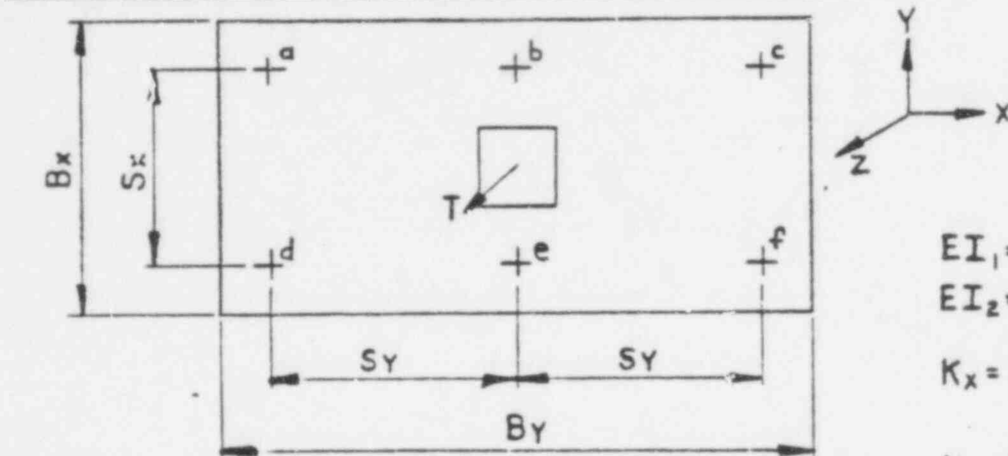
$F_{Tb} = F_{Tg} = [DFM_Y]\left[\frac{T_Y}{2}\right]$

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

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

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:



$EI_1 = 2417 B_X t^3$

$EI_2 = 2417 B_Y t^3$

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

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

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

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

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

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

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

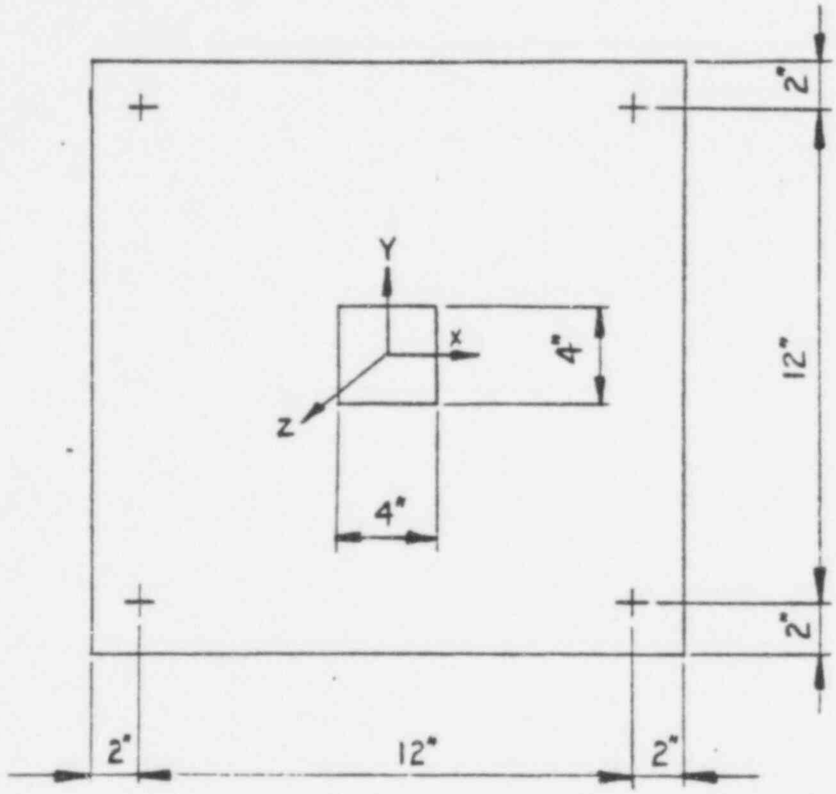
BASED ON THE ABOVE EQUATION, IF $F_{Ta} (= F_{Tc} = F_{Td} = F_{Tf}) > F_{Tb} (= F_{Te})$, AS MAY BE THE CASE WHERE $S_X \geq 2S_Y$, THEN $F_{Ta} = F_{Tc} = F_{Td} = F_{Tf} = F_{Tb} = F_{Te} = \frac{T}{6}$

(IV) COMPARISON OF RESULTS:

FINITE ELEMENT METHOD VS BECHTEL MODEL

SKETCHES OF BASE PLATES ANALYSED:

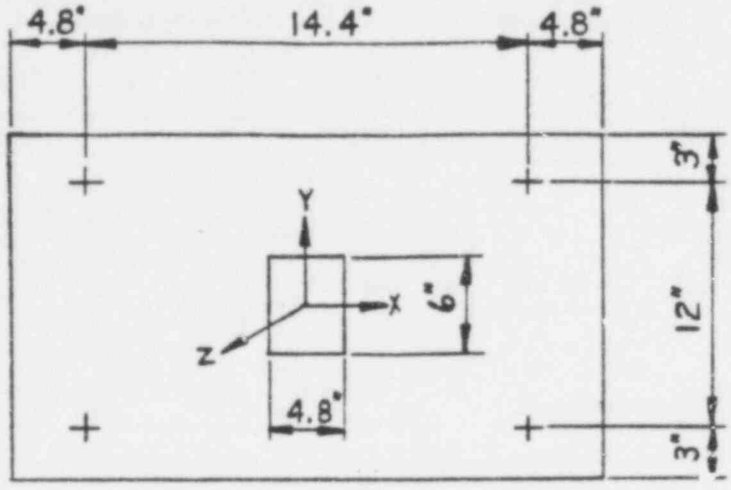
(A) 4-BOLT PATTERN



℄	t	K_B	LOADING
1	½"	44	Mx = 18K"
2	½"	44	Mx = 18K", My = 36K"
3	½"	44	Mx = 18K", Fz = 4K"
4	¾"	44	Mx = 18K"
5	¾"	150	Mx = 18K"
6	¾"	300	Mx = 18K"

K_B = BOLT STIFFNESS (K/IN)

t = PLATE THICKNESS



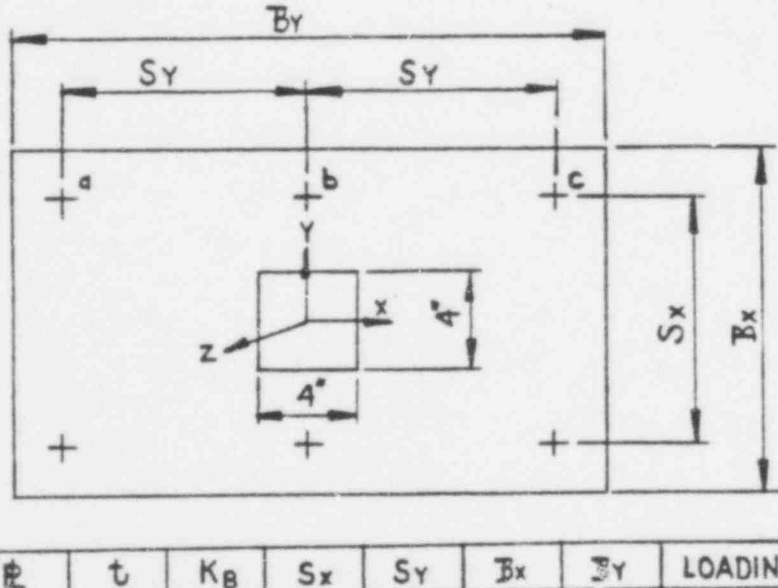
℞	t	K_B	LOADING
7	3/8"	44	M_Y=247.5K"
8	2"	44	M_Y=247.5K"
9	1/2"	44	M_Y=247.5K' M_X=247.5K"

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

℞	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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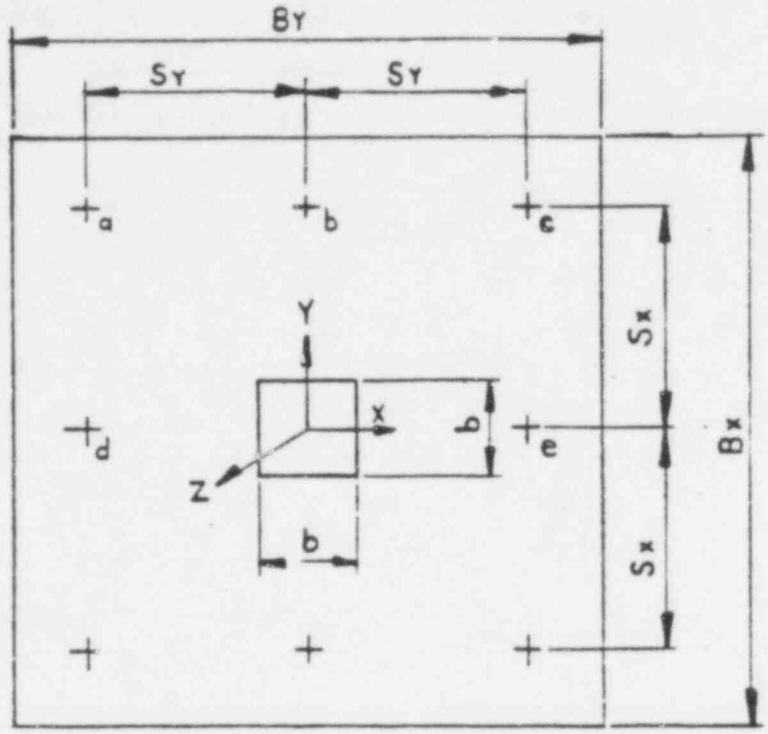
(C) 8-BOLT PATTERN:



℄	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	1¼"	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	$F_Z = 8^K$
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:

PLATE \ ANALYSIS METHOD	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		
PLATE \ ANALYSIS METHOD	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

8-BOLT PATTERN:

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

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)

Description of ANSYS Model

The ANSYS finite element computer program was utilized to verify the analyses of surface mounted plates in determining loads in the expansion anchor bolts. The computer model was formulated with finite element representations for the base plate, anchor bolts, and concrete.

The base plate was modeled using a mesh of 2-D rectangular plate elements (STIF46) interconnected at corner nodes. The size of the element used varies with the size of the plate being analyzed, from 1-3/4" x 1-3/4" for small plates to 4" x 4" for large plates. These elements have pure bending capabilities. The membrane stiffness of the plate is not included so that no in-plane forces are permitted. The element has three degrees of freedom at each of the four nodes: one displacement normal to the plate; and a rotation about each of the two orthogonal axes in the plane of the plate. The in-plane (shear) loads on the plate, omitted from the computer analysis, are subsequently combined in the interaction analysis.

A mesh of compression-only spring elements is provided using the combination element (STIF40) to represent concrete behind the plate. A combination element is used at each plate element nodal point with its axis oriented perpendicular to the plate. The element has one translational degree of freedom and is capable of resisting compression loads only.

Tension-only spring elements are provided using the combination element (STIF40) to represent the expansion anchor bolts. A combination element is used at each plate element nodal point that coincides with a bolt location, with its axis oriented perpendicular to the plate. The element has one translational degree of freedom and is capable of resisting tension loads only.

Preloading conditions of the expansion bolt are included in the analysis by applying corresponding initial tension loads in the bolt spring elements and compression loads in the surrounding concrete spring elements.