IOWA ELECTRIC LIGHT AND POWER COMPANY

DUANE ARNOLD ENERGY CENTER

CALCULATION COVERSHEET

ANALYSIS/CALCULATION NO: M84-11

ANALYSIS/CALCULATION TITLE: SEISMIC STRESS ANALYSIS

HILLS - McCANNA DAMPER ACTUATORS R-260 FS

REFERENCE DOCUMENTS

MAR NO: ________

DCR NO: ________

OTHERS: DDC 769

calc M84-12

PREPARED BY: Donald W. Church DATE: 4/25/84

REVIEWED BY: A.S Radmife AJR DATE: 4-26/84

APPROVED BY: Mike McDermott DATE: 4/30/84

FINAL APPROVAL BY: DATE: 30. April 1984

FORM NG-007Z REV. 0

REGULATORY DOCKET FILE COPY

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Background

The purpose for compiling calculations M84-11, 12, 13, 14, 15 was to perform a seismic analysis on the critical components of the Hills-McCanna Pneumatic Damper Actuators. These actuators are part of the secondary containment isolation system at the Duane Arnold Energy Center.

On January 26, 1984, Iowa Electric notified the NRC by telephone that the above mentioned actuators were potentially deficient in meeting their purchase specification. A review of the documents relating to this discrepancy revealed that the isolation damper assemblies were purchased originally as complete assemblies which included the damper actuators. Subsequent orders for "like-for-like" replacement actuators were placed directly with the actuator manufacturer who was a subvendor to the damper manufacturer. This most recent purchase order for actuators revealed that a quality assurance program, as required for safety related equipment per 10CFR Part 50, is not currently in effect at the actuators manufacturer's facility.

Further review of the damper assembly documentation revealed that the seismic analysis performed on the damper assemblies did not seismically analyze the actuators themselves, but only considered their weight as it seismically affected the damper frame. This information prompted Iowa Electric to audit the damper manufacturer and check for documentation that pertained to the seismic qualifications of the isolation damper actuators. Results from the audit of the damper manufacturer revealed that the actuators were never purchased by the damper manufacturer as seismically qualified components nor did the damper manufacturer administer a Quality Assurance program concerning the purchase of the actuators.

Since no traceability or Certificate of Conformance was available for the seismic qualifications of the actuators, a seismic analysis was performed on the critical components of the actuators in order to seismically qualify the damper actuators for use in the Duane Arnold Energy Center. This seismic analysis followed the guidelines set forth in the original purchase specification for the isolation dampers (ref. Bechtel 7884-M-100). By seismically qualifying the isolation damper actuators, Iowa Electric will be able to buy Quality Level I actuators in accordance with Revision 1, Chapter 4 of the Quality Assurance Manual under Standard Industrial Quality Items 4.7.3.

Solution

A seismic analysis was performed on five models of the Rockwell Hills-McCanna Ramcon Pneumatic Actuator product line that are installed as isolation damper actuators at the Duane Arnold Energy Center. These five models include the following:

- R-260 FS
- R-450 FS
- R-960 FS
- R-2000 FS
- R-4200 FS

The seismic analysis on the actuators followed the general project seismic requirements for frequency-not-determined class 1 equipment in the reactor building and in the control building (ref. Bechtel 7884-M-100, Technical Specifications for Isolation Dampers for the Duane Arnold Energy Center Unit 1, Revision 0, 12-28-70).

A visual inspection of all isolation damper actuators at the Duane Arnold Energy Center was made in order to verify model number, serial number and elevation location in the plant. After verifying the elevation location in the plant, static coefficients (g units) were determined for the highest installed actuator for each of the five actuator models. The horizontal static coefficient was then applied to all three of the orientation axis which eliminated many repetitious calculations and the need for detailed actuator orientation information. Applying the horizontal static coefficient to each axis provided conservative results since the horizontal coefficient is always greater than one plus the vertical coefficient ($F_{vertical} = (Weight)\ (1 + g_v)$, $F_{horizontal} = (Weight)\ (g_h)$, $g_h > 1 + g_v$).

The seismic analysis concentrated on the critical areas of the damper actuator where the seismically induced loads could possibly make the actuator fail, malfunction, or prevent operation. Five areas on each actuator model were identified as critical areas requiring a seismic analysis of the various components interfacing with that critical area. These five critical areas are identified as the following:

- Retaining key which holds the spring cylinder assembly to the main body cylinder
- Main body cylinder
- Press fit between main body cylinder and the mounting yoke
- Mounting hardware
- Mounting yoke

Dimensions and material specifications for the seismic analysis were obtained through the use of proprietary component drawings that were on loan to Iowa Electric from Rockwell Hills-McCanna of Carpentersville, Illinois. All prints applicable to this seismic analysis are listed in the reference section of the referenced calculations.

Four basic assumptions are applied throughout the entire seismic analysis of the damper actuators. These assumptions allow Iowa Electric to use the floor response spectra as the design/qualification spectra for the seismic analysis. The four basic assumptions are as follows:

- The mounting of the damper is a rigid structure ($f > 33$ cps)
- The damper itself is a rigid structure ($f > 33$ cps)
- The support bracket for the actuator is a rigid structure ($f > 33$ cps)
- The seismic requirements for evaluating the actuators are the same as those for the isolation dampers.

III

The maximum seismic stresses were calculated by using the square root sum of the squares method for combining the three earthquake direction stresses as recommended in the UFSAR for seismic analysis at the Duane Arnold Energy Center. A second method, the distortion energy method was used for combining stresses at the press fit between the main body cylinder and the mounting yoke. The distortion energy method was used in place of the square root sum of the squares method because the stresses due to the press-fit condition exceeded and dominated those caused by the seismic event. All maximum stresses were then compared to some fraction of the yield strength depending on the material type and stress type. Operability after a DBE event was ensured by requiring that the maximum stress from combined seismic and normal loads should not exceed 90% of the yield stress of the material.

Conclusion

After completing the above described seismic analysis on the five models of Hills-McCanna actuators installed on the isolation dampers at the Duane Arnold Energy Center, it was found that the maximum stresses from the combined seismic and normal loads do not exceed the material yield requirements defined in the isolation damper purchase specification. The results of this seismic analysis reveal that the five models of Hills-McCanna actuators are seismically qualified for use at the Duane Arnold Energy Center.

References

Bechtel Purchase Specification 7884-M-100

Formulas for Stress and Strain; Raymond J. Roark, Warren C. Young, Fifth Edition, McGraw-Hill Book Co. 1975

Hills-McCanna Information Bulletins; R-1090, R-1090A, R110C, R1100A, R-111C, R-1110A, R-112D, R-1120A, R-113D, R-1130A

Marks' Standard Handbook for Mechanical Engineers' Baumeister Eighth Edition, McGraw-Hill Book Company 1978

Materials Selector 75; Reinhold Publishing Co. Mid September 1974, Vol. 80, No. 4, Brown Printing Co.

Mechanical Engineering Design; Joseph E. Shigley, Third Edition, McGraw-Hill Book Co. 1977

Mechanics of Materials; Higdon, Ohlsen, Stiles, Weese, Riley Third Edition, John Wiley and Sons 1978

IV

Rockwell Hills-McCanna; Proprietary Drawings

DATA: Information contained on drawings is proprietary and confidential and is not to be given or loaned to others. Drawings are to be returned to Rockwell upon completion of their intended use in making the seismic analysis.

R260	R450-R960	R2000-R4200
430-1004	450-7511	460-7511
430-7510	450-1005	460-1001
430-7511	450-7512	460-7509
430-3003	450-3005	460-3001
430-3005	450-3007	460-3003
430-4101	450-4101	460-4101
430-4102	450-4102	460-4102
430-2101	450-2101	460-2101
430-2904	450-2906	460-2904
430-2502	450-2507	460-2503
430-2501	450-2501	460-2502
430-3321	450-3201	460-3208
430-3322	450-3202	460-3209
430-3325	450-3203	460-3210
430-3201	450-3326	460-3317
430-3202	450-3325	460-3316
430-3203	450-3321	460-3320
	450-3320	460-3321
		460-3314
		460-3315

U.S.S. Steel Design Manual; R.L. Brockenbrough and B.G. Johnson, Jan. 1981

V

MARTIN REIFSCHNEIDER Reviewer for Calculations M84-11,12,13,14,15

POSITION

Senior Civil/Structural Engineer

EDUCATION

BS, Civil Engineering, University of Michigan
MS, Civil/Structural Engineering, University of Michigan

PROFESSIONAL DATA

Registered Professional Engineer in Michigan

SUMMARY

1 year: Senior Engineer; Civil/Structural Staff
4 years: Senior Engineer; Midland, Palisades, and Big Rock Point Nuclear Power Plants
1 year: Resident Engineer, Midland Nuclear Power Plant

EXPERIENCE

Mr. Reifschneider is currently assigned as a civil/structural engineer on the civil/structural staff. His duties include; preparation of design standards; review of project calculations, drawings, specifications and seismic qualification of equipment; providing consultation to civil/structural engineers engaged in the design of nuclear and fossil power plants; solving special static and dynamic structural problems.

Prior to joining the civil/structural staff, Mr. Reifschneider was a civil/structural engineer on Consumers Power Company's Palisades project. His duties included finite element analysis of the biological shield wall, seismic analysis and design of blockwall supports, and seismic analysis and design of the auxiliary building addition including the review of seismic equipment qualifications.

Prior to joining the Palisades project, Mr. Reifschneider was a civil/structural resident engineer at the jobsite of Consumers Power company's Midland nuclear plant project. His duties included interfacing with construction personnel on the design, erection, and construction of seismic instrument and equipment supports.

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MARTIN REIFSCHNEIDER Reviewer for Calculations M84-11,12,13,14,15

Prior to his jobsite assignment, Mr. Reifschneider conducted research on the inelastic design and behavior of braced structural steel systems, moment frame structural steel system, and reinforced concrete shear wall systems. He co-authored three Bechtel reports on the findings of this research.

Prior to his research assignment, Mr. Reifschneider was a civil/structural engineer on the Midland nuclear plant project. His duties included designing seismic supports for HVAC ducts and electrical cabletrays.

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DEPT. DESIGN ENGINEERING
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. VII of VIII
SUBJECT SEISMIC ANALYSIS HILLS-McCANNA ACTUATORS
Computed by ____ Date ____ Checked by ____ Date ____

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SUMMARY OF RESULTS R-260 FS

COMPONENT	MANUFACTURED MATERIAL ALLOWABLE STRESS	LOW GRADE MATERIAL ALLOWABLE STRESS	* CALCULATED STRESS (σ_F, τ_F) STRESS COMPARISON
RETAINING KEY	303 STAINLESS STEEL $S_{\tau_A} = (0.5) S_y$ $S_{\tau_A} = 17500$ psi	NOT APPLICABLE NOT APPLICABLE	$\tau_F = 1360$ psi $1360 \ll 17500$ psi
MAIN BODY CYLINDER OUTSIDE SURFACE INSIDE SURFACE	1020 STEEL $S_{Y_A} = (0.9)(S_Y)$ $S_{Y_A} = 43200$ psi	1006 STEEL $S_{Y_A} (0.9) S_Y$ $S_{Y_A} \cdot 36900$	$\sigma_F = 15092$ psi $15092 < 36900$ $\sigma_F = 17014$ psi $17014 < 36900$
MOUNTING HARDWARE 3/8-16 BOLTS		A 307 GRADE 1 BOLT $\sigma_A : 20000$ psi $\tau_A = 10000$ psi	$\sigma_F = 3455$ psi $\tau_F = 1759$ psi

NOTE: LOWEST GRADE BOLT ASSUMED INSTALLED

BASIS FOR COMPARISON: $\frac{\tau_F}{\tau_A} + \frac{\sigma_F}{\sigma_A} \leq 1.5$ FOR DBE ANALYSIS

$0.349 \leq 1.5$

* CALCULATED STRESS USING SRSS OF THREE EARTHQUAKE DIRECTIONS OR MAXIMUM DISTORTION ENERGY THEORY

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PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. VIII of VIII
SUBJECT SEISMIC ANALYSIS HILLS-McCANNA ACTUATORS
Computed by DV Date ______ Checked by ______ Date ______

SUMMARY OF RESULTS CONTINUED R-260 FS

COMPONENT	MANUFACTURED MATERIAL ALLOWABLE STRESS	LOW GRADE MATERIAL ALLOWABLE STRESS	*CALCULATED STRESS STRESS COMPARISON
BODY CASTING (MOUNTING YOKE)	CLASS 35 CAST IRON $S_{y_A}=(0.6)(S_u)$ $S_{y_A}=18000$ psi $S_{\tau_A}=(0.4)(S_u)$ $S_{\tau_A}=12000$ psi	CLASS 20 CAST IRON $S_{y_A}=(0.6)(S_u)$ $S_{y_A}=12000$ $S_{\tau_A}=(0.4)(S_u)$ $S_{\tau_A}=8000$ psi	$\sigma_F = 1137$ psi $\tau_F = 122$ psi $1137 << 12000$ $122 << 8000$
PRESS FIT BETWEEN MAIN CYLINDER AND MOUNTING YOKE	CAST IRON-1020 STEEL MINIMUM INTERFERENCE = 0.001" FORCE REQUIRED TO SLIDE CYLINDER FROM MOUNTING YOKE = 1005#		RESULTANT AXIAL FORCE = 237# $237 < 1005$

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SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
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WEIGHT DETERMINATION

R-260 FS

CYLINDER - SPRING CYLINDER

$D_O = 3.62"$
$D_I = 3.25"$
$h = 5.84"$
$\rho = 0.283 \#/in^3$

$$\text{WEIGHT} = \frac{\pi(3.62^2 - 3.25^2)(5.84)(0.283)}{4}$$

WEIGHT = 3.30 #

MAIN BODY CYLINDER

$D_O = 3.871"$
$D_I = 3.520"$
$h = 12.605"$
$\rho = 0.283 \#/in^3$

$$\text{WEIGHT} = \frac{\pi(3.871^2 - 3.520^2)(12.605)(0.283)}{4}$$

WEIGHT = 7.27 #

END CAP SPRING CYLINDER

$D_1 = 3.31"$
$D_2 = 2.14"$
$\rho = 0.283 \#/in^3$

$$\text{WEIGHT} = 0.283\left[\frac{\pi(3.31)^2(0.25)}{4} + \frac{\pi(2.14)^2(0.25)}{4}\right]$$

WEIGHT = 0.86 #

SPRING

LENGTH OF ONE COIL = $\sqrt{(2\pi r)^2 + h^2}$

r = radius

h = DISTANCE BETWEEN TWO COILS OF HELIX

SPRING OD = 2.88

SPRING ID = 2.17

$h = 0.331$

$$r = \frac{(2.88 - 2.17)/2 + 2.17}{2} = 1.26"$$

$$\text{LENGTH OF ONE COIL} = \sqrt{\left[(2)(\pi)(1.26)\right]^2 + 0.331^2}$$

LENGTH OF ONE COIL = 7.94"

$$(13.0 \# \text{COILS})(7.94")(\pi)\frac{(0.331)^2}{4}(0.283) = 2.51 \#$$

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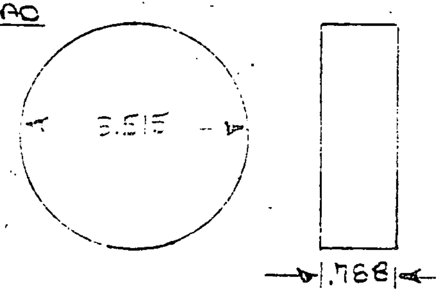
WEIGHT DETERMINATION CONTINUED

PISTON

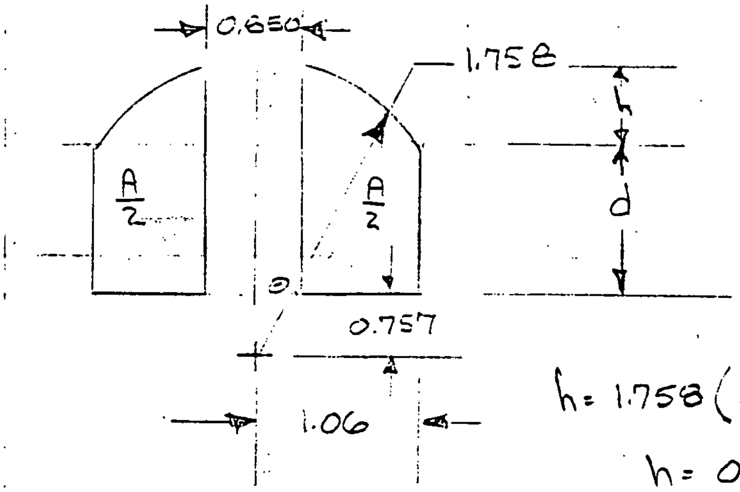
HEAD



$$VOLUME_1 = \frac{\pi(3.515^2)(0.788)}{4} =$$

$$V_1 = 7.65 \text{ in}^3$$

LOWER SKIRT



$$\theta \quad \sin^{-1}\frac{1.06}{1.758} = 37.1^\circ$$

$$d = 1.758 \cos 37.1^\circ - 0.757$$

$$d = 0.6452$$

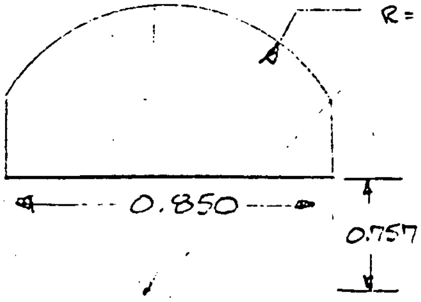
$$h = 1.758\left(\cos\left[\sin^{-1}\frac{0.425}{1.758}\right] - \cos\theta\right) =$$

$$h = 0.304$$

$$AREA = \left(\frac{37.1}{180}\right)(\pi)(1.758)^2 - (1.4022)(1.06) + (2)(0.6452)(0.635)$$

$$-(0.850)0.304) = 1.076 \text{ in}^2$$

$$V_2 = 1.076 \text{ in}^2 \times 4.808 \text{ in} = 5.173 \text{ in}^3$$



$$\theta = \sin^{-1}\left(\frac{0.425}{1.758}\right) = 14^\circ$$

$$A = \left[\frac{14^\circ}{180}\pi(1.758)^2\right] - 1.758(\cos 14^\circ)(0.425) +$$

$$\left[1.758 \cos 14^\circ - 0.757\right](0.85) = 0.837 \text{ in}^2$$

$$V_3 = (0.837)(1.448) = 1.212 \text{ in}^3$$

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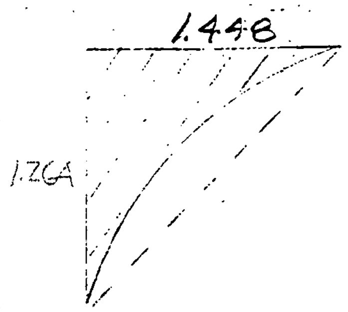
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by Date Checked by /AJR Date

WEIGHT DETERMINATION CONTINUED

R-260 FS

PISTON CONTINUED



$V_4 = \frac{1}{2}(1.448)(1.264) \times 2.12 = 1.940 \text{ IN}^3$
(CONSERVATIVE)

$V_{PISTON} = V_1 + V_2 + V_3 + V_4 = 7.65 + 5.173 + 1.212 + 1.940$
$= 15.975$

WEIGHT PISTON $= \rho V = (0.26)(15.975) = 4.1$ #

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R-260 FS

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SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by DA Date ______ Checked by MR / AJR Date ______

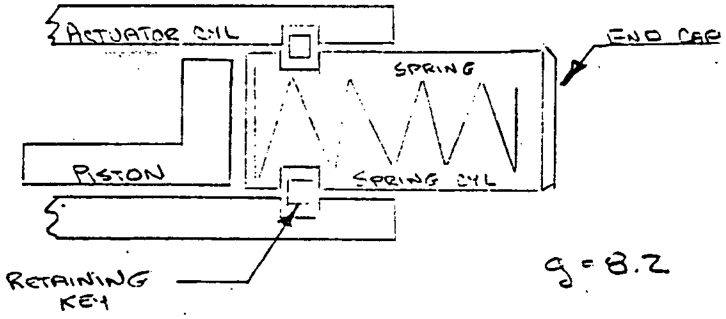
REFERENCE BECHTEL 7884-M-100

		HORIZONTAL g LOADS OBE	 DBE
IV-AO-15A & B	REACTOR BUILDING ELEVATION 822	4.1	8.2
IV-AO-51A & B	REACTOR BUILDING ELEVATION 779	3.5	7.0

FREQUENCY NOT DETERMINED, BOLTED SUPPORT SYSTEM

- MAXIMUM HORIZONTAL (g) LOAD FOR WORST CASE ACTUATOR ELEVATION APPLIED TO ALL AXIS OF SEISMIC ANALYSIS. HORIZONTAL (g) LOAD IS GREATER THAN (1+g) LOAD ON VERTICAL
- MAXIMUM AIR PRESSURE = 100 PSI ACTING ON PISTON 3.524" IN DIAMETER $F_{AP} = \frac{(100^{\#}/in^2)(3.524)^2 \pi}{4} = 975.35^{\#}$

SHEAR STRESS ON THE RETAINING KEY AXIAL ORIENTATION



M_1 (END CAP) = 0.86#
M_2 (SPRING CYL) = 3.30#
M_3 (SPRING) = 2.51#
M_4 (PISTON) = 4.10#
10.77#

g = 8.2

SPRING TEST LENGTH REFERENCE 430-3003
AT 7.88" SPRING LOAD = 257#
SPRING RATE = 100 #/IN
MAXIMUM SPRING COMPRESSION = 5.81"

$F_{SPRING} = 257^{\#} + 100(7.88 - 5.81) = 464.00^{\#}$

$F_{WEIGHT} = (8.2)(10.77) = 88.31^{\#}$

$F_{AIR\ PRESSURE} = \frac{(100\ PSI)(\pi)(3.524)^2}{4} = 975.35^{\#}$

$F_{TOTAL} = 464^{\#} + 88.31^{\#} + 975.35^{\#} = 1527.66^{\#}$ CONSERVATIVE APPROXIMATION

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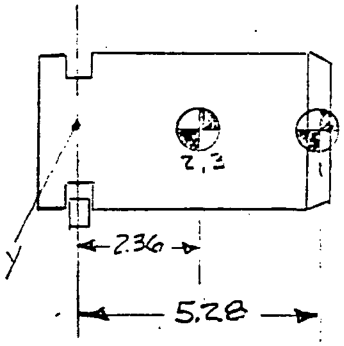
SHEAR STRESS ON THE RETAINING KEY

RETAINING KEY 303 STAINLESS STEEL 0.125" SQUARE

ACTIVE CIRCUMFERENTIAL LENGTH = $11.20 - 0.355 - \frac{0.125}{\tan 15°} = 10.39"$

$$\tau_A = \frac{F_T}{A} = \frac{1527.66}{(0.125)(10.39)} = \underline{\underline{1176.25 \text{ PSI}}}$$

STRESS ON THE RETAINING KEY FROM MOMENTS CAUSED BY THE SPRING CYLINDER ASSEMBLY



$$M_Y = 8.2 \left[(0.86)(5.28) + (2.36)(3.30 + 2.51) \right]$$

$$M_Y = 149.67 \text{ IN-lb}$$

$$\int \tau(\theta)\, t r^2 \sin\theta \, d\theta = \frac{M}{4}$$

REFERENCE R-450 FS CALC Pg. 6

$$\tau(\theta) = K r \sin\theta$$

QUAD ACTIVE LENGTH = $\frac{10.39}{4} = 2.60"$

$$\int K t r^3 \sin^2\theta \, d\theta$$

$$K t r^3 \int \sin^2 d\theta = K t r^3 \left[-\frac{1}{4}\sin 2\theta + \frac{\theta}{2} \right]_0^\theta = \frac{M}{4}$$

t = 0.125"
r = 3.568"/2 = 1.78"
M = 149.67 IN-lb

$$C_{QUAD} = \frac{2\pi(1.78)}{4} = 2.80$$

$$\theta = \frac{2.60"}{2.80"} \times \frac{\pi}{2} = 1.46 \text{ RADIAN}$$

$$-\frac{1}{4}\sin(2)(1.46) + \frac{1.46}{2} = 0.6751$$

$$\frac{M}{4} = K t r^3 (0.6751) \qquad \frac{149.67}{(4)(0.125)(1.78)^3(0.6751)} = K$$

$$K = 78.62$$

$$\tau(\theta) = (78.62)(1.78)\sin(1.46) = \underline{139.09 \text{ PSI}}$$

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R:260 FS SHEAR STRESS ON THE RETAINING KEY

$\tau_{TOTAL} = \tau_A + \tau(\theta) = 1176.25 + 139.09 = 1315.34$ PSI

S_y = YIELD STRENGTH 303 STAINLESS STEEL = 35,000 PSI
S_γ = SHEAR STRENGTH $= (0.5)(S_y) = (0.5)(35,000) = 17500$ PSI
ALLOWABLE SHEAR STRESS = 17500 PSI

1315.34 PSI < 17500 PSI

STRESSES DUE TO THE PRESS FIT CONDITIONS BETWEEN THE YOKE AND THE CYLINDER BODY

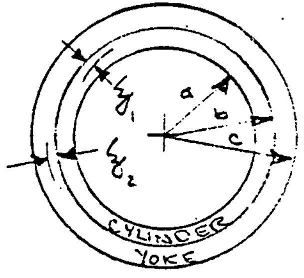
- REFERENCE HIGDON "MECHANICS OF MATERIALS" JOHN WILEY & SONS 1978 Pg 163, 164

I (INTERFERENCE) = 3.856 − 3.852 = 0.004" (MAXIMUM)

YOKE BODY = $\frac{3.852}{3.853}$

$I = 2\xi_1 + 2\xi_2$

MAIN CYLINDER = $\frac{3.856}{3.854}$



$$\xi_1 = \frac{b_1^2 P_s}{(c^2 - b_1^2) E_y b_1}\left[(1-\nu)b_1^2 + (1+\nu)c^2\right]$$

$$\xi_2 = \frac{b_2^2 P_s}{(b_2^2 - a^2) E_c b_2}\left[(1-\nu)b_2^2 + (1+\nu)a^2\right]$$

a = 1.762"
b_1 = 1.926"
b_2 = 1.928"
c = 2.30"

SOLVE FOR P_s INTERFACIAL PRESSURE

$$0.004 = 2\left[\frac{1.926^2 P_s}{(2.30^2 - 1.926^2)(15\times10^6)(1.926)}\right]\left[(0.71)(1.926)^2 + (1.29)(2.30)^2\right]$$
$$+ 2\left[\frac{1.928^2 P_s}{(1.928^2 - 1.762^2)(30\times10^6)(1.928)}\right]\left[(0.70)(1.928)^2 + (1.3)(1.762)^2\right]$$

$$0.004 = 1.5367\times10^{-6} P_s + 1.3929\times10^{-6}$$

P_s = 1365.37 # (MAXIMUM INTERFERENCE)

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R-260 FS

DEPT. DESIGN ENGINEERING CALC. M84-11
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 7 of 18
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATE
Computed by BW Date Checked by MR / AJR Date

STRESSES DUE TO THE PRESS FIT CONDITIONS BETWEEN THE YOKE AND THE CYLINDER BODY

EXTERNAL PRESSURE

$$\sigma_r = \frac{-b^2 P_o}{b^2 - a^2}\left[1 - \frac{a^2}{\rho^2}\right]$$

$$\sigma_t = \frac{-b^2 P_o}{b^2 - a^2}\left[1 + \frac{a^2}{\rho^2}\right]$$

INTERNAL PRESSURE

$$\sigma_r = \frac{a^2 P_I}{b^2 - a^2}\left[1 - \frac{b^2}{\rho^2}\right]$$

$$\sigma_t = \frac{a^2 P_I}{b^2 - a^2}\left[1 + \frac{b^2}{\rho^2}\right]$$

STRESS IN BODY CASTING INTERNAL PRESSURE

$$\sigma_r = \frac{(1.926)^2(1365.37)}{(2.30^2 - 1.926^2)}\left(1 - \frac{2.30^2}{1.926^2}\right) = -1365.37 \text{ PSI}$$

$$\sigma_t = \frac{(1.926)^2(1365.37)}{(2.30^2 - 1.926^2)}\left(1 + \frac{2.30^2}{1.926^2}\right) = 7774.39 \text{ PSI}$$

STRESS IN MAIN CYLINDER EXTERNAL PRESSURE

OUTSIDE CYLINDER SURFACE

$$\sigma_r' = -\frac{(1.928)^2(1365.37)}{(1.928^2 - 1.762^2)}\left(1 - \frac{1.762^2}{1.928^2}\right) = -1365.37 \text{ PSI}$$

$$\sigma_t' = \frac{-(1.928)^2(1365.37)}{(1.928^2 - 1.762^2)}\left(1 + \frac{1.762^2}{1.928^2}\right) = -15206.06 \text{ PSI}$$

FOR INFORMATION ONLY

STRESSES DUE TO THE PRESS FIT CONDITIONS BETWEEN THE YOKE AND THE CYLINDER BODY

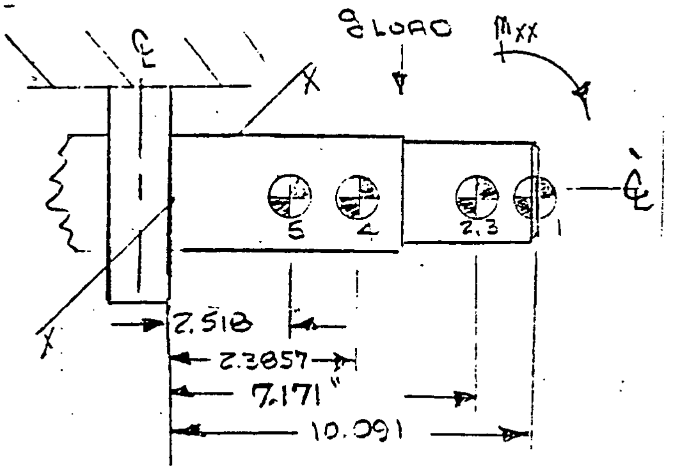
STRESS IN THE MAIN CYLINDER EXTERNAL PRESSURE

INSIDE CYLINDER SURFACE

$$\sigma_r = \frac{-(1.928)^2(1365.37)}{(1.928^2 - 1.762^2)}\left(1 - \frac{1.762^2}{1.762^2}\right) = 0$$

$$\sigma_t = -\frac{(1.928)^2(1365.37)}{(1.928^2 - 1.762^2)}\left(1 + \frac{1.762^2}{1.762^2}\right) = -16571.43 \quad \text{PSI}$$

STRESS ON THE MAIN CYLINDER DUE TO MOMENTS CAUSED BY THE MAIN BODY CYLINDER, PISTON, SPRING CYLINDER AND END CAP



M_1 (END CAP) = 0.86#
M_2 (SPRING CYL) = 3.30#
M_3 (SPRING) = 2.51#
M_4 (PISTON) = 4.10#
M_5 (MAIN CYL) = 7.27#

NOTE: $l_5 = 2.54$ WHEN CALCULATED BY CENTERING MOUNTING YOKE ON MAIN CYLINDER. (NOT MACHINED DIAMETER)

- MASS OF CYLINDER IS MODELLED TO ACT ON THE RIDE SIDE OF THE YOKE. EXCLUDES COUNTERACTING MOMENT DUE TO MASS ON THE LEFT SIDE OF YOKE ℄

$$M_{xx} = 8.2\Big[(10.091)(0.86) + (3.30 + 2.51)(7.171) + (4.10)(2.3857) + (7.27)(2.518)$$

$$M_{xx} = 643.11 \text{ IN-lb}$$

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IOWA ELECTRIC LIGHT AND POWER COMPANY
CEDAR RAPIDS, IOWA
R-260 FS

DEPT. DESIGN ENGINEERING CALC M84-11
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 9 of 18
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by DW Date Checked by R / ASR Date

STRESSES ON THE MAIN CYLINDER

MOMENT OF INERTIA @ AXIS X-X ACTUATOR ℄ IS NEUTRAL AXIS

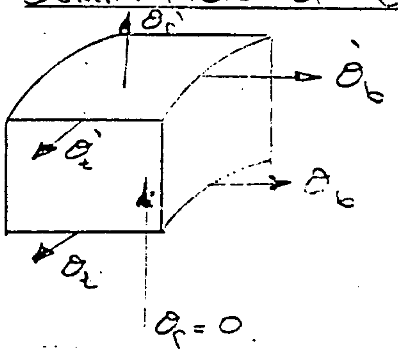
$$I = \frac{\pi}{64}(d_o^4 - d_i^4) = \frac{\pi}{64}(3.856^4 - 3.524^4) = 3.282 \text{ IN}^4$$

$$\theta' = \frac{Mc}{I} = \frac{(643.11 \text{ IN-lb})(3.856)}{3.282\ (2)} = 377.8 \text{ PSI}$$

$$\theta = \frac{Mc}{I} = \frac{(643.11)(3.524)}{3.282\ (2)} = 345.3 \text{ PSI}$$

$$\theta_{\text{AIR PRESSURE}} = \frac{975.35^{\#}}{(3.856^2 - 3.524^2)\pi/4} = 506.85 \text{ PSI}$$

SUMMATION OF CYLINDER STRESSES



$$\theta_b' = \theta' + \theta_{AP} = 377.8 + 506.85 = 884.7 \text{ PSI}$$
$$\theta_r' = -1365.37 \text{ PSI}$$
$$\theta_\gamma' = -15206.06 \text{ PSI}$$

$$\theta_b = \theta + \theta_{AP} = 345.3 + 506.85 = 852.1 \text{ PSI}$$
$$\theta_r = 0$$
$$\theta_\gamma = -16571.43$$

MAXIMUM DISTORTION ENERGY STRESS THEORY

$$\theta_F = \left\{ \frac{1}{2}\left[(\theta_b - \theta_t)^2 + (\theta_t - \theta_r)^2 + (\theta_r - \theta_b)^2 \right] \right\}^{1/2}$$

• REFERENCE MECHANICS OF MATERIALS Pg. 489

SUMMATION OF CYLINDER STRESSES

$$\sigma_F = \left\{ \frac{1}{2} \left[(852.1 + 16571.4)^2 + (-16571.4 - 0)^2 + (0 - 852.1)^2 \right] \right\}^{1/2}$$

$\sigma_F = 17013.5$ PSI

$$\sigma_F' = \left\{ \frac{1}{2} \left[(884.7 + 15206.06)^2 + (-15206.06 + 1365.37) + (-1365.37 - 884.7) \right] \right\}^{1/2}$$

✓

$\sigma_F' = 15092.0$ PSI

S_y 1020 STEEL = 48,000 PSI

$90\% \, S_y = (0.90)(48000) = 43200$ PSI

$\sigma_F = 17013.5 \text{ PSI} < 43200 \text{ PSI}$

$\sigma_F' = 15092.0 \text{ PSI} < 43200 \text{ PSI}$

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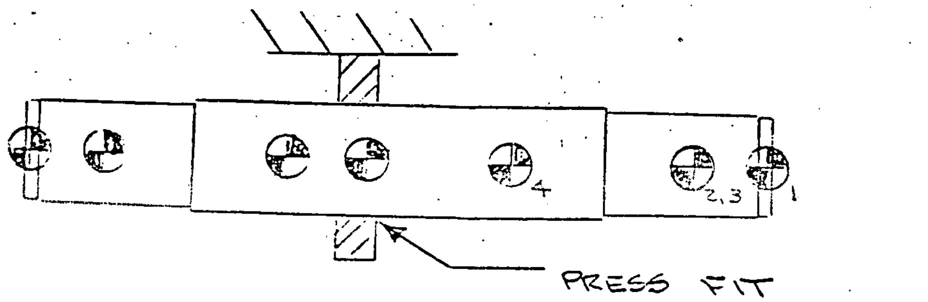
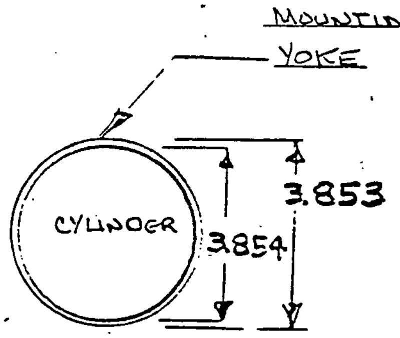
IOWA ELECTRIC LIGHT AND POWER COMPANY
CEDAR RAPIDS, IOWA
R-260 FS

DEPT. DESIGN ENGINEERING CALC. M84-11
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 11 of 18
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by Date Checked by R / AJR Date

SEISMIC AXIAL LOAD ACTING ON THE PRESS FIT OF THE MAIN CYLINDER AND MOUNTING YOKE



MINIMUM INTERFERENCE
I = 3.854" - 3.853"
I = 0.001"



MINIMUM PRESSURE FROM PRESS FIT WITH MINIMUM INTERFERENCE

SOLVING FOR MINIMUM PRESSURE (P) Pg 164 MECHANICS OF MATLS.

$$0.001 = 2\left[\frac{1.9265^2 P_s}{(2.30^2 - 1.9265^2)(15\times10^6)(1.9265)}\right]\left[(0.71)(1.9265)^2 + (1.29)(2.30)^2\right]$$

$$+ 2\left[\frac{1.9270^2 P_s}{(1.9270^2 - 1.762^2)(30\times10^6)(1.927)}\right]\left[(0.70)(1.927)^2 + (1.3)(1.762)^2\right]$$

$$0.001 = 1.400 \times 10^{-6} P_s + 1.5392 \times 10^{-6} P_s$$
$$P_s = 340.2 \ \#$$

DETERMINATION OF AXIAL LOAD

M1 (END CAPS) = (2)(0.86) = 1.72
M2 (SPRING CYL) = (2)(3.30) = 6.60
M3 (SPRING) = (2)(2.51) = 5.02
M4 (PISTON) = (2)(4.10) = 8.20
M5 (MAIN CYL) = (7.27)
TOTAL WEIGHT = 28.81

AXIAL FORCE = (28.81)(8.2) = 236.24#

FOR INFORMATION ONLY

FORCE REQUIRED TO SLIDE CYLINDER FROM MOUNTING YOKE

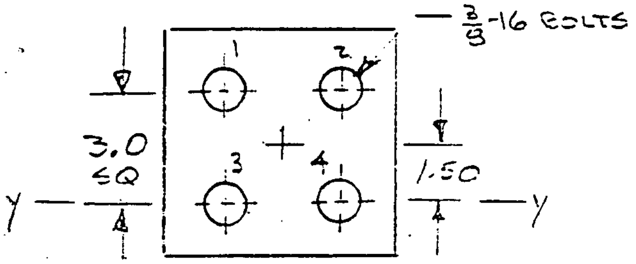
$F_S = \pi f P d l$ REFERENCE: MARKS HANDBOOK 8-47

$l = 2.44''$
$d = 3.854''$
$P = 314.99^{\#}$
f = COEFFICIENT OF FRICTION AVERAGE RANGE 0.10 → 0.15
LET f = 0.10

$$F_S = \pi(0.10)(340.2)(3.854)(2.44) = 1005^{\#}$$

$$\underline{\underline{1005^{\#} > 236.24^{\#}}}$$

SEISMIC LOADING ON THE MOUNTING HARDWARE



TENSION AREA = 0.0775 IN²
WEIGHT OF TOTAL ACTUATOR ASSEMBLY = 47#

g_Z LOADING

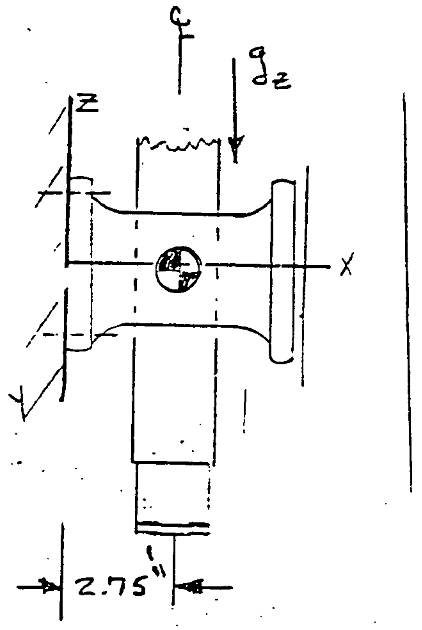
$$M_Y = (8.2)(47^{\#})(2.75) - 1059.85 \text{ IN-lb}$$

$M_Y = 2F_T(3)$ F_T = TENSION IN BOLTS 1 & 2

$$F_T = \frac{(1059.85)}{(2)(3.0)} = 176.64^{\#}$$

$$\sigma_{X_T} = \frac{176.64^{\#}}{0.0775 \text{ IN}^2} = 2279.25 \text{ PSI}$$

$$\tau_{YZ} = \frac{(47^{\#})(8.2)}{(0.0775)(4 \text{ BOLT})} = 1243.23 \text{ PSI}$$



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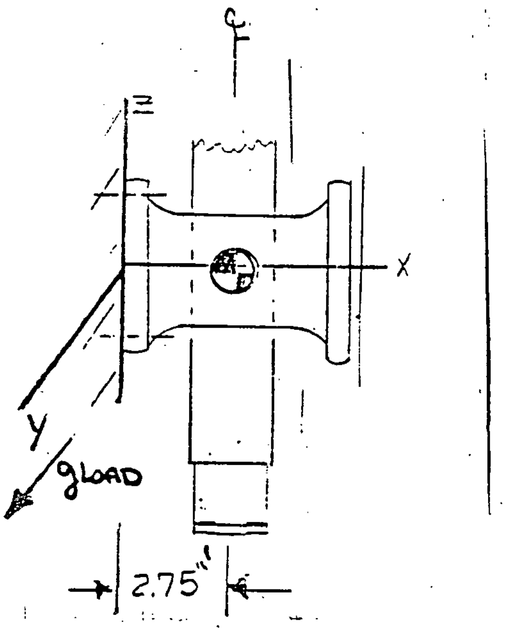
IOWA ELECTRIC LIGHT AND POWER COMPANY
CEDAR RAPIDS, IOWA
K-260 FS

DEPT. DESIGN ENGINEERING CALC M84-11
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 13 of 18
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by Date Checked by /AJR Date

SEISMIC LOADING ON THE MOUNTING HARDWARE

g_Y LOADING



$M_Z = (8.2)(47^{\#})(2.75\text{IN}) = 1059.85\text{IN-lb}$

$M_Y = 2(F_T)(3.0)$ F_T = TENSION BOLTS 2 : 4

$$F_T = \frac{(1059.85)}{(2)(3.0)} = 176.64^{\#}$$

$\sigma_{X_2} = 2279.25$ PSI

$$\tau_{YZ} = \frac{(47^{\#})(8.2)}{(0.0775)(4)} = 1243.23 \text{ PSI}$$

g_X LOADING

TENSION ONLY = $F_{T_X} = MA$

$$\text{FORCE TENSION} = \frac{(47^{\#})(8.2)}{4 \text{ BOLTS}} = 96.35^{\#}$$

$$\sigma_{X_3} = \frac{96.35^{\#}}{0.0775\text{IN}^2} = 1243.26 \text{ PSI}$$

SUMMATION OF STRESSES

BASIS FOR COMPARISON $\frac{\tau_F}{\tau_A} + \frac{\sigma_F}{\sigma_A} \leq 1.5$ FOR DBE CONDITIONS

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CEDAR RAPIDS, IOWA
R-260 FS

DEPT. DESIGN ENGINEERING CALC M84-11
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 14 of 18
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by Date Checked by R / AJR Date

SUMMATION OF STRESSES ON THE MOUNTING HARDWARE

$$\sigma_F = \left[\sigma_{x_1}^2 + \sigma_{x_2}^2 + \sigma_{x_3}^2\right]^{1/2} = \left[2279.25^2 + 2279.25^2 + 1243.26^2\right]^{1/2}$$

$$\sigma_F = 3454.79 \text{ PSI}$$

$$\tau_F = \left[\tau_{zy_1}^2 + \tau_{zy_2}^2 + \tau_{zy_3}^2\right]^{1/2} = \left[1243.23^2 + 1243.23^2 + 0^2\right]^{1/2}$$

$$\tau_F = 1758.19 \text{ PSI}$$

BOLTS ASSUMED TO BE A307 GRADE (1) BOLTS

$\sigma_A = 20000$ PSI
$\tau_A = 10000$ PSI

$$\frac{1758.19}{10,000} + \frac{3454.79}{20,000} = 0.3486$$

$$\underline{\underline{0.349 \leq 1.5}}$$

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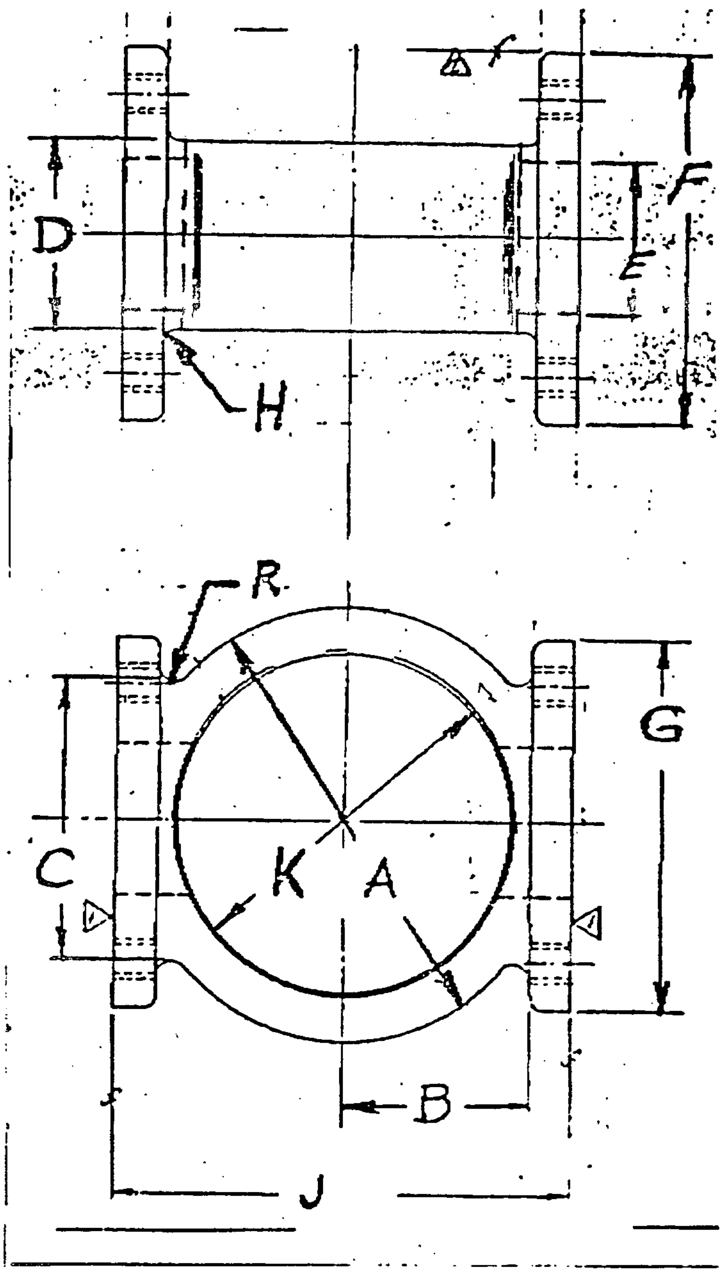
CEDAR RAPIDS, IOWA

DEPT. DESIGN ENGINEERING CALC ME4-11
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 15 of 18
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by Date Checked by MR / AJK Date

R-260 FS

SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE



A = 4.60
B = 2.25
C = 2.50
D = 2.50
E = 1.50 " DIA.
F = 4.00
G = 4.00
H = 0.12
J = 5.50
K = 3.85
R = 0.22

ELASTIC STRESS IN-PLANE BENDING

REF: FORMULAS FOR STRESS AND STRAIN Pg 593

$$K_T = K_1 + K_2\left(\frac{2h}{d}\right) + K_3\left(\frac{2h}{d}\right)^2 + K_4\left(\frac{2h}{d}\right)^3$$

$$K_1 = 1.042 + 0.982\,(h/r)^{1/2} - 0.036\,(h/r)$$

$$K_2 = -3.599 + 1.619\,(h/r)^{1/2} - 0.431\,(h/r)$$

$$K_3 = 6.084 - 5.607\,(h/r)^{1/2} + 1.158\,(h/r)$$

$$K_4 = -2.527 + 3.006\,(h/r)^{1/2} - 0.631\,(h/r)$$

g_z BENDING

$h = \frac{1}{2}(G - D)$ $r = H$ $d = G$

$h = \frac{1}{2}(4.0 - 2.50) = 0.750$
$r = 0.12$
$d = 4.00$

$K_1 = 3.272$
$K_2(2h/d) = -0.842$
$K_3(2h/d)^2 = -0.098$
$K_4(2h/d)^3 = 0.035$

$K_z = 2.367$

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DEPT. DESIGN ENGINEERING CALC M84-11
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 16 of 18
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by DW Date ______ Checked by R / AJR Date ______

SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE

g_y LOADING

$h = \frac{1}{2}(G-C) \quad r = R \quad d = G$

$h = \frac{1}{2}(4.0-2.50) = 0.750$

$r = 0.22$

$d = 4.0$

$h/r = 0.750/0.22 = 6.250$

$K_1 = 2.732$

$K_2\left(\frac{2h}{d}\right) = -0.780$

$K_3\left(\frac{2h}{d}\right)^2 = -0.045$

$K_4\left(\frac{2h}{d}\right)^3 = 0.035$

$K_y = 1.942$

ELASTIC STRESS AXIAL TENSION

$h = \frac{1}{2}(G-D) = \frac{1}{2}(4.0-2.50) = 0.750$

$r = H = 0.12$

$d = G = 4.00$

$K_1 = 1.042 + 0.982(6.250)^{1/2} - 0.036(6.250) = 3.2720$

$K_2 = -0.074 - 0.156(6.250)^{1/2} - 0.010(6.250) = -0.5265$

$K_3 = -3.418 + 1.220(6.250)^{1/2} - 0.005(6.250) = -0.3993$

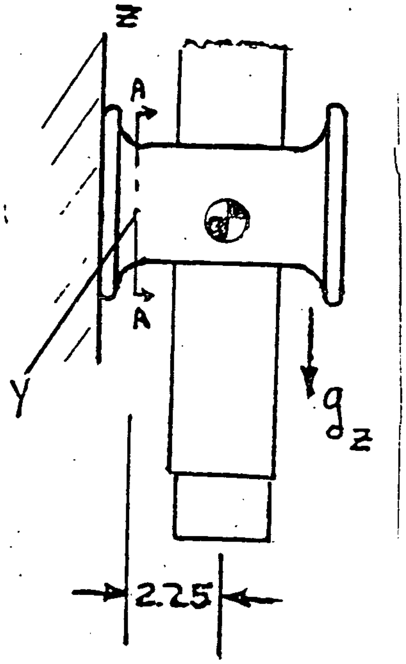
$K_4 = 3.450 - 2.046(6.250)^{1/2} + 0.051(6.250) = -1.3463$

$K_x = K_1 + K_2\left(\frac{2h}{D}\right) + K_3\left(\frac{2h}{D}\right)^2 + K_4\left(\frac{2h}{D}\right)^3 \qquad \frac{h}{D} = \frac{0.750}{4.0} = 0.1875$

$K_x = 3.2720 + (-0.5265)(0.1875) + (-0.3993)(0.1875)^2 + (-1.3463)(0.1875)^3$

$K_x = 3.1504$

g_z LOADING



$M_y = (Wt) \times (\text{dim } b) \times (g \text{ LOAD})$

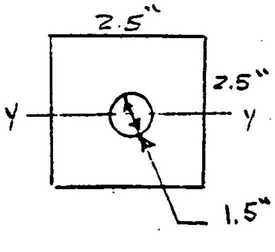
$M_y = (47^{\#})(2.25)(8.2) = 867.15 \text{ IN-lb}$

$I = \frac{(2.5)^4}{12} - \frac{\pi}{4}\left(\frac{1.5}{2}\right)^4 = 3.007 \text{ IN}^4$

$\sigma_{z_B} = \frac{Mc}{I} = \frac{(867.15)(1.25)}{3.007} = 360.51 \text{ PSI}$

$\sigma_x = \sigma_{z_B} K_z = (360.51)(2.367) = 853.32 \text{ PSI}$

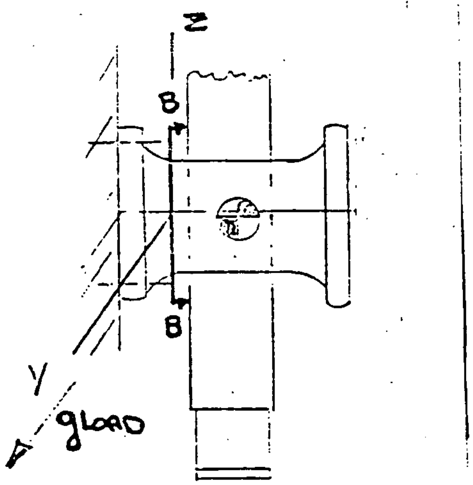
$\tau_{zy} = (47^{\#})(8.2) \Big/ (2.5)^2 - \pi(0.75)^2 = 85.97 \text{ PSI}$



FOR INFORMATION ONLY

SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE

g_y LOADING



$$M_Z = (Wt)(\dim B)(g\ \text{LOAD})$$

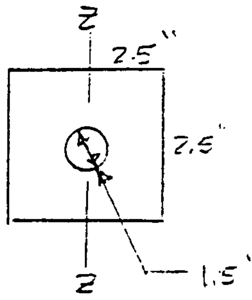
$$M_Z = (47^{\#})(2.25)(8.2) = 867.15\ \text{IN-LB}$$

$$I = \frac{(2.50)^4}{12} - \frac{\pi}{4}\left(\frac{1.50}{2}\right)^4 = 3.007\ \text{IN}^4$$

$$\theta_{Y_B} = \frac{Mc}{I} = \frac{(867.15)(1.25)}{3.007} = 360.51\ \text{PSI}$$

$$\theta_X = \theta_{Y_B} K_Y = (360.51)(1.942) = 700.10\ \text{PSI}$$

$$\tau_{ZY} = \frac{(47^{\#})(8.2)}{2.5^2 - \pi(0.75)^2} = 85.97\ \text{PSI}$$



g_x LOADING

$$F(\text{TENSION})_X = (8.2)(47^{\#}) = 385.4^{\#}$$

$$\text{CROSS SECTIONAL AREA} = 2.5^2 - \pi(0.75)^2 = 4.483\ \text{IN}^2$$

$$\theta_{X_A} = \frac{385.4^{\#}}{4.483\ \text{IN}^2} = 85.97\ \text{PSI}$$

$$\theta_X = K_X\,\theta_{X_A} = (85.97)(3.1504) = 270.85\ \text{PSI}$$

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R-260 FS

DEPT. DESIGN ENGINEERING CALC. M24-11
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SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by ______ Date ______ Checked by R / AJR Date ______

SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE

SQUARE ROOT SUM OF THE SQUARES

$$\sigma_F = \left[853.32^2 + 700.10^2 + 270.85^2 \right]^{1/2} = 1136.51 \text{ PSI}$$

$$\tau_F = \left[85.97^2 + 85.97^2 + 0^2 \right]^{1/2} = 121.58 \text{ PSI}$$

$S_U = 30{,}000$ PSI GRADE 30 CAST IRON
NOTCHED FATIQUE STRENGTH GRADE 30 C.I. = 13,500 PSI
$\sigma_F = 1136.51 < 0.6(30000) = 18{,}000$ PSI
$< 13{,}500$ PSI NOTCHED FATIQUE STRENGTH

$\tau_F = 121.58$ PSI $< 0.4(30{,}000) = 12{,}000$ PSI
$< 13{,}500$ NOTCHED FATIQUE STRENGTH

- STRESSES ON THE FOLLOWING COMPONENTS ARE GOVERENED BY THE OPERATING LOADS AND NOT THE DESIGN BASIS EARTHQUAKE CONDITIONS.

EXAMPLES : SCOTCH YOKE, CONNECTING PINS, SHAFT, PISTON

SCOTCH YOKE:

OPERATING SPRING LOADS APPROX = 257#
SEISMIC LOADS = (8.2)(4.10") = 33.62#

ALLOWABLE STRESSES $\dfrac{257}{1.0} \geq \dfrac{257 + 33.62}{1.5}$

$257 \geq 193.75$

∴ NO DETAILED ANALYSIS REQUIRED

CALC No:
~~DCR No~~: M84-11

Sheet 19A of 19A

DESIGN/REVIEW COMMENTS SHEET.

FOR INFORMATION ON

[✓ DESIGN VERIFICATION] ALTERNATE CALCULATIONS

NO.	COMMENT	RESOLUTION/APPROVAL
	No Comments A J Rodenik 4-26/84 Verifying Engineer Date	Donald W. Church 4/25/84 Design Engineer Date A J Rodenik 4-26/84 Verifying Engineer Date M. McDermott 4/30/84 Technical Group Leader Date 30 April 1984 Supervising Engr. Nuclear Projects Date

Form No. NG-009Z* Rev. 0

IOWA ELECTRIC LIGHT AND POWER COMPANY

DUANE ARNOLD ENERGY CENTER

CALCULATION COVERSHEET

FOR INFORMATION ON

ANALYSIS/CALCULATION NO: M84-12

ANALYSIS/CALCULATION TITLE: SEISMIC STRESS ANALYSIS
HILLS-McCANNA DAMPER ACTUATORS R-450 FS

REFERENCE DOCUMENTS

MAR NO: ________

DCR NO: ________

OTHERS: DDC 769

PREPARED BY: Donald W. Church DATE: 4/19/84

REVIEWED BY: DATE: 4-19/84

APPROVED BY: Mike McDermott DATE: 4/30/84

FINAL APPROVAL BY: DATE: 30 April

FORM NG-007Z REV. 0

Background

The purpose for compiling calculations M84-11, 12, 13, 14, 15 was to perform a seismic analysis on the critical components of the Hills-McCanna Pneumatic Damper Actuators. These actuators are part of the secondary containment isolation system at the Duane Arnold Energy Center.

On January 26, 1984, Iowa Electric notified the NRC by telephone that the above mentioned actuators were potentially deficient in meeting their purchase specification. A review of the documents relating to this discrepancy revealed that the isolation damper assemblies were purchased originally as complete assemblies which included the damper actuators. Subsequent orders for "like-for-like" replacement actuators were placed directly with the actuator manufacturer who was a subvendor to the damper manufacturer. This most recent purchase order for actuators revealed that a quality assurance program, as required for safety related equipment per 10CFR Part 50, is not currently in effect at the actuators manufacturer's facility.

Further review of the damper assembly documentation revealed that the seismic analysis performed on the damper assemblies did not seismically analyze the actuators themselves, but only considered their weight as it seismically affected the damper frame. This information prompted Iowa Electric to audit the damper manufacturer and check for documentation that pertained to the seismic qualifications of the isolation damper actuators. Results from the audit of the damper manufacturer revealed that the actuators were never purchased by the damper manufacturer as seismically qualified components nor did the damper manufacturer administer a Quality Assurance program concerning the purchase of the actuators.

Since no traceability or Certificate of Conformance was available for the seismic qualifications of the actuators, a seismic analysis was performed on the critical components of the actuators in order to seismically qualify the damper actuators for use in the Duane Arnold Energy Center. This seismic analysis followed the guidelines set forth in the original purchase specification for the isolation dampers (ref. Bechtel 7884-M-100). By seismically qualifying the isolation damper actuators, Iowa Electric will be able to buy Quality Level I actuators in accordance with Revision 1, Chapter 4 of the Quality Assurance Manual under Standard Industrial Quality Items 4.7.3.

Solution

A seismic analysis was performed on five models of the Rockwell Hills-McCanna Ramcon Pneumatic Actuator product line that are installed as isolation damper actuators at the Duane Arnold Energy Center. These five models include the following:

- R-260 FS
- R-450 FS
- R-960 FS
- R-2000 FS
- R-4200 FS

The seismic analysis on the actuators followed the general project seismic requirements for frequency-not-determined class 1 equipment in the reactor building and in the control building (ref. Bechtel 7884-M-100, Technical Specifications for Isolation Dampers for the Duane Arnold Energy Center Unit 1, Revision 0, 12-28-70).

A visual inspection of all isolation damper actuators at the Duane Arnold Energy Center was made in order to verify model number, serial number and elevation location in the plant. After verifying the elevation location in the plant, static coefficients (g units) were determined for the highest installed actuator for each of the five actuator models. The horizontal static coefficient was then applied to all three of the orientation axis which eliminated many repetitious calculations and the need for detailed actuator orientation information. Applying the horizontal static coefficient to each axis provided conservative results since the horizontal coefficient is always greater than one plus the vertical coefficient ($F_{vertical} = (Weight)\ (1 + g_v)$, $F_{horizontal} = (Weight)\ (g_h)$, $g_h > 1 + g_v$).

The seismic analysis concentrated on the critical areas of the damper actuator where the seismically induced loads could possibly make the actuator fail, malfunction, or prevent operation. Five areas on each actuator model were identified as critical areas requiring a seismic analysis of the various components interfacing with that critical area. These five critical areas are identified as the following:

- Retaining key which holds the spring cylinder assembly to the main body cylinder
- Main body cylinder
- Press fit between main body cylinder and the mounting yoke
- Mounting hardware
- Mounting yoke

Dimensions and material specifications for the seismic analysis were obtained through the use of proprietary component drawings that were on loan to Iowa Electric from Rockwell Hills-McCanna of Carpentersville, Illinois. All prints applicable to this seismic analysis are listed in the reference section of the referenced calculations.

Four basic assumptions are applied throughout the entire seismic analysis of the damper actuators. These assumptions allow Iowa Electric to use the floor response spectra as the design/qualification spectra for the seismic analysis. The four basic assumptions are as follows:

- The mounting of the damper is a rigid structure ($f > 33$ cps)
- The damper itself is a rigid structure ($f > 33$ cps)
- The support bracket for the actuator is a rigid structure ($f > 33$ cps)
- The seismic requirements for evaluating the actuators are the same as those for the isolation dampers.

III

The maximum seismic stresses were calculated by using the square root sum of the squares method for combining the three earthquake direction stresses as recommended in the UFSAR for seismic analysis at the Duane Arnold Energy Center. A second method, the distortion energy method was used for combining stresses at the press fit between the main body cylinder and the mounting yoke. The distortion energy method was used in place of the square root sum of the squares method because the stresses due to the press-fit condition exceeded and dominated those caused by the seismic event. All maximum stresses were then compared to some fraction of the yield strength depending on the material type and stress type. Operability after a DBE event was ensured by requiring that the maximum stress from combined seismic and normal loads should not exceed 90% of the yield stress of the material.

Conclusion

After completing the above described seismic analysis on the five models of Hills-McCanna actuators installed on the isolation dampers at the Duane Arnold Energy Center, it was found that the maximum stresses from the combined seismic and normal loads do not exceed the material yield requirements defined in the isolation damper purchase specification. The results of this seismic analysis reveal that the five models of Hills-McCanna actuators are seismically qualified for use at the Duane Arnold Energy Center.

References

Bechtel Purchase Specification 7884-M-100

Formulas for Stress and Strain; Raymond J. Roark, Warren C. Young, Fifth Edition, McGraw-Hill Book Co. 1975

Hills-McCanna Information Bulletins; R-1090, R-1090A, R110C, R1100A, R-111C, R-1110A, R-112D, R-1120A, R-113D, R-1130A

Marks' Standard Handbook for Mechanical Engineers' Baumeister Eighth Edition, McGraw-Hill Book Company 1978

Materials Selector 75; Reinhold Publishing Co. Mid September 1974, Vol. 80, No. 4, Brown Printing Co.

Mechanical Engineering Design; Joseph E. Shigley, Third Edition, McGraw-Hill Book Co. 1977

Mechanics of Materials; Higdon, Ohlsen, Stiles, Weese, Riley Third Edition, John Wiley and Sons 1978

IV

FOR INFORMATION ONLY

Rockwell Hills-McCanna; Proprietary Drawings

DATA: Information contained on drawings is proprietary and confidential and is not to be given or loaned to others. Drawings are to be returned to Rockwell upon completion of their intended use in making the seismic analysis.

R260	R450–R960	R2000–R4200
430-1004	450-7511	460-7511
430-7510	450-1005	460-1001
430-7511	450-7512	460-7509
430-3003	450-3005	460-3001
430-3005	450-3007	460-3003
430-4101	450-4101	460-4101
430-4102	450-4102	460-4102
430-2101	450-2101	460-2101
430-2904	450-2906	460-2904
430-2502	450-2507	460-2503
430-2501	450-2501	460-2502
430-3321	450-3201	460-3208
430-3322	450-3202	460-3209
430-3325	450-3203	460-3210
430-3201	450-3326	460-3317
430-3202	450-3325	460-3316
430-3203	450-3321	460-3320
	450-3320	460-3321
		460-3314
		460-3315

U.S.S. Steel Design Manual; R.L. Brockenbrough and B.G. Johnson, Jan. 1981

V

MARTIN REIFSCHNEIDER Reviewer for Calculations M84-11,12,13,14,15

POSITION	Senior Civil/Structural Engineer
EDUCATION	BS, Civil Engineering, University of Michigan MS, Civil/Structural Engineering, University of Michigan
PROFESSIONAL DATA	Registered Professional Engineer in Michigan
SUMMARY	1 year: Senior Engineer; Civil/Structural Staff 4 years: Senior Engineer; Midland, Palisades, and Big Rock Point Nuclear Power Plants 1 year: Resident Engineer, Midland Nuclear Power Plant

EXPERIENCE

Mr. Reifschneider is currently assigned as a civil/structural engineer on the civil/structural staff. His duties include; preparation of design standards; review of project calculations, drawings, specifications and seismic qualification of equipment; providing consultation to civil/structural engineers engaged in the design of nuclear and fossil power plants; solving special static and dynamic structural problems.

Prior to joining the civil/structural staff, Mr. Reifschneider was a civil/structural engineer on Consumers Power Company's Palisades project. His duties included finite element analysis of the biological shield wall, seismic analysis and design of blockwall supports, and seismic analysis and design of the auxiliary building addition including the review of seismic equipment qualifications.

Prior to joining the Palisades project, Mr. Reifschneider was a civil/structural resident engineer at the jobsite of Consumers Power company's Midland nuclear plant project. His duties included interfacing with construction personnel on the design, erection, and construction of seismic instrument and equipment supports.

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MARTIN REIFSCHNEIDER Reviewer for Calculations M84-11,12,13,14,15

Prior to his jobsite assignment, Mr. Reifschneider conducted research on the inelastic design and behavior of braced structural steel systems, moment frame structural steel system, and reinforced concrete shear wall systems. He co-authored three Bechtel reports on the findings of this research.

Prior to his research assignment, Mr. Reifschneider was a civil/structural engineer on the Midland nuclear plant project. His duties included designing seismic supports for HVAC ducts and electrical cabletrays.

IOWA ELECTRIC LIGHT AND POWER COMPANY
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PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. VII of VIII
SUBJECT SEISMIC ANALYSIS HILLS-McCANNA ACTUATORS
Computed by DW Date Checked by Date

FOR INFORMATION ONLY

SUMMARY OF RESULTS R-450 FS

COMPONENT	MANUFACTURED MATERIAL ALLOWABLE STRESS	LOW GRADE MATERIAL ALLOWABLE STRESS	* CALCULATED STRESS (σ_F, τ_F) STRESS COMPARISON
RETAINING KEY	303 STAINLESS STEEL $S_{Y_A} = (0.5) S_Y$ $S_{Y_A} = 17500$ psi	NOT APPLICABLE NOT APPLICABLE	$\tau_F = 1019$ psi $1019 << 17500$
MAIN BODY CYLINDER	1020 STEEL	1006 STEEL	
OUTSIDE SURFACE	$S_{Y_A} = (0.9)(S_Y)$ $S_{Y_A} = 43200$ psi	$S_{Y_A} = (0.9)(S_Y)$ $S_{Y_A} = 36900$	$\sigma_F = 12317$ psi $12317 < 36900$
INSIDE SURFACE			$\sigma_F = 12791$ psi $12791 < 36900$
MOUNTING HARDWARE 1/2-13 BOLTS		A307 GRADE 1 BOLT $\sigma_A = 20000$ psi $\tau_A = 10000$ psi	$\sigma_F = 6019$ $\tau_F = 3765$

NOTE: LOWEST GRADE BOLT ASSUMED INSTALLED

BASIS FOR COMPARISON : $\frac{\tau_F}{\tau_A} + \frac{\sigma_F}{\sigma_A} \leq 1.5$ FOR OBE CONDITIONS

$0.677 < 1.5$

* CALCULATED STRESS USING SRSS OF THE EARTHQUAKE DIRECTIONS OR MAXIMUM DISTORTION ENERGY THEORY.

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DEPT. DESIGN ENGINEERING
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SUBJECT SEISMIC ANALYSIS HILLS-MCCANNA ACTUATORS
Computed by DV Date ______ Checked by ______ Date ______

SUMMARY OF RESULTS CONTINUED R-450 FS

COMPONENT	MANUFACTURED MATERIAL ALLOWABLE STRESS	LOW GRADE MATERIAL ALLOWABLE STRESS	*CALCULATED STRESS STRESS COMPARISON
BODY CASTING (MOUNTING YOKE)	CLASS 35 CAST IRON $S_{Y_A} = (0.6)(S_u)$ $S_{Y_A} = 18000$ psi $S_{\tau_A} = (0.4)(S_u)$ $S_{\tau_A} = 12000$ psi	CLASS 20 CAST IRON $S_{Y_A} = (0.6)(S_u)$ $S_{Y_A} = 12000$ $S_{\tau_A} = (0.4)(S_u)$ $S_{\tau_A} = 8000$ psi	$\sigma_F = 2575$ psi $\tau_F = 1113$ psi $2575 < 12000$ $1113 < 8000$
PRESS FIT BETWEEN MAIN CYLINDER AND MOUNTING YOKE	CAST IRON - 1020 STEEL MINIMUM INTERFERENCE = 0.001 FORCE REQUIRED TO SLIDE CYLINDER FROM MOUNTING YOKE = 1349#		RESULTANT AXIAL FORCE = 418# $418 < 1349$

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R-450 FS

FOR INFORMATION ONLY

WEIGHT DETERMINATION

CYLINDER - SPRING CYLINDER (R-450, R-960)

$D_o = 5.50"$
$D_i = 4.87"$
$h = 9.67"$
$\rho = 0.283 \frac{\#}{IN^3}$

$$\text{VOLUME} = \frac{\pi(D_o^2 - D_i^2)\,h}{4}$$

$$\text{VOLUME} = \frac{\pi(5.50^2 - 4.87^2)(9.67)}{4} = 49.62\ IN^3$$

$$\underline{\text{WEIGHT} = (49.62\ IN^3)(0.283) = 14.04^{\#}}$$

REFERENCE: 450-7512

MAIN BODY CYLINDER (R-450)

$D_o = 5.86"$
$D_i = 5.27"$
$h = 14.204$
$\rho = 0.283\ \#/IN^3$

$$\text{VOLUME} = \frac{\pi(5.86^2 - 5.27^2)(14.204)}{4}$$

$$\text{VOLUME} = 73.26\ IN^3$$

$$\underline{\text{WEIGHT} = (73.26\ IN^3)(0.283) = 20.73^{\#}}$$

REFERENCE: 450-3325

END CAP (SPRING CYLINDER) (R-450, R-960)

$D_1 = 5.138"$
$D_2 = 2.11"$
$\rho = 0.283\ \#/IN^3$

$$\text{VOLUME} = \frac{\pi(5.138^2)(0.75)}{4} - \frac{\pi(5.138^2 - 2.11^2)(0.28)}{4}$$

$$\text{VOLUME} = 10.72\ IN^3$$

$$\underline{\text{WEIGHT} = (10.72\ IN^3)(0.238\ \#/IN^3) = 3.03^{\#}}$$

REFERENCE: 450-1005

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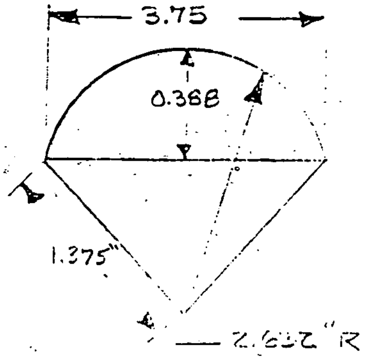
Computed by ____ Date ____ Checked by ____ Date ____

R-450 FS

WEIGHT DETERMINATION PISTON (R-450, R-460)



X 2.27 DEEP

$$\frac{1}{2.27} V = \pi (2.632)^2 \left(\frac{\sin^{-1} \frac{1.375}{2.632}}{180} \right) - (1.375)(2.244)$$

$$V = 1.64 \text{ IN}^3$$

REFERENCE : 450-3202
450-3203

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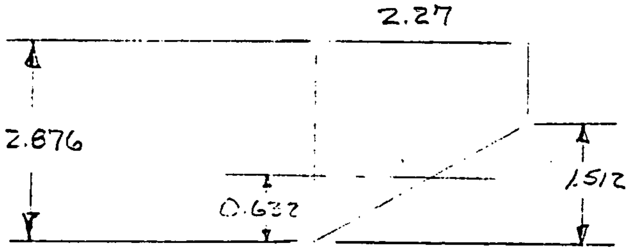
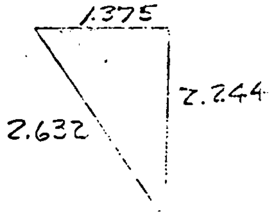
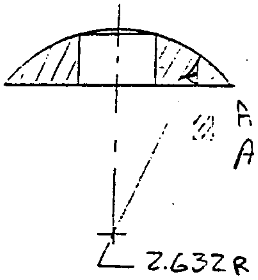


X 3.75 DEEP

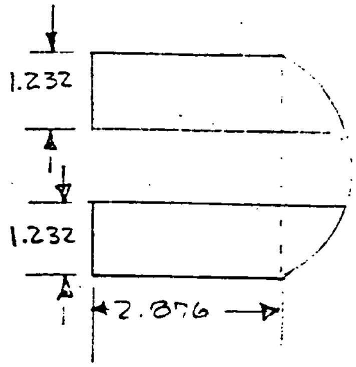
$$V = 3.75 \left[\tfrac{1}{2}(1.512)(2.27) + 2.27(2.876 - 1.512) \right]$$

$$V = 18.047 \text{ IN}^3$$





$A = 0.7225 - 0.388(1.286)$
$A = 0.223 \text{ in}^2$



X 5.2 DEEP

$$V = \left[2(1.232)(2.876) + 0.223 \right] 5.2 = 38.009 \text{ IN}^3$$

VOLUME PISTON HEAD = $\pi(2.632)^2(1) + \pi(1.625)^2(0.03) - \pi(2.632^2 - 2.402^2)(0.378)$
$V_H = 20.637 \text{ IN}^3$

VOLUME OF MACHINED HOLES = $\pi\left(\frac{0.437}{2}\right)^2 (2.464) = 0.37 \text{ IN}^3$

TOTAL VOLUME = $1.64 + 18.047 + 38.009 + 20.637 - 0.37 =$
$= 77.96 \text{ IN}^3$

DENSITY $\rho = 0.26 \#/\text{IN}^3$ WEIGHT = $\rho V_T = (77.96 \text{ IN}^3)(0.26 \#/\text{IN}^3) =$

WEIGHT = 20.27#

R-450 FS (R-450)

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WEIGHT DETERMINATION

END CAP (MAIN CYLINDER)

$D_o = 5.428''$

$h = 1''$

$\rho = 0.283 \ \#/in^3$

$$\text{VOLUME} = \frac{\pi (5.348)^2 (1'')}{4} = 22.46 \ in^3$$

$$\text{WEIGHT} = (22.46)(0.283) = 6.36 \#$$

SPRINGS (R-450, R-960)

$SPRING_1 = 3.34 \#$

$SPRING_2 = 9.64 \#$

NESTED SPRINGS

TOTAL SPRING WEIGHT = 12.98 #

REFERENCE: PRINT A-450-3007
A-450-3005

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SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATR
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R-450 FS

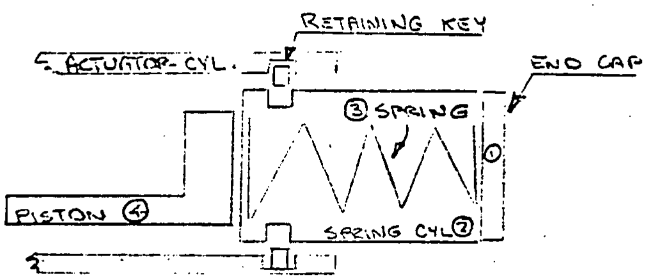
HORIZONTAL g LOADS

	REFERENCE: BECHTEL 7884-M-100		OBE	DBE
IV-AO-42 A & B	REACTOR BUILDING	ELEVATION 776	2.7	5.4
IV-AO-44 A & B	CONTROL BUILDING	ELEVATION 786	1.7	3.3

- MAXIMUM HORIZONTAL (g) LOAD FOR WORST CASE ACTUATOR ELEVATION APPLIED TO ALL AXIS OF SEISMIC ANALYSIS. HORIZONTAL (g) LOAD IS GREATER THAN (1+g) LOAD ON VERTICAL.

- MAXIMUM AIR PRESSURE = 100 PSI ACTING ON PISTON 5.27" DIA

SHEAR STRESS ON THE RETAINING KEY AXIAL ORIENTATION.



M_1 (END CAP) = 3.03#
M_2 (SPRING CYL) = 14.04#
M_3 (SPRING) = 12.98#
M_4 (PISTON) = 20.27#
50.32#

g = 5.4

SPRING TEST LENGTHS (NESTED SPRINGS)

A-450-3005 @ 12.22" = 501# WITH 115 lb/in RATE
A-450-3007 @ 12.16" = 151# WITH 35 lb/in RATE
9.6" MAXIMUM SPRING COMPRESSION LENGTH WITH PISTON AT STOP.

$F_{SPRING} = 151^{\#} + 35(12.16-9.60) + 501 + 115(12.22-9.60) = 1043^{\#}$

$F_{MASS} = 5.4(50.32) = 271.73^{\#}$

$F_{AIR\ PRESSURE} = \frac{(100\ PSI)(\pi)(5.27)^2}{4}$

$F_{AP} = 2181.3^{\#}$

$F_{TOTAL} = 272 + 1043 + (2181.3 - 1043)$
$2453.3^{\#}$ ON CROSS SECTION OF RETAINING KEY.

RETAINING KEY
303 STAINLESS
□ WITH APPROX 16" CIRCUMFERENTIAL ACTIVE LENGTH
0.187 SQUARE

$\tau = F/A = \frac{2453.3}{0.187(16)}$ 820 PSI

YIELD STRENGTH OF 303 SS
$S_y = 35000$ PSI
SHEAR STRENGTH S_τ
$S_\tau = 0.5 S_y = (0.5)(35000)$
$S_\tau = 17500$ PSI

820 PSI << 17500 PSI

ALLOWABLE SHEAR STRENGTH = 17500 psi

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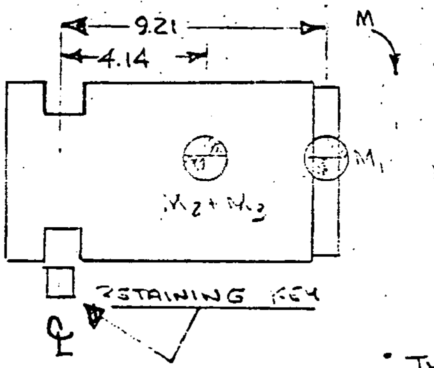
R-450 FS

STRESS ON THE RETAINING KEY FROM MOMENT CAUSED BY THE SPRING CYLINDER ASSEMBLY



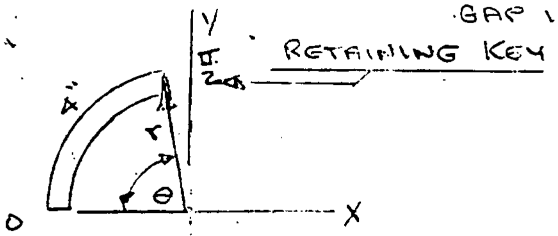
M MOMENT ABOUT RETAINING KEY ℄

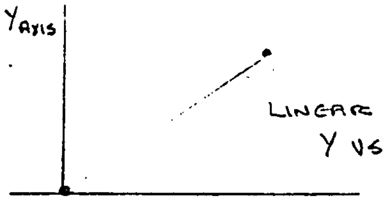
$M = 4.14(M_2+M_3)g + 9.21(M_1)g$

$M = 4.14(14.04+12.98)5.4 + 9.21(3.03)5.4$

$M = 754.8$ IN-lb

• THETA (θ) IS THE ANGLE THAT CORRESPONDS TO THE RETAINING RING GAP FOR ONE QUADRANT GAP IS DIVIDED INTO TWO EQUAL PARTS AT +Y AND -Y





RETAINING KEY ACTIVE LENGTH = 4"/QUAD

F_S = SHEAR FORCE

$C = \frac{2\pi(2.632)}{4} = 4.1343$

$\theta = \frac{4}{4.1343} \times \frac{\pi}{2} = 1.519$

SHEAR STRESS = $\tau(\theta)$
t = THICKNESS RETAINING RING
t = 0.187"
r = 2.632"
M = 754.8 IN-lb
θ = 1.52

$$\int_0^{1.52} \tau(\theta)\, t\, r^2 \sin\theta \, d\theta = \frac{M}{4}$$

$$\tau(\theta) = K r \sin\theta$$

$$\int_0^{1.52} K t\, r^3 \sin^2\theta \, d\theta$$

$$\int_0^{\theta} \sin^2 d\theta = \left[-\frac{1}{4}\sin 2\theta + \frac{1}{2}\theta\right]_0^{\theta} = -\frac{1}{4}\sin 2(1.52) + \frac{1.52}{2} = 0.735$$

$$\frac{M}{4} = K t r^2 (0.735) \qquad K = \frac{(754.8)}{(4)(0.187)(2.632)^3(0.735)}$$

$K = 75.30$

$\tau(\theta) = (75.30)(2.632)\sin\left(\frac{\pi}{2}\right) = 198.2$ PSI

$\tau_{TOTAL} = \tau(\theta) + \tau = 820 + 198.2 = 1018.19$ PSI

$1018.19 < 17500$ PSI

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SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATOR
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R-450 FS

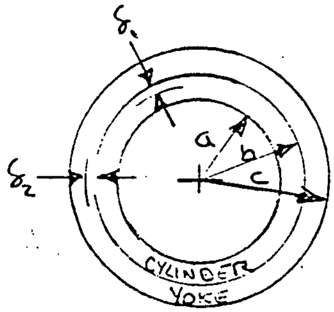
FOR INFORMATION ONLY

STRESSES DUE TO THE PRESS FIT CONDITIONS BETWEEN THE YOKE AND THE CYLINDER BODY

- REFERENCE HIGDON "MECHANICS OF MATERIALS" JOHN WILEY & SONS 1978 Pg. 164, 163

$$I \text{ (INTERFERENCE)} = 0.005'' = 2\delta_1 + 2\delta_2$$

$$\delta_1 = \frac{b_1^2 P_S}{(c^2 - b_1^2) E_Y b_1}\left[(1-\nu) b_1^2 + (1+\nu) c^2\right]$$



$$\delta_2 = \frac{b_2^2 P_S}{(b^2 - a^2) E_C b_2}\left[(1-\nu) b_2^2 + (1+\nu) a^2\right]$$

$a = 2.6375$
$b_1 = 2.9205$ $b_2 = 2.923$
$c = 3.435$

SOLVE FOR P_S INTERFACIAL PRESSURE

$$0.005 = 2\left[\frac{(2.9205)^2 P}{[3.435^2 - 2.9205^2](15\times10^6)(2.9205)}\right]\left[(1-0.29)(2.9205)^2 + (1.29)(3.435)^2\right]$$

$$+ 2\left[\frac{(2.923)^2 P}{(2.923^2 - 2.6375^2)(30\times10^6)(2.923)}\right]\left[(1-0.3)(2.923)^2 + (1.3)(2.6375)^2\right]$$

$$0.005 = 2.533\times10^{-6} P + 1.8442\times10^{-6} P$$

$P = 1142$ PSI (MAXIMUM INTERFERENCE)

EXTERNAL PRESSURE

$$\sigma_r = -\frac{b^2 P_o}{b^2 - a^2}\left(1 - \frac{a^2}{\rho^2}\right)$$

$$\sigma_t = -\frac{b^2 P_o}{b^2 - a^2}\left(1 + \frac{a^2}{\rho^2}\right)$$

INTERNAL PRESSURE

$$\sigma_r = \frac{a^2 P_I}{b^2 - a^2}\left(1 - \frac{b^2}{\rho^2}\right)$$

$$\sigma_t = \frac{a^2 P_I}{b^2 - a^2}\left(1 + \frac{b^2}{\rho^2}\right)$$

R-450 FS

FOR INFORMATION ONLY

STRESS IN BODY CASTING INTERNAL PRESSURE

$$\sigma_r = \frac{(2.9205)^2(1142)}{(3.435^2-2.9205^2)}\left(1-\frac{(3.435^2)}{(2.9205)^2}\right) = -1142 \text{ PSI}$$

$$\sigma_t = \frac{(2.9205)^2(1142)}{(3.435^2-2.9205^2)}\left(1+\frac{3.435^2}{2.9205^2}\right) = 7100 \text{ PSI}$$

STRESS IN CYLINDER EXTERNAL PRESSURE

OUTSIDE CYLINDER SURFACE

$$\sigma_r' = -\frac{(2.923)^2(1142)}{(2.923^2-2.6375^2)}\left(1-\left(\frac{2.6375}{2.9232}\right)^2\right) = -1143 \text{ PSI}$$

$$\sigma_t' = -\frac{(2.923)^2(1142)}{(2.923^2-2.6375^2)}\left(1+\left(\frac{2.6375}{2.9232}\right)^2\right) = -11150 \text{ PSI}$$

INSIDE CYLINDER SURFACE

$$\sigma_r = -\frac{(2.923)^2(1142)}{(2.923^2-2.6375^2)}\left(1-\frac{2.6375^2}{2.6375^2}\right) = 0 \text{ PSI}$$

$$\sigma_t = -\frac{(2.923)^2(1142)}{(2.923^2-2.6375^2)}\left(1+\frac{2.6375^2}{2.6375^2}\right) = -12292 \text{ PSI}$$

R-450 FS

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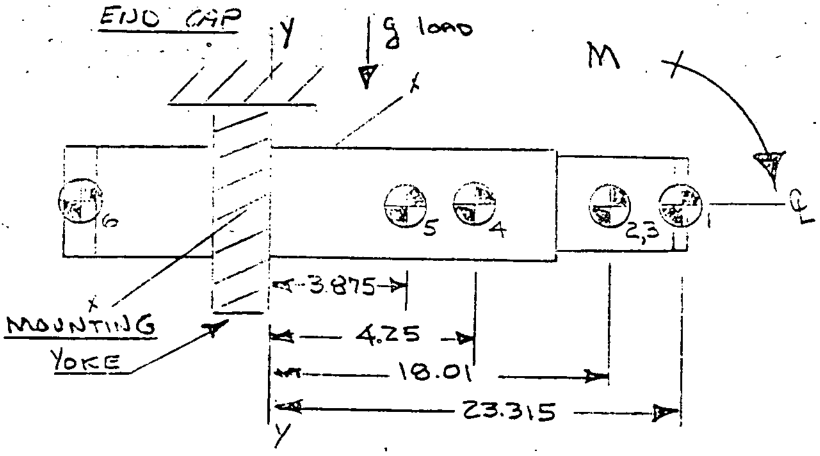
STRESS ON THE CYLINDER DUE TO MOMENT CAUSED BY MAIN BODY CYLINDER, PISTON, SPRING CYLINDER AND END CAP



M₁ (END CAP) = 3.03#
M₂ (SPRING CYL) = 14.04#
M₃ (SPRING) = 12.98#
M₄ (PISTON) = 20.27#
M₅ (MAIN CYL) = 20.73#
M₆ (MAIN END CAP) = 6.36#

- MASS OF CYLINDER IS MODELLED TO ACT ON RIGHT SIDE OF YOKE. EXCLUDES COUNTERACTING MOMENT DUE TO MASS OF CYLINDER ON LEFT SIDE OF YOKE ℄. CONSERVATIVE RESULTS
- M_6 (MAIN CYLINDER END CAP) COUNTERACTING MOMENT IS NEGLECTED. THIS PROVIDES CONSERVATIVE RESULTS.

SUMMING MOMENTS ABOUT X-X

$$M_{xx} = (5.4)(20.73)(3.875) + (5.4)(20.27)(4.25) + (5.4)(14.04 + 12.98)(18.01)$$
$$+ (5.4)(3.03)(23.315) = 3908.25 \text{ in-lb}$$

MOMENT OF INERTIA @ AXIS X-X NEUTRAL AXIS ℄

$$I = \frac{\pi}{64}\left(d_o^4 - d_i^4\right) = \frac{\pi}{64}\left(5.860^4 - 5.275^4\right)$$

$$I = 19.88 \text{ in}^4$$

$$\sigma_T = \frac{Mc}{I} \qquad c = 2.93''$$

$$\sigma_T = \frac{(3908.25)(2.93)}{19.88} = 576 \text{ PSI}$$

STRESSES DUE TO AIR PRESSURE ACTING ON PISTON

$$\text{FORCE AIR PRESSURE} = \frac{(100 \text{ PSI})\,\pi(5.27)^2}{4} = 2181.3^{\#}$$

$$\sigma_{\text{AIR PRESSURE}} = \frac{2181.3^{\#}}{\pi(5.860^2 - 5.275^2)/4} = 426.4 \text{ PSI}$$

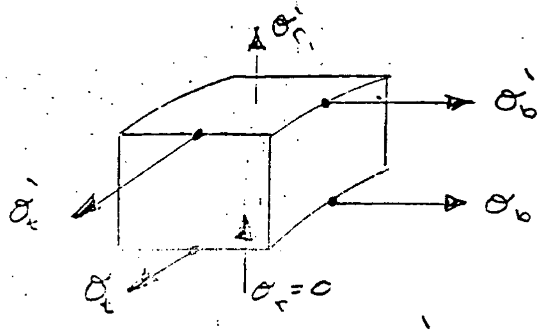
IOWA ELECTRIC LIGHT
AND POWER COMPANY
CEDAR RAPIDS, IOWA

DEPT. DESIGN ENGINEERING CALC M84-12
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 9 of 19
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by Date Checked by Date

R-450 FS

FOR INFORMATION ONLY

CYLINDER STRESSES CONTINUED



MOMENT = 3908.3 IN-lb

$C = \frac{5.27}{2} = 2.635''$

$C' = \frac{5.86}{2} = 2.93''$

$I = 20.02 \text{ IN}^4$

$\sigma_b' = \sigma_{AP} + \sigma_T' = 426.4 + 576 = 1{,}002.4 \text{ PSI}$

$\sigma_b = \sigma_{AP} + \sigma_T = 426.4 + \frac{(3908.3)(2.635)}{19.88} = 944.4 \text{ PSI}$

$\sigma_t' = -11150 \text{ PSI}$

$\sigma_t = -12292 \text{ PSI}$

$\sigma_r' = -1143 \text{ PSI}$

$\sigma_r = 0 \text{ PSI}$

Sy OF 1020 STEEL = 48000 PSI

90% $S_y = (0.9)(48000) = 43200$ PSI

SUMMATION OF STRESSES USING MAXIMUM DISTORTION ENERGY THEORY

- REFERENCE MECHANICS OF MATERIALS Pg 489

$$\sigma_f = \left\{ \frac{1}{2} \left[(\sigma_b - \sigma_t)^2 + (\sigma_t - \sigma_r)^2 + (\sigma_r - \sigma_b)^2 \right] \right\}^{1/2}$$

$$\sigma_f = \left\{ \frac{1}{2} \left[(944.4 + 12292)^2 + (-12292 + 0)^2 + (0 - 944.4)^2 \right] \right\}^{1/2}$$

$\underline{\underline{\sigma_f = 12790.50 \text{ PSI} < 43{,}200 \text{ PSI}}}$

$$\sigma_f' = \left\{ \frac{1}{2} \left[(1002.4 + 11150)^2 + (-11150 + 1143)^2 + (-1143 - 1002.4)^2 \right] \right\}^{1/2}$$

$\underline{\underline{\sigma_f' = 12316.7 \text{ PSI} < 43{,}200 \text{ PSI}}}$

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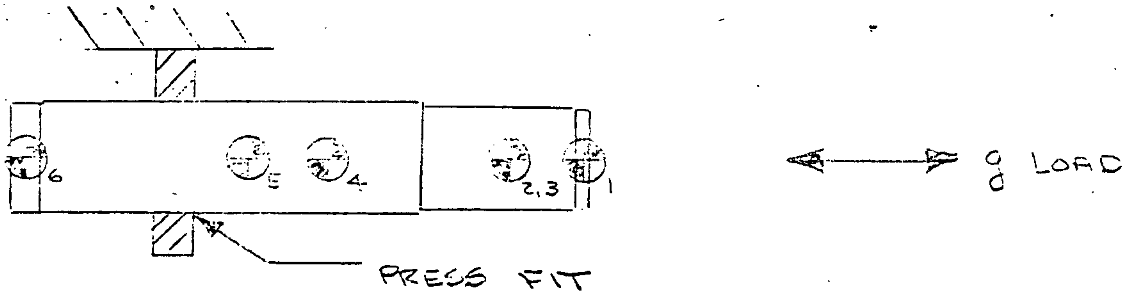
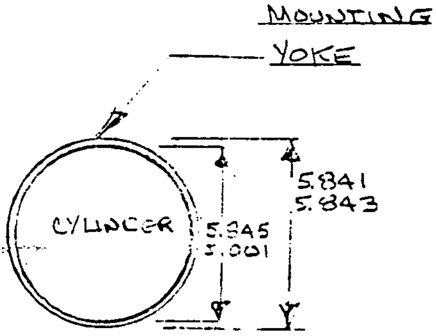
SEISMIC AXIAL LOAD ACTING ON PRESS FIT OF CYLINDER THROUGH THE MOUNTING YOKE





MINMUM INTERFERENCE ON RADIUS

$$I = \frac{5.843}{2} - \frac{5.844}{2} = 0.0005 \text{ INCH}$$

REFERENCE PRINTS 450-3321
450-3325

ON DIAMETER $I = 0.001$

MINIMUM PRESSURE FROM PRESS FIT WITH MINIMUM INTERFERENCE

SOLVING FOR MINIMUM PRESSURE (P) - Pg 164 MECHANICS OF MATLS.

$$0.001 \text{ IN} = 2\left[\frac{(2.9215)^2 P}{\{(3.435^2 - 2.9215^2)(15 \times 10^6)(2.9215)\}}\right]\left[(0.71)(2.9215)^2 + (1.29)(3.435)^2\right]$$

$$+ \; 2\left[\frac{(2.922)^2 P}{\{(2.922^2 - 2.635^2)(30 \times 10^6)(2.922)}\right]\left[(0.7)(2.922)^2 + (1.3)(2.635)^2\right]$$

$$0.001 = 2.5392(10)^{-6} P + 1.8324(10)^{-6} P$$

$$0.001 = P(4.371)10^{-6}$$

$$P = 229 \text{ PSI}$$

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DETERMINATION OF AXIAL LOAD

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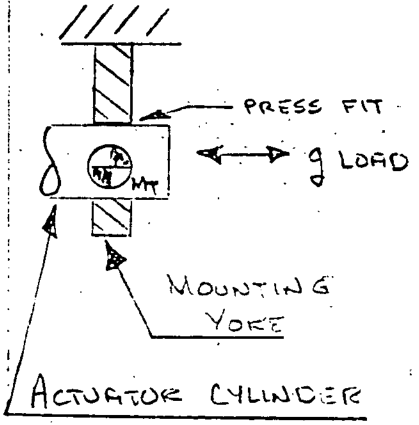

$M_T = M_1 + M_2 + M_3 + M_4 + M_5 + M_6$

M_1 (END CAP) = 3.03#
M_2 (SPRING CYL) = 14.04#
M_3 (SPRING) = 12.98#
M_4 (PISTON) = 20.27#
M_5 (MAIN CYL) = 20.73#
M_6 (MAIN CYL. END CAP) = 6.36#

M_{TOTAL} = 77.41#

AXIAL FORCE = $F_A = M_T(g) = (77.41\#)(5.4) = 418.0\#$

FORCE REQUIRED TO SLIDE CYLINDER FROM MOUNTING YOKE

$F = \pi f P d l$ REFERENCE: MARKS HANDBOOK 8-47

l = LENGTH OF FIT = 3.21
d = CYLINDER DIAMETER = 5.841 P = 229 PSI
P = UNIT PRESSURE FIT PRESSURE BETWEEN CYLINDER AND YOKE.
f = COEFFICIENT OF FRICTION AVERAGE RANGE 0.10 → 0.15
USE f = 0.10

$F = \pi(0.10)(229)(5.841)(3.21) = 1349\#$

$\underline{\underline{1349\# > 418.0\#}}$

IOWA ELECTRIC LIGHT AND POWER COMPANY
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Computed by [illegible] Date ______ Checked by MR Date ______

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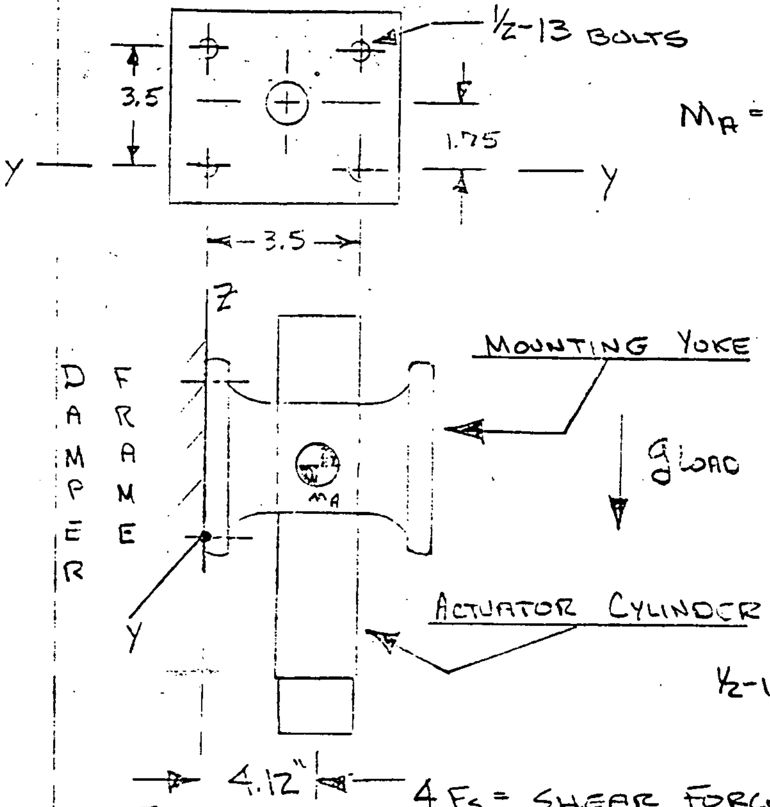
SEISMIC LOADINGS ON MOUNTING HARDWARE



(g_z) LOADING

M_A = MASS OF ACTUATOR INCLUDING MOUNTING YOKE = 104 #

MOMENT ABOUT (Y) = $(M_A)(g)(x)$

$$M_y = (104)(5.4)(4.12) = 2313.8 \text{ IN-lb}$$

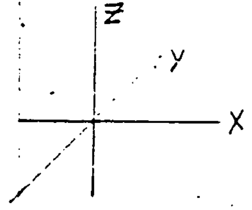
$$M_y = (2)(F_T)(3.5)$$

$2F_T$ = TENSION FORCE IN TWO TOP BOLTS

$$F_T = \frac{2313.8}{(2)(3.5)} = 330.5\#$$

1/2-13 BOLT EFFECTIVE AREA = 0.1419 IN^2
TENSILE STRESS AREA Pg 230
SHIGLEY MECH. ENG DESIGN

4 F_s = SHEAR FORCE IN (4) MOUNTING BOLT



$$F_s = \frac{(104\#)(5.4g)}{4} = 140.4\#$$

$$\tau_{zy} = \frac{140.4\#}{0.1419 \text{ IN}^2} = 989.4 \text{ PSI}$$

REF: MECHANICS OF MATERIALS P.36

$$\sigma_{x_t} = \frac{330.5\#}{0.1419 \text{ IN}^2} = 2329.1 \text{ PSI}$$

IOWA ELECTRIC LIGHT AND POWER COMPANY
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DEPT. DESIGN ENGINEERING CALC M84-12
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 13 of 19
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SEISMIC LOADINGS ON MOUNTING HARDWARE

(g_{0y}) LOADING

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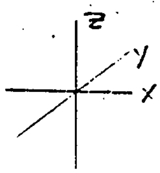
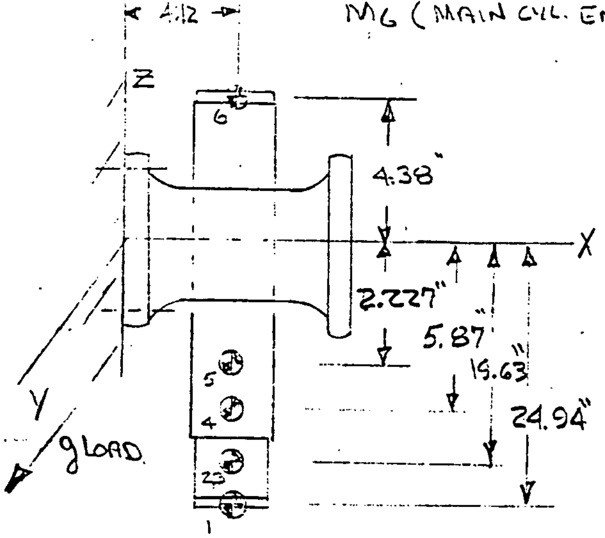


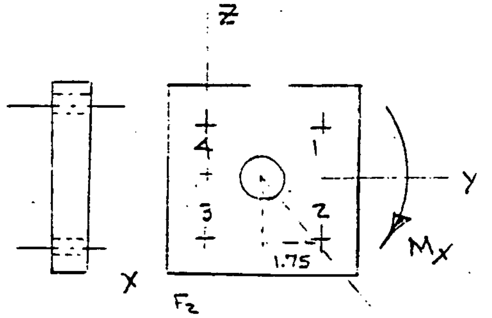
M_1 (END CAP) = 303#
M_2 (SPRING CYL.) = 14.04#
M_3 (SPRING) = 12.98#
M_4 (PISTON) = 20.27#
M_5 (MAIN CYL) = 20.73#
M_6 (MAIN CYL. END CAP) = 6.36#



$$M_X = g(M_1)(D_1) + g(M_{23})(D_2) + g(M_4)(D_4) + g(M_5)D_5 - g(M_6)D_6$$

$$M_X = 5.4\Big[(3.03)(24.94) + (14.04+12.98)(19.63) + (20.27)(5.87) + (20.73)(2.227) - (6.36)(4.38)\Big]$$

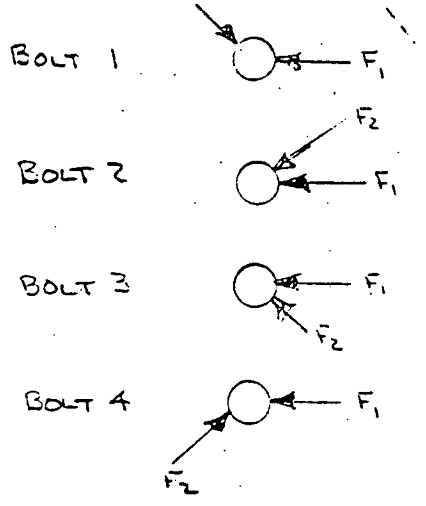
$$M_X = 4014 \quad \text{IN-lb}$$



$$M_Z = (104^{\#})(5.4)(4.12") = 2313.8 \text{ IN-lb}$$

FORCE (TENSION BOLT 1 AND 2) = F_T

$$F_X = \frac{2313.8 \text{ IN-lb}}{(2 \text{ BOLTS})(3.5 \text{IN})} = 331^{\#} \text{ TENSION}$$



F_{ZY} = SHEAR FORCE FROM TOTAL ACTUATOR MASS

$$F_{ZY} = \frac{(104^{\#})(5.4)}{4 \text{ BOLTS}} = 141^{\#}$$

F_{ZY} = SHEAR FORCE FROM MOMENT M_X ON BOLT 2 WORST CASE BOLT

$$F_{ZY} = \frac{4014 \text{ IN-lb}}{(4 \text{ BOLTS})(1.75 \text{IN})(\sqrt{2})} = 405.5^{\#}$$

$$\sigma_{X_2} = \frac{331^{\#}}{0.1419} = 2333 \quad \text{PSI}$$

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DEPT.: DESIGN ENGINEERING CALC. M[illegible]
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SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
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FOR INFORMATION ONLY

SEISMIC LOADING OF MOUNTING HARDWARE

$$F_{SHEAR} = \left[(F_{ZY} + F_{ZY} \cos 45°)^2 + (F_{ZY} \sin 45°)^2 \right]^{1/2}$$

$$F_{SHEAR} = \left[(141 + 406 \cos 45°)^2 + (406 \sin 45°)^2 \right]^{1/2}$$

$$F_{SHEAR} = 515.4^{\#}$$

$$\tau_{ZY} = \frac{F_{SHEAR}}{A_{BOLT}} = \frac{515.4^{\#}}{0.1419} = 3632.4 \text{ PSI}$$

g_X LOADING

$$\text{FORCE TENSION} = \frac{(104^{\#})(5.4)}{4 \text{ BOLTS}} + \frac{(4014 \text{ IN-lb})}{(2 \text{BOLTS})(3.5 \text{IN})} = 713.8^{\#}$$

BASIS OF COMPARISON $\frac{\tau_F}{\tau_A} + \frac{\sigma_F}{\sigma_A} \leq 1.5$ FOR DBE CONDITIONS

$\tau_{ALLOWABLE}$ FOR A307 GRADE (1) BOLT = 10,000 PSI
$\sigma_{ALLOWABLE}$ FOR A307 GRADE (1) BOLT = 20,000 PSI

$$\sigma_F = \left[\sigma_{X_1}^2 + \sigma_{X_2}^2 + \sigma_{X_3}^2 \right]^{1/2} = \left[2329.1^2 + 2333^2 + 5035^2 \right]^{1/2}$$

$$\sigma_F = 6018.21 \text{ PSI}$$

$$\tau_F = \left[\tau_{XY_1}^2 + \tau_{XY_2}^2 + \tau_{XY_3}^2 \right]^{1/2} = \left[989.4^2 + 3632.4^2 + 0^2 \right]^{1/2}$$

$$\tau_F = 3764.74 \text{ PSI}$$

$$\frac{3764.74}{10,000} + \frac{6018.21}{20,000} = 0.677$$

$$0.677 \leq 1.5$$

Iowa Electric Light and Power Company
Cedar Rapids, Iowa

DEPT. DESIGN ENGINEERING CAL M-4-12
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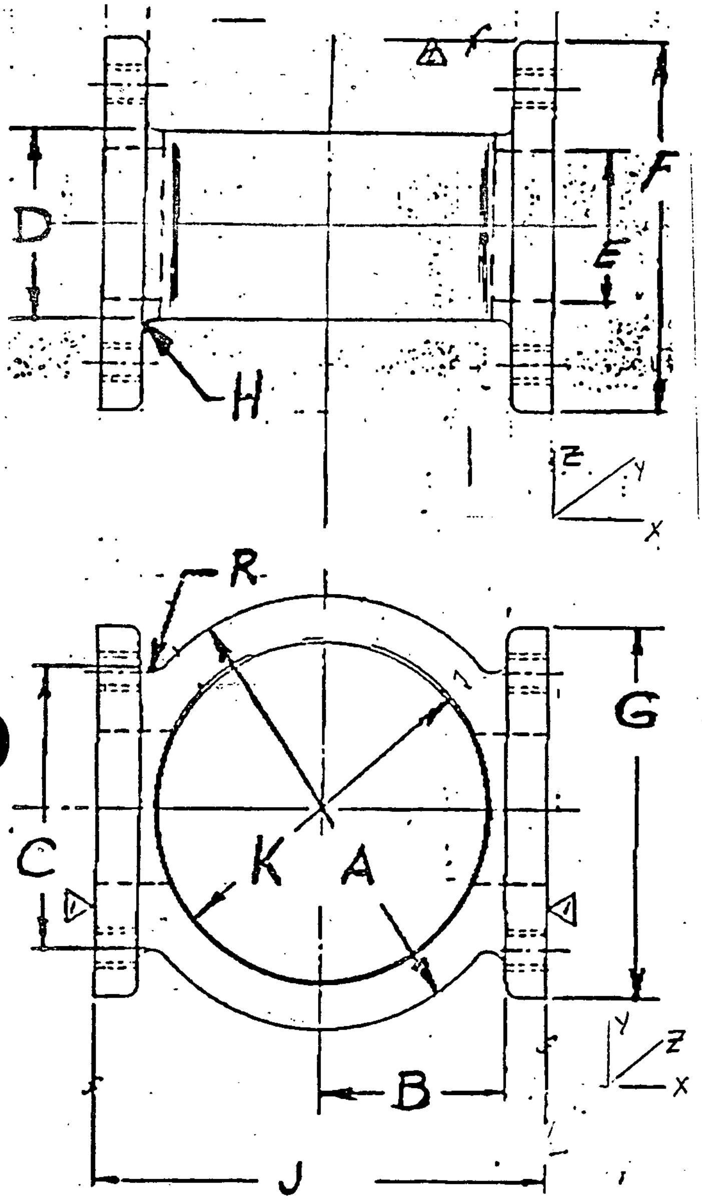
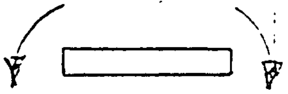
SEISMIC STRESSES ON THE MOUNTING YOKE



A = 6.87"
B = 3.50"
C = 3.25"
D = 3.25"
E (DIA) = 2.125"
F = 5.00"
G = 5.00"
H = 0.12"
J = 8.00"
K (DIA) = 5.84"
R (RADIUS) = 0.31"


ELASTIC STRESS IN-PLANE BENDING

REF: FORMULAS FOR STRESS AND STRAIN; STRESS CONCENTRATION FACTORS pg 593

$$K_T = K_1 + K_2\left(\frac{2h}{d}\right) + K_3\left(\frac{2h}{d}\right)^2 + K_4\left(\frac{2h}{d}\right)^3$$

$$K_1 = 1.042 + 0.982\,(h/r)^{1/2} - 0.036\,(h/r)$$

$$K_2 = -3.599 + 1.619\,(h/r)^{1/2} - 0.431\,(h/r)$$

$$K_3 = 6.084 - 5.607\,(h/r)^{1/2} + 1.158\,(h/r)$$

$$K_4 = -2.527 + 3.006\,(h/r)^{1/2} - 0.691\,(h/r)$$

g_Z AND g_X

$h = \frac{1}{2}(G-D)$ $r = H$ $d = G$

g_Y LOADING

$h = \frac{1}{2}(G-C)$ $r = R$ $d = G$

g_X LOADING g_Z LOADING

$h = \frac{1}{2}(5.00 - 3.25) = 0.875$
$r = 0.12$
$d = 5.00$

$K_1 = 3.431$
$K_2(2h/d) = -0.829$
$K_3(2h/d)^2 = -0.075$
$K_4(2h/d)^3 = 0.024$
$K_Z = 2.551$

g_Y LOADING

$h = \frac{1}{2}(5.00 - 3.25) = 0.875$
$r = 0.31$
$d = 5.00$

$K_1 = 2.590$
$K_2 = -0.733$
$K_3 = -0.008$
$K_4 = -0.025$
$K_Y = 1.874$

IOWA ELECTRIC LIGHT AND POWER COMPANY
CEDAR RAPIDS, IOWA

DEPT. DESIGN ENGINEERING CALC M84-13
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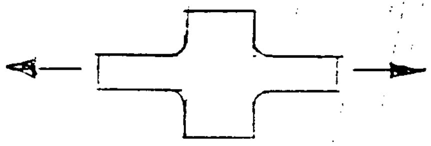
FOR INFORMATION ONLY

SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE

STRESS CONCENTRATION FACTORS ELASTIC STRESS AXIAL TENSION Pg 593 FORMULAS FOR STRESS AND STRAIN

$h = \frac{1}{2}(G-D)$; $r = H$ $d = G$
$h = 0.875$ $r = 0.12$ $d = 5.00$
$h/r = 7.2917$

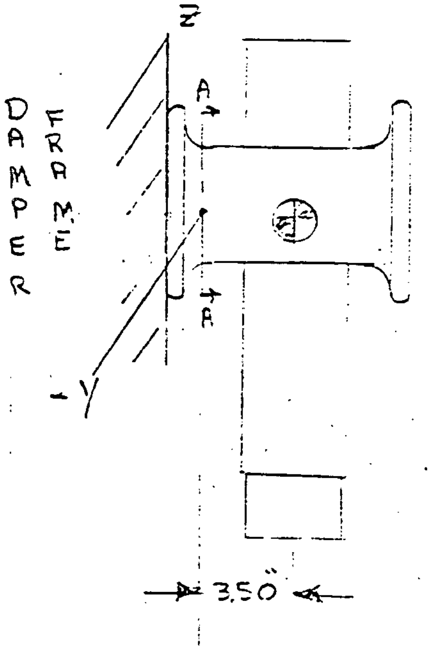


$$K_1 = 1.042 + 0.982(7.2917)^{1/2} - 0.036(7.2917) = 3.4312$$
$$K_2 = -0.074 - 0.156(7.2917)^{1/2} - 0.010(7.2917) = -0.5682$$
$$K_3 = -3.418 + 1.220(7.2917)^{1/2} - 0.005(7.2917) = -0.1601$$
$$K_4 = 3.450 - 2.046(7.2917)^{1/2} + 0.051(7.2917) = \underline{-1.7030}$$

$$K_X = 3.4312 + (-0.5682)(0.1750) + (-0.1601)(0.1750)^2 + (-1.7030)(0.1750)^3$$

$$K_X = 3.318$$

g_z LOADINGS



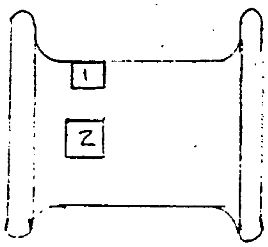
$$M_y = (104^{\#})(3.5\text{ IN})(5.4g) = 1965.6 \text{ IN-lb}$$

$$I = \frac{(3.25)^4}{12} - \frac{\pi}{4}\left(\frac{2.125}{2}\right)^4 = 8.3 \text{ IN}^4$$

$$\sigma_{x_1} = \frac{MC}{I} = \frac{(1965.6)(1.625)}{8.3} = 384.83 \text{ PSI}$$

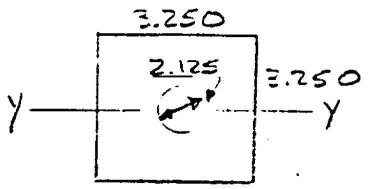
$$K_Z \sigma_{x_1} = (2.551)(384.83) = \underline{981.70 \text{ PSI}}$$

$$g_{Z\,\text{BENDING}} = 981.70 \text{ PSI}$$



STRESSES AT A POINT DESIGNATION SUBSCRIPT

SECTION A-A



$$\tau_{xz} = \tau_{yz} = \frac{(104^{\#})(5.4)}{3.250^2 - \frac{2.125^2\pi}{4}} = 80.05 \text{ PSI}$$

$$g_{Z\tau} = 80.05 \text{ PSI}$$

IOWA ELECTRIC LIGHT
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DEPT. DESIGN ENGINEERING CALC M84-12
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Computed by _____ Date _____ Checked by _____ Date _____

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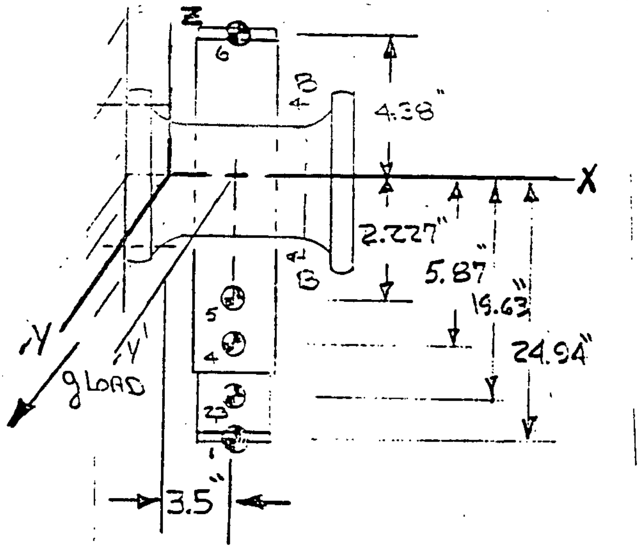
FOR INFORMATION ONLY

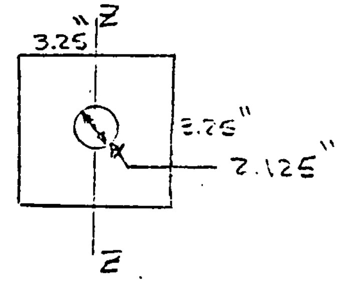
SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE

g_Y LOADING



M_1 (END CAP) = 3.03#
M_2 (SPRING CYL.) = 14.04#
M_3 (SPRING) = 12.98#
M_4 (PISTON) = 20.27#
M_5 (MAIN CYL) = 20.73#
M_6 (MAIN CYL. END CAP) = 6.58#

SECTION B-B



$$M_Z = (Wt^{\#})(g)(3) =$$

$$M_Z = (104^{\#})(5.4)(3.5) = 1965.60$$

$$I = \frac{(3.25)^4}{12} - \frac{\pi}{4}\left(\frac{2.125}{2}\right)^4 = 8.3\,\text{IN}^4$$

$$\sigma_{X_Z} = \frac{Mc}{I} = \frac{(1965.6)(1.625)}{8.3} = 384\,\text{PSI}$$

$$g_Y\ \text{BENDING} = K_Y\sigma_{X_Z} = (1.874)(384) = 719.7\ \text{PSI}$$

$$\tau_{YZ} = \frac{(104^{\#})(5.4)}{3.25^2 - \frac{\pi(2.125)^2}{4}} = 80.05\ \text{PSI}$$

$$g_{Y_\tau} = 80.05$$

SHEAR STRESS CAUSED BY MOMENT M_X

$$M_X = g\left[M_1D_1 + M_{23}D_2 + M_4D_4 + M_5D_5 - M_6D_6\right]$$

$$M_X = 5.4\Big[(3.03)(24.94) + (14.04 + 12.98)(19.63) + (20.27)(5.87)$$
$$+ (20.73)(2.227) - (6.58)(4.38)\Big]$$

$$M_X = 4010\ \text{IN-lb}$$

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SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE

- MODEL CROSS-SECTION AS AN APPROXIMATE CIRCULAR SECTION FOR COMPUTING TORSIONAL SHEAR STRESSES

REFERENCE: USS STEEL DESIGN MANUAL (JAN 1981) R.L. BROCKENBROUGH & B.G. JOHNSON.

$\tau_s = \frac{TR}{I_p}$

T = TORSIONAL LOAD
R = RADIUS FOR LOCATION OF STRESS
I_p = POLAR MOMENT OF INERTIA

$$I_p = (R_1^4 - R_2^4)\frac{\pi}{2} = \frac{(1.63^4 - 1.063^4)\pi}{2}$$

$I_p = 8.95$

$$\tau_s = \frac{(4010 \text{ IN-lb})(1.625)(\sqrt{2})}{8.95} = 1030 \text{ PSI}$$

$g_{\sigma x}$ LOADINGS

$F\,(\text{TENSION})_x = MA = (104^{\#})(5.4g) = 561.60^{\#}$

CROSS SECTIONAL AREA = $(3.25)(3.25) - \frac{\pi(2.125)^2}{4} = 7.02 \text{ IN}^2$

$\sigma_{x_A} = \frac{561.60^{\#}}{7.02 \text{ IN}^2} = 80.05 \text{ PSI}$ $\sigma_{x_A}K_x = (80.05)(3.318)$

$g_{\sigma x}$ AXIAL $= 265.61$ PSI

$$M_y' = 5.4\left[(3.03)(24.94) + (14.04 + 12.98)(19.63) + (20.27)(5.87) + (20.73)(2.227) - (6.58)(4.38)\right] =$$

$= 4010$ IN-lb

$\sigma_{x_1} = \frac{Mc}{I} = \frac{(4010)(1.625)}{8.3} = 785 \text{ PSI}$ $\sigma_{x_1}K_z = (2.551)(785) = 2003 \text{ PSI} = g_{\sigma x\,\text{BEND}}$

R-450 FS

FOR INFORMATION ONLY

SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE

SQUARE ROOT SUM OF THE SQUARES

$$\sigma_F = \left[(265.6 + 2003)^2 + (981.7)^2 + (719.7)^2 \right]^{1/2}$$

$$\sigma_F = 2575 \text{ PSI}$$

$$\tau_F = \left[(80.05)^2 + (80.05 + 1030)^2 + (0)^2 \right]^{1/2} = 1113 \text{ PSI}$$

$$\tau_F = 1113 \text{ PSI}$$

$$\sigma_F = 2575 < 0.6(30{,}000) = 18000 \text{ PSI}$$

< 13500 NOTCHED FATIQUE STRENGTH

$$\tau_F = 1113 < 0.4(30{,}000) = 12000 \text{ PSI}$$

< 13500 NOTCHED FATIQUE STRENGTH

- STRESSES ON THE FOLLOWING COMPONENTS ARE GOVERNED BY THE OPERATING LOADS AND NOT THE DESIGN BASIS EARTHQUAKE LOAD CONDITIONS.

EXAMPLES: SCOTCH YOKE, CONNECTING PINS, SHAFT, PISTON

SCOTCH YOKE: OPERATING SPRING LOADS APPROX. $510^{\#} + 150^{\#} = 660$ lb
SEISMIC LOADS APPROX $20^{\#} \times 5.4g = 108$ lb

ALLOWABLE STRESSES $\dfrac{660}{1.0} \geq \dfrac{108 + 660}{1.5}$

$$660 \geq 512$$

∴ NO DETAILED ANALYSIS REQUIRED.

CALC. ~~DCR~~ No: M84-12

Sheet 20A of 20C

FOR INFORMATION ONLY

DESIGN/REVIEW COMMENTS SHEET

[✓ DESIGN VERIFICATION] ALTERNATE CALCULATIONS

NO.	COMMENT	RESOLUTION/APPROVAL
	SEE PAGES 20 B/20C	COMMENTS INCORPORATED
		Donald W. Church 4/19/84 Design Engineer Date
		4-19/84 Verifying Engineer Date
		Mike McDermott 4/30/84 Technical Group Leader Date
	4-19/84 Verifying Engineer Date	30 APRIL 1984 Supervising Engr. Nuclear Projects Date

Form No. NG-009Z* Rev. 0

IOWA ELECTRIC LIGHT AND POWER COMPANY
CEDAR RAPIDS, IOWA

DEPT. DESIGN ENGINEERING CALC. M84-12
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 20B of 20C
SUBJECT ACTUATOR QUALIFICATION R450
Computed by Date Checked by M. REITSCHNEIDER Date 4-18/84

FOR INFORMATION ONLY

REVIEW COMMENTS

1. STATE BASIC ASSUMPTIONS: THESE ASSUMPTIONS ALLOW YOU TO USE FLOOR RESPONSE SPECTRA AS THE DESIGN/QUALIFICATION SPECTRA FOR YOUR ACUATORS

   a) THE MOUNTING OF THE DAMPER IS RIGID (f > 33cps)
   b.) THE DAMPER ITSELF IS RIGID (f > 33cps)
   c.) THE SUPPORT BRACKET FOR THE ACTUATOR IS RIGID (f > 33cps)
   d.) THE SEISMIC REQUIREMENTS FOR EVALUATING THE ACTUATORS ARE THE SAME AS FOR THE DAMPERS (i.e. SPEC 7884-M-10? REV. 1)

2. PG. 4 : REMOVE REFERENCE OF R-960 FOR "END-CAP" WT. CALC. R-960 HAS NO "END-CAP"

3. PG 5 & 6 : 0.9 F_y APPLIES TO TENSILE STRESSES UNDER DBE LOADS USE 0.5 F_y FOR SHEAR STRESSES UNDER DBE LOADS

4. PG. 13-15: DO NOT SOLVE FOR PRINCIPLE STRESSES IN ANCHOR BOLTS, RESOLVE INTO TENSION (T) AND SHEAR (V) AND USE INTERACTION AS FOLLOWS

$$\frac{T}{T_a} + \frac{V}{V_a} \leq 1.5 \text{ — FOR DBE LOADS.}$$

$$T = \sqrt{T_x^2 + T_y^2 + T_z^2}$$
$$V = \sqrt{V_x^2 + V_y^2 + V_z^2}$$

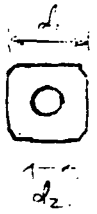
T_n = LOAD DUE TO COMPONENT ACCELERATION
V_n = " " " " "

STATE THAT BOLTS ARE ASSUMED TO BE A307 (GRADE 1)

THEREFORE:

$$T_a = 20{,}000 \text{ psi}$$
$$V_a = 10{,}000 \text{ psi}$$

5. PG. 19 : TREAT YOUR CROSS-SECTION AS AN APPROXIMATELY CIRCULAR SECTION FOR COMPUTING TORSIONAL SHEAR STRESSES.



$$f_s = \frac{TR}{I_p}$$

T = TORSIONAL LOAD
R = RADIUS FOR LOCATION OF STRESS
I_p = POLAR MOMENT OF INERTIA
$= (R_1^4 - R_2^4)\pi/2 = 6.95$

$$f_s \approx \frac{4010 \text{ in-lb } (3.25/2)\sqrt{2}}{8.95} = 1030 \text{ psi}$$

REF. USS STEEL DESIGN MANUAL (JAN 1981) by R.L. BROCKENBROUGH & B.G. JOHNSTON.

IOWA ELECTRIC LIGHT AND POWER COMPANY
CEDAR RAPIDS, IOWA

DEPT. DESIGN ENGINEERING — CALC M84-12
PROJECT DUANE ARNOLD ENERGY CENTER — Sheet No. 20 C of 20C
SUBJECT ACUATOR QUALIFICATION R450
Computed by DW Date — Checked by M. Reifschneider Date 4-18/84

FOR INFORMATION ONLY

6. PG. 20 & 22 : STATE THAT THE SEISMIC STRESSES [illegible] ABS (ABSOLUTE SUM) WHICH IS CONSERVATIVE COMPARED TO SRSS.

7. PG. 21 & 22 : STATE THAT NOTCH FATIGUE STRESS STRENGTH IS A CONSERVATIVE VALUE AS COMPARED TO 0.6 F_u TYPICALLY USED FOR DBE LOADS WHEN A 0.9 F_y VALUE IS NOT APPLICABLE.

8. PG. 24-26 : STATE THAT STRESSES ON THE SCOTCH YOKE ARE GOVERNED BY OPERATING LOAD AND NOT DBE LOAD CONDITIONS.

EXAMPLE : SPRING LOADS ~ 510 + 150 = 660 lb.
SEISMIC LOADS ~ 20 lb × 5.4g = 108 lb.

$$\underset{\text{ALLOWABLE STRESS}}{\frac{660}{1.0}} \geq \frac{660+108}{1.5}$$

$$660 \geq 512$$ ∴ NO DETAILED ANALYSIS REQ'D.

→ REMOVE ANALYSIS AND MAKE ABOVE STATEMENT.

GENERAL :

A) PROCEDURES VERIFIED BY EITHER VERIFICATION OF ANALYSIS SHOWN IN CALC OR OUTSIDE ANALYSIS YIELDING SAME RESULTS.

B) COMPONENTS SELECTED IN THE VERIFICATION APPEAR TO BE THE HIGHEST STRESSED COMPONENTS.

C) ALL FOLLOW-UP CALCS SHOULD REFERENCE THIS CALC FOR EXPLANATION OF ALLOWABLES, ASSUMPTIONS AND METHODOLOGY.

D) STATE; THAT ACTUATOR MOUNTING MAY BE IN ANY ORIENTATION THEREFORE "WORST CASE" ANALYSIS ASSUMES HORIZONTAL ACCELERATION COEFFICIENTS IN ALL 3 DIRECTIONS (SINCE HORIZ > VERT + 1g IN ALL CASES)

IOWA ELECTRIC LIGHT AND POWER COMPANY

DUANE ARNOLD ENERGY CENTER

FOR INFORMATION ONLY

CALCULATION COVERSHEET

ANALYSIS/CALCULATION NO: M84-13

ANALYSIS/CALCULATION TITLE: SEISMIC STRESS ANALYSIS

HILLS-McCANNA DAMPER ACTUATORS R-960FS

REFERENCE DOCUMENTS

MAR NO: ______

DCR NO: ______

OTHERS: DDC 769

Calc M84-12

PREPARED BY: Donald W Church DATE: 4/19/84

REVIEWED BY: DATE: 4-19/84

APPROVED BY: Mike McDermott DATE: 4/30/84

FINAL APPROVAL BY: DATE: 30 April 1984

FORM NG-007Z REV. 0

FOR INFORMATION ONLY

Background

The purpose for compiling calculations M84-11, 12, 13, 14, 15 was to perform a seismic analysis on the critical components of the Hills-McCanna Pneumatic Damper Actuators. These actuators are part of the secondary containment isolation system at the Duane Arnold Energy Center.

On January 26, 1984, Iowa Electric notified the NRC by telephone that the above mentioned actuators were potentially deficient in meeting their purchase specification. A review of the documents relating to this discrepancy revealed that the isolation damper assemblies were purchased originally as complete assemblies which included the damper actuators. Subsequent orders for "like-for-like" replacement actuators were placed directly with the actuator manufacturer who was a subvendor to the damper manufacturer. This most recent purchase order for actuators revealed that a quality assurance program, as required for safety related equipment per 10CFR Part 50, is not currently in effect at the actuators manufacturer's facility.

Further review of the damper assembly documentation revealed that the seismic analysis performed on the damper assemblies did not seismically analyze the actuators themselves, but only considered their weight as it seismically affected the damper frame. This information prompted Iowa Electric to audit the damper manufacturer and check for documentation that pertained to the seismic qualifications of the isolation damper actuators. Results from the audit of the damper manufacturer revealed that the actuators were never purchased by the damper manufacturer as seismically qualified components nor did the damper manufacturer administer a Quality Assurance program concerning the purchase of the actuators.

Since no traceability or Certificate of Conformance was available for the seismic qualifications of the actuators, a seismic analysis was performed on the critical components of the actuators in order to seismically qualify the damper actuators for use in the Duane Arnold Energy Center. This seismic analysis followed the guidelines set forth in the original purchase specification for the isolation dampers (ref. Bechtel 7884-M-100). By seismically qualifying the isolation damper actuators, Iowa Electric will be able to buy Quality Level I actuators in accordance with Revision 1, Chapter 4 of the Quality Assurance Manual under Standard Industrial Quality Items 4.7.3.

Solution

A seismic analysis was performed on five models of the Rockwell Hills-McCanna Ramcon Pneumatic Actuator product line that are installed as isolation damper actuators at the Duane Arnold Energy Center. These five models include the following:

- R-260 FS
- R-450 FS
- R-960 FS
- R-2000 FS
- R-4200 FS

FOR INFORMATION ONLY

The seismic analysis on the actuators followed the general project seismic requirements for frequency-not-determined class 1 equipment in the reactor building and in the control building (ref. Bechtel 7884-M-100, Technical Specifications for Isolation Dampers for the Duane Arnold Energy Center Unit 1, Revision 0, 12-28-70).

A visual inspection of all isolation damper actuators at the Duane Arnold Energy Center was made in order to verify model number, serial number and elevation location in the plant. After verifying the elevation location in the plant, static coefficients (g units) were determined for the highest installed actuator for each of the five actuator models. The horizontal static coefficient was then applied to all three of the orientation axis which eliminated many repetitious calculations and the need for detailed actuator orientation information. Applying the horizontal static coefficient to each axis provided conservative results since the horizontal coefficient is always greater than one plus the vertical coefficient ($F_{vertical} = (Weight)\ (1 + g_v)$, $F_{horizontal} = (Weight)\ (g_h)$, $g_h > 1 + g_v$).

The seismic analysis concentrated on the critical areas of the damper actuator where the seismically induced loads could possibly make the actuator fail, malfunction, or prevent operation. Five areas on each actuator model were identified as critical areas requiring a seismic analysis of the various components interfacing with that critical area. These five critical areas are identified as the following:

- Retaining key which holds the spring cylinder assembly to the main body cylinder
- Main body cylinder
- Press fit between main body cylinder and the mounting yoke
- Mounting hardware
- Mounting yoke

Dimensions and material specifications for the seismic analysis were obtained through the use of proprietary component drawings that were on loan to Iowa Electric from Rockwell Hills-McCanna of Carpentersville, Illinois. All prints applicable to this seismic analysis are listed in the reference section of the referenced calculations.

Four basic assumptions are applied throughout the entire seismic analysis of the damper actuators. These assumptions allow Iowa Electric to use the floor response spectra as the design/qualification spectra for the seismic analysis. The four basic assumptions are as follows:

- The mounting of the damper is a rigid structure ($f > 33$ cps)
- The damper itself is a rigid structure ($f > 33$ cps)
- The support bracket for the actuator is a rigid structure ($f > 33$ cps)
- The seismic requirements for evaluating the actuators are the same as those for the isolation dampers.

The maximum seismic stresses were calculated by using the square root sum of the squares method for combining the three earthquake direction stresses as recommended in the UFSAR for seismic analysis at the Duane Arnold Energy Center. A second method, the distortion energy method was used for combining stresses at the press fit between the main body cylinder and the mounting yoke. The distortion energy method was used in place of the square root sum of the squares method because the stresses due to the press-fit condition exceeded and dominated those caused by the seismic event. All maximum stresses were then compared to some fraction of the yield strength depending on the material type and stress type. Operability after a DBE event was ensured by requiring that the maximum stress from combined seismic and normal loads should not exceed 90% of the yield stress of the material.

Conclusion

After completing the above described seismic analysis on the five models of Hills-McCanna actuators installed on the isolation dampers at the Duane Arnold Energy Center, it was found that the maximum stresses from the combined seismic and normal loads do not exceed the material yield requirements defined in the isolation damper purchase specification. The results of this seismic analysis reveal that the five models of Hills-McCanna actuators are seismically qualified for use at the Duane Arnold Energy Center.

References

Bechtel Purchase Specification 7884-M-100

Formulas for Stress and Strain; Raymond J. Roark, Warren C. Young, Fifth Edition, McGraw-Hill Book Co. 1975

Hills-McCanna Information Bulletins; R-1090, R-1090A, R110C, R1100A, R-111C, R-1110A, R-112D, R-1120A, R-113D, R-1130A

Marks' Standard Handbook for Mechanical Engineers' Baumeister Eighth Edition, McGraw-Hill Book Company 1978

Materials Selector 75; Reinhold Publishing Co. Mid September 1974, Vol. 80, No. 4, Brown Printing Co.

Mechanical Engineering Design; Joseph E. Shigley, Third Edition, McGraw-Hill Book Co. 1977

Mechanics of Materials; Higdon, Ohlsen, Stiles, Weese, Riley Third Edition, John Wiley and Sons 1978

FOR INFORMATION ONLY

Rockwell Hills-McCanna; Proprietary Drawings

DATA: Information contained on drawings is proprietary and confidential and is not to be given or loaned to others. Drawings are to be returned to Rockwell upon completion of their intended use in making the seismic analysis.

R260

430-1004
430-7510
430-7511
430-3003
430-3005
430-4101
430-4102
430-2101
430-2904
430-2502
430-2501
430-3321
430-3322
430-3325
430-3201
430-3202
430-8203

R450-R960

450-7511
450-1005
450-7512
450-3005
450-3007
450-4101
450-4102
450-2101
450-2906
450-2507
450-2501
450-3201
450-3202
450-3203
450-3326
450-3325
450-3321
450-3320

R2000-R4200

460-7511
460-1001
460-7509
460-3001
460-3003
460-4101
460-4102
460-2101
460-2904
460-2503
460-2502
460-3208
460-3209
460-3210
460-3317
460-3316
460-3320
460-3321
460-3314
460-3315

U.S.S. Steel Design Manual; R.L. Brockenbrough and B.G. Johnson, Jan. 1981

FOR INFORMATION ONLY

V

MARTIN REIFSCHNEIDER Reviewer for Calculations M84-11,12,13,14,15

POSITION Senior Civil/Structural Engineer

EDUCATION
BS, Civil Engineering, University of Michigan
MS, Civil/Structural Engineering, University of Michigan

PROFESSIONAL DATA Registered Professional Engineer in Michigan

SUMMARY

1 year:	Senior Engineer; Civil/ Structural Staff
4 years:	Senior Engineer; Midland, Palisades, and Big Rock Point Nuclear Power Plants
1 year:	Resident Engineer, Midland Nuclear Power Plant

EXPERIENCE

Mr. Reifschneider is currently assigned as a civil/structural engineer on the civil/ structural staff. His duties include; preparation of design standards; review of project calculations, drawings, specifications and seismic qualification of equipment; providing consultation to civil/structural engineers engaged in the design of nuclear and fossil power plants; solving special static and dynamic structural problems.

Prior to joining the civil/structural staff, Mr. Reifschneider was a civil/ structural engineer on Consumers Power Company's Palisades project. His duties included finite element analysis of the biological shield wall, seismic analysis and design of blockwall supports, and seismic analysis and design of the auxiliary building addition including the review of seismic equipment qualifications.

Prior to joining the Palisades project, Mr. Reifschneider was a civil/structural resident engineer at the jobsite of Consumers Power company's Midland nuclear plant project. His duties included interfacing with construction personnel on the design, erection, and construction of seismic instrument and equipment supports.

FOR INFORMATION ONLY

VI

MARTIN REIFSCHNEIDER Reviewer for Calculations M84-11,12,13,14,15

Prior to his jobsite assignment, Mr. Reifschneider conducted research on the inelastic design and behavior of braced structural steel systems, moment frame structural steel system, and reinforced concrete shear wall systems. He co-authored three Bechtel reports on the findings of this research.

Prior to his research assignment, Mr. Reifschneider was a civil/structural engineer on the Midland nuclear plant project. His duties included designing seismic supports for HVAC ducts and electrical cabletrays.

FOR INFORMATION ONLY

IOWA ELECTRIC LIGHT AND POWER COMPANY CEDAR RAPIDS, IOWA	DEPT. DESIGN ENGINEERING PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. VII of VIII SUBJECT SEISMIC ANALYSIS HILLS-MCCANNA ACTUATORS Computed by ______ Date ______ Checked by ______ Date ______

SUMMARY OF RESULTS R-960 FS

COMPONENT	MANUFACTURED MATERIAL ALLOWABLE STRESS	LOW GRADE MATERIAL ALLOWABLE STRESS	*CALCULATED STRESS (σ_F, τ_F) STRESS COMPARISON
RETAINING KEY	303 STAINLESS STEEL $S\tau_A = (0.5) S_y$ $S\tau_A = 17500$ psi	NOT APPLICABLE NOT APPLICABLE	$\tau_F = 1168$ psi $1168 < 17500$
MAIN BODY CYLINDER	1020 STEEL	1006 STEEL	
OUTSIDE SURFACE	$S_{y_A} = (0.9)(S_y)$ $S_{y_A} = 43200$	$S_{y_A} = (0.9)(S_y)$ $S_{y_A} = 36900$	$\sigma_F = 11461$ psi $11461 < 36900$
INSIDE SURFACE			$\sigma_F = 12968$ psi $12968 < 36900$
MOUNTING HARDWARE 1/2-13 BOLTS		A 307 GRADE 1 BOLT $\sigma_A = 20000$ psi $\tau_A = 10000$ psi	$\sigma_F = 7735$ psi $\tau_F = 3147$ psi

NOTE: LOWEST GRADE BOLT ASSUMED INSTALLED

BASIS FOR COMPARISON: $\frac{\tau_F}{\tau_A} + \frac{\sigma_F}{\sigma_A} \leq 1.5$ FOR DBE CONDITIONS

$0.701 \leq 1.5$

* CALCULATED STRESS USING SRSS OF THE EARTH QUAKE DIRECTIONS OR MAXIMUM DISTORTION ENERGY THEORY.

DEPT. DESIGN ENGINEERING
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. VIII of VIII
SUBJECT SEISMIC ANALYSIS HILLS-McCANNA ACTUATORS
Computed by ______ Date ______ Checked by ______ Date ______

SUMMARY OF RESULTS CONTINUED R-960 FS

COMPONENT	MANUFACTURED MATERIAL ALLOWABLE STRESS	LOW GRADE MATERIAL ALLOWABLE STRESS	*CALCULATED STRESS STRESS COMPARISON
BODY CASTING (MOUNTING YOKE)	CLASS 35 CAST IRON $S_{Y_A} = (0.6)(S_{\mu})$ $S_{Y_A} = 18000 psi$ $S_{\tau_A} = (0.4)(S_{\mu})$ $S_{\tau_A} = 12000$	CLASS 20 CAST IRON $S_{Y_A} = (0.6)(S_{\mu})$ $S_{Y_A} = 12000$ $S_{\tau_A} = (0.4)(S_{\mu})$ $S_{\tau_A} = 8000 psi$	$\sigma_F = 2804 psi$ $\tau_F = 255 psi$ $2804 < 12000$ $255 < 8000$
PRESS FIT BETWEEN MAIN CYLINDER AND MOUNTING YOKE	CAST IRON - 1020 STEEL MINIMUM INTERFERENCE = 0.001" FORCE REQUIRED TO SLIDE CYLINDER FROM MOUNTING YOKE = 1349#		RESULTANT AXIAL FORCE = 1055# $1055 < 1349$

IOWA ELECTRIC LIGHT
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CEDAR RAPIDS, IOWA

DEPT. DESIGN ENGINEERING CALC M84-13
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 1 of 15
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by CW Date Checked by Date

R-960 FS

WEIGHT DETERMINATION

FOR INFORMATION ONLY

CYLINDER - SPRING CYLINDER

WEIGHT = 14.04# REFERENCE R-450 FS Pg 1

MAIN BODY CYLINDER

$D_o = 5.86^*$
$D_i = 5.27^\#$
$h = 18.795$
$\rho = 0.282\ \#/in^3$

$$\text{WEIGHT} = \frac{\pi(5.86^2 - 5.27^2)(18.795)(0.283)}{4}$$

WEIGHT = 27.92# REFERENCE : R450-3326

END CAP (SPRING CYLINDER)

WEIGHT = 3.03# REFERENCE : R450 FS Pg 1

YOKE

WEIGHT = 2.28#

PISTON

WEIGHT = 20.27# REFERENCE : R-450 FS Pg 3

END CAPS (MAIN CYLINDER)

WEIGHT = 6.58# REFERENCE : R-450 FS Pg 4

SPRINGS

TOTAL SPRING WEIGHT = 12.98# REFERENCE : R450 FS Pg 4

IOWA ELECTRIC LIGHT AND POWER COMPANY
CEDAR RAPIDS, IOWA

DEPT. DESIGN ENGINEERING CALC M84-13
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 2 of 15
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by DW Date ______ Checked by ______ Date ______

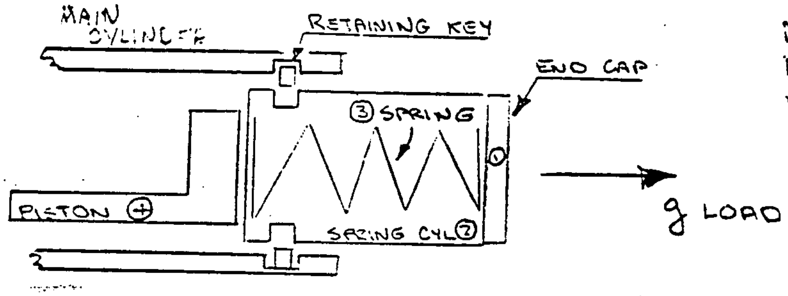
R-960 FS

		HORIZONTAL (g) LOADS	
		OBE	DBE
IV-AO-19A & B	REACTOR BUILDING ELEVATION 833'-6"	4.1	8.2
IV-AO-14A & B	BOLTED SUPPORT SYSTEMS		
IV-AO-17A1 & B1			

FOR INFORMATION ONLY

- MAXIMUM HORIZONTAL (g) LOAD FOR WORST CASE ACTUATOR ELEVATION APPLIED TO ALL AXIS OF SEISMIC ANALYSIS. 8.2 g LOAD IS GREATER THAN (1+g) LOAD ON VERTICAL (g) LOAD SPECIFICATION.
- MAXIMUM AIR PRESSURE = 100 PSI ACTING ON PISTON 5.27" DIA

SHEAR STRESS ON THE RETAINING KEY AXIAL ORIENTATION



M_1 (END CAP) = 3.03#
M_2 (SPRING CYL) = 14.04#
M_3 (SPRING) = 12.98#
M_4 (PISTON) = 20.27#
50.32#

g = 5.4

SPRING TEST LENGTHS (NESTED SPRINGS)

A-450-3005 @ 12.22" = 501# WITH 115 lb/IN RATE
A-450-3007 @ 12.16" = 151# WITH 35 lb/IN RATE
9.6" MAXIMUM SPRING COMPRESSION LENGTH WITH PISTON AT STOP.

$F_{SPRING} = 151^{\#} + 35(12.16-9.60) + 501 + 115(12.22-9.60) = 1043^{\#}$

$F_{MASS} = (8.2)(50.32) = 412.62^{\#}$

$F_{AIR\ PRESSURE} = \frac{(100\,PSI)(\pi)(5.27)^2}{4}$

$F_{AP} = 2181.3^{\#}$

$F_{TOTAL} = 412.62^{\#} + 1043^{\#} + (2181.3^{\#} - 1043^{\#})$

$F_{TOTAL} = 2593.9^{\#}$

RETAINING KEY
303 STAINLESS

16" CIRCUMFERENTIAL LENGTH

0.187 SQ

$\tau_A = F/A = \frac{2593.9^{\#}}{(0.187)(16)} = 867$ PSI

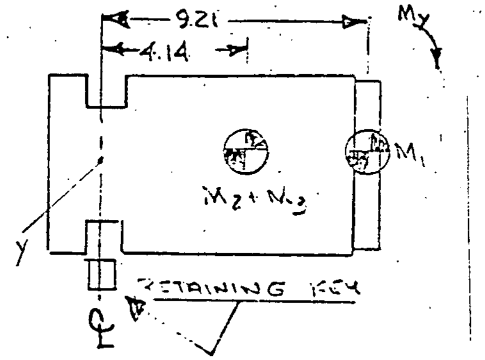
S_y = YIELD STRENGTH 303 S.S. = 35,000 PSI
S_{sy} = SHEAR STRENGTH = $(0.5)(S_y) = (0.5)(35000) = 17500$ PSI
ALLOWABLE SHEAR STRESS = 17500 PSI

867 PSI < 17500 PSI

R-560 FS

STRESS ON THE RETAINING KEY FROM MOMENTS CAUSED BY SPRING CYLINDER ASSEMBLY

FOR INFORMATION ONLY

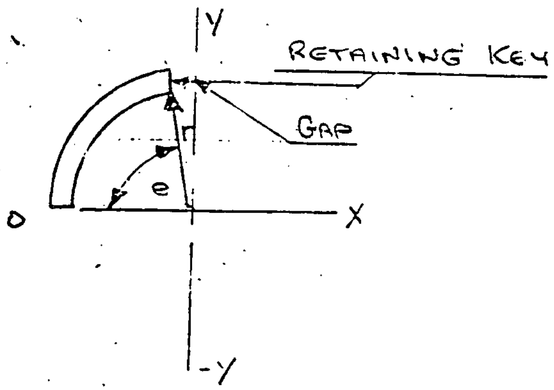


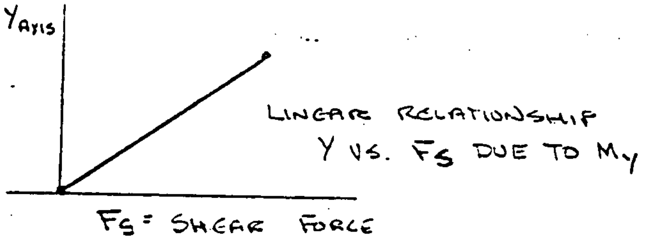
$M_y = 4.14(M_2+M_3)g + 9.21(M_1)g$

$M_y = 8.2\left[4.14(4.04+12.98) + 9.21(3.03)\right]$

$M_y = 1146.1$ IN-lb

- THETA (θ) IS THE ANGLE THAT CORRESPONDS TO THE RETAINING RING GAP FOR ONE QUADRANT. GAP IS DIVIDED IN TWO EQUAL PARTS AT +Y AND -Y.





SHEAR STRESS = $\tau(\theta)$

t = THICKNESS RETAINING RING

t = 0.187"

r = 2.632"

M = 1146

$$\int_0 \tau(\theta)\, t\, r^2 \sin\theta \, d\theta = \frac{M}{4}$$

$$\tau(\theta) = K r \sin\theta$$

RETAINING ACTIVE LENGTH = 4"/QUADRANT

$C_{QUAD} = \frac{2\pi r}{4} = \frac{2\pi(2.632)}{4} = 4.1343"$

$\theta = \frac{4.0}{4.1343} = 1.52$ RAD

$$\int_0 K t\, r^3 \sin^2\theta \, d\theta$$

$$\int_0^\theta \sin^2 d\theta = \left[-\frac{1}{4}\sin 2\theta + \frac{1}{2}\theta\right]_0^\theta = -\frac{1}{4}\sin 2(1.52) + \frac{1.52}{2} = 0.735$$

$\frac{M}{4} = K t r^3 (0.735)$ $K = \frac{1146.1}{(4)(0.187)(2.632)^3(0.735)}$

$K = 114.33$

$\tau(\theta) = K r \sin\theta = (114.33)(2.632)\sin(\pi/2) = 300.93$ PSI

$\tau_{TOTAL} = \tau_A + \tau(\theta) = 300.93 + 867 = 1167.93$ PSI

1167.93 < 17500 PSI

R-960 FS

STRESSES DUE TO THE PRESS FIT CONDITIONS
BETWEEN THE YOKE AND THE CYLINDER BODY

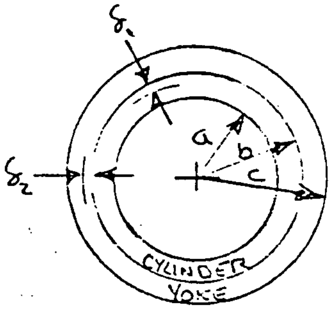
FOR INFORMATION ONLY

- REFERENCE HIGDON "MECHANICS OF MATERIALS"
  JOHN WILEY & SONS 1978 pg. 164, 163

I (INTERFERENCE) = 0.005" = $2\delta_1 + 2\delta_2$

$$\delta_1 = \frac{b_1^2 P_s}{(c^2 - b_1^2) E_h b_1}\left[(1-\nu)b_1^2 + (1+\nu)c^2\right]$$

$$\delta_2 = \frac{b_2^2 P_s}{(b^2 - a^2) E_s b_2}\left[(1-\nu)b_2^2 + (1+\nu)a^2\right]$$



a = 2.6375
b_1 = 2.9205 b_2 = 2.923
c = 3.435

SOLVE FOR P_s INTERFACIAL PRESSURE

$$0.005 = 2\left[\frac{(2.9205)^2 P}{[3.435^2 - 2.9205^2](15\times10^6)(2.9205)}\right]\left[(1-0.29)(2.9205)^2 + (1.29)(3.435)^2\right]$$

$$+\ 2\left[\frac{(2.923)^2 P}{(2.923^2 - 2.6375^2)(30\times10^6)(2.923)}\right]\left[(1-0.3)(2.923)^2 + (1.3)(2.6375)^2\right]$$

$$0.005 = 2.533\times10^{-6} P + 1.8442\times10^{-6} P$$

P = 1142 PSI (MAXIMUM INTERFERENCE)

EXTERNAL PRESSURE

$$\sigma_r = -\frac{b^2 P_o}{b^2 - a^2}\left(1 - \frac{a^2}{\rho^2}\right)$$

$$\sigma_t = -\frac{b^2 P_o}{b^2 - a^2}\left(1 + \frac{a^2}{\rho^2}\right)$$

INTERNAL PRESSURE

$$\sigma_r = \frac{a^2 P_I}{b^2 - a^2}\left(1 - \frac{b^2}{\rho^2}\right)$$

$$\theta_t = \frac{a^2 P_I}{b^2 - a^2}\left(1 + \frac{b^2}{\rho^2}\right)$$

IOWA ELECTRIC LIGHT AND POWER COMPANY
CEDAR RAPIDS, IOWA

DEPT. DESIGN ENGINEERING CALC M84-13
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 5 of 15
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by ______ Date ______ Checked by ______ Date ______

R-960 FS

FOR INFORMATION ONLY

STRESS IN BODY CASTING INTERNAL PRESSURE

$$\sigma_r = \frac{(2.9205)^2(1142)}{(3.435^2 - 2.9205^2)}\left(1 - \frac{(3.435^2)}{(2.9205)^2}\right) = {}^{-}1142 \text{ PSI}$$

$$\sigma_t = \frac{(2.9205)^2(1142)}{(3.435^2 - 2.9205^2)}\left(1 + \frac{3.435^2}{2.9205^2}\right) = 7100 \text{ PSI}$$

STRESS IN CYLINDER EXTERNAL PRESSURE

OUTSIDE CYLINDER SURFACE

$$\sigma_r' = -\frac{(2.923)^2(1142)}{(2.923^2 - 2.6375^2)}\left(1 - \frac{2.6375^2}{2.9232}\right) = -1143 \text{ PSI}$$

$$\sigma_t' = -\frac{(2.923)^2(1142)}{(2.923^2 - 2.6375^2)}\left(1 + \left(\frac{2.6375}{2.9232}\right)^2\right) = -11150 \text{ PSI}$$

INSIDE CYLINDER SURFACE

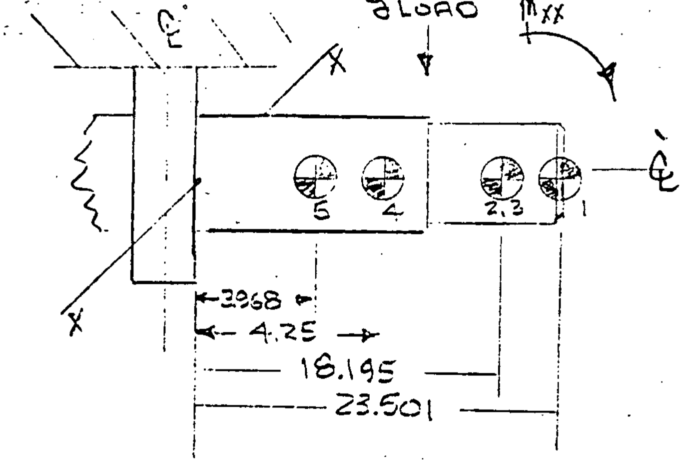
$$\sigma_r = -\frac{(2.923)^2(1142)}{(2.923^2 - 2.6375^2)}\left(1 - \frac{2.6375^2}{2.6375^2}\right) = 0 \text{ PSI}$$

$$\sigma_t = -\frac{(2.923)^2(1142)}{(2.923^2 - 2.6375^2)}\left(1 + \frac{2.6375^2}{2.6375^2}\right) = {}^{-}12292 \text{ PSI}$$

R-960 FS

FOR INFORMATION ONLY

STRESS ON THE CYLINDER DUE TO MOMENT CAUSED BY MAIN BODY CYLINDER, PISTON, SPRING CYLINDER AND END CAP.



M_1 (END CAP) = 3.03#
M_2 (SPRING CYL) = 14.04#
M_3 (SPRING) = 12.98
M_4 (PISTON) = 20.27
M_5 (CYLINDER) = 27.92

- MASS OF CYLINDER IS MODELLED TO ACT ON RIGHT SIDE OF YOKE. EXCLUDES COUNTERACTING MOMENT DUE TO MASS ON THE LEFT SIDE OF YOKE ℄.

SUMMING MOMENTS ABOUT X-X

$$M_{XX} = 8.2\Big[(27.92)(3.968) + (20.27)(4.25) + (12.98 + 14.04)(18.195) + (3.03)(23.501)\Big] = 6230.12 \text{ IN-lb}$$

MOMENT OF INERTIA @ AXIS XX NEUTRAL AXIS ℄ ACTUATOR

$$I = \frac{\pi}{64}\left(d_o^4 - d_i^4\right) = \frac{\pi}{64}\left(5.860^4 - 5.275^4\right)$$

$$I = 20.02$$

$$\sigma = \frac{Mc}{I} = \frac{(6230.12)(2.93)}{19.88} = 918.22 \text{ PSI}$$

$$\sigma_{\text{AIR PRESSURE}} = \frac{2181.3^{\#} \text{ (AIR FORCE)}}{\pi(5.850^2 - 5.275^2)/4} = 434.2 \text{ PSI}$$

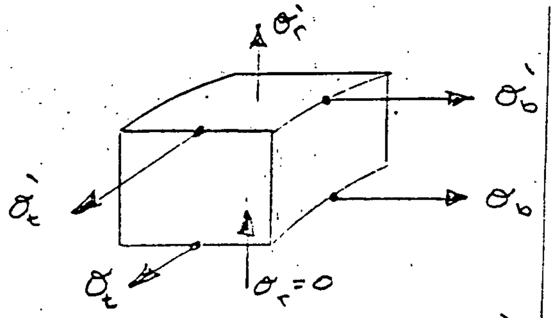
IOWA ELECTRIC LIGHT AND POWER COMPANY
CEDAR RAPIDS, IOWA

DEPT: DESIGN ENGINEERING CALC M84-13
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 7 of 15
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by DW Date Checked by M Date

FOR INFORMATION ONLY

R-960 FS

CYLINDER STRESSES CONTINUED



MOMENT = 3908.3 IN-lb

$C = \frac{5.27}{2} = 2.635''$

$C' = \frac{5.86}{2} = 2.93''$

$I = 19.88 \text{ IN}^4$

$S_y = 48000$ PSI 1020 STEEL

$90\% \ S_y = (.9)(48000 \text{ PSI})$

$0.9 S_y = 43200$ PSI

$$\sigma_b' = \frac{Mc}{I} + \sigma_{AP} = \frac{(6230.12)(2.93)}{19.88} + 434.2$$
$$= 13524 \text{ PSI}$$

$$\sigma_b = \frac{Mc}{I} + \sigma_{AP} = \frac{(6230.12)(2.635)}{19.88} + 434.2$$
$$= 1259.97 \text{ PSI}$$

$\sigma_t' = -11150$ PSI

$\sigma_t = -12292$ PSI

$\sigma_r' = -1143$ PSI

$\sigma_r = 0$ PSI

SUMMATION OF STRESSES USING MAXIUM DISTORTION ENERGY THEORY

- REFERENCE MECHANICS OF MATERIALS Pg 489

$$\sigma_f = \left\{ \frac{1}{2}\left[(\sigma_b - \sigma_t)^2 + (\sigma_t - \sigma_r)^2 + (\sigma_r - \sigma_b)^2 \right] \right\}^{1/2}$$

$$\sigma_F = \left\{ \frac{1}{2}\left[(1259.97 + 12292)^2 + (-12292 + 0)^2 + (0 - 1259.97)^2 \right] \right\}^{1/2}$$

$\sigma_F = 12967.98$ PSI < 43200 PSI (YIELD 1020 @ 90%)

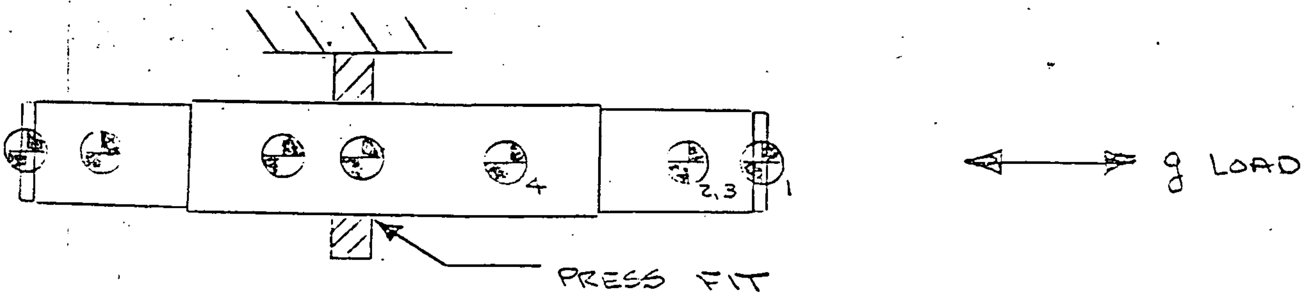
$$\sigma_F' = \left\{ \frac{1}{2}\left[(13524 + 11150)^2 + (-11150 + 1143)^2 + (-1143 - 13524)^2 \right] \right\}^{1/2}$$

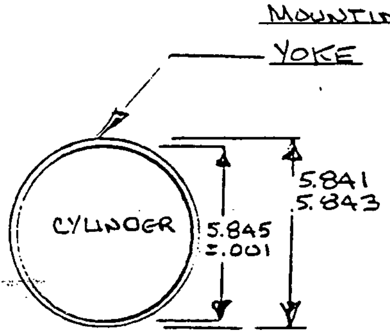
$\sigma_F' = 11460.30$ PSI < 43200 PSI (YIELD 1020 @ 90%)

R-960 FS

FOR INFORMATION ONLY

SEISMIC AXIAL LOAD ACTING ON PRESS FIT OF CYLINDER THROUGH THE MOUNTING YOKE





MINMUM INTERFERENCE ON RADIUS

$$I = \frac{5.843}{2} - \frac{5.844}{2} = 0.0005 \text{ INCH}$$

REFERENCE PRINTS 450-3321
450-3325

ON DIAMETER $I = 0.001$

MINIMUM PRESSURE FROM PRESS FIT WITH MINIMUM INTERFERENCE

SOLVING FOR MINIMUM PRESSURE (P) - Pg 164 MECHANICS OF MATLS.

$$0.001 \text{ IN} = 2\left[\frac{(2.921.5)^2 P}{\{(3.435^2 - 2.9215^2)(15\times10^6)\cancel{(2.9215)}\}}\right]\left[(0.71)(2.9215)^2 + (1.29)(3.435)^2\right]$$

$$+ \; 2\left[\frac{(2.922)^2 P}{\{(2.922^2 - 2.635^2)(30\times10^6)\cancel{(2.922)}}\right]\left[(0.7)(2.922)^2 + (1.3)(2.635)^2\right]$$

$$0.001 = 2.5392\,(10^{-6})\,P + 1.8324\,(10)^{-6} P$$

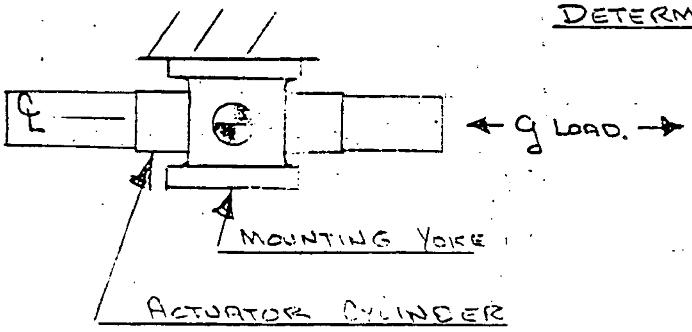
$$0.001 = P(4.371)10^{-6}$$

$$P = 229 \text{ PSI}$$

R-960 FS

FOR INFORMATION ONLY

DETERMINATION OF AXIAL LOAD



M_1 (END CAPS) = (2)(3.03)
M_2 (SPRING CYL) = (2)(14.04)
M_3 (SPRING) = (2)(12.98)
M_4 (PISTON) = (2)(20.27)
M_5 (MAIN CYL) = 27.92

M_T - TOTAL MASS = 128.56#

AXIAL FORCE = $F_A = M_T(g) = (128.56)(8.2) = 1054.19$#

FORCE REQUIRED TO SLIDE CYLINDER FROM MOUNTING YOKE

SLIDE FORCE $= F_S = \pi f P d l$

l = LENGTH OF FIT = 3.21" REF: MARKS HAND BOOK 8-47
d = CYLINDER DIA = 5.841
P = UNIT FIT PRESSURE
f = COEFFICIENT OF FRICTION AVERAGE RANGE 0.10 → 0.15
USE $f = 0.10$

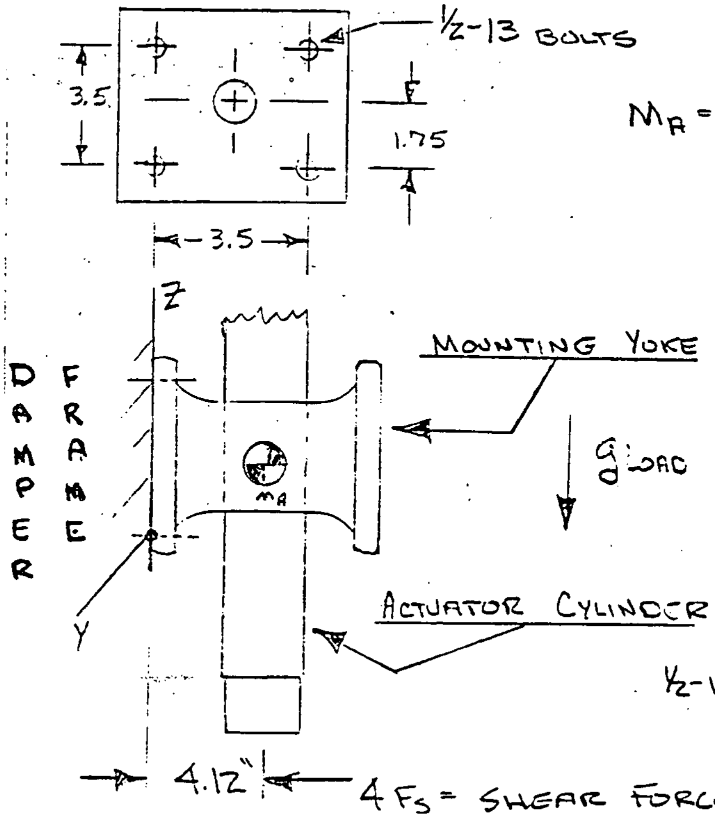
$F_S = \pi(0.10)(229)(5.841)(321) - 1349$#

$\underline{\underline{1349^{\#} > 1054^{\#}}}$

R-960 FS

FOR INFORMATION ONLY

SEISMIC LOADINGS ON MOUNTING HARDWARE



(g_z) LOADING

M_A = MASS OF ACTUATOR INCLUDING MOUNTING YOKE = 154#

MOMENT ABOUT (Y) = $(M_A)(g)(L)$

$M_y = (154)(8.2)(4.12) = 5202.7$

$M_y = (2)(F_T)(3.5)$

$2F_T$ = TENSION FORCE IN TWO TOP BOLTS

$$F_T = \frac{(5202.7)}{(2)(3.5)} = 743.25$$

1/2-13 BOLT **EFFECTIVE AREA = 0.1419 in²**
TENSILE STRESS AREA Pg 230
SHIGLEY MECH ENG DESIGN

$4F_S$ = SHEAR FORCE IN (4) MOUNTING BOLT

$$F_S = \frac{(154^{\#})(8.2g)}{4} = 315.7^{\#}$$

$$\sigma_{x_1} = \frac{F_T}{A_{BOLT}} = \frac{743.25}{0.1419} = 5237.8 \text{ ps}$$

$$\tau_{ZY_1} = \frac{315.7}{0.1419} = 2224.8 \text{ PSI}$$

IOWA ELECTRIC LIGHT AND POWER COMPANY
CEDAR RAPIDS, IOWA

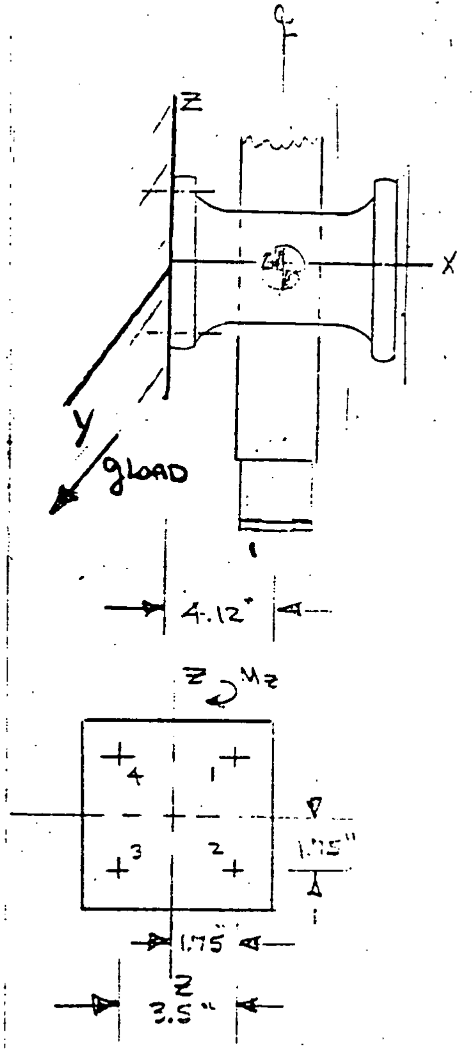
DEPT. DESIGN ENGINEERING CALC M24-13
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 11 of 15
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by DW Date Checked by KR Date

R-960 FS

FOR INFORMATION ONLY

SEISMIC LOADINGS ON MOUNTING HARDWARE

g_Y LOADING



$M_Z = (154^{\#})(8.2)(4.12") = 5202.7$ IN-lb

TENSION FORCE IN BOLTS 1 & 2 DUE TO MOMENT M_Z

$$F_T = \frac{(5202.7 \text{ IN-lb})}{(3.5 \text{ IN})(2 \text{ BOLTS})} = 743.25^{\#}$$

F_1 = SHEAR FORCE FROM TOTAL ACTUATOR MASS

$$F_1 = \frac{(154^{\#})(8.2)}{4 \text{ BOLTS}} = 315.7^{\#}$$

EFFECTIVE AREA ½-13 BOLT = 0.1419 IN^2

$$\sigma_{X_2} (\text{STRESS - TENSION}) = \frac{743.25^{\#}}{0.1419 \text{ IN}^2} = 5238 \text{ PSI}$$

$$\tau_{ZY_2} (\text{SHEAR STRESS}) = \frac{315.7^{\#}}{0.1419 \text{ IN}^2} = 2225 \text{ PSI}$$

R-960 FS

SEISMIC LOADING OF MOUNTING HARDWARE

g_x LOADING

TENSION ONLY $F_{T_X} = MA$

FORCE TENSION = $\dfrac{(154^{\#})(8.2)}{(4\text{ BOLTS})} = 315.7^{\#}$

$$\theta_{x_3} = \frac{315.7^{\#}}{0.1419\text{ in}^2} = 2224.8 \text{ PSI}$$

SUMMATION OF STRESSES

BASIS FOR COMPARISON = $\dfrac{\tau_F}{\tau_A} + \dfrac{\theta_F}{\theta_A} \leq 1.5$ FOR DBE CONDITIONS

$$\theta_F = \left[\theta_{x_1}^2 + \theta_{x_2}^2 + \theta_{x_3}^2\right]^{1/2} = \left[5237.8^2 + 5238^2 + 2224.8^2\right]^{1/2}$$

$$\theta_F = 7734.40 \text{ PSI}$$

$$\tau_F = \left[\tau_{zy_1}^2 + \tau_{zy_2}^2 + \tau_{zy_3}^2\right]^{1/2} = \left[2224.8^2 + 2225^2 + 0^2\right]^{1/2}$$

$$\tau_F = 3146.63 \text{ PSI}$$

BOLTS ASSUMED TO BE A307 GRADE (1) BOLTS

$\theta_A = 20000$ PSI
$\tau_A = 10000$ PSI

$$\frac{3146.63}{10000} + \frac{7734.4}{20000} = 0.701$$

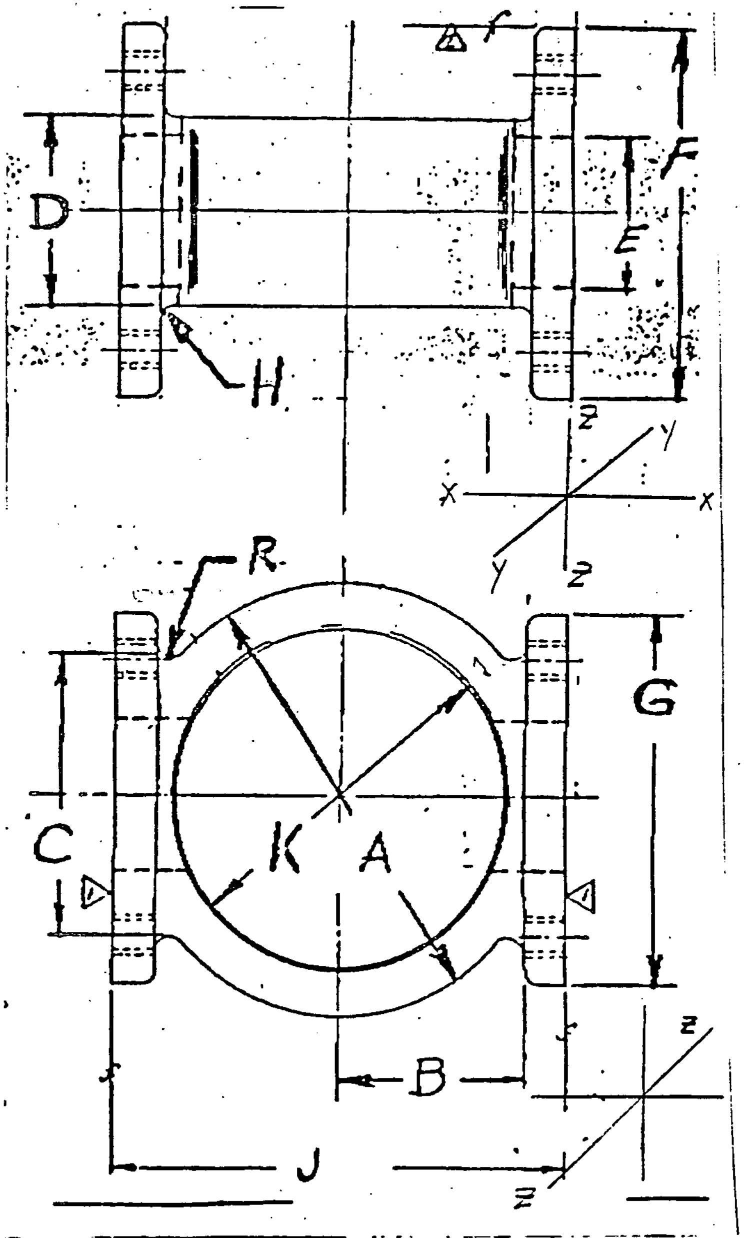
$$0.701 \leq 1.5$$

DEPT. DESIGN ENGINEERING CALC M84-13
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 13 of 15
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by ___ Date ___ Checked by ___ Date ___

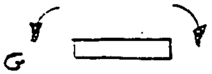
R-960 FS

FOR INFORMATION ONLY

SEISMIC STRESSES ON THE MOUNTING YOKE



ELASTIC STRESS

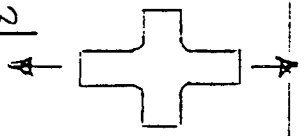


IN PLANE BENDING STRESS CONCENTRATION FACTORS THE SAME AS R-450 FS Pg 16

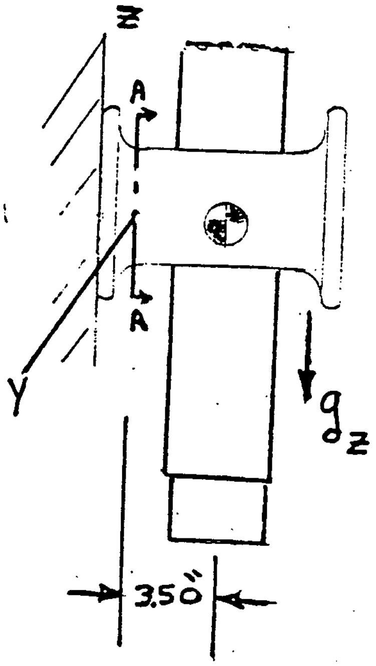
VERTICAL LOADS (g_z)
$K_z = 2.551$

HORIZONTAL LOADS (g_y)
$K_y = 1.874$

AXIAL TENSION



R-450 FS Pg 17
HORIZONTAL LOADS (g_x)
$K_x = 3.318$



g_{cz} LOADINGS

$M_y = (W_t) \times (\text{dim } B) \times (g \text{ LOAD})$

$M_y = (154^{\#})(3.5)(8.2) = 4420$ IN-lb

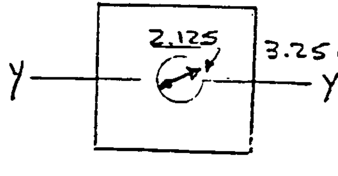
$I = \frac{(3.25)^4}{12} - \frac{\pi}{4}\left(\frac{2.125}{2}\right)^4 = 8.3 \text{ IN}^4$

$\sigma_{zB} = \frac{Mc}{I} = \frac{(4420)(1.625)}{8.3} = 865.4$ PSI

$K_z \sigma_{zB} = (2.551)(865.4) = 2207.5$ PSI

$\tau_{zy} = (154^{\#})(8.2) / 3.250^2 - \pi(2.125)^2 = 180$ PSI

SECTION A-A

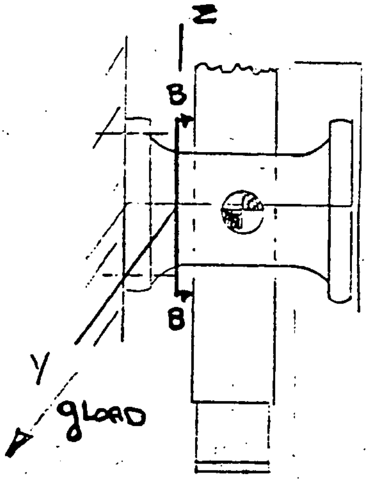


$c = \frac{3.250}{2} = 1.625$

R-960 FS

SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE

g_Y LOADING



M_Z = (Wt)(dim B)(g Load)

M_Z = (154)(3.5)(8.2) = 4420 IN-lb

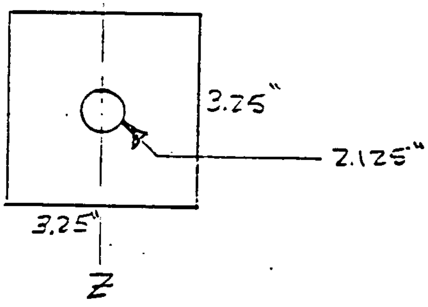
$$I = \frac{(3.25)^4}{12} - \frac{\pi}{4}\frac{(2.125)^4}{4} = 8.3 \text{ IN}^4$$

$$\theta_{Y_B} = \frac{Mc}{I} = \frac{(4420)(1.625)}{8.3} = 865.4 \text{ IN-lb}$$

$$K_Y \theta_{Y_B} = (1.874)(865.4) = 1621.7 \text{ PSI}$$

$$\tau_{ZY} = \frac{(154^{\#})(8.2)}{3.250^2 - \frac{\pi(2.125)^2}{4}} = 180 \text{ psi}$$

SECTION B-B



g_X LOADINGS

F (TENSION)$_X$ = MA = (154 #)(8.2g) = 1262.8 #

CROSS SECTIONAL AREA = (3.25)(3.25) − $\frac{\pi(2.125)^2}{4}$ = 7.02 IN^2

$$\theta_{Y_A} = \frac{1262.8^{\#}}{7.02 \text{ IN}^2} = 180 \text{ PSI}$$

$\theta_{Y_A} K_X$ = (180)(3.318) = 597.2 PSI

R-960 FS

FOR INFORMATION ONLY

SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE
SQUARE ROOT SUM OF THE SQUARES

$$\sigma_F = \left[(597.2)^2 + (1621.7)^2 + (2207.5)^2 \right]^{1/2}$$

$$\sigma_F = 2803.11 \text{ PSI}$$

$$\tau_F = \left[(180)^2 + 180^2 + 0^2 \right]^{1/2}$$

$$\tau_F = 254.56 \text{ PSI}$$

$$\sigma_F = 2803.11 < 0.6(30000) = 18000 \text{ PSI}$$
$$< 13500 \text{ NOTCHED FATIQUE STRENGTH}$$

$$\tau_F = 254.56 < 0.4(30,000) = 12000$$
$$< 13500 \text{ NOTCHED FATIQUE STRENGTH}$$

- ANALYSIS OF INTERNAL ACTUATOR NOT REQUIRED
  REFERENCE R-450 FS CALCULATIONS Pg. 20

CALC. NO:
~~DCR No~~: M84-13

Sheet 16A of 16A

FOR INFORMATION ONLY

DESIGN/REVIEW COMMENTS SHEET

[✓ DESIGN VERIFICATION] ALTERNATE CALCULATIONS

NO.	COMMENT	RESOLUTION/APPROVAL
	NO COMMENTS 4-19/84 Verifying Engineer Date	Donald W. Church 4/19/84 Design Engineer Date 4-19/84 Verifying Engineer Date Mike McDermott 4/30/84 Technical Group Leader Date 4/30/84 Supervising Engr. Nuclear Projects Date

Form No. NG-009Z* Rev. 0

FOR INFORMATION ONLY

IOWA ELECTRIC LIGHT AND POWER COMPANY

DUANE ARNOLD ENERGY CENTER

CALCULATION COVERSHEET

ANALYSIS/CALCULATION NO: M84-14

ANALYSIS/CALCULATION TITLE: SEISMIC STRESS ANALYSIS
HILLS-McCANNA DAMPER ACTUATORS R-2000FS

REFERENCE DOCUMENTS

MAR NO: ________

DCR NO: ________

OTHERS: DDC 769
Calc M84-12

PREPARED BY: David W. Church DATE: 4/20/84

REVIEWED BY: DATE: 4-24/84

APPROVED BY: DATE: 4/30/84

FINAL APPROVAL BY: DATE: 4/30/84

FORM NG-007Z REV. 0

Background

The purpose for compiling calculations M84-11, 12, 13, 14, 15 was to perform a seismic analysis on the critical components of the Hills-McCanna Pneumatic Damper Actuators. These actuators are part of the secondary containment isolation system at the Duane Arnold Energy Center

On January 26, 1984, Iowa Electric notified the NRC by telephone that the above mentioned actuators were potentially deficient in meeting their purchase specification. A review of the documents relating to this discrepancy revealed that the isolation damper assemblies were purchased originally as complete assemblies which included the damper actuators. Subsequent orders for "like-for-like" replacement actuators were placed directly with the actuator manufacturer who was a subvendor to the damper manufacturer. This most recent purchase order for actuators revealed that a quality assurance program, as required for safety related equipment per 10CFR Part 50, is not currently in effect at the actuators manufacturer's facility.

Further review of the damper assembly documentation revealed that the seismic analysis performed on the damper assemblies did not seismically analyze the actuators themselves, but only considered their weight as it seismically affected the damper frame. This information prompted Iowa Electric to audit the damper manufacturer and check for documentation that pertained to the seismic qualifications of the isolation damper actuators. Results from the audit of the damper manufacturer revealed that the actuators were never purchased by the damper manufacturer as seismically qualified components nor did the damper manufacturer administer a Quality Assurance program concerning the purchase of the actuators.

Since no traceability or Certificate of Conformance was available for the seismic qualifications of the actuators, a seismic analysis was performed on the critical components of the actuators in order to seismically qualify the damper actuators for use in the Duane Arnold Energy Center. This seismic analysis followed the guidelines set forth in the original purchase specification for the isolation dampers (ref. Bechtel 7884-M-100). By seismically qualifying the isolation damper actuators, Iowa Electric will be able to buy Quality Level I actuators in accordance with Revision 1, Chapter 4 of the Quality Assurance Manual under Standard Industrial Quality Items 4.7.3.

Solution

A seismic analysis was performed on five models of the Rockwell Hills-McCanna Ramcon Pneumatic Actuator product line that are installed as isolation damper actuators at the Duane Arnold Energy Center. These five models include the following:

- R-260 FS
- R-450 FS
- R-960 FS
- R-2000 FS
- R-4200 FS

FOR INFORMATION ONLY

The seismic analysis on the actuators followed the general project seismic requirements for frequency-not-determined class 1 equipment in the reactor building and in the control building (ref. Bechtel 7884-M-100, Technical Specifications for Isolation Dampers for the Duane Arnold Energy Center Unit 1, Revision 0, 12-28-70).

A visual inspection of all isolation damper actuators at the Duane Arnold Energy Center was made in order to verify model number, serial number and elevation location in the plant. After verifying the elevation location in the plant, static coefficients (g units) were determined for the highest installed actuator for each of the five actuator models. The horizontal static coefficient was then applied to all three of the orientation axis which eliminated many repetitious calculations and the need for detailed actuator orientation information. Applying the horizontal static coefficient to each axis provided conservative results since the horizontal coefficient is always greater than one plus the vertical coefficient ($F_{vertical} = (\text{Weight})(1 + g_v)$, $F_{horizontal} = (\text{Weight})(g_h)$, $g_h > 1 + g_v$).

The seismic analysis concentrated on the critical areas of the damper actuator where the seismically induced loads could possibly make the actuator fail, malfunction, or prevent operation. Five areas on each actuator model were identified as critical areas requiring a seismic analysis of the various components interfacing with that critical area. These five critical areas are identified as the following:

- Retaining key which holds the spring cylinder assembly to the main body cylinder
- Main body cylinder
- Press fit between main body cylinder and the mounting yoke
- Mounting hardware
- Mounting yoke

Dimensions and material specifications for the seismic analysis were obtained through the use of proprietary component drawings that were on loan to Iowa Electric from Rockwell Hills-McCanna of Carpentersville, Illinois. All prints applicable to this seismic analysis are listed in the reference section of the referenced calculations.

Four basic assumptions are applied throughout the entire seismic analysis of the damper actuators. These assumptions allow Iowa Electric to use the floor response spectra as the design/qualification spectra for the seismic analysis. The four basic assumptions are as follows:

- The mounting of the damper is a rigid structure ($f > 33$ cps)
- The damper itself is a rigid structure ($f > 33$ cps)
- The support bracket for the actuator is a rigid structure ($f > 33$ cps)
- The seismic requirements for evaluating the actuators are the same as those for the isolation dampers.

The maximum seismic stresses were calculated by using the square root sum of the squares method for combining the three earthquake direction stresses as recommended in the UFSAR for seismic analysis at the Duane Arnold Energy Center. A second method, the distortion energy method was used for combining stresses at the press fit between the main body cylinder and the mounting yoke. The distortion energy method was used in place of the square root sum of the squares method because the stresses due to the press-fit condition exceeded and dominated those caused by the seismic event. All maximum stresses were then compared to some fraction of the yield strength depending on the material type and stress type. Operability after a DBE event was ensured by requiring that the maximum stress from combined seismic and normal loads should not exceed 90% of the yield stress of the material.

Conclusion

After completing the above described seismic analysis on the five models of Hills-McCanna actuators installed on the isolation dampers at the Duane Arnold Energy Center, it was found that the maximum stresses from the combined seismic and normal loads do not exceed the material yield requirements defined in the isolation damper purchase specification. The results of this seismic analysis reveal that the five models of Hills-McCanna actuators are seismically qualified for use at the Duane Arnold Energy Center.

References

Bechtel Purchase Specification 7884-M-100

Formulas for Stress and Strain; Raymond J. Roark, Warren C. Young, Fifth Edition, McGraw-Hill Book Co. 1975

Hills-McCanna Information Bulletins; R-1090, R-1090A, R110C, R1100A, R-111C, R-1110A, R-112D, R-1120A, R-113D, R-1130A

Marks' Standard Handbook for Mechanical Engineers' Baumeister Eighth Edition, McGraw-Hill Book Company 1978

Materials Selector 75; Reinhold Publishing Co. Mid September 1974, Vol. 80, No. 4, Brown Printing Co.

Mechanical Engineering Design; Joseph E. Shigley, Third Edition, McGraw-Hill Book Co. 1977

Mechanics of Materials; Higdon, Ohlsen, Stiles, Weese, Riley Third Edition, John Wiley and Sons 1978

IV

FOR INFORMATION ONLY

Rockwell Hills-McCanna; Proprietary Drawings

DATA: Information contained on drawings is proprietary and confidential and is not to be given or loaned to others. Drawings are to be returned to Rockwell upon completion of their intended use in making the seismic analysis.

R260	R450-R960	R2000-R4200
430-1004	450-7511	460-7511
430-7510	450-1005	460-1001
430-7511	450-7512	460-7509
430-3003	450-3005	460-3001
430-3005	450-3007	460-3003
430-4101	450-4101	460-4101
430-4102	450-4102	460-4102
430-2101	450-2101	460-2101
430-2904	450-2906	460-2904
430-2502	450-2507	460-2503
430-2501	450-2501	460-2502
430-3321	450-3201	460-3208
430-3322	450-3202	460-3209
430-3325	450-3203	460-3210
430-3201	450-3326	460-3317
430-3202	450-3325	460-3316
430-3203	450-3321	460-3320
	450-3320	460-3321
		460-3314
		460-3315

U.S.S. Steel Design Manual; R.L. Brockenbrough and B.G. Johnson, Jan. 1981

V

MARTIN REIFSCHNEIDER Reviewer for Calculations M84-11,12,13,14,15

POSITION Senior Civil/Structural Engineer

EDUCATION

BS, Civil Engineering, University of Michigan

MS, Civil/Structural Engineering, University of Michigan

PROFESSIONAL DATA Registered Professional Engineer in Michigan

SUMMARY

1 year:	Senior Engineer; Civil/ Structural Staff
4 years:	Senior Engineer; Midland, Palisades, and Big Rock Point Nuclear Power Plants
1 year:	Resident Engineer, Midland Nuclear Power Plant

EXPERIENCE

Mr. Reifschneider is currently assigned as a civil/structural engineer on the civil/ structural staff. His duties include; preparation of design standards; review of project calculations, drawings, specifications and seismic qualification of equipment; providing consultation to civil/structural engineers engaged in the design of nuclear and fossil power plants; solving special static and dynamic structural problems.

Prior to joining the civil/structural staff, Mr. Reifschneider was a civil/ structural engineer on Consumers Power Company's Palisades project. His duties included finite element analysis of the biological shield wall, seismic analysis and design of blockwall supports, and seismic analysis and design of the auxiliary building addition including the review of seismic equipment qualifications.

Prior to joining the Palisades project, Mr. Reifschneider was a civil/structural resident engineer at the jobsite of Consumers Power company's Midland nuclear plant project. His duties included interfacing with construction personnel on the design, erection, and construction of seismic instrument and equipment supports.

MARTIN REIFSCHNEIDER   Reviewer for Calculations M84-11,12,13,14,15

Prior to his jobsite assignment, Mr. Reifschneider conducted research on the inelastic design and behavior of braced structural steel systems, moment frame structural steel system, and reinforced concrete shear wall systems. He co-authored three Bechtel reports on the findings of this research.

Prior to his research assignment, Mr. Reifschneider was a civil/structural engineer on the Midland nuclear plant project. His duties included designing seismic supports for HVAC ducts and electrical cabletrays.

IOWA ELECTRIC LIGHT AND POWER COMPANY
CEDAR RAPIDS, IOWA

DEPT. DESIGN ENGINEERING
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. VII of VIII
SUBJECT SEISMIC ANALYSIS HILLS-McCANNA ACTUATORS
Computed by DW Date Checked by Date

SUMMARY OF RESULTS R-2000 FS

FOR INFORMATION ONL

COMPONENT	MANUFACTURED MATERIAL ALLOWABLE STRESS	LOW GRADE MATERIAL ALLOWABLE STRESS	*CALCULATED STRESS (σ_F, τ_F) STRESS COMPARISON
RETAINING KEY	303 STAINLESS STEEL $S_{\tau_A} = (0.5)(S_Y)$ $S_{\tau_A} = 17500$ psi	NOT APPLICABLE NOT APPLICABLE	$\tau_F = 2691$ psi $2691 < 17500$
MAIN BODY CYLINDER OUTSIDE SURFACE INSIDE SURFACE	1020 STEEL $S_{Y_A} = (0.9)(S_Y)$ $S_{Y_A} = 43200$ psi	1006 STEEL $S_{Y_A} = (0.9)(S_Y)$ $S_{Y_A} = 36900$	$\sigma_F = 9015$ psi $9015 < 36900$ $\sigma_F = 9667$ psi $9667 < 36900$
MOUNTING HARDWARE 5/8-11 BOLT		A307 GRADE 1 BOLT $\sigma_A = 20000$ psi $\tau_A = 10000$ psi	$\sigma_F = 14053$ psi $\tau_F = 4283$ psi

NOTE: LOWEST GRADE BOLT ASSUMED INSTALLED

BASIS FOR COMPARISON: $\frac{\tau_F}{\tau_A} + \frac{\sigma_F}{\sigma_A} \leq 1.5$ FOR DBE CONDITIONS

$1.131 < 1.5$

* CALCULATED STRESS USING SRSS OF THE EARTHQUAKE DIRECTIONS OR MAXIMUM DISTORTION ENERGY THEORY.

IOWA ELECTRIC LIGHT AND POWER COMPANY
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DEPT. DESIGN ENGINEERING
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SUBJECT SEISMIC ANALYSIS HILLS-MCCANNA ACTUATORS
Computed by DW Date Checked by Date

SUMMARY OF RESULTS CONTINUED R-2000 FS

COMPONENT	MANUFACTURED MATERIAL ALLOWABLE STRESS	LOW GRADE MATERIAL ALLOWABLE STRESS	*CALCULATED STRESS STRESS COMPARISON
E004 CASTING (MOUNTING YOKE)	CLASS 35 CAST IRON $S_{y_A} = (0.6)(S_y)$ $S_{y_A} = 18000$ psi $S_{\tau_A} = (0.4)(S_y)$ $S_{\tau_A} = 12000$ psi	CLASS 20 CAST IRON $S_{y_A} = (0.6)(S_y)$ $S_{y_A} = 12000$ psi $S_{\tau_A} = (0.4)(S_y)$ $S_{\tau_A} = 8000$ psi	$\sigma_F = 3331$ psi $\tau_F = 1894$ psi $3331 < 12000$ $1894 < 8000$
PRESS FIT BETWEEN MAIN CYLINDER AND MOUNTING YOKE	CAST IRON-1020 STEEL MINIMUM INTERFERENCE = 0.001" FORCE REQUIRED TO SLIDE MAIN CYLINDER FROM MOUNTING YOKE = 2970#		RESULTANT AXIAL FORCE = 1902# $1902 < 2970$

FOR INFORMATION ONLY

Iowa Electric Light and Power Company
Cedar Rapids, Iowa
R-2000 FS

DEPT. DESIGN ENGINEERING CALC. M84-14
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SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by ______ Date ______ Checked by ______ Date ______

WEIGHT DETERMINATION

FOR INFORMATION ONLY

END CAP (MAIN CYLINDER)

$D_o = 8.644''$
$h = 1.125$
$\rho = 0.283 \,\#/\text{in}^3$

$$\text{WEIGHT} = \frac{\pi (8.644)^2 (1.125)(0.283)}{4} = 18.68\#$$

SPRINGS

$$\text{LENGTH OF ONE COIL} = \sqrt{(2\pi r)^2 + h^2}$$ MARKS HANDBOOK Pg 2-41

r = radius
h = distance BETWEEN TWO COILS OF HELIX

SPRING$_1$
SPRING O.D. = 7.40 SPRING I.D. = 5.60"
WIRE DIA = 0.812" ± 0.010
TOTAL # OF COILS = 13.5 $\rho = 0.283 \,\#/\text{in}^3$
LET h = 0.822"

$$\text{LET } r = \frac{(7.40 - 5.60)\tfrac{1}{2} + 5.60}{2} = 3.25''$$

$$\text{LENGTH OF ONE COIL} = \sqrt{\left[2\pi(3.25)\right]^2 + (0.822)^2}$$

LENGTH OF ONE COIL = 20.44"

(13.5 TOTAL NO COILS)(20.44") = 275.90 INCHES

$$\text{CROSS SECTIONAL AREA} = \frac{\pi(0.822)^2}{4} = 0.531 \text{ in}^2$$

$$\text{VOLUME} = (0.531 \text{ in}^2)(275.90) = 146.42 \text{ in}^3$$

$$\text{WEIGHT} = (146.42)(0.283 \,\#/\text{in}^3) = 41.44 \,\#$$

SPRING$_2$
WIRE DIA = 0.532"
SPRING O.D = 5.25" MEAN DIA = 4.66"

$$\text{TOTAL \# COILS} = \frac{\text{SOLID HEIGHT}}{\text{WIRE DIA}} = \frac{10.75''}{0.532''} = 20.21 \text{ COILS}$$

LET h = 0.532
r = 4.66/2 = 2.33"

$$\text{LENGTH ONE COIL} = \left[\left[2\pi(2.33)\right]^2 + 0.532^2\right]$$

LENGTH 1 COIL = 14.65"

$$\text{WEIGHT} = (20.21)(14.65'')(\pi)(0.532)^2(0.283)/4 = 18.63\#$$

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FOR INFORMATION ONLY

WEIGHT DETERMINATION

SPRINGS CONTINUED

TOTAL SPRING WEIGHT = $WEIGHT_1 + WEIGHT_2$

TOTAL SPRING WEIGHT = $41.44^{\#} + 18.63^{\#} = 60.07^{\#}$

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R-2000FS

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WEIGHT DETERMINATION

FOR INFORMATION ONLY

MAIN BODY CYLINDER

$D_o = 9.2310''$
$D_i = 8.560''$
$h = 21.262''$
$\rho = 0.282\ \#/\text{in}^3$

$$\text{VOLUME} = \frac{\pi(D_o^2 - D_i^2)\,h}{4}$$

$$\text{VOLUME} = \frac{\pi(9.2310^2 - 8.560^2)(21.262)}{4}$$

$$\text{VOLUME} = 199.35\ \text{IN}^3$$

$$\text{WEIGHT} = (199.35\ \text{IN}^3)(0.283\ \#/\text{IN}^3) = 56.42\ \#$$

REFERENCE: 460-3316

CYLINDER - SPRING CYLINDER

$D_o = 8.775''$
$D_i = 7.975''$
$h = 14.63$

$$\text{VOLUME} = \frac{\pi(8.775^2 - 7.475^2)\,14.63}{4}$$

$$\text{VOLUME} = 154.08\ \text{IN}^3$$

$$\text{WEIGHT} = (154.08\ \text{IN}^3)(0.283\ \#/\text{IN}^3) = 43.60\ \#$$

REFERENCE: 460-7509

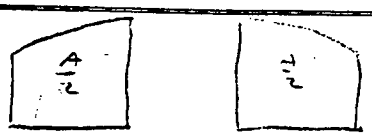
SPRING CYLINDER END CAP

$$\text{VOLUME} = \frac{(\pi)(4.00)^2(1.00 - 0.31)}{4} + \frac{\pi(8.260)^2(0.31)}{4}$$

$$\text{VOLUME} = 25.28\ \text{IN}^3$$

$$\text{WEIGHT} = (25.28\ \text{IN}^3)(0.283) = 7.15\ \#$$

REFERENCE: 460-1001



PISTON

$\theta = \sin^{-1} \frac{2.68}{4.275} = 42.4°$

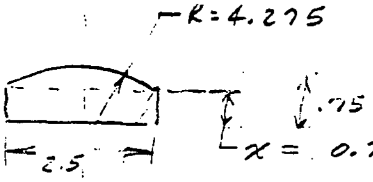
$d = 4.275 \cos\theta - 1.63 = 1.527$

$h = 4.275(\cos[\sin^{-1} \frac{1.25}{4.275}]) - \cos\theta) = 0.931$

$A = (\frac{42.4}{180})(\pi)(4.275^2) - (3.157)(2.88) + (2)(1.527)(1.63)$

$- (2.5)(0.931) = 7.083 \text{ in}^2$

$V_2 = (7.083)(11.836) = 83.834$



17°

$x = 0.75 - 4.275(1 - \cos[\sin^{-1} \frac{1.25}{4.275}])$
$= 0.563$

$A = (\frac{17}{180} \pi 4.275^2) - (4.088)(1.25) + (2.5)(.563)$

$A = 1.72 \text{ in}^2$

$V = (1.72)(5.26) = 9.047$

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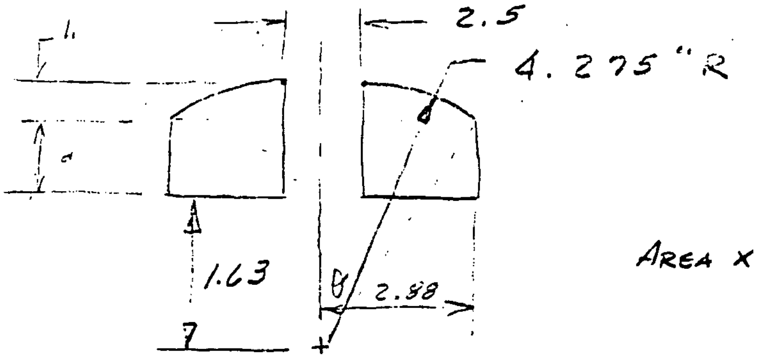
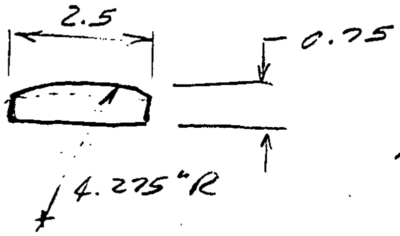
PISTON - CAST IRON ASTM 126-71 CLASS B

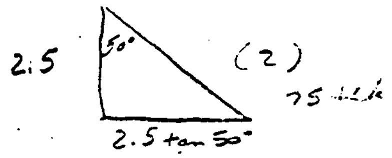
HEAD. 8.525" ⌀ 1.378" THK $\Longrightarrow V_1 = 78.655 \text{ in}^3$



$\text{AREA} \times 11.836 = 83.834 \text{ in}^3 = V_2$



$\text{AREA} \times 5.26 = 9.047 \text{ in}^3 = V_3$



$(2.5)^2(\tan 50°)(0.75) = 5.586 \text{ in}^2 = V_3$

$V_{piston} = V_1 + V_2 + V_3 + V_4 = 177.122 \text{ in}^3$

$W_{piston} = \rho V = (0.26)(177.122) = 46 \#$

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FOR INFORMATION ONLY

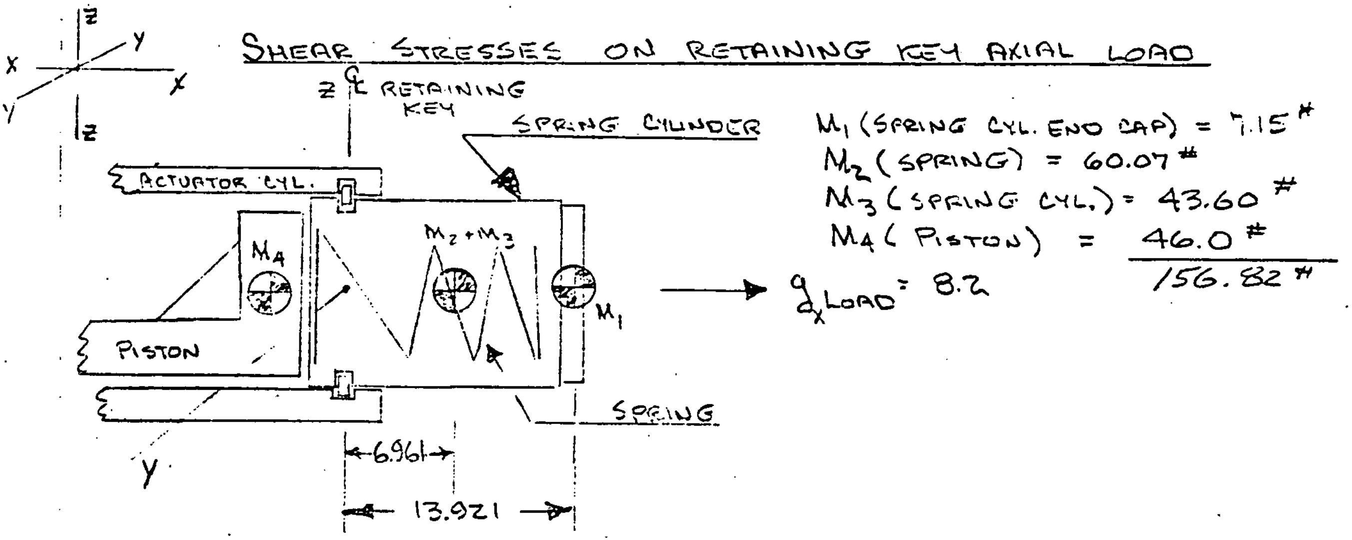
IV-AD-13 A1 & B1
IV-AD-17 A2 & B2
IV-AD-17 A3 & B3
IV-AD-30 A & B
IV-AD-31 A & B

	HORIZONTAL (g) LOADS	
	OBE	DBE
REACTOR BUILDING ELEVATION 833'-6" BOLTED SUPPORT SYSTEM	4.1	8.2

- MAXIMUM HORIZONTAL (g) LOAD FOR WORST CASE ACTUATOR ELEVATION APPLIED TO ALL AXIS OF SEISMIC ANALYSIS. 8.2 g LOAD IS GREATER THAN (1+g) LOAD FROM THE VERTICAL (g) LOAD SPECIFICATION FOR REACTOR BUILDING ELEVATION 833'-6".

- MAXIMUM AIR PRESSURE = 100 PSI ACTING ON PISTON 8.565" DIAMETER.

SHEAR STRESSES ON RETAINING KEY AXIAL LOAD



M1 (SPRING CYL. END CAP) = 7.15#
M2 (SPRING) = 60.07#
M3 (SPRING CYL.) = 43.60#
M4 (PISTON) = 46.0#
156.82#

SPRING TEST LENGTHS (NESTED SPRINGS)
REFERENCE:
460-3001 @ 20.05" = 1263# WITH 181#/IN SPRING RATE
460-3002 @ 20.05" = 368# WITH 64#/IN SPRING RATE

14.55" MAXIMUM SPRING COMPRESSION LENGTH WITH PISTON AT STOP.

$F_{SPRING} = 1263^{\#} + (20.05 - 14.55)181 + 368 + (20.05 - 14.55)64$

$F_{SPRING} = 2978.5^{\#}$

$F_{AIR\ PRESSURE} = (100\ PSI)\pi\frac{(8.565)^2}{4} = 5761.6^{\#}$

$F_{WEIGHT} = (8.2)(156.82) = 1285.92^{\#}$

$F_{x\,TOTAL} = 1285.92 + 5761.6 + 2978.5 = 10026.02$ (CONSERVATIVE ESTIMATE)

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R2000 FS SHEAR STRESSES ON THE RETAINING RING AXIAL LOAD

FOR INFORMATION ONLY

RETAINING KEY CROSS SECTION
REFERENCE : 460-2904

0.187" SQUARE

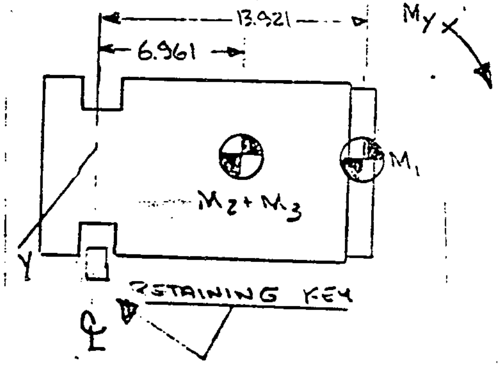
ACTIVE CIRCUMFERENTIAL LENGTH = 26.3 INCHES

$$\tau_A = \frac{F_{X\,TOTAL}}{(26.3)(0.187)} = \frac{10026.02}{(26.3)(0.187)} = 2038.60 \text{ PSI}$$

STRESS ON THE RETAINING RING RESULTING FROM THE MOMENT INDUCED BY THE SPRING CYLINDER

$$M_y = g\left[M_1(13.921) + (M_2+M_3)(6.961)\right]$$

$$M_y = 8.2\left[7.15(13.921) + (60.07+43.60)(6.961)\right] = 6733.7 \text{ in-lb}$$



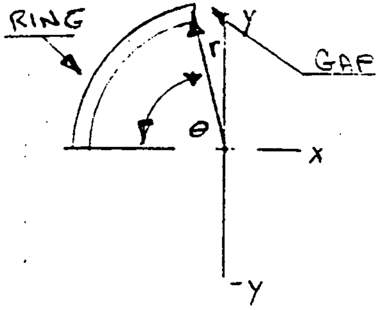
SHEAR STRESS = $\tau(\theta)$
t = THICKNESS OF RETAINING RING = 0.187"
r = 4.2770"
M = 6733.7 IN-lb

ACTIVE CIRCUMFERENTIAL RETAINING RING LENGTH = 26.3 INCH
ACTIVE LENGTH PER QUADRANT = 6.575"

$$\text{QUADRANT CIRCUM} = \frac{2\pi(4.277)}{4} = 6.7183"$$

$$\theta = \frac{6.575}{6.7183} \times \frac{\pi}{2} = 1.5373 \text{ RAD}$$

- THETA (θ) IS THE ANGLE THAT CORRESPONDS TO THE RETAINING RING GAP FOR ONE QUADRANT. GAP IS DIVIDED IN TWO EQUAL PARTS AT +Y AND -Y.



$\tau(\theta)$ = SHEAR STRESS DUE TO M_y

$$\int_0^\theta \tau(\theta)\, t\, r^2 \sin\theta\, d\theta = \frac{M_y}{4}$$

$$\tau(\theta) = K r \sin\theta$$

$$\int_0^\theta K t r^3 \sin^2\theta\, d\theta = K t r^3 \int_0^\theta \sin^2\theta\, d\theta = \frac{M_y}{4}$$

$$\int_0^\theta \sin^2\theta\, d\theta = \left[-\frac{1}{4}\sin 2\theta + \frac{1}{2}\theta\right]_0^{1.54} = -\frac{1}{4}\sin(2)(1.54) + \frac{1.54}{2}$$

$$= 0.755$$

$$\frac{M_y}{4} = (K)t(r^3)(0.755)$$

SOLVE FOR K

$$K = \frac{(6733.7)}{(4)(0.187)(4.277)^3(0.755)} = 152.4$$

IOWA ELECTRIC LIGHT
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CEDAR RAPIDS, IOWA

DEPT. DESIGN ENGINEERING CALC. M84-14
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R2000 FS

STRESSES ON THE RETAINING RING CONTINUED

$\tau(\theta) = K r \sin\theta = (152.4)(4.2770)\sin(1.54) = 651.51$ PSI

$\tau_{TOTAL} = \tau_A + \tau_\theta = 2038.60 + 651.51 = 2690.11$ PSI

S_τ = SHEAR STRENGTH = $0.5(S_y)$

S_y = YIELD STRENGTH 303 SS. = 35000 PSI

50% SHEAR STRENGTH = (0.5)(35,000) = 17500 PSI

ALLOWABLE SHEAR STRESS = 17500 PSI

2690.11 PSI < 17500 PSI

FOR INFORMATION ONLY

STRESSES DUE TO THE PRESS FIT CONDITIONS BETWEEN THE MOUNTING YOKE AND THE CYLINDER BODY.

- REFERENCE HIGDON "MECHANICS OF MATERIALS" JOHN WILEY & SONS 1978 Pg 163, 164

I (INTERFERENCE) = $2\delta_1 + 2\delta_2$

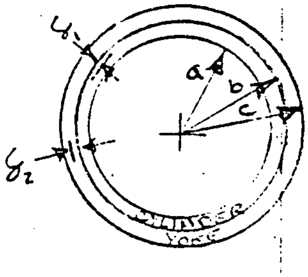
MOUNTING YOKE = $\frac{9.141}{9.143}$" DIA REF: 460-3321

ACTUATOR MAIN CYLINDER = $\frac{9.144}{9.146}$" DIA REF: 460-3316

MAXIMUM INTERFERENCE = $|9.141 - 9.146| = 0.005$

$$\delta_1 = \frac{b_1^2 P_s}{(c^2 - b_1^2) E_y b_1}\left[(1-\nu)b_1^2 + (1+\nu)c^2\right]$$

$$\delta_2 = \frac{b_2^2 P_s}{(b_2^2 - a^2) E_c b_2}\left[(1-\nu)b_2^2 + (1+\nu)a^2\right]$$



$a = \frac{8.560}{2} = 4.280$ $b_1 = \frac{9.143}{2} = 4.5715$ $b_2 = \frac{9.144}{2} = 4.572$ $C = \frac{10.44}{2} = 5.220$

FOR INFORMATION ONLY

STRESSES DUE TO THE PRESS FIT CONDITION BETWEEN THE MOUNTING YOKE AND THE CYLINDER BODY

$$0.005 = \frac{(4.5715)^2 P_s (2)}{(5.22^2 - 4.5715^2)(15\times10^6)(4.5715)}\left[(1-0.29)(4.5715)^2 + (1.29)(5.22)^2\right]$$

$$+ \frac{(4.572)^2 P_s (2)}{(4.572^2 - 4.28^2)(30\times10^6)(4.572)}\left[(1-0.30)(4.572)^2 + (1.30)(4.28)^2\right]$$

$$0.005 = 4.7985(10)^{-6} P_s + 4.5336(10)^{-6} P_s$$

P_s 535.78 PSI (MAXIMUM INTERFERENCE)

EXTERNAL PRESSURE

$$\sigma_r = -\frac{b_2^2 P_o}{b_2^2 - a^2}\left[1 - \frac{a^2}{\rho^2}\right]$$

$$\sigma_t = \frac{-b_2^2 P_o}{b_2^2 - a^2}\left[1 + \frac{a^2}{\rho^2}\right]$$

INTERNAL PRESSURE

$$\sigma_r = \frac{b_1^2 P_I}{c^2 \; b_1^2}\left[1 - \frac{c^2}{\rho^2}\right]$$

$$\sigma_t = \frac{b_1^2 P_I}{c^2 \; b_1^2}\left[1 + \frac{c^2}{\rho^2}\right]$$

STRESS IN MOUNTING YOKE CASTING INTERNAL PRESSURE

INSIDE SURFACE

$$\sigma_r = \frac{(4.5715)^2(535.78)}{5.22^2 - 4.5715^2}\left[1 - \frac{5.220^2}{4.5715^2}\right] = -535.78 \text{ PSI}$$

$$\sigma_t = \frac{(4.5715^2)(535.78)}{5.220^2 - 4.5715^2}\left[1 + \frac{5.220^2}{4.5715^2}\right] = 4062.53 \text{ PSI}$$

- INSIDE SURFACE WORST CASE CONDITION

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STRESS IN CYLINDER EXTERNAL PRESSURE

OUTSIDE CYLINDER SURFACE

$$\theta_r' = \frac{-(4.572)^2(535.78)}{4.572^2 - 4.280^2}\left[1 - \frac{4.280^2}{4.572^2}\right] = -535.78 \text{ PSI}$$

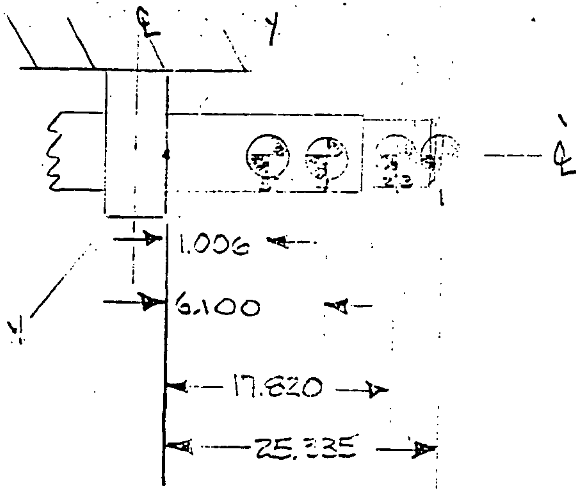
$$\theta_t' = \frac{-(4.572)^2(535.78)}{4.572^2 - 4.280^2}\left[1 + \frac{4.280^2}{4.572^2}\right] = -8129.94 \text{ PSI}$$

INSIDE CYLINDER SURFACE

$$\theta_r = \frac{-(4.572)^2(535.78)}{4.572^2 - 4.280^2}\left[1 - \frac{4.280^2}{4.280^2}\right] = 0 \text{ PSI}$$

$$\theta_t = \frac{-(4.572)^2(535.78)}{4.572^2 - 4.280^2}\left[1 + \frac{4.280^2}{4.280^2}\right] = -8665.72 \text{ PSI}$$

STRESS ON THE CYLINDER DUE TO MOMENT CAUSED BY MAIN BODY CYLINDER, PISTON, SPRING CYLINDER AND SPRING CYL END CAP



M_1 (END CAP) = 7.15#
M_2 (SPRING) = 60.07#
M_3 (SPRING CYL) = 43.60#
M_4 (PISTON) = 46.00#
M_5 (MAIN CYL) = 56.42#

- MASS OF CYLINDER IS MODELLED TO ACT ON RIGHT SIDE OF YOKE. EXCLUDES COUNTER ACTING MOMENT DUE TO MASS OF CYLINDER AND END CAP ON THE LEFT SIDE OF YOKE ℄

SUMMING MOMENTS ABOUT Y-Y

$$M_y = g\left[M_1 l_1 + (M_2 + M_3) l_2 + M_4 l_4 + M_5 l_5 \right]$$

$$M_y = 8.2\left[(7.15)(25.335) + (60.07 + 43.60)(17.82) + (6.100)(46.00) + 1.006(56.42) \right] =$$

$$M_y = 19400.41 \text{ IN-lb}$$

MOMENT OF INERTIA @ NEUTRAL AXIS ℄ ACTUATOR

$$I_{yy} = \frac{\pi}{64}(d_o^4 - d_i^4) = \frac{\pi}{64}(9.146^4 - 8.565^4) =$$

$$I_{yy} = 79.31 \text{ IN}^4$$

$$\sigma_T' = \frac{M_y c}{I_{yy}} = \frac{(19400.41)(9.146)}{(79.31)(2)} = 1118.67 \text{ PSI}$$

$$\sigma_{\text{AIR PRESSURE}} = \frac{5761.6\#}{\pi(9.146^2 - 8.565^2)/4} \cong 712.91 \text{ PSI}$$

CYLINDER STRESSES CONTINUED

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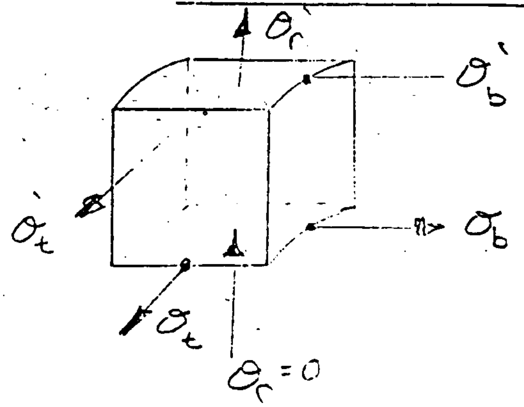


$$\sigma_T = \frac{(19400.41)(8.565)}{79.31\ (2)} =$$

$\sigma_T = 1047.6$ PSI

$\sigma'_b = \sigma_{AP} + \sigma'_T = 712.91 + 1118.6 = 1831.51$

$\sigma_b = \sigma_{AP} + \sigma_T = 712.91 + 1047.6 = 1760.51$ PSI

$\sigma'_t = -8129.94$ PSI

$\sigma_t = -3665.72$ PSI

$\sigma'_r = -535.78$ PSI

$\sigma_r = 0$ PSI

SUMMATION OF CYLINDER STRESSES USING MAXIMUM DISTORTION ENERGY THEORY

- REFERENCE MECHANICS OF MATERIALS Pg 489

$$\sigma_f = \left\{ \frac{1}{2}\left[(\sigma_b - \sigma_t)^2 + (\sigma_t - \sigma_r)^2 + (\sigma_r - \sigma_b)^2 \right] \right\}^{1/2}$$

$$\sigma'_f = \left\{ \frac{1}{2}\left[(1831.5 + 8129.94)^2 + (-8129.94 + 535.78)^2 + (-535.78 - 1831.5)^2 \right] \right\}^{1/2}$$

$\sigma'_f = 9014.3$ PSI

$$\theta_F = \left\{ \tfrac{1}{2}\left[(1760.5 + 8665.7)^2 + (8665.7 - 0)^2 + (0 - 1760.5)^2 \right] \right\}$$

$\theta_F = 9666.9$ PSI

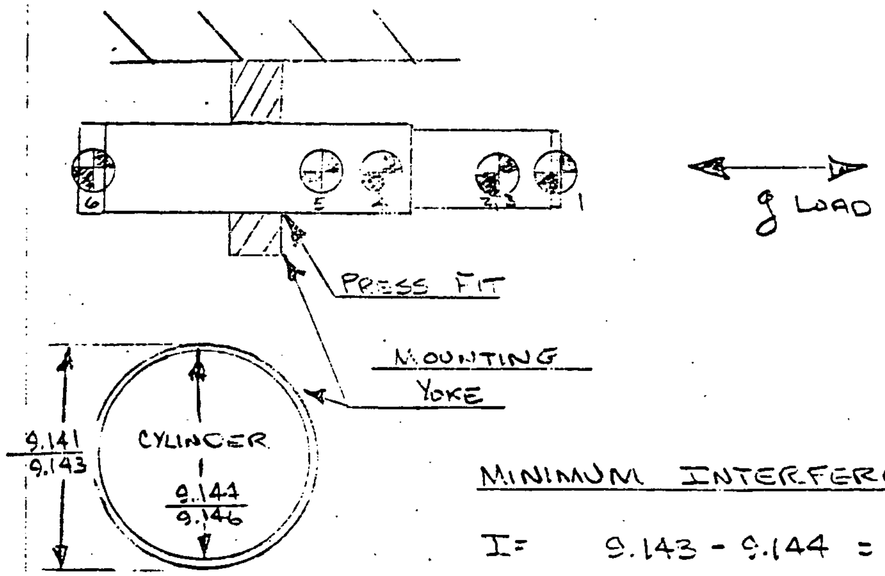
FOR INFORMATION ONLY

$S_y = 43{,}200$ PSI (YIELD 1020 @ 90%)

$\theta_F = 9014.3 < 43200$ PSI

$\theta_F = 9666.9 < 43200$ PSI

SEISMIC AXIAL LOAD ACTING ON PRESS FIT OF CYLINDER THROUGH MOUNTING YOKE



MINIMUM INTERFERENCE

$I = 9.143 - 9.144 = 0.001''$

ON DIAMETER

SOLVING FOR INTERFACIAL PRESSURE P_S. Pg 164 MECHANICS OF MATL'S.

$$0.001 \text{ IN} = 2\left[\frac{(4.572)^2 (P_S)}{(5.22^2 - 4.572^2)(15\times10^6)(4.572)}\right]\left[(1-0.29)(4.572)^2 + (1.29)(5.22)^2\right]$$

$$+ \; 2\left[\frac{(4.572)^2 P_S}{(4.572^2 - 4.283^2)(30\times10^6)(4.572)}\right]\left[(1-0.29)(4.572)^2 + (1.29)(4.283)^2\right]$$

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SEISMIC AXIAL LOAD ACTING ON PRESS FIT OF CYLINDER THROUGH MOUNTING YOKE

$$0.001\text{ IN} = P_s\left[4.803\times10^{-6} + 1.003\times10^{-6}\right]$$

$$P_s = 172.24\text{ PSI}$$

DETERMINATION OF AXIAL LOAD (SEISMIC INDUCED)

TOTAL WEIGHT = $M_1 + M_2 + M_3 + M_4 + M_5 + M_6$

M_1 (END CAP) = 7.15$^{\#}$
M_2 (SPRING CYL) = 60.07$^{\#}$
M_3 (SPRING) = 43.60$^{\#}$
M_4 (PISTON) = 46.00$^{\#}$
M_5 (MAIN CYL) = 56.42$^{\#}$
M_6 (MAIN CYL END CAP) = 18.68$^{\#}$

TOTAL WEIGHT = 231.92$^{\#}$ = M_T

AXIAL FORCE = $F_A = M_T\left(\frac{a}{c}\right) = (231.92)(8.2) = 1901.74^{\#}$

FORCE REQUIRED TO SLIDE CYLINDER FROM MOUNTING YOKE

$F = \pi f P_s d l$ REFERENCE: MARKS HANDBOOK 8-47

l = LENGTH OF FIT = 6.00"
d = CYLINDER DIAMETER = 9.146"
P_s = UNIT PRESSURE FIT = 172.24 PSI
f = COEFFICIENT OF FRICTION = 0.10 (AVERAGE VALUES 0.10 → 0.15)

$$F = (3.1415)(0.10)(172.24)(9.146)(6.00) = 2969.38^{\#}$$

$$\underline{2969.38^{\#} > 1901.74^{\#}}$$

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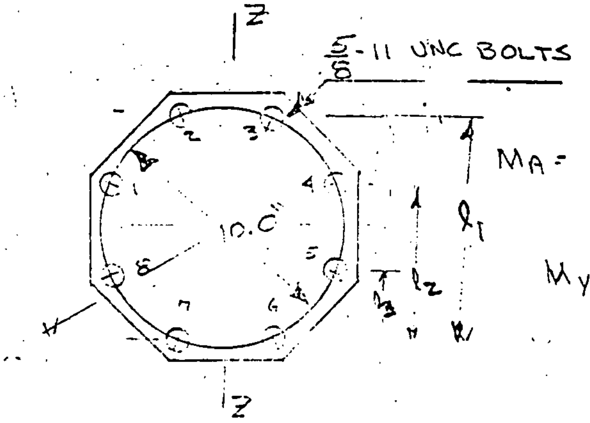
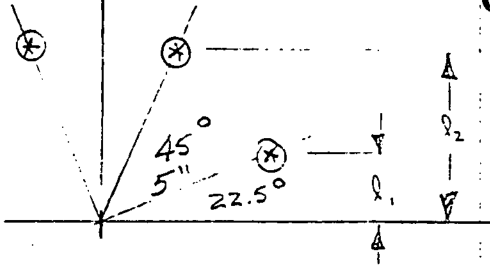
SEISMIC LOADING ON MOUNTING HARDWARE

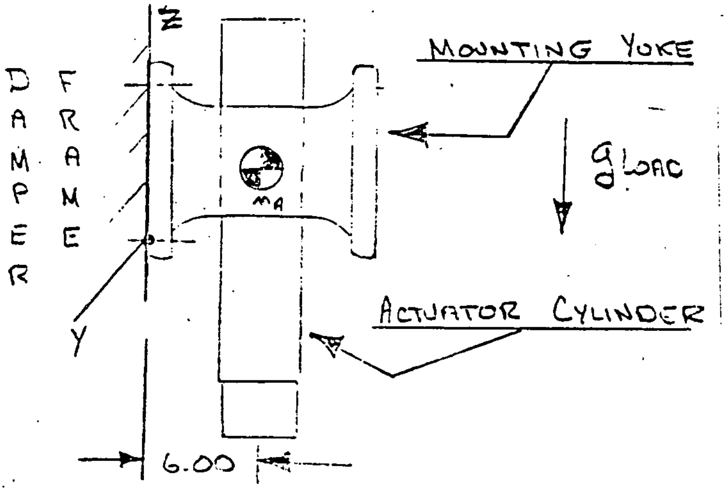


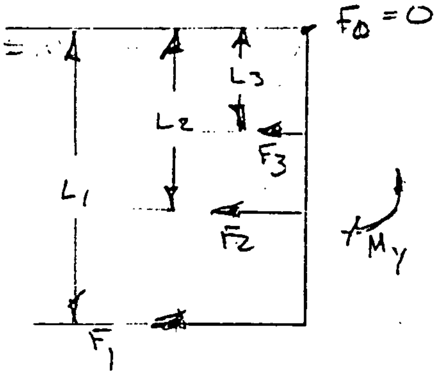
g_Z LOADING

MA = MASS OF ACTUATOR INCLUDING MOUNTING YOKE = 315#

$M_{y\text{-}y}$ = (8.2)(315)(6.0) = 15498.0 IN-lb







TENSION IN BOLTS

$L_3 = 1.913"$
$L_2 = 4.619"$
$L_1 = 1.913 + 4.619 = 6.532"$

$$F_1(L_1) + F_2(L_2) + F_3(L_3) = M_Y$$

$$\frac{F_1}{L_1} = \frac{F_2}{L_2} = \frac{F_3}{L_3}$$

$$F_2 = F_1 \frac{L_2}{L_1}$$

$$F_3 = F_1 \frac{L_3}{L_1}$$

$$F_1(L_1) + F_1 \frac{(L_2)^2}{L_1} + F_1 \frac{(L_3)^2}{L_1} = M_Y$$

$$F_1 \left(6.532 + \frac{(4.619)^2}{6.532} + \frac{(1.913)^2}{6.532}\right) = 15498.0$$

F_1 = 1496.16 # TENSION WORST CASE BOLT 6

FORCE @ BOLT (5) = $F_1 \frac{(L_2)}{L_1} = \frac{(1496.16)(4.619)}{6.532}$ = 1058.0 #

SEISMIC LOADING ON MOUNTING HARDWARE

g_z LOADING CONTINUED

F_S = SHEAR FORCE IN MOUNTING BOLTS

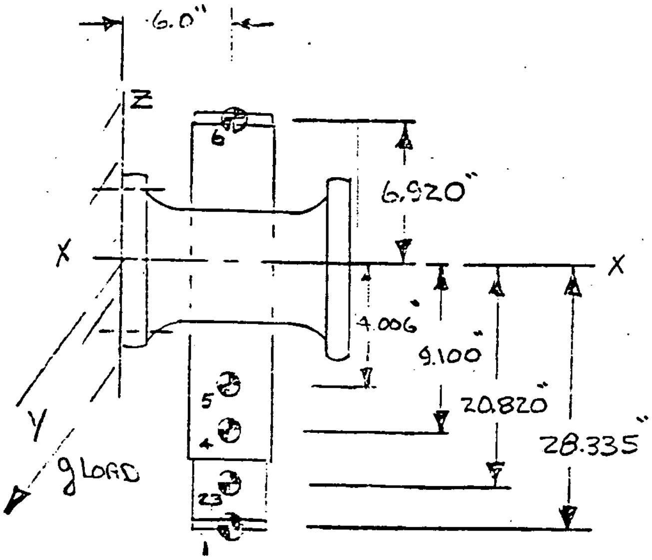
$$F_S = \frac{(315^{\#})(8.2g)}{8 \text{ BOLTS}} = 322.88^{\#} \text{ PER BOLT}$$

TENSILE STRESS AREA $\frac{5}{8}$-11 UNC = 0.226 IN^2

$$\tau = \frac{322.88^{\#}}{0.226 \, IN^2} = 1428.31 \text{ PSI}$$

$$\sigma_T = \frac{1496.16^{\#}}{0.226 \, IN^2} = 6620.19 \text{ PSI (WORST CASE BOLT)}$$

g_y LOADING



M_1 (END CAP) = 7.15 #
M_2 (SPRING) = 60.07 #
M_3 (SPRING CYL) = 43.60 #
M_4 (PISTON) = 46.00 #
M_5 (MAIN CYL) = 56.42 #
M_6 (MAIN CYL END CAP) = 18.68 #

$$M_{X\text{-}X} = g\left[m_1 l_1 + (m_2 + m_3) l_2 + M_4 l_4 + M_5 l_5 - M_6 l_6\right]$$

$$M_{X\text{-}X} = 8.2\left[(7.15)(28.335) + (60.07 + 43.60)(20.82) + (46.0)(9.10) + (56.42)(4.006) - (18.68)(6.920)\right] = 23586.13 \text{ IN-lb}$$

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SEISMIC LOADING ON MOUNTING HARDWARE

g_y LOADING

TENSION ON BOLT 5 FROM g_y LOADING

$F_{T_5} = 1496.16^{\#}$, THE SAME AS BOLT SIX WITH g_z LOADING

TENSION OF BOLT 6 FROM g_y LOADING

$F_{T_6} = 1058^{\#}$ THE SAME AS BOLT FIVE WITH g_z LOADING

$$\theta_{T_6} = \frac{1058^{\#}}{0.226} = 4620.1 \text{ PSI}$$

$$F_{Y_{EX}} = \frac{(23586.13 \text{ in-lb})}{(8 \text{ BOLTS})(5.0'')} = 589.65^{\#}$$

$$F_{Y_{5_Y}} = \frac{(8.24)(315^{\#})}{8 \text{ BOLT}} = 322.8^{\#}$$

$F_{\text{TOTAL SHEAR}} \cong 589.65^{\#} + 322.8^{\#}$

$F_{\text{TOTAL SHEAR}} = 912.45^{\#}$

$$\tau_{\text{TOTAL}} = \frac{912.45}{0.226} = 4037.4 \text{ PSI}$$

g_x LOADING

$M_{Y-Y} = 23586.13$ IN-lb $= M_{XX}$ (g_Y LOADING)

$$F_1\left(6.532 + \frac{(4.619)^2}{6.532} + \frac{(1.913)^2}{6.532}\right) = 23586.13$$

$$F_1 (10.36) = 23586.13$$

$F_1 = 2276.65^{\#}$ TENSION IN BOLT 6

$\theta_1 = 2276.65^{\#} / 0.226 \text{ IN}^2 = 10073.7 \text{ PSI}$

$$\text{AXIAL TENSION} = \frac{(8.29)(315^{\#})}{8 \text{ BOLT}} = 322.88^{\#}$$

$\theta_{A_T} = 322.88^{\#} / 0.226 \text{ IN}^2 = 1428.7$ PSI

SQUARE ROOT SUM OF THE SQUARES

$$\theta_F = \left[6620.1^2 + 4620.1^2 + (10073.7 + 1428.7)^2 \right]^{1/2} \text{ BOLT 6}$$

$\theta_F = 14052.66$ PSI BOLT 6

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SEISMIC LOADING ON MOUNTING HARDWARE

SQUARE ROOT SUM OF THE SQUARES

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$$\tau_F = \left[\tau_{xy_1}^2 + \tau_{xy_2}^2 + \tau_{xy_3}^2\right]^{1/2} = \left[1428.31^2 + 4037.4^2 + 0^2\right]^{1/2}$$ BOLT 6

τ_F: 4282.60 PSI BOLT 6

BASIS FOR COMPARISON $\frac{\tau_F}{\tau_A} + \frac{\theta_F}{\theta_A} \leq 1.5$ FOR DBE CONDITIONS

ASSUME BOLTS TO BE A307 GRADE (1) BOLTS

$\tau_{ALLOWABLE}$ = 10000 PSI

$\theta_{ALLOWABLE}$ = 20000 PSI

$$\frac{4282.6}{10000} + \frac{14052.67}{20,000} = 1.131$$ BOLT 6

$\underline{\underline{1.131 \leq 1.5}}$ BOLT 6

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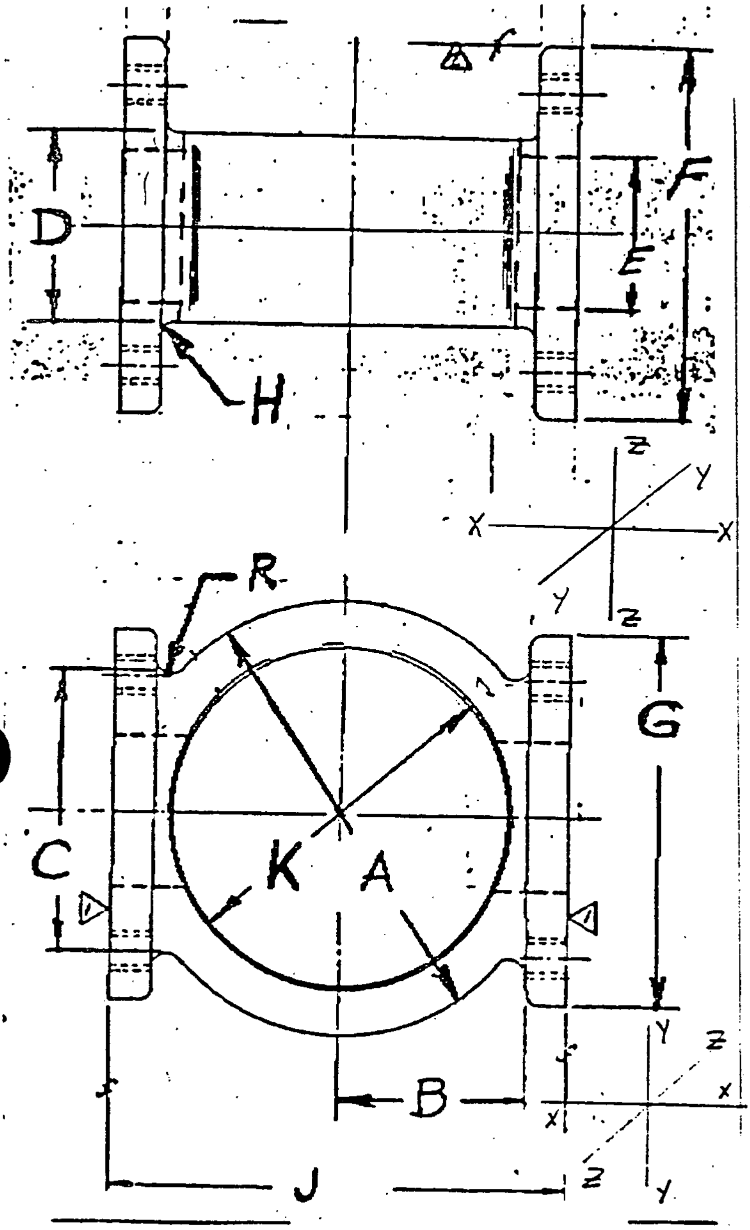
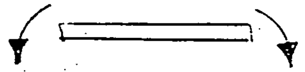
SEISMIC STRESSES ON THE MOUNTING YOLK



A = 10.44
B = 5.25
C = 5.00
D = 6.00
E (DIA) = 3.126
F = 8.00
G = 8.00
H = 0.12
J = 12.00
K (DIA) = 9.14
R = 0.50

R-4200 FS HAS THE SAME STRESS CONCENTRATOR VALUES

ELASTIC STRESS IN-PLANE BENDING



REFERENCE: FORMULAS FOR STRESS AND STRAIN CONCENTRATION FACTORS Pg. 593

$K_T = K_1 + K_2\left(\frac{2h}{d}\right) + K_3\left(\frac{2h}{d}\right)^2 + K_4\left(\frac{2h}{d}\right)^3$

VERTICAL LOADS g_z LOADING

$h = \frac{1}{2}(G-D)$ $r = H$ $d = G$

$h = \frac{1}{2}(8.00-6.00) = 1.00$
$r = 0.12$
$d = 8.00$

$K_1 = 3.577$
$K_2\left(\frac{2h}{d}\right) = -0.629$
$K_3\left(\frac{2h}{d}\right)^2 = -0.028$
$K_4\left(\frac{2h}{d}\right)^3 = 0.006$
K_Z 2.9260

HORIZONTAL LOADS g_y LOADING

$h = \frac{1}{2}(8.00-5.00) = 1.50$ $r = R$ $h = \frac{1}{2}(G-C)$
$r = 0.50$
$d = 8.00$

$K_1 = 2.635$
$K_2\left(\frac{2h}{d}\right) = -0.783$
$K_3\left(\frac{2h}{d}\right)^2 = -0.022$
$K_4\left(\frac{2h}{d}\right)^3 = 0.032$
$K_Y =$ 1.862

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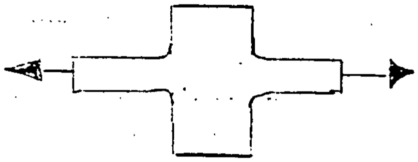
SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE

ELASTIC STRESS AXIAL TENSION
REFERENCE: FORMULAS FOR STRESS AND STRAIN Pg 593



$h = \frac{1}{2}(G-D) \quad r = H \quad d = G$

$h = \frac{1}{2}(8.00-6.00) = 1.00 \quad r = 0.12 \quad d = 8.00$

$h/r = 8.33 \quad 2h/d = (2)(1.0)/8.00 = 0.250$

$K_1 = 1.042 + 0.982(8.333)^{1/2} - 0.036(8.333) = 3.577$

$K_2 = -0.074 - 0.156(8.333)^{1/2} - 0.010(8.333) = -0.608$

$K_3 = -3.418 + 1.220(8.333)^{1/2} - 0.005(8.333) = 0.0622$

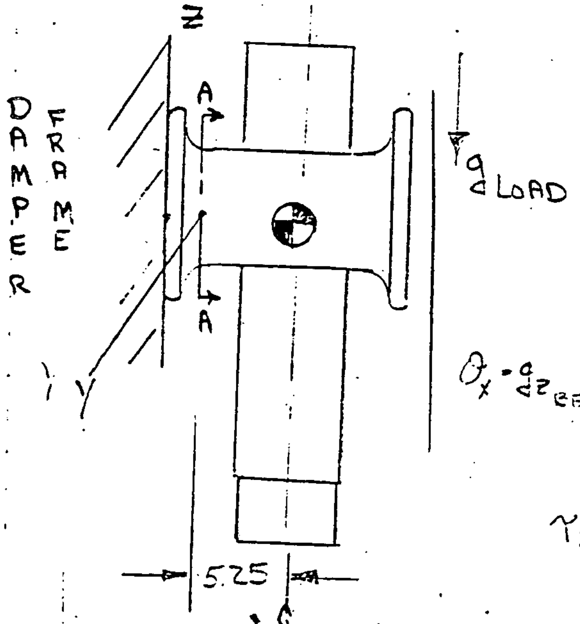
$K_4 = 3.450 - 2.046(8.333)^{1/2} + 0.051(8.333) = -2.0312$

$K_x = K_1 + K_2\left(\frac{2h}{d}\right) + K_3\left(\frac{2h}{d}\right)^2 + K_4\left(\frac{2h}{d}\right)^3$

$K_x = 3.577 - 0.608(0.25) + 0.0622(0.25)^2 - 2.0312(0.25)^3$

$K_x = 3.397$

g_z LOADINGS



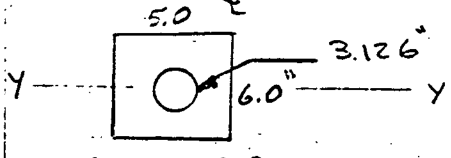
$M_y = (315^{\#})(5.25\text{ IN})(8.2) = 13560.75\text{ IN-lb}$

$I = \frac{(5)(6)^3}{12} - \frac{\pi}{4}\left(\frac{3.126}{2}\right)^4 = 85.3\text{ IN}^4$

$\theta_{Tz} = \frac{Mc}{I} = \frac{(13560.75)(3.0)}{85.3} = 476.93\text{ PSI}$

$\theta_x - g_{z_{BEND}} = K_z\,\theta_{Tz} = (476.93)(2.926) = 1395.5\text{ PSI}$

$\tau_{zy} = \frac{(315^{\#})(8.2)}{(5.0)(6.0) - \frac{\pi(3.126)^2}{4}} = 115.70\text{ PSI}$



SECTION A-A

SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE

g_Y LOADING

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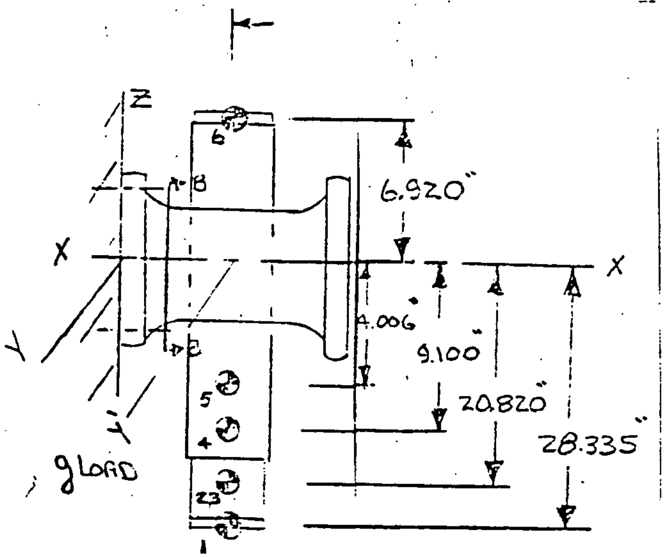


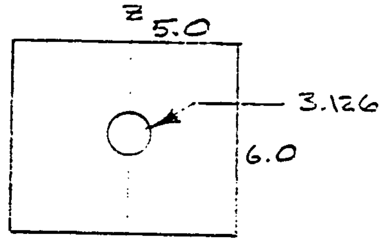
M_1 (END CAP) = 7.15#
M_2 (SPRING) = 60.07#
M_3 (SPRING CYL) = 43.60#
M_4 (PISTON) = 46.00#
M_5 (MAIN CYL) = 56.42#
M_6 (MAIN CYL END CAP) = 18.68#

SHEAR STRESS = $\frac{(wt)(g_Y)}{A}$

$$\tau_{ZY} = \frac{(315^{\#})(8.2)}{(5.0)(6.0) - \frac{\pi(3.126)^2}{4}}$$

τ_{ZY} = 115.70 PSI

SECTION B-B



$M_Z = (Wt)(g)(B) = (315^{\#})(8.2)(5.25)$
M_Z = 13560.75 IN-lb

$$I = \frac{(6)(5)^3}{12} - \frac{\pi}{4}\left(\frac{3.126}{2}\right)^4 = 57.8 \text{ IN}^4$$

$$\sigma_Y = \frac{Mc}{I} = \frac{(13560.75)(2.5)}{57.8} = 586.54 \text{ PSI}$$

$$^{Z}\sigma_X = g_{Y_{BENDING}} = K_Y \sigma_Y = (1.862)(586.54) = 1092.13 \text{ PSI}$$

SHEAR STRESS CAUSED BY MOMENT M_X

$$M_X = g\left[M_1D_1 + M_{23}D_2 + M_4D_4 + M_5D_5 - M_6D_6\right]$$

$$M_X = 8.2\left[(28.335)(7.15) + (60.07 + 43.60)20.820 + (46.0)(9.10) + (56.42)(4.006) - (6.920)(18.68)\right]$$

M_X = 23586.13 IN-lb

IOWA ELECTRIC LIGHT AND POWER COMPANY
CEDAR RAPIDS, IOWA
R-2000 FS

DEPT. DESIGN ENGINEERING CALC. M84-14
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 22 of 23
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by Date Checked by Date

SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE

- MODEL CROSS-SECTION AS AN APPROXIMATE CIRCULAR SECTION FOR COMPUTING TORSIONAL SHEAR STRESSES

REFERENCE: USS STEEL DESIGN MANUAL (JAN 1981)
R.L. BROCKENBROUGH & B.G. JOHNSON

$$\tau_s = \frac{TR}{I_P}$$

LET $R_1 = \frac{5.0''}{2} = 2.5''$ ∴ CONSERVATIVE I_P
T = TORSIONAL LOAD
R = RADIUS FOR LOCATION OF STRESS
I_P = POLAR MOMENT OF INERTIA

$$I_P = \frac{(R_1^4 - R_2^4)\pi}{2} = \frac{(2.5^4 - 1.563^4)\pi}{2} = 51.98 \text{ IN}^4$$

$$\tau_s = \frac{(23586.13 \text{ IN-lb})(3.91 \text{ IN})}{51.98 \text{ IN}^4} = 1774.18 \text{ PSI}$$

$$R = (3^2 + 2.5^2)^{1/2} = 3.91''$$

FOR INFORMATION ONLY

g_x LOADINGS

$$F(\text{TENSION})_x = MA = (315^{\#})(8.2g) = 2583^{\#}$$

$$\text{CROSS SECTIONAL AREA} = (6.0)(5.0) - \frac{\pi(3.126)^2}{4} = 22.33 \text{ IN}^2$$

$$\sigma_{x_A} = \frac{2583^{\#}}{22.33 \text{ IN}^2} = 115.70 \text{ PSI}$$

$$g_{AXIAL} = (K_x)(\sigma_{x_A}) = (3.397)(115.7) = 393.03 \text{ PSI}$$

$$M_y' = 8.2\Big[(28.335)(7.15) + (60.07 + 43.60)(20.820) + (46.0)\,9.10 + (56.42)(4.006) - (6.920)(18.68)\Big]$$

$$M_y' = 23586.13 \text{ IN-lb}$$

$$\sigma_{x_{BENDING}} = \frac{Mc}{I} = \frac{(23586.13)(3.0)}{(85.3)} = 829.52 \text{ PSI}$$

$$g_{x_{BEND}} = \sigma_{x_{BEND}} K_z = (829.52)(2.9260) = 2427.18 \text{ PSI}$$

SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE

SQUARE ROOT SUM OF THE SQUARES

$$\sigma_F = \left[(1395.5)^2 + (1092.13)^2 + (393.03 + 2427.18)^2 \right]^{1/2}$$

$$\sigma_F = 3330.72 \text{ psi}$$

$$\tau_F = \left[(1157)^2 + (1157 + 1774.18)^2 + (0)^2 \right]^{1/2}$$

$$\tau_F = 1893.42 \text{ PSI}$$

FOR INFORMATION ONLY

$$\sigma_F = 3330.72 < (0.6)(30{,}000) = 18000 \text{ PSI}$$
< 13500 NOTCHED FATIQUE STRENGTH

$$\tau_F = 1893.42 < (0.4)(30{,}000) = 12{,}000 \text{ PSI}$$
< 13500 NOTCHED FATIQUE STRENGTH

- STRESSES ON THE FOLLOWING COMPONENTS ARE GOVERENED BY THE OPERATING LOADS AND NOT THE DESIGN BASIS EARTHQUAKE CONDITIONS.

EXAMPLES: SCOTCH YOKE, CONNECTING PINS, SHAFT, PISTON.

SCOTCH YOKE:

OPERATING SPRING LOADS APPROX. $1270^{\#} + 190^{\#} = 1460^{\#}$
SEISMIC LOADS APPROX. $(46.0^{\#})(8.2) = 377.20^{\#}$

ALLOWABLE STRESSES

$$\frac{1460^{\#}}{1.0} \geq \frac{1460^{\#} + 377.2^{\#}}{1.5}$$

$$1460 \geq 1224.8$$

$\therefore$ NO DETAILED ANALYSIS REQUIRED

CALC NO:
~~DCR No~~: M84-14

Sheet 24A of 24A

FOR INFORMATION ONLY

DESIGN/REVIEW COMMENTS SHEET

[✓ DESIGN VERIFICATION] ALTERNATE CALCULATIONS

NO.	COMMENT	RESOLUTION/APPROVAL
	NO COMMENTS 4-24/84 Verifying Engineer Date	Donald W. Church 4/20/84 Design Engineer Date 4-24/84 Verifying Engineer Date 4/30/84 Technical Group Leader Date 4/30/84 Supervising Engr. Nuclear Projects Date

Form No. NG-009Z* Rev. 0

FOR INFORMATION ONLY

IOWA ELECTRIC LIGHT AND POWER COMPANY
DUANE ARNOLD ENERGY CENTER

CALCULATION COVERSHEET

ANALYSIS/CALCULATION NO: M84-15

ANALYSIS/CALCULATION TITLE: SEISMIC STRESS ANALYSIS
HILLS-McCANNA DAMPER ACTUATORS R-4200FS

REFERENCE DOCUMENTS

MAR NO: ________

DCR NO: ________

OTHERS: DDC 769
Calc M84-12

PREPARED BY: Donald W. Church DATE: 4-23-84

REVIEWED BY: DATE: 4-24/84

APPROVED BY: DATE: 4/30/84

FINAL APPROVAL BY: DATE: 4/130/84

FORM NG-007Z REV. 0

Background

The purpose for compiling calculations M84-11, 12, 13, 14, 15 was to perform a seismic analysis on the critical components of the Hills-McCanna Pneumatic Damper Actuators. These actuators are part of the secondary containment isolation system at the Duane Arnold Energy Center

On January 26, 1984, Iowa Electric notified the NRC by telephone that the above mentioned actuators were potentially deficient in meeting their purchase specification. A review of the documents relating to this discrepancy revealed that the isolation damper assemblies were purchased originally as complete assemblies which included the damper actuators. Subsequent orders for "like-for-like" replacement actuators were placed directly with the actuator manufacturer who was a subvendor to the damper manufacturer. This most recent purchase order for actuators revealed that a quality assurance program, as required for safety related equipment per 10CFR Part 50, is not currently in effect at the actuators manufacturer's facility.

Further review of the damper assembly documentation revealed that the seismic analysis performed on the damper assemblies did not seismically analyze the actuators themselves, but only considered their weight as it seismically affected the damper frame. This information prompted Iowa Electric to audit the damper manufacturer and check for documentation that pertained to the seismic qualifications of the isolation damper actuators. Results from the audit of the damper manufacturer revealed that the actuators were never purchased by the damper manufacturer as seismically qualified components nor did the damper manufacturer administer a Quality Assurance program concerning the purchase of the actuators.

Since no traceability or Certificate of Conformance was available for the seismic qualifications of the actuators, a seismic analysis was performed on the critical components of the actuators in order to seismically qualify the damper actuators for use in the Duane Arnold Energy Center. This seismic analysis followed the guidelines set forth in the original purchase specification for the isolation dampers (ref. Bechtel 7884-M-100). By seismically qualifying the isolation damper actuators, Iowa Electric will be able to buy Quality Level I actuators in accordance with Revision 1, Chapter 4 of the Quality Assurance Manual under Standard Industrial Quality Items 4.7.3.

Solution

A seismic analysis was performed on five models of the Rockwell Hills-McCanna Ramcon Pneumatic Actuator product line that are installed as isolation damper actuators at the Duane Arnold Energy Center. These five models include the following:

- R-260 FS
- R-450 FS
- R-960 FS
- R-2000 FS
- R-4200 FS

II

The seismic analysis on the actuators followed the general project seismic requirements for frequency-not-determined class 1 equipment in the reactor building and in the control building (ref. Bechtel 7884-M-100, Technical Specifications for Isolation Dampers for the Duane Arnold Energy Center Unit 1, Revision 0, 12-28-70).

A visual inspection of all isolation damper actuators at the Duane Arnold Energy Center was made in order to verify model number, serial number and elevation location in the plant. After verifying the elevation location in the plant, static coefficients (g units) were determined for the highest installed actuator for each of the five actuator models. The horizontal static coefficient was then applied to all three of the orientation axis which eliminated many repetitious calculations and the need for detailed actuator orientation information. Applying the horizontal static coefficient to each axis provided conservative results since the horizontal coefficient is always greater than one plus the vertical coefficient ($F_{vertical} = (Weight)\ (1 + g_v)$, $F_{horizontal} = (Weight)\ (g_h)$, $g_h > 1 + g_v$).

The seismic analysis concentrated on the critical areas of the damper actuator where the seismically induced loads could possibly make the actuator fail, malfunction, or prevent operation. Five areas on each actuator model were identified as critical areas requiring a seismic analysis of the various components interfacing with that critical area. These five critical areas are identified as the following:

- Retaining key which holds the spring cylinder assembly to the main body cylinder
- Main body cylinder
- Press fit between main body cylinder and the mounting yoke
- Mounting hardware
- Mounting yoke

Dimensions and material specifications for the seismic analysis were obtained through the use of proprietary component drawings that were on loan to Iowa Electric from Rockwell Hills-McCanna of Carpentersville, Illinois. All prints applicable to this seismic analysis are listed in the reference section of the referenced calculations.

Four basic assumptions are applied throughout the entire seismic analysis of the damper actuators. These assumptions allow Iowa Electric to use the floor response spectra as the design/qualification spectra for the seismic analysis. The four basic assumptions are as follows:

- The mounting of the damper is a rigid structure ($f > 33$ cps)
- The damper itself is a rigid structure ($f > 33$ cps)
- The support bracket for the actuator is a rigid structure ($f > 33$ cps)
- The seismic requirements for evaluating the actuators are the same as those for the isolation dampers.

III

The maximum seismic stresses were calculated by using the square root sum of the squares method for combining the three earthquake direction stresses as recommended in the UFSAR for seismic analysis at the Duane Arnold Energy Center. A second method, the distortion energy method was used for combining stresses at the press fit between the main body cylinder and the mounting yoke. The distortion energy method was used in place of the square root sum of the squares method because the stresses due to the press-fit condition exceeded and dominated those caused by the seismic event. All maximum stresses were then compared to some fraction of the yield strength depending on the material type and stress type. Operability after a DBE event was ensured by requiring that the maximum stress from combined seismic and normal loads should not exceed 90% of the yield stress of the material.

Conclusion

After completing the above described seismic analysis on the five models of Hills-McCanna actuators installed on the isolation dampers at the Duane Arnold Energy Center, it was found that the maximum stresses from the combined seismic and normal loads do not exceed the material yield requirements defined in the isolation damper purchase specification. The results of this seismic analysis reveal that the five models of Hills-McCanna actuators are seismically qualified for use at the Duane Arnold Energy Center.

References

Bechtel Purchase Specification 7884-M-100

Formulas for Stress and Strain; Raymond J. Roark, Warren C. Young, Fifth Edition, McGraw-Hill Book Co. 1975

Hills-McCanna Information Bulletins; R-1090, R-1090A, R110C, R1100A, R-111C, R-1110A, R-112D, R-1120A, R-113D, R-1130A

Marks' Standard Handbook for Mechanical Engineers' Baumeister Eighth Edition, McGraw-Hill Book Company 1978

Materials Selector 75; Reinhold Publishing Co. Mid September 1974, Vol. 80, No. 4, Brown Printing Co.

Mechanical Engineering Design; Joseph E. Shigley, Third Edition, McGraw-Hill Book Co. 1977

Mechanics of Materials; Higdon, Ohlsen, Stiles, Weese, Riley Third Edition, John Wiley and Sons 1978

IV

FOR INFORMATION ONLY

Rockwell Hills-McCanna; Proprietary Drawings

DATA: Information contained on drawings is proprietary and confidential and is not to be given or loaned to others. Drawings are to be returned to Rockwell upon completion of their intended use in making the seismic analysis.

R260	R450-R960	R2000-R4200
430-1004	450-7511	460-7511
430-7510	450-1005	460-1001
430-7511	450-7512	460-7509
430-3003	450-3005	460-3001
430-3005	450-3007	460-3003
430-4101	450-4101	460-4101
430-4102	450-4102	460-4102
430-2101	450-2101	460-2101
430-2904	450-2906	460-2904
430-2502	450-2507	460-2503
430-2501	450-2501	460-2502
430-3321	450-3201	460-3208
430-3322	450-3202	460-3209
430-3325	450-3203	460-3210
430-3201	450-3326	460-3317
430-3202	450-3325	460-3316
430-3203	450-3321	460-3320
	450-3320	460-3321
		460-3314
		460-3315

U.S.S. Steel Design Manual; R.L. Brockenbrough and B.G. Johnson, Jan. 1981

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V

MARTIN REIFSCHNEIDER Reviewer for Calculations M84-11,12,13,14,15

POSITION Senior Civil/Structural Engineer

EDUCATION
BS, Civil Engineering, University of Michigan
MS, Civil/Structural Engineering, University of Michigan

PROFESSIONAL DATA Registered Professional Engineer in Michigan

SUMMARY
1 year: Senior Engineer; Civil/Structural Staff
4 years: Senior Engineer; Midland, Palisades, and Big Rock Point Nuclear Power Plants
1 year: Resident Engineer, Midland Nuclear Power Plant

EXPERIENCE

Mr. Reifschneider is currently assigned as a civil/structural engineer on the civil/structural staff. His duties include; preparation of design standards; review of project calculations, drawings, specifications and seismic qualification of equipment; providing consultation to civil/structural engineers engaged in the design of nuclear and fossil power plants; solving special static and dynamic structural problems.

Prior to joining the civil/structural staff, Mr. Reifschneider was a civil/structural engineer on Consumers Power Company's Palisades project. His duties included finite element analysis of the biological shield wall, seismic analysis and design of blockwall supports, and seismic analysis and design of the auxiliary building addition including the review of seismic equipment qualifications.

Prior to joining the Palisades project, Mr. Reifschneider was a civil/structural resident engineer at the jobsite of Consumers Power company's Midland nuclear plant project. His duties included interfacing with construction personnel on the design, erection, and construction of seismic instrument and equipment supports.

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VI

MARTIN REIFSCHNEIDER   Reviewer for Calculations M84-11,12,13,14,15

Prior to his jobsite assignment, Mr. Reifschneider conducted research on the inelastic design and behavior of braced structural steel systems, moment frame structural steel system, and reinforced concrete shear wall systems. He co-authored three Bechtel reports on the findings of this research.

Prior to his research assignment, Mr. Reifschneider was a civil/structural engineer on the Midland nuclear plant project. His duties included designing seismic supports for HVAC ducts and electrical cabletrays.

FOR INFORMATION ONLY

IOWA ELECTRIC LIGHT AND POWER COMPANY CEDAR RAPIDS, IOWA	DEPT. DESIGN ENGINEERING
	PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. VII of VIII
	SUBJECT SEISMIC ANALYSIS HILLS-McCANNA ACTUATORS
	Computed by Date Checked by Date

SUMMARY OF RESULTS R-4200 FS

COMPONENT	MANUFACTURED MATERIAL ALLOWABLE STRESS	LOW GRADE MATERIAL ALLOWABLE STRESS	*CALCULATED STRESS (σ_F, τ_F) STRESS COMPARISON
RETAINING KEY	303 STAINLESS STEEL $S_{Y_A} = (0.5)(S_y)$ $S_{Y_A} = 17500$ psi	NOT APPLICABLE NOT APPLICABLE	$\tau_F = 2379$ psi $2379 < 17500$
MAIN BODY CYLINDER	1020 STEEL $S_{Y_A} = (0.9)(S_y)$ $S_{Y_A} = 43200$ psi	1006 STEEL $S_{Y_A} = (0.9)(S_y)$ $S_{Y_A} = 36900$	
OUTSIDE SURFACE			$\sigma_F = 8811$ psi $8811 < 36900$
INSIDE SURFACE			$\sigma_F = 9492$ psi $9492 < 36900$
MOUNTING HARDWARE 5/8-11 BOLT		A307 GRADE 1 BOLT $\sigma_A = 20000$ psi $\tau_A = 10000$ psi	$\sigma_F = 7918$ psi $\tau_F = 1943$ psi

NOTE: LOWEST GRADE BOLT ASSUMED INSTALLED.

BASIS FOR COMPARISON: $\frac{\tau_F}{\tau_A} + \frac{\sigma_F}{\tau_F} \leq 1.5$ FOR OBE CONDITIONS

$0.590 \leq 1.5$

* CALCULATED STRESS USING SRSS OF THE EARTHQUAKE DIRECTONS OR MAXIMUM DISTORTION ENERGY THEORY.

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IOWA ELECTRIC LIGHT AND POWER COMPANY
CEDAR RAPIDS, IOWA

DEPT. DESIGN ENGINEERING
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. VIII of VIII
SUBJECT SEISMIC ANALYSIS HILLS-McCANNA ACTUATORS
Computed by TW Date Checked by Date

SUMMARY OF RESULTS CONTINUED R-4200 FS

COMPONENT	MANUFACTURED MATERIAL ALLOWABLE STRESS	LOW GRADE MATERIAL ALLOWABLE STRESS	*CALCULATED STRESS (σ_F, τ_F) STRESS COMPARISON
BODY CASTING (MOUNTING YOKE)	CLASS 35 CAST IRON $S_{y_A} = (0.6)(S_y)$ $S_{y_A} = 15000$ psi $S_{\tau_A} = (0.4)(S_y)$ $S_{\tau_A} = 12000$ psi	CLASS 20 CAST IRON $S_{y_A} = (0.6)(S_y)$ $S_{y_A} = 12000$ psi $S_{\tau_A} = (0.4)(S_y)$ $S_{\tau_A} = 8000$ psi	$\sigma_F = 1746$ psi $\tau_F = 158$ psi $1746 < 12000$ $158 < 8000$
PRESS FIT BETWEEN MAIN CYLINDER AND MOUNTING YOKE	CAST IRON - 1020 STEEL MINIMUM INTERFERENCE = 0.001" FORCE REQUIRED TO SLIDE MAIN CYLINDER FROM MOUNTING YOKE = 2970#		RESULTANT AXIAL FORCE = 2102# $2102 < 2970$

~~IOWA ELECTRIC LIGHT~~ AND POWER COMPANY CEDAR RAPIDS, IOWA R-4200 FS	DEPT. DESIGN ENGINEERING CALC- M84-15 PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 1 of 16 SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS Computed by DJ Date Checked by MR Date

FOR INFORMATION ONL

WEIGHT DETERMINATION

CYLINDER - SPRING CYLINDER

WEIGHT = 43.60# REFERENCE: R-2000FS Pg 3

MAIN BODY CYLINDER

$D_o = 9.2310"$

$D_i = 8.560"$

$h = 28.445"$

$\rho = 0.283 \ \#/IN^3$

$$\text{VOLUME} = \frac{\pi(9.2310^2 - 8.560^2)(28.445)}{4}$$

$$\text{VOLUME} = 266.70 \ IN^3$$

$$\text{WEIGHT} = (266.70 \ IN^3)(0.283 \ \#/IN^3) = 75.48\#$$

SPRING CYLINDER END CAP

WEIGHT = 7.15# REFERENCE: R-2000FS Pg 3

END CAP (MAIN CYLINDER)

WEIGHT = 18.68# REFERENCE: R2000 FS Pg 1

SPRINGS

WEIGHT = 60.07# REFERENCE R2000 FS Pg 1

PISTON

WEIGHT = 46.0# REFERENCE R2000FS Pg

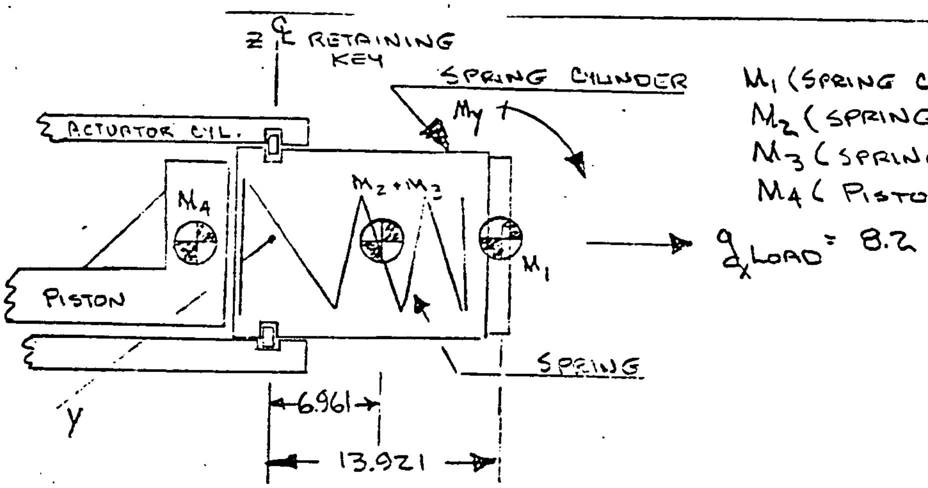
DEPT. DESIGN ENGINEERING CALC M84-15
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 2 of 16
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by DW Date ____ Checked by MR Date ____

1V-AO-52 A & B REACTOR BUILDING ELEVATION 786'0"
BOLTED SUPPORT SYSTEM

HORIZONTAL (g) LOADS	OBE	DBE
	2.7	5.4

- MAXIMUM HORIZONTAL (g_c) LOAD FOR WORST CASE ACTUATOR ELEVATION APPLIED TO ALL AXIS OF SEISMIC ANALYSIS. 5.4 g LOAD IS GREATER THAN (1+g) LOAD ON VERTICAL (g_d) LOAD SPECIFICATION.
- MAXIMUM AIR PRESSURE = 100 PSI ACTING ON PISTON @ 8.565" DIAMETER.

SHEAR STRESSES ON RETAINING KEY AXIAL ORIENTATION



M_1 (SPRING CYL. END CAP) = 7.15#
M_2 (SPRING) = 60.07#
M_3 (SPRING CYL.) = 43.60#
M_4 (PISTON) = 46.0#
156.82#

SPRING TEST LENGTHS (NESTED SPRINGS)
REFERENCE:
460-3001 @ 20.05" = 1263# WITH 181#/IN SPRING RATE
460-3002 @ 20.05" = 368# WITH 64#/IN SPRING RATE

14.55" MAXIMUM SPRING COMPRESSION LENGTH WITH PISTON AT STOP.

$F_{SPRING} = 1263\# + (20.05-14.55)181 + 368 + (20.05-14.55)64$
$F_{SPRING} = 2978.5\#$

$F_{AIR\ PRESSURE} = (100\ PSI)\frac{\pi(8.565)^2}{4} = 5761.6\#$

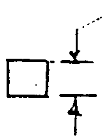
$F_{WEIGHT} = (5.4)(156.82) = 846.83\#$

$F_{X\ TOTAL} = 2978.5\# + 5761.6\# + 846.83\# = 9586.93\#$
(CONSERVATIVE APPROACH)

DEPT. DESIGN ENGINEERING CALC. M44-75
PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 3 of 16
SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by DW Date Checked by Date
SHEAR STRESSES ON THE RETAING KEY AXIAL LOAD

R-4200 FS

RETAINING KEY CROSS SECTION
REFERENCE: 460-2904



303 STAINLESS STEEL

ACTIVE CIRCUMFERENTIAL LENGTH = 26.3"

$$\tau_A = \frac{F}{A} = \frac{9586.93^{\#}}{(26.3)(0.187)} = 1949.32 \text{ PSI}$$

FOR INFORMATION ONLY

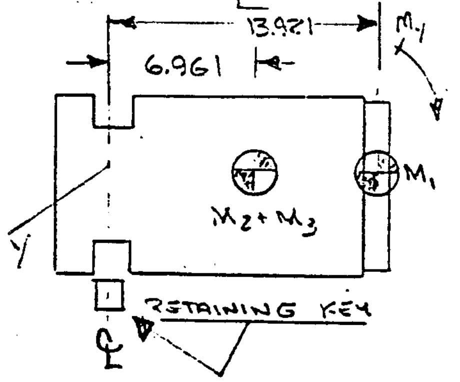
S_y = YIELD STRENGTH S.S. 303 = 35,000 PSI
S_y = SHEAR STRENGTH = $(0.5)(S_y) = (0.5)(35000) = 17500$ PSI
ALLOWABLE SHEAR STRESS = 17500 PSI

$1949.32 < 17500$ PSI

STRESS ON THE RETAINING RING FROM MOMENTS ABOUT THE KEY ℄ DUE TO THE SPRING CYLINDER

$$M_y = g\left[M_1(13.921) + (M_2+M_3)(6.961)\right]$$

$$M_y = 5.4\left[(7.15)(13.921) + (60.07+43.6)(6.961)\right] = 4434.38 \text{ IN-lb}$$



SHEAR STRESS = $\tau(\theta)$ DUE TO M_y

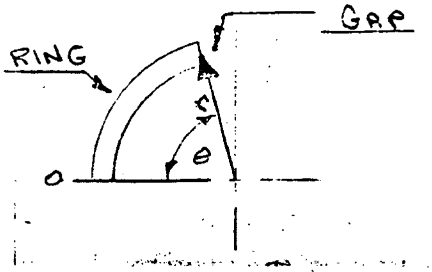
t = THICKNESS OF RETAINING RING = 0.187"
r = 4.2770
M = 4434.38

ACTIVE CIRCUMFERENTIAL RETAINING RING LENGTH = 26.3 INCH
ACTIVE LENGTH PER QUADRANT = 6.575"

$$\text{QUADRANT CIRCUMFERENCE} = \frac{2\pi(4.277)}{4} = 6.7183"$$

$$\theta = \frac{6.575"}{6.7183"} \times \frac{\pi}{2} = 1.5373 \text{ RADIANS}$$

- THETA (θ) IS THE ANGLE THAT CORRESPONDS TO THE RETAINING RING GAP FOR ONE QUADRANT. GAP IS DIVIDED INTO TWO EQUAL PARTS AT +Y AND −Y.



$$\int_0^{\theta} \tau(\theta)\, t r^2 \sin\theta \, d\theta = \frac{M_y}{4}$$

R-4200 FS

FOR INFORMATION ONLY

STRESS ON THE RETAINING RING FROM MOMENTS ABOUT Y (M_y) DUE TO THE SPRING CYLINDER ASSEMBLY

$\tau(\theta) = K r \sin\theta$ K = CONSTANT FROM THE LINEAR RELATIONSHIP BETWEEN SHEAR FORCE AND DISTANCE (Y)

$$\int_0^\theta K t r^3 \sin^2\theta \, d\theta = K t r^3 \int_0^\theta \sin^2\theta \, d\theta = \frac{M_Y}{4}$$

$$\int_0^\theta \sin^2\theta \, d\theta = \left[-\frac{1}{4}\sin 2\theta + \frac{1}{2}\theta \right]_0^{1.54} = -\frac{1}{4}\sin(2)(1.54) + \frac{1.54}{2} = 0.755$$

SOLVE FOR K

$$\frac{M_y}{4} = K(t)(r)^3(0.755) \qquad K = \frac{(4434.38)}{(4)(0.187)(4.277)^3(0.755)}$$

$$K = 100.41$$

$$\tau(\theta) = K r \sin\theta = (100.41)(4.277)\sin(1.54) = 429.26 \text{ PSI}$$

$$\tau_{TOTAL} = \tau(\theta) + \tau_A = 429.26 + 1949.32 = 2378.79 \text{ PSI}$$

S_τ = SHEAR STRENGTH = $0.5(S_y)$
S_y = 35,000 PSI FOR 303 S.S.
$S_\tau = (0.5)(35000) = 17500$ PSI

$$\underline{2378.79 \text{ PSI} < 17500 \text{ PSI}}$$

STRESSES DUE TO THE PRESS FIT CONDITION BETWEEN THE MOUNTING YOKE AND THE CYLINDER BODY

$$\text{INTERFERENCE } (I) = 2\delta_1 + 2\delta_2$$

MOUNTING YOKE = $\frac{9.141}{9.143}$" DIA

MAIN CYLINDER BODY = $\frac{9.144}{9.146}$" DIA

MAXIMUM INTERFERENCE = $|9.146 - 9.141| = 0.005$ IN

STRESS DUE TO THE PRESS FIT CONDITIONS BETWEEN THE MOUNTING YOKE AND THE CYLINDER BODY

- REFERENCE : HIGDON "MECHANICS OF MATERIALS" JOHN WILEY & SONS 1978 pg 163, 164

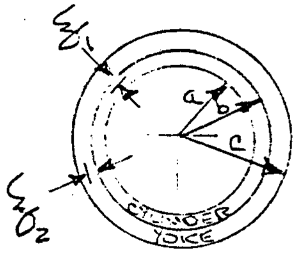
$$\delta_1 = \frac{b_1^2 P_s}{(c^2 - b_1^2)} \left[(1-\nu) b_1^2 + (1+\nu) c^2 \right]$$

$$\delta_2 = \frac{b_2^2 P_s}{(b_2^2 - a^2) E_c b_2} \left[(1-\nu) b_2^2 + (1+\nu) a^2 \right]$$

		PRINT REF.
$a = \frac{8.560''}{2} = 4.280''$	CYLINDER	460-3317
$b_1 = \frac{9.143''}{2} = 4.5715''$	YOKE	460-3311
$b_2 = \frac{9.144''}{2} = 4.572''$	CYLINDER	460-3317
$c = \frac{10.44}{2} = 5.220''$	YOKE	460-3311

$$I = 2\delta_1 + 2\delta_2$$

$$I = 0.005 \text{ in}$$



$$0.005 = \frac{(4.5715)^2 P_s (2)}{(5.22^2 - 4.5715^3)(15 \times 10^6)(4.5715)} \left[(1-0.29)(4.5715)^2 + (1.29)(5.22)^2 \right]$$

$$+ \frac{(4.572)^2 P_s (2)}{(4.572^2 - 4.28^2)(30 \times 10^6)(4.572)} \left[(1-0.30)(4.572)^2 + (1.30)(4.28)^2 \right]$$

$$0.005 = 4.7985 (10)^{-6} P_s + 4.5336 (10)^{-6} P_s$$

P_s 535.78 PSI (MAXIMUM INTERFERENCE)

FOR INFORMATION ONLY

STRESSES DUE TO THE PRESS FIT CONDITION BETWEEN THE MOUNTING YOKE AND THE CYLINDER BODY

EXTERNAL PRESSURE

$$\sigma_r = -\frac{b_2^2 P_o}{b_2^2 - a^2}\left[1 - \frac{a^2}{\rho^2}\right]$$

$$\sigma_t = \frac{-b_2^2 P_o}{b_2^2 - a^2}\left[1 + \frac{a^2}{\rho^2}\right]$$

INTERNAL PRESSURE

$$\sigma_r = \frac{b_1^2 P_I}{c^2 - b_1^2}\left[1 - \frac{c^2}{\rho^2}\right]$$

$$\sigma_t = \frac{b_1^2 P_I}{c^2 - b_1^2}\left[1 + \frac{c^2}{\rho^2}\right]$$

STRESS IN MOUNTING YOKE CASTING INTERNAL PRESSURE

INSIDE SURFACE

$$\sigma_r = \frac{(4.5715)^2(535.78)}{5.22^2 - 4.5715^2}\left[1 - \frac{5.220^2}{4.5715^2}\right] = -535.78 \text{ PSI}$$

$$\sigma_t = \frac{(4.5715^2)(535.78)}{5.220^2 - 4.5715^2}\left[1 + \frac{5.220^2}{4.5715^2}\right] = 4062.53 \text{ PSI}$$

- INSIDE SURFACE WORST CASE CONDITION

STRESS IN CYLINDER EXTERNAL PRESSURE

OUTSIDE CYLINDER SURFACE

$$\sigma_r' = \frac{-(4.572)^2(535.78)}{4.572^2 - 4.280^2}\left[1 - \frac{4.280^2}{4.572^2}\right] = -535.78 \text{ PSI}$$

$$\sigma_t' = \frac{-(4.572)^2(535.78)}{4.572^2 - 4.280^2}\left[1 + \frac{4.280^2}{4.572^2}\right] = -8129.94 \text{ PSI}$$

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DEPT. DESIGN ENGINEERING CALC. M84-15
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SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS
Computed by DW Date ______ Checked by ______ Date ______

STRESSES DUE TO THE PRESS FIT CONDITION BETEEN THE MOUNTING YOKE AND THE CYLINDER BODY

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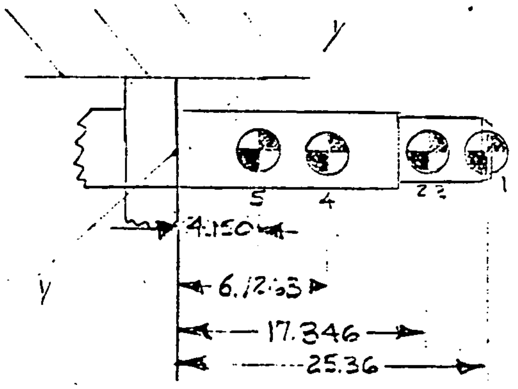
INSIDE CYLINDER SURFACE

$$\sigma_r = \frac{-(4.572)^2(53578)}{4.572^2 - 4.280^2}\left[1 - \frac{4.280^2}{4.280^2}\right] = 0 \text{ PSI}$$

$$\sigma_t = \frac{-(4.572)^2(53578)}{4.572^2 - 4.280^2}\left[1 + \frac{4.280^2}{4.280^2}\right] = -8665.72 \text{ PSI}$$

STRESS ON THE CYLINDER DUE TO MOMENT CAUSED BY MAIN CYLINDER BODY, PISTON, SPRING CYLINDER, AND SPRING CYLINDER END CAP



M_1 (END CAP) = 7.15#
M_2 (SPRING) = 60.07#
M_3 (SPRING CYL) = 43.6#
M_4 (PISTON) = 46.0#
M_5 (MAIN CYL) = 75.48#

- MASS OF CYLINDER IS MODELED TO ACT ON RIGHT SIDE OF YOKE. EXCLUDES COUNTERACTING MOMENT DUE TO MASS OF CYLINDER AND END CAP ON THE LEFT SIDE OF YOKE ℄

SUMMING MOMENTS ABOUT Y-Y

$$M_y = g_c\left[M_1 l_1 + (M_2 + M_3) l_2 + M_4 l_4 + M_5 l_5\right]$$

$$M_y = 5.4\left[(7.15)(25.36) + (60.07 + 43.6)(17.846) + (46.0)(6.1263) + (75.48)(4.15)\right]$$

M_y = 14182.12 IN-lb

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STRESSES ON THE CYLINDER CONTINUED

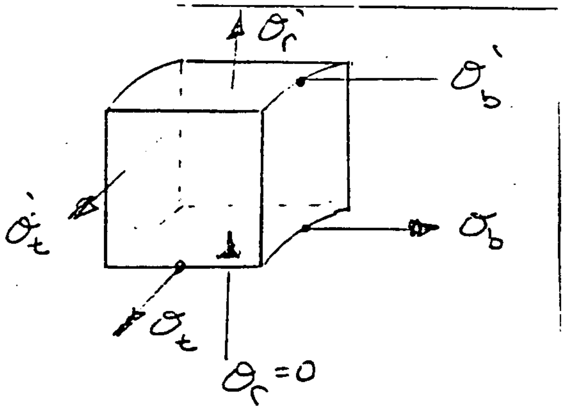
MOMENT OF INERTIA I_{YY} ℄ ACTUATOR NEUTRAL AXIS

$$I_{YY} = \frac{\pi}{64}(d_o^4 - d_i^4) = \frac{\pi}{64}(9.146^4 - 8.565^4) =$$

$$I_{YY} = 79.31 \text{ IN}^4$$

$$\sigma_T' = \frac{M_{YY} C'}{I_{YY}} = \frac{(14182.12 \text{ IN-lb})(4.573)}{79.31} = 817.74 \text{ PSI}$$

$$\sigma_{\text{AIR PRESSURE}} = \frac{5761.6^{\#}}{\pi(9.146^2 - 8.565^2)/4} = 712.91 \text{ PSI}$$



$$\sigma_T = \frac{M_{YY} C}{I_{YY}} = \frac{(14182.12)(4.2825)}{79.31 \text{ IN}^4}$$

$$\sigma_T = 765.79 \text{ PSI}$$

$\sigma_b' = \sigma_{AP} + \sigma_T' = 712.91 + 817.74 = 1530.65$

$\sigma_t' = -8129.94$

$\sigma_r' = -535.78$

$\sigma_b = \sigma_{AP} + \sigma_T = 712.91 + 765.79 = 1478.7$ PSI

$\sigma_t = -8665.77$ PSI

$\sigma_r = 0$

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SUMMATION OF CYLINDER STRESSES USING MAXIMUM DISTORTION ENERGY THEORY

- REFERENCE MECHANICS OF MATERIALS Pg. 489

$$\sigma_F = \left\{ \frac{1}{2}\left[(\sigma_b - \sigma_t)^2 + (\sigma_t - \sigma_r)^2 + (\sigma_r - \sigma_b)^2 \right] \right\}^{1/2}$$

$$\sigma_F' = \left\{ \frac{1}{2}\left[(1530.65 + 8129.94)^2 + (-8129.94 + 535.78)^2 + (-535.78 - 1530.65)^2 \right] \right\}^{1/2}$$

$$\sigma_F' = 8811.03 \text{ PSI}$$

$$\sigma_F = \left\{ \frac{1}{2}\left[(1478.7 + 8665.72)^2 + (-8665.72)^2 + (0 - 1478.7)^2 \right] \right\}^{1/2}$$

$$\sigma_F = 9491.85 \text{ PSI}$$

$S_y = 43,200$ PSI (1020 STEEL YIELD @ 90%)

$\sigma_F' = 8811.03 < 43200$ PSI

$\sigma_F = 9491.85 < 43200$ PSI

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IOWA ELECTRIC LIGHT AND POWER COMPANY CEDAR RAPIDS, IOWA	DEPT. DESIGN ENGINEERING CALC-M84-15 PROJECT DUANE ARNOLD ENERGY CENTER Sheet No. 10 of 16 SUBJECT SEISMIC STRESS ANALYSIS HILLS-McCANNA ACTUATORS Computed by DW Date : Checked by MP Date

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SEISMIC AXIAL LOAD ACTING ON PRESS FIT OF CYLINDER THROUGH MOUNTING YOKE

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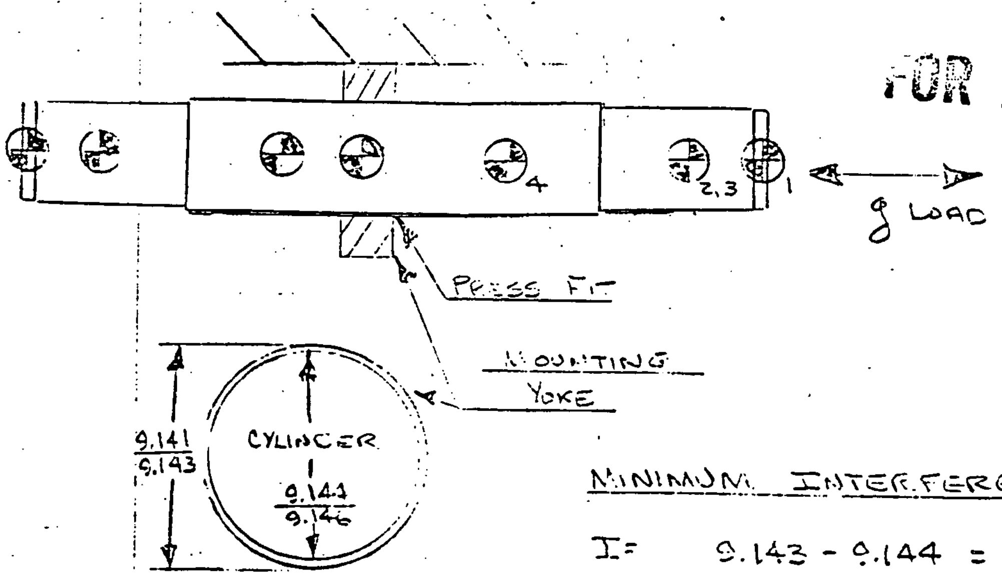

MINIMUM INTERFERENCE

$$I = 9.143 - 9.144 = 0.001''$$

ON DIAMETER

SOLVING FOR INTERFACIAL PRESSURE P_S, Pg 164 MECHANICS OF MATL'S.

$$0.001 \text{ IN} = 2\left[\frac{(4.572)^2(P_S)}{(5.22^2 - 4.572^2)(15\times10^6)(4.572)}\right]\left[(1-0.29)(4.572)^2 + (1.29)(5.22)^2\right]$$

$$+ \; 2\left[\frac{(4.572)^2 P_S}{(4.572^2 - 4.283^2)(30\times10^6)(4.572)}\right]\left[(1-0.29)(4.572)^2 + (1.29)(4.283)^2\right]$$

$$0.001 \text{ IN} = P_S\left[4.803\times10^{-6} + 1.003\times10^{-6}\right]$$

$$P_S = 172.24$$

M_1 (END CAP) = 7.15# (2) = 14.30
M_2 (SPRING CIL) = 60.07# (2) = 120.14
M_3 (SPRING) = 43.60# (2) = 87.20
M_4 (PISTON) = 46.0# (2) = 92.0
M_5 (MAIN CYL) = 75.48 = 75.48
TOTAL MASS M_T = 389.12#

AXIAL FORCE = $M_T(g)$ = (389.12)(5.4) = 2101.25#

FORCE REQUIRED TO SLIDE CYLINDER FROM MOUNTING YOKE

SLIDE FORCE = $F_S = \pi f P d l$

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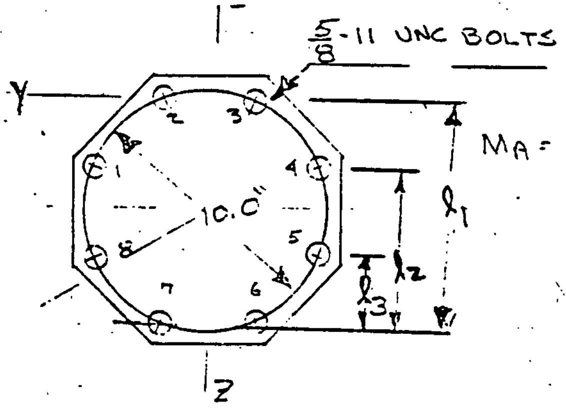
l = LENGTH OF FIT = 6.00"
d = CYLINDER DIA = 9.146"
P_S = UNIT PRESSURE FIT = 172.24 PSI
f = COEFFICENT OF FRICTION = 0.10 (AVERAGE VALUES 0.10 → 0.15)
USE 0.10

$$F = \pi(0.10)(172.24)(9.146)(6.00) = 2969.38^{\#}$$

$$\underline{\underline{2969.38^{\#} > 2101.25^{\#}}}$$

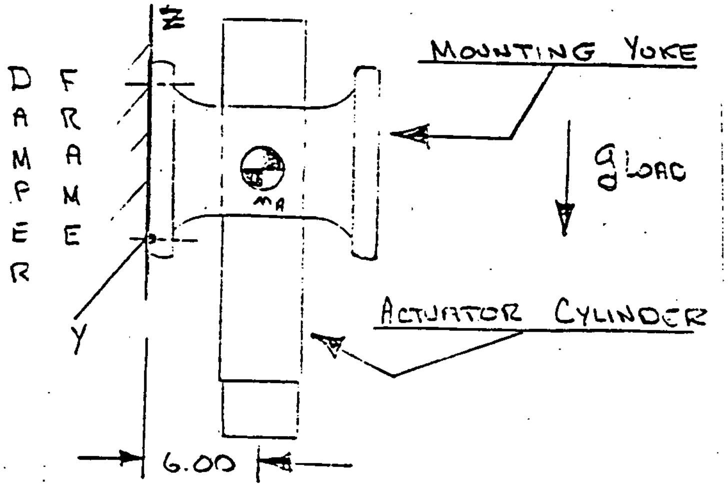
SEISMIC LOADING ON MOUNTING HARDWARE

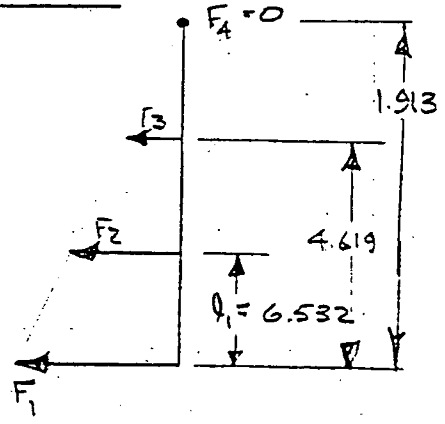


g_z LOADING

M_A = MASS OF ACTUATOR INCLUDING MOUNTING YOKE = 315#

g_z LOADING





$$F_1(L_1) + F_2(L_2) + F_3(L_3) = M_y$$

$$\frac{F_1}{L_1} = \frac{F_2}{L_2} = \frac{F_3}{L_3} \quad F_2 = F_1\frac{L_2}{L_1}$$

$$F_3 = F_1\frac{L_3}{L_1}$$

$$F_1 L_1 + F_1\frac{L_2^2}{L_1} + F_1\frac{L_3^2}{L_1} = M_y$$

$$M_y = (5.4)(460^{\#})(6.0) = 14904.00 \text{ IN-lb}$$

SEISMIC LOADING ON MOUNTING HARDWARE

g_z LOADING CONTINUED

$$F_1\left[6.532 + \frac{4.619^2}{6.532} + \frac{1.913^2}{6.532}\right] = 14904.0 \text{ IN-lb}$$

$$F_1(10.359) = 14904.0 \text{ IN-lb}$$

$$F_1 \quad 1438.82^{\#} \quad \text{BOLT 6}$$

$$F_2 = \frac{F_1 L_2}{L_1} = \frac{(1438.82)(4.619)}{6.532} = 1017.44^{\#} \quad \text{BOLT 5}$$

F_S = FORCE SHEAR IN MOUNTING BOLTS

$$F_S = \frac{(460)(5.4)}{8 \text{ BOLTS}} = 310.5^{\#} \text{ PER BOLT}$$

TENSILE STRESS AREA $\frac{5}{8}$-11UNC = 0.226 IN^2

$$\tau_{xy_1} = \frac{310.5^{\#}}{0.226 \text{ IN}^2} = 1373.90 \text{ PSI}$$

$$\sigma_x = \frac{1438.82^{\#}}{0.226 \text{ IN}^2} = 6366.5 \text{ PSI}$$

g_y LOADING

TENSION ON BOLT 5 FROM g_y LOADING $F_{T_5} = 1438.82^{\#}$,
THE SAME LOAD AS WITH A g_z LOAD ON BOLT 6

TENSION ON BOLT 6 FROM g_y LOADING $F_{T_6} = 1017.44^{\#}$
THE SAME LOAD AS WITH A g_z LOAD ON BOLT 5

$$\sigma_x = \frac{1017.44^{\#}}{0.226 \text{ IN}^2} = 4501.95 \text{ PSI}$$

$$\tau_{xy_2} = \frac{(5.4g)(460^{\#})}{(8)(0.226 \text{ IN}^2)} = 1373.89 \text{ PSI}$$

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SEISMIC LOADING ON MOUNTING HARDWARE

g_x LOADING

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$$\text{AXIAL TENSION} = F_x = \frac{(5.4g)(460^{\#})}{8 \text{ BOLTS}} = 310.5^{\#}$$

$$\sigma_x = \frac{310.5^{\#}}{0.226 \text{ in}^2} = 1373.89 \text{ PSI}$$

SQUARE ROOT SUM OF THE SQUARES

$$\sigma_F = \left[6366.5^2 + 4501.95^2 + 1373.89^2 \right]^{1/2}$$

$$\sigma_F = 7917.54 \text{ PSI}$$

$$\tau_F = \left[1373.9^2 + 1373.9^2 + 0^2 \right]^{1/2}$$

$$\tau_F = 1942.98 \text{ PSI}$$

BASIS FOR COMPARISON $\frac{\tau_F}{\tau_A} + \frac{\sigma_F}{\sigma_A} \leq 1.5$ FOR DBE CONDITIONS

BOLTS ASSUMED TO BE A307 GRADE (1) BOLTS

$\sigma_A = 20{,}000$ PSI
$\tau_A = 10{,}000$ PSI

$$\frac{1942.98}{10{,}000} + \frac{7917.54}{20{,}000} = 0.5902$$

$$0.5902 \leq 1.5$$

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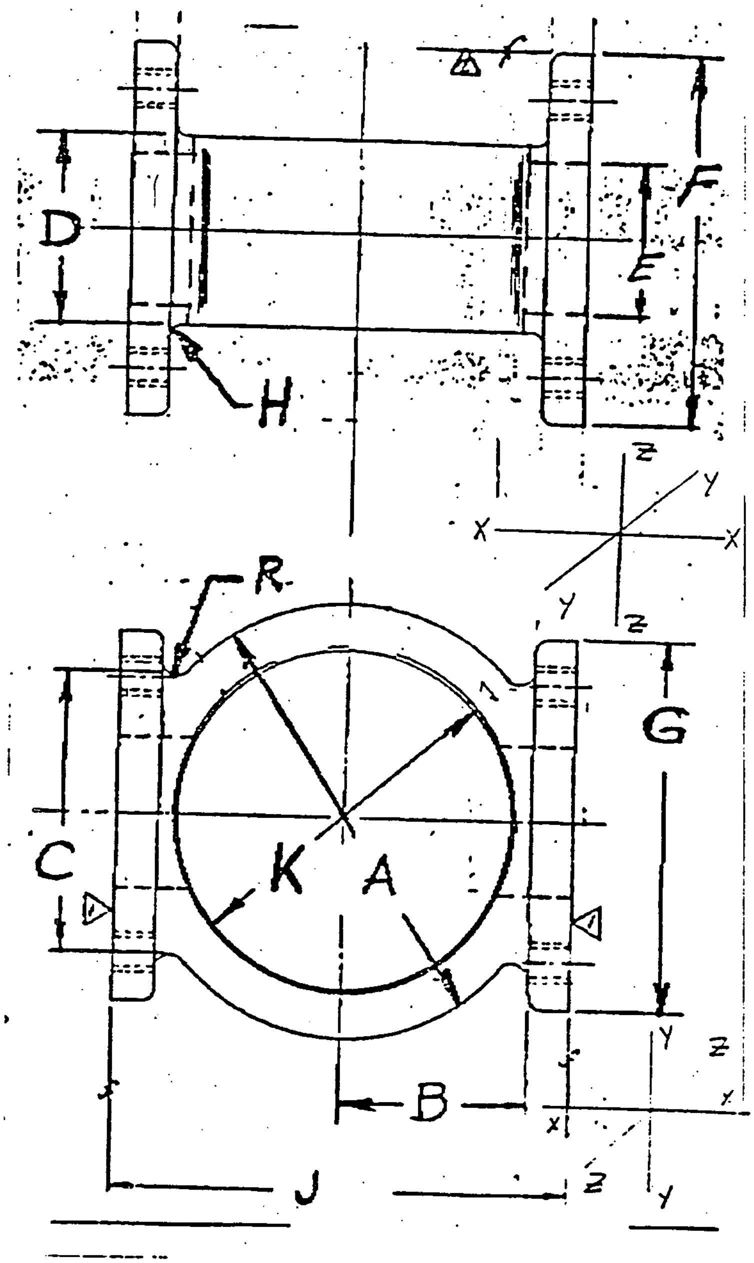
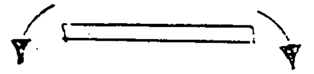
SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE



A = 10.44
B = 5.25
C = 5.00
D = 6.00
E (DIA) = 3.126
F = 8.00
G = 8.00
H = 0.12
J = 12.00
K (DIA) = 9.14
R = 0.50

R-4200 FS HAS THE SAME STRESS CONCENTRATOR VALUES

ELASTIC STRESS IN-PLANE BENDING



REFERENCE: FORMULAS FOR STRESS AND STRAIN CONCENTRATION FACTORS Pg. 593

$$K_T = K_1 + K_2\left(\frac{2h}{d}\right) + K_3\left(\frac{2h}{d}\right)^2 + K_4\left(\frac{2h}{d}\right)^3$$

VERTICAL LOADS g_Z LOADING

$h = \frac{1}{2}(G-D)$ $r = H$ $d = G$

$h = \frac{1}{2}(8.00 - 6.00) = 1.00$
$r = 0.12$
$d = 8.00$

$K_1 = 3.577$
$K_2\left(\frac{2h}{d}\right) = -0.629$
$K_3\left(\frac{2h}{d}\right)^2 = -0.028$
$K_4\left(\frac{2h}{d}\right)^3 = 0.006$
K_Z 2.9260

HORIZONTAL LOADS g_Y LOADING

$h = \frac{1}{2}(8.00 - 5.00) = 1.50$ $r = R$ $h = \frac{1}{2}(G-C)$
$r = 0.50$
$d = 8.00$

$K_1 = 2.635$
$K_2\left(\frac{2h}{d}\right) = -0.783$
$K_3\left(\frac{2h}{d}\right)^2 = -0.022$
$K_4\left(\frac{2h}{d}\right)^3 = 0.032$
$K_Y = 1.862$

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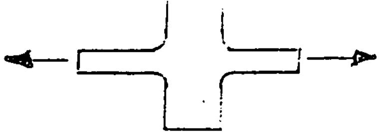
R-4200 FS SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE

ELASTIC STRESS AXIAL TENSION



$h = \frac{1}{2}(G-D) \quad r = H \quad d = G$

$h = \frac{1}{2}(8.00 - 6.00) = 1.00 \quad r = 0.12 \quad d = 8.00$

$h/r = 8.33 \quad 2h/d = (2)(1.0)/8.00 = 0.250$

$K_x = 3.397$ REFERENCE R2000 FS CALCULATION Pg 20

g_Z LOADING

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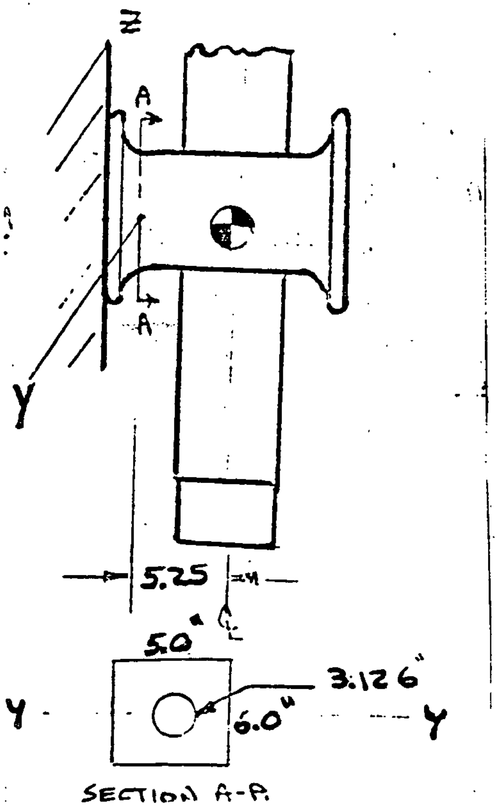

$M_y = (460^{\#})(5.25\,\mathrm{IN})(5.4) = 13041\ \mathrm{IN\text{-}lb}$

$I = \frac{(5)(6)^3}{12} - \frac{\pi}{4}\left(\frac{3.126}{2}\right)^4 = 85.3\ \mathrm{IN}^4$

$\theta_{Z_{BENDING}} = \frac{Mc}{I} = \frac{(13041)(3.0)}{85.3} = 458.6\ \mathrm{PSI}$

$\theta_X = K_Z\,\theta_{Z_{BEND}} = (458.6)(2.926) = 1341.82\ \mathrm{PSI}$

$\tau_{ZY} = \frac{(460^{\#})(5.4)}{(5.0)(6.0) - \frac{\pi(3.126)^2}{4}} = 111.26\ \mathrm{PSI}$

g_Y LOADING

$M_Z = (460^{\#})(5.25\,\mathrm{IN})(5.4) = 13041\ \mathrm{IN\text{-}lb}$

$I = \frac{(6)(5)^3}{12} - \frac{\pi}{4}\left(\frac{3.126}{2}\right)^4 = 57.8\ \mathrm{IN}^4$

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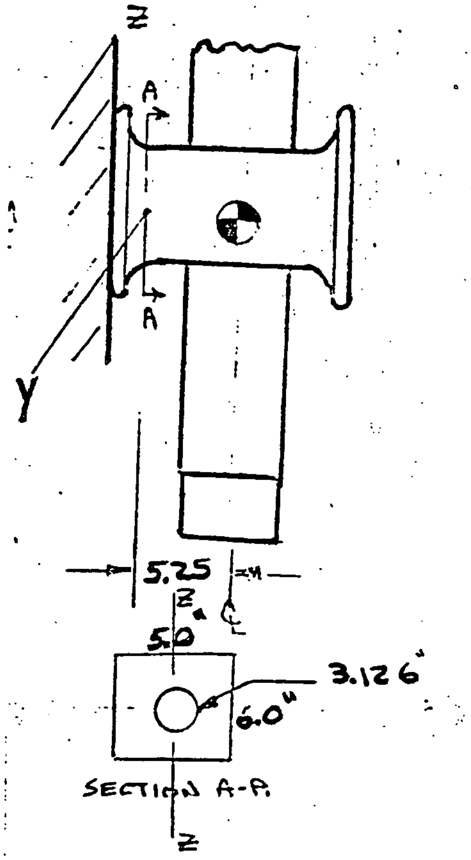
SEISMIC STRESS ANALYSIS ON THE MOUNTING YOKE



g_Y LOADING CONTINUED

$$\sigma_{Y_{BEND}} = \frac{Mc}{I} = \frac{(13041\text{ in-lb})(2.5)}{57.8\text{ IN}^4} = 563.93\text{ PSI}$$

$$\sigma_X = K_Y \sigma_{Y_{BEND}} = (563.93\text{ PSI})(1.862) = 1050.0\text{ PSI}$$

$$\tau_{ZY} = \frac{(460\#)(5.4)}{(5.0)(6.0) - \frac{\pi(3.126)^4}{4}} = 111.26\text{ PSI}$$

g_X LOADING

$$F(\text{TENSION})_X = M g_X = (460\#)(5.4)$$

$$= 2484\#$$

$$\sigma_X = \frac{2484}{(6.0)(5.0) - \frac{\pi(3.126)^2}{4}} = 111.26\text{ PSI}$$

$$\sigma_X K_X = (111.26\text{ PSI})(3.397) = 377.95\text{ PSI}$$

SQUARE ROOT SUM OF THE SQUARES

$$\sigma_F = \left[1341.82^2 + 1050.0^2 + 377.95^2\right]^{1/2} = 1745.23\text{ PSI}$$

$$\tau_F \left[111.26^2 + 111.26^2 + 0^2\right]^{1/2} = 157.35\text{ PSI}$$

$$\sigma_F = 1745.23 < (0.6)(30000) = 18000\text{ PSI}$$
$$< 13500\text{ NOTCHED FATIQUE STRENGTH}$$

$$\tau_F = 157.35 < (0.4)(30000) = 12000\text{ PSI}$$
$$< 13500\text{ NOTCHED FATIQUE STRENGTH}$$

- ANALYSIS OF INTERNAL ACTUATOR NOT REQUIRED REFERENCE R-2000 FS Pg. 23

FOR INFORMATION ONLY

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Sheet 16A of 16A

DESIGN/REVIEW COMMENTS SHEET

[✓ DESIGN VERIFICATION] ALTERNATE CALCULATIONS

NO.	COMMENT	RESOLUTION/APPROVAL
	NO COMMENTS 4-24/84 Verifying Engineer Date	Donald W. Church 4-23-84 Design Engineer Date 4-24/84 Verifying Engineer Date Mike McDermott 4/30/84 Technical Group Leader Date 4/30/84 Supervising Engr. Nuclear Projects Date

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