3.0 PUMP MODEL DESCRIPTION

02-0660-1089
Revision 0

3.0 PUMP MODEL DESCRIPTION

3.1 General

The computer analyses performed in evaluating the Service Water Pumps were carried out on two distinct mathematical models. The first model (Figure 3.1), utilized the EDS Computer Program "SUPERPIPE" and was a "stick" model which represented the pump motor, discharge head, column and lower bowl assembly as a series of pipe (or beam) members (Reference 4). Each component had appropriate cross sectional properties computed in hand calculations (References 6 and 7) which reflected the weight, and section modulus of the corresponding part of the pump. This "stick" was supported at the base plate elevation by an anchor with stiffnesses specified in each of the three translational and three rotational directions. Additionally two lateral supports located at elevation 583'-2 3/4" were modelled with stiffness specified in their axial directions. Table 3.1 is a summary of the materials, cross sectional properties, component lengths and lumped and distributed weights. A more detailed explanation of this model is given in the following sections.

The second model (Figure 3.2) was developed using the computer program "ANSYS" which is maintained by Swanson Analysis Systems, Inc. This model was developed using quadilateral shell elements to represent the base plate support. A portion of the pump column was incorporated into this model to allow for a more accurate transfer of load. Further discussion of this model is given in Section 4.0.

3.2 Motor Unit

The motor which drives the Essential Service Water Pump is a General Electric vertical hollow shaft induction motor (Model 5K6328XC185A) (Reference 8). The overall length of the motor is 66.75". In the mathematical model the motor was represented as a pipe with its outside diameter equal to 24.5" which corresponds to the outside diameter of the upper discharge head flange to which the motor attaches. This pipe member was 65.75" long. The motor mounting plate was also modelled as a pipe section, for the remaining 1". The moment of inertia of the 65.75" pipe section was calculated from the value of static deflection at the motor center of gravity for the case when the motor is bolted to a rigid mass and considered a horizontal cantilever beam. This deflection was given as .0063 inches (Reference 8). Therefore,

$$I = \frac{W \ell^3}{3E\Delta}$$

Where

- I = moment of inertia
- ℓ = distance from fixed base to center of gravity
- E = modulus of elasticity
- W = total weight of motor
- Δ = static deflection

The moment of inertia was calculated to be 151 in^4 . Thus, with the outside diameter set at 24.5", the wall thickness was back-calculated as .026" to obtain the proper moment of inertia.

The entire weight of the motor unit, 3500 lb, was lumped at the location of its center of gravity, 28" up from the base. The motor mounting plate was assumed identical to the upper discharge head flange and was modelled as a pipe cross section with an outside diameter equal to 24.5" and a wall thickness equal to 6.25". Since the entire motor weight was lumped at its center of gravity, the individual pipe components comprising the motor unit had no weight per unit length.

3.3 Discharge Head Assembly

The discharge head assembly shown in Reference 9 is bolted to the motor unit at its upper end and is bolted to both the upper most pump column flange and to the base plate at its lower end. The discharge head measures 37" in length. The top head flange comprises the upper inch. This flange was modelled with the identical cross-sectional properties of the motor mounting plate to which it is bolted. The flange member has no weight per unit length. Instead, one-half the total flange weight of 102 lb was lumped at each end of the member. The next 1.5" of the discharge head assembly (referred to as the "upper" section) was modelled as a pipe with an outside diameter of 24" and a wall thickness of .441". This thickness was back-calculated from the section's moment of inertia value. The moment of inertia of this section was taken as the sum of the inertias for the 24" diameter, .375" thick outer discharge head shell and the four .375"x5" stiffening ribs.

The section modelled next was 9.5" long (referred to as the "window" section), and represented the portion of the discharge head containing the two 70° windows (cut-outs). The effect of the windows is to reduce the moments of inertia such that section properties about the two horizontal axes were no longer equal. Since the pipe member of "SUPERPIPE" requires that moments of inertia about the two horizontal axes be equal, a beam member was used for this 9.5" section. This beam member was modelled with a moment of inertia of 927 in^4 about the axis bisecting the windows, and of 2090 in^4 about the perpendicular axis as calculated in Reference 7. Additionally a cross sectional area of 24.51 in^2 and a torsional moment of inertia of 1.132 in^4 were calculated. It is noted that the value of torsional stiffness is under-predicted by the inertia value used for this section due to the overprediction of the member's ability to warp (made by neglecting the stiffness of the adjacent members). This is not considered a significant factor since the "window" section is above the point of input nozzle loads and will therefore experience no torsional loads. Shear areas for this member were taken as one-half the cross-sectional area.

The "upper" section and the "window" section had a weight per unit length of 225 lb/ft (calculated in Reference 10). The next 23.75" of discharge head (referred to as the "lower section) had an additional weight of 79.1 lb/ft due to the contained fluid. Otherwise this "lower" section had the same member properties as the "upper" section of the discharge head. Proceeding in the downward vertical direction, the bottom head flange was modeled next in the mathematical model as a pipe member, 1.25" in length, with its outside diameter equal to 36" and its wall thickness equal to 10" (in accordance with Reference 11). A lumped weight was placed at each end of the flange in addition to the distributed fluid weight.

The discharge head assembly was the only portion of the pump modelled, in part, in a direction other than vertical (global y axis). At a point 17.25" above the base plate a "rigid member" was modelled in the horizontal direction for 12". This member brought the model to the outside wall of the discharge head shell from the centerline axis. This member was made very stiff (O.D. = 30", I.D. = 10") to most accurately transfer the input nozzle loads to the center line of the vertically oriented members. Modelled after this member was a 4.0625" horizontal pipe section having the properties of standard 16" carbon steel pipe. At the extreme end of the horizontally oriented portion of the discharge head the discharge flange was modelled. This flange was represented as a pipe of 23.50" outside diameter and 3.67" wall thickness in accordance with the dimensional data of Reference 12 for a 16", 150 lb slip on flange. Because the weight of the horizontally oriented members was already accounted for in the mathematical model along the pump's vertical centerline, the weight per unit length of these members was input as zero lb/ft.

3.4 Pump Column

The discharge column of the Essential Service Water Pump consists of a series of 16", standard schedule carbon steel (ASTM SA-53 Grade B) pipe sections connected by

1.38" thick flanges. All column flanges were modelled as pipe members with outside diameters of 21" and wall thicknesses of 3.262". This thickness was back-calculated from a moment of inertia value of 7391 in^4 determined in Reference 7 where the stiffness contributions of the "spider" ribs and the 16", schedule 30 pipe were considered. A lumped weight of 32 lb was placed at the end of each column flange. An additional 20 lb was coded at the center of a flange union to account for the bronze spider assembly.

The upper most column flange is bolted to the bottom discharge head flange. Next in the mathematical model was coded a 2'-2.875" section of 16", standard schedule pipe. One column flange was then modelled followed by six 5'-0" long sections of a flange, followed by 4'-9 1/4" of 16" pipe, followed by another column flange. The very last column flange is bolted to the upper end of the discharge nozzle in the lower bowl assembly to be described in the following section. In addition to the lumped weight at the flange ends a component distributed weight of 75.4 lb/ft and a fluid distributed weight of 79.1 lb/ft was input for all pump column members identified as above the submerged water level. For members below this level an additional 87.1 lb/ft was coded to account for the effects of the external fluid (Section 2.2).

The pump column is restrained against lateral translation by two composite plate-angle members attached to the top of one of the column flanges at elevation 583'-2 3/4". The axial stiffness of the members which represented these supports was taken as 2.0×10^6 lb/in. The orientation of these member is shown in Reference 2.

3.5 Lower Bowl Assembly

The Essential Service Water Pump is a two-stage pump which means that there are two impellers. Each impeller is housed in a cast iron enclosure referred to as an "intermediate bowl".

The discharge nozzle attached to the lower column flange is 1'-0" in length. As was the case for the entire lower bowl assembly, the discharge nozzle was modelled with pipe cross sectional properties of 24" outside diameter and .785" wall thickness. This wall thickness was back-calculated from a moment of inertia value determined in Reference 7. The stiffness contribution of the internal shell section and ribs were taken into consideration when the moment of inertia was computed. A lumped weight of 438 lb was placed at the centroid of the discharge nozzle taken as the center of the bearing indicated in Reference 11. In addition, a fluid weight per unit length of 166.2 lb/ft was coded for the member. This weight accounts for the weight of fluid running through the lower bowl assembly and also for the effects of the external fluid. The upper and lower intermediate bowls were modelled next each for 1'-6 1/4" with lumped weights of 794 lb placed at the centers of their bearings. Coded at the ends of each bowl was an additional lumped weight of 116 lbs which accounted for the impellers. Finally the suction nozzle was modelled for 10" with a lumped weight of

242 lb placed at the center of the suction bearing. Protruding from the bottom of the suction nozzle was a 6" section which was modelled consistent with the entire lower bowl assembly.

FIGURE 3.1
PUMP MATHEMATICAL MODEL

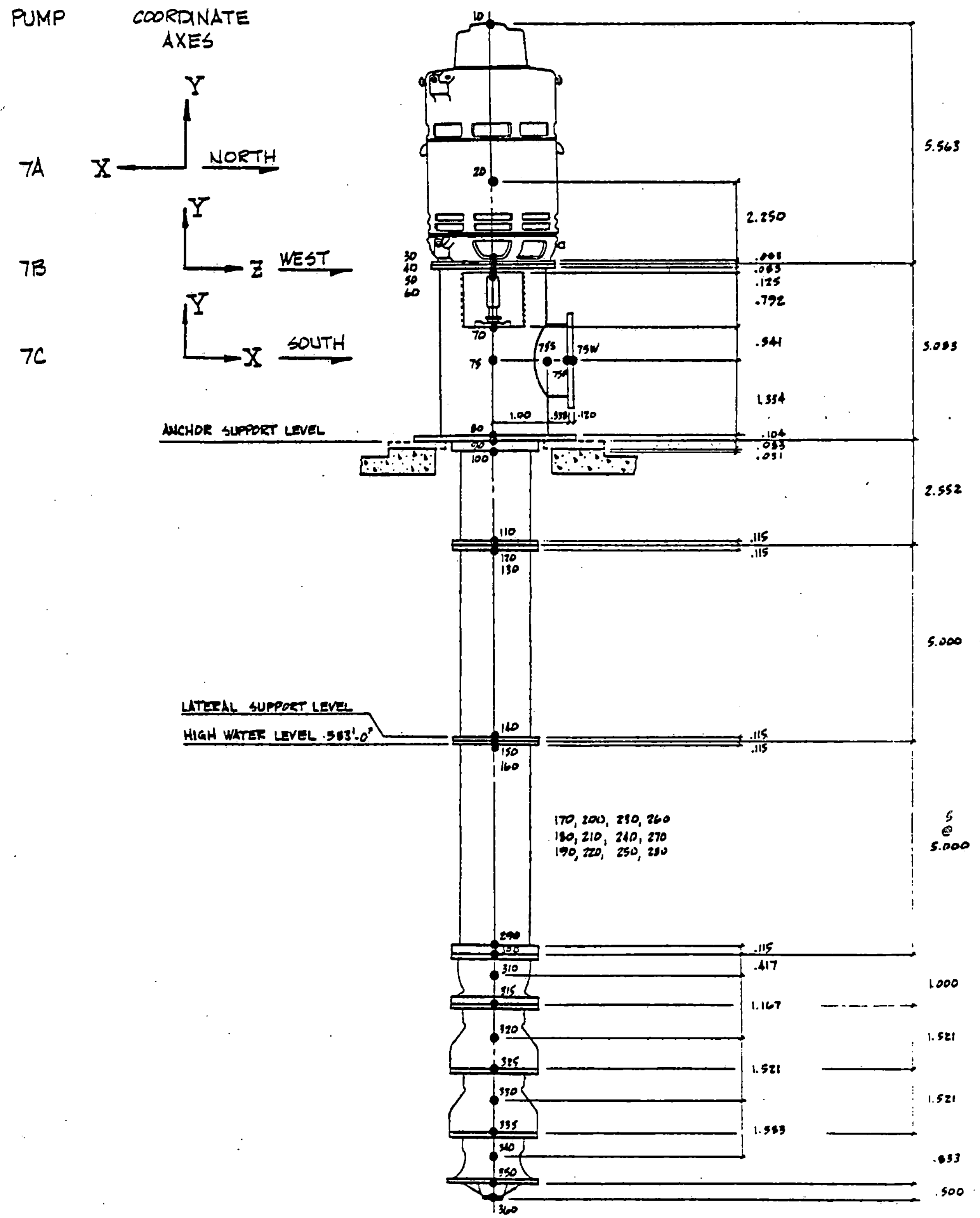


TABLE 3.1

ESW PUMP "STICK" MODEL

TERMS:

- W = lumped weight
- w_c = component weight per unit length
- w_f = fluid weight per unit length
- I = moment of inertia about the X & Y axes
- L = component length
- O.D. = outside diameter
- t = wall thickness
- C.I. = cast iron
- C.S. = carbon steel

NODE NO.	COMPONENT NO.	DESCRIPTION	W (lb)	w_c (lb/ft)	w_f (lb/ft)	I (in4)	L ft.	O.D. (in)	t (in)	MATERIAL/DESIGNATION
10										
	1	Upper Motor	-	0	0	151	3.229	24.5	0.026	C.S./ASTM A36 (assumed)
20			3500							
	1	Lower Motor	-	0	0	151	2.25	24.5	0.026	C.S./ASTM A36 (assumed)
30			0							
	2	Mounting Plate	-	0	0	16668	0.083	24.5	6.25	C.S./ASTM A36 (assumed)
40			51							
	3	Top Head Flange	-	0	0	16668	0.083	24.5	6.25	C.S./ASTM A36

NODE NO.	COMPONENT NO.	COMPONENT DESCRIPTION	W (lb)	w_c (lb/ft)	w_f (lb/ft)	I (in4)	L ft.	O.D. (in)	t (in)	MATERIAL/DESIGNATION
50			51							
	4	Upper Cylinder	-	225	0	2264	0.125	24	0.441	C.S./ASTM A53 Gr. B
60			0							
	5	Window Cylinder	-	225	0	See Note 1	0.792	N/A	N/A	C.S./ASTM A53 Gr. B
70			0							
	6	Lower Cylinder	-	225	79.1	2264	1.979	24	0.441	C.S./ASTM A53 Gr. B
80			151							
	7	Bottom Head Flange	-	0	79.1	79231	0.104	36	10.0	C.S./ASTM A36
90			182							
	8	Column Flange	-	75.4	79.1	7391	0.115	21	3.262	C.S./ASTM A36
100			32							
	9	Column	-	75.4	79.1	562	2.239	16	0.375	C.S./ASTM A53 Gr. B
110			32							
	10	Column Flange	-	75.4	79.1	7391	0.115	21	3.262	C.S./ASTM A36
120			82							
	10	Column Flange	-	75.4	79.1	7391	0.115	21	3.262	C.S./ASTM A36

NODE NO.	COMPONENT NO.	COMPONENT DESCRIPTION	W (lb)	w_c (lb/ft)	w_f (lb/ft)	I (in4)	L ft.	O.D. (in)	t (in)	MATERIAL/DESIGNATION
130			32							
	11	Column	-	75.4	79.1	562	4.77	16	0.375	C.S./ASTM A53 Gr. B
140			32							
	12	Column Flange	-	75.4	79.1	7391	0.115	21	3.262	C.S./ASTM A36
150			82							
	12	Column Flange	-	75.4	79.1	7391	0.115	21	3.262	C.S./ASTM A36
160			32							
	13	Column	-	75.4	166.2	562	4.77	16	0.375	C.S./ASTM A53 Gr. B
170			32							
	14	Column Flange	-	75.4	166.2	7391	0.115	21	3.262	C.S./ASTM A36
180			82							
	14	Column Flange	-	75.4	166.2	7391	0.115	21	3.262	C.S./ASTM A36
190			32							
	15	Column	-	75.4	166.2	562	4.77	16	0.375	C.S./ASTM A53 Gr. B
200			32							
	16	Column Flange	-	75.4	166.2	7391	0.115	21	3.262	C.S./ASTM A36

NODE NO.	COMPONENT NO.	COMPONENT DESCRIPTION	W (lb)	w_c (lb/ft)	w_f (lb/ft)	I (in4)	L ft.	O.D. (in)	t (in)	MATERIAL/DESIGNATION
210			82							
	16	Column Flange	-	75.4	166.2	7391	0.115	21	3.262	C.S./ASTM A36
220			32							
	17	Column	-	75.4	166.2	562	4.77	16	0.375	C.S./ASTM A53 Gr. B
230			32							
	18	Column Flange	-	75.4	166.2	7391	0.115	21	3.262	C.S./ASTM A36
240			82							
	18	Column Flange	-	75.4	166.2	7391	0.115	21	3.262	C.S./ASTM A36
250			32							
	19	Column	-	75.4	166.2	562	4.77	16	0.375	C.S./ASTM A53 Gr. B
260			32							
	20	Column Flange	-	75.4	166.2	7391	0.115	21	3.262	C.S./ASTM A36
270			82							
	20	Column Flange	-	75.4	166.2	7391	0.115	21	3.262	C.S./ASTM A36
280			32							
	21	Column	-	75.4	166.2	562	4.77	16	0.375	C.S./ASTM A53 Gr. B

NODE NO.	COMPONENT NO.	DESCRIPTION	W (lb)	w_c (lb/ft)	w_f (lb/ft)	I (in4)	L ft.	O.D. (in)	t (in)	MATERIAL/DESIGNATION
290			32							
	22	Column Flange	-	75.4	166.2	6892	0.115	21	2.875	C.S./ASTM A36
300			32							
	23	Discharge Bowl	-	0	166.2	3862	0.417	24	0.785	C.I./ASTM A48 Class 30
310			438							
	23	Discharge Bowl	-	0	166.2	3862	0.583	24	0.785	C.I./ASTM A48 Class 30
315			0							
	23	Intermediate Bowl	-	0	166.2	3862	0.584	24	0.785	C.I./ASTM A48 Class 30
320			794							
	23	Intermediate Bowl	-	0	166.2	3862	0.937	24	0.785	C.I./ASTM A48 Class 30
325			116							
	23	Intermediate Bowl	-	0	166.2	3862	0.584	24	0.785	C.I./ASTM A48 Class 30
330			794							
	23	Intermediate Bowl	-	0	166.2	3862	0.937	24	0.785	C.I./ASTM A48 Class 30

NODE NO.	COMPONENT NO.	DESCRIPTION	W (lb)	w_c (lb/ft)	w_f (lb/ft)	I (in4)	L ft.	O.D. (in)	t (in)	MATERIAL/DESIGNATION
335			116							
	23	Suction Bowl	-	0	166.2	3862	0.646	24	0.785	C.I./ASTM A48 Class 30
340			242							
	23	Suction Bowl	-	0	166.2	3862	0.187	24	0.785	C.I./ASTM A48 Class 30
350			0							
	23	Suction Bowl	-	0	166.2	3862	0.5	24	0.785	C.I./ASTM A48 Class 30
360			0							
	75		0							
	24	Rigid** Member	-	0	0	39270	1.0	30.0	10.0	C.S./ASTM A53 Gr. B (arbitrarily assumed)
75S			0							
	25	Straight** Pipe	-	0	0	562	0.338	16.0	0.375	C.S./ASTM A53 Gr. B
75F			0							
	26	Discharge Flange	-	0	0	11623	0.12	23.5	3.67	C.S./ASTM A36
75N			0							

* A rigid straight member assumed with the above cross sectional properties

** A section of elbow that protrudes from the discharge head is assumed to be a straight member with cross sectional properties equal to column pipe.

Additional Cross-Sectional Properties of Discharge Head "Window" Section

NOTE 1. SUPERPIPE computer analysis requires the following additional input for discharge head "window" section

Cross-sectional area = 24.50 in^2

Effective shear area = 12.25 in^2
Torsional moment of inertia, I_x = 1.132 in^4

I_y = 927 in^4

I_z = 2090 in^4

4.0 SOLE PLATE SUPPORT MODEL DESCRIPTION

02-0660-1089
Revision 0

4.0 SOLE PLATE SUPPORT MODEL DESCRIPTION

4.1 General

In conjunction with the seismic qualification of the Essential Service Water Pumps, the stiffnesses of the supporting structures have been investigated. The service water pump supports are located at the 583'-2 3/4" elevation and the 590'-7" elevation. The latter support consists of a base plate pinned at its four corners with a hole centrally located. This support must react out both vertical, lateral, and rotational motions of the pump. Due to its configuration a detailed analysis was required to determine the support stiffness.

Specifically, a finite element analysis was performed to accurately determine the stiffness characteristics for the base plate support configuration described below. The finite element approach used, employed a model representing one-half the total configuration with the appropriate symmetry boundary conditions applied. The following sections describe the geometry and the model, the applied loadings with their corresponding boundary conditions, and the results obtained.

4.2 Geometry and Mathematical Model

The overall support configuration modeled included the base plate, the pump discharge head assembly lower flange, and a portion of the lower pump column, Figure 4.1. The lower flange is included since it serves as the means by which the load from the motor unit and pump column is transmitted to the base plate. The lower pump column is included to facilitate the application of the various loadings onto the base plate while preventing local distortion at the pump column-lower flange juncture.

The base plate measures 40" square by 1" thick with a 26" diameter opening centrally located. The base plate is rigidly attached to the concrete base mat by four (4) anchor bolts typically located 2" from each edge at the four corners. Located on top of the base plate is the lower flange measuring 36" O.D., 26" I.D., and 1 1/4" thick. It is attached to the base plate by eight (8) bolts equally spaced with a bolt ring diameter of 32". The pump column, joined to the lower flange from below, measures 16" O.D. by 0.375" thick. A 2" length of pipe was modeled. The material for all these components is carbon steel.

The mathematical model of the base plate support configuration used in the analysis was developed using ANSYS, a finite element computer program which is maintained by Swanson Analysis Systems, Inc. The four-node quadrilateral shell element, STIF 63, is used in the analysis. Due to symmetry and the proper placement of boundary conditions only one-half of the total configuration is modeled. The model consists of 256 elements and 264 nodes. Figures 4.2 to 4.7 show the locations of the nodes and elements of the model. Detailed modeling of the bolts is not done, although, the effective restraint of the bolts are included in the model.

4.3 Loadings and Boundary Conditions

Four (4) loadings have been considered (bending, compression - tension, torsion, and shear) in the determination of the stiffness characteristics. Due to symmetry, the bending and shear load cases account for two components of stiffness each. The load case, type, direction, and magnitude of loading are listed in Table 4.1.

The nodal forces for each load case are tabulated in Reference 13. Load cases 1A and 2A represent revisions to their initial load cases. After review of the original analysis it became apparent that addtional boundary conditions were in order. The later revision more accurately describes the probable support deflections.

The boundary conditions used in this analysis varied for the different loadings. In all cases the nodes at which the bolts joining the lower flange and base plate were located were coupled for translation. Symmetry planes prohibit displacement perpendicular to the plane. For load cases 1, 1A, 2, 2A, and 4 the XZ plane is a symmetry plane. Asymmetry planes prohibit displacement in the plane. For load case 3 the XZ plane is an asymmetry plane.

Additional boundary conditions were kept to a minimum thereby permitting maximum flexibility. For load case 1/1A it was deemed necessary to account for the presence of the concrete base mat. To the left of node 122, inclusive of the base plate the direction of loading is such that the base plate would be placed in compression. Therefore the vertical translation of the base plate was held fixed.

The results from load cases 1 and 2 indicate that the lower flange and the base plate intersect. Since this is not physically possible, an additional constraint was imposed at the 26" diameter coupling the translations of the corresponding nodes of the lower flange and base plate.

For load case 2 the direction of load was also changed since preliminary analysis indicated that the base plate support would never realize a net positive upward (tension) load. The nodes at the 26" diameter of the base plate were also held fixed in the vertical direction following the same reasoning as described above concerning the bending load case.

The boundary conditons for all load cases are included in Reference 13.

4.4 Stiffness Results

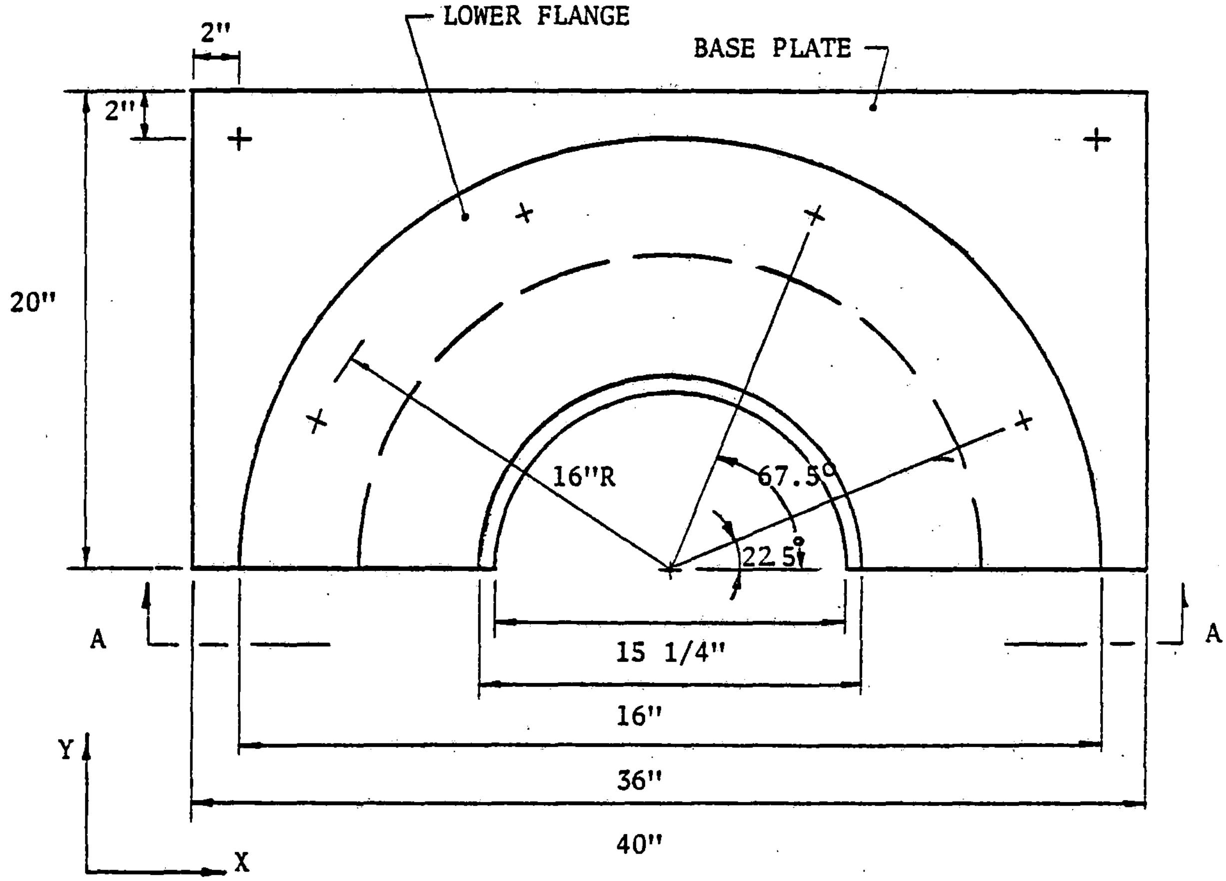
The stiffness of the base plate support configuraton was determined (Reference 14) as the ratio of the applied loading to the respective maximum deflection of the lower flange inner diameter, neglecting any deflection of the pump column. In the case of rotational stiffness, the lateral deflection was resolved into a rotation about the pump column centerline. The computed stiffnesses are listed in Table 4.2.

Table 4.1

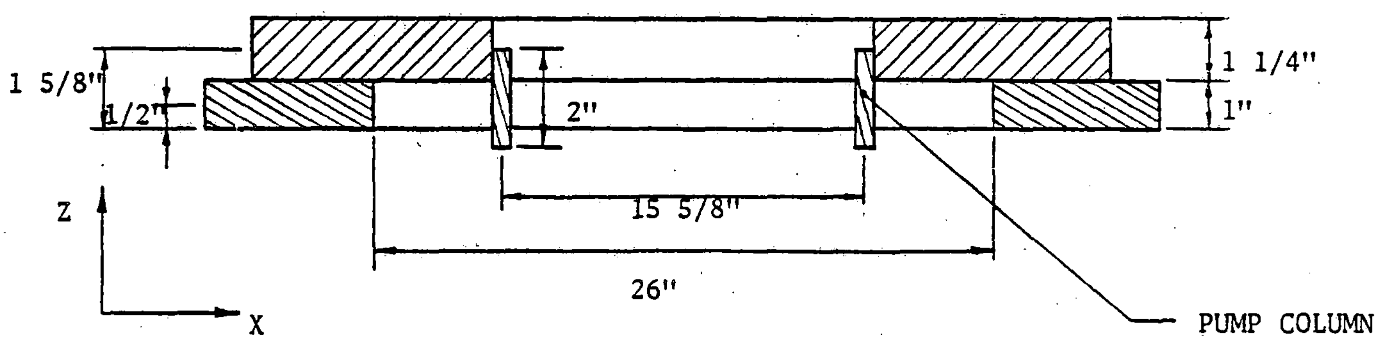
Load Case	Type	Direction	Magnitude
1	Bending	Negative Y	245437 in-lb
1A	Bending	Negative Y	245437 in-lb
2	Tension	Positive Z	24,000 lb
2A	Compression	Negative Z	24,000 lb
3	Torsion	Negative Z	187,500 in-lb
4	Shear	Positive X	24,000 lb

Table 4.2

Translational Stiffness (lb/in)	Rotational Stiffness (in-lb/rad)
$K_x = 2.94 \times 10^7$	$K_{\theta x} = 3.54 \times 10^7$
$K_y = 2.94 \times 10^7$	$K_{\theta y} = 3.54 \times 10^7$
$K_z = 2.08 \times 10^6$	$K_{\theta z} = 1.96 \times 10^9$



PLAN VIEW



Section "A-A"

FIGURE 4.1

PUMP DISCHARGE HEAD ASSEMBLY LOWER FLANGE - ELEMENTS

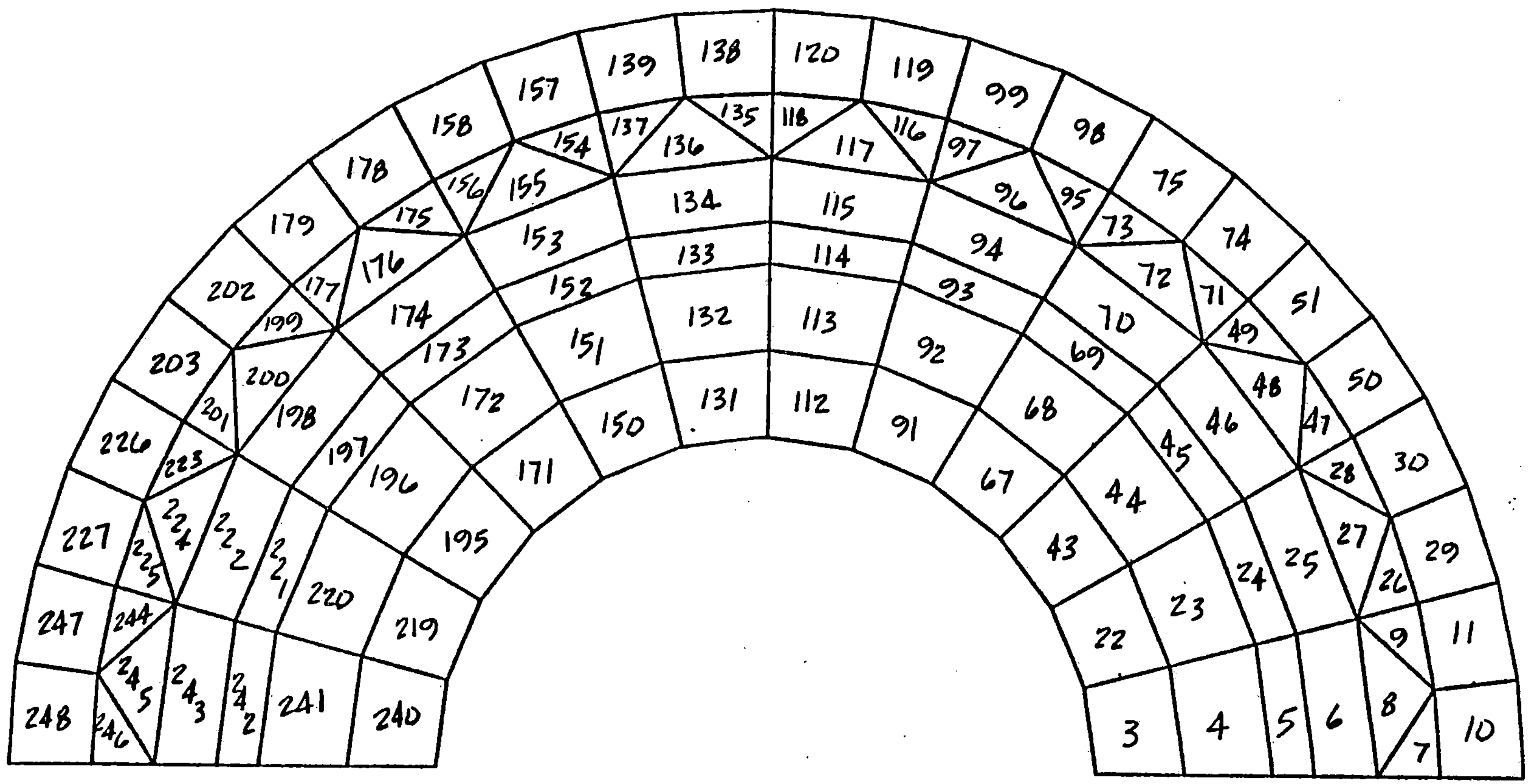


FIGURE 4.2

PUMP DISCHARGE HEAD ASSEMBLY LOWER FLANGE - NODES

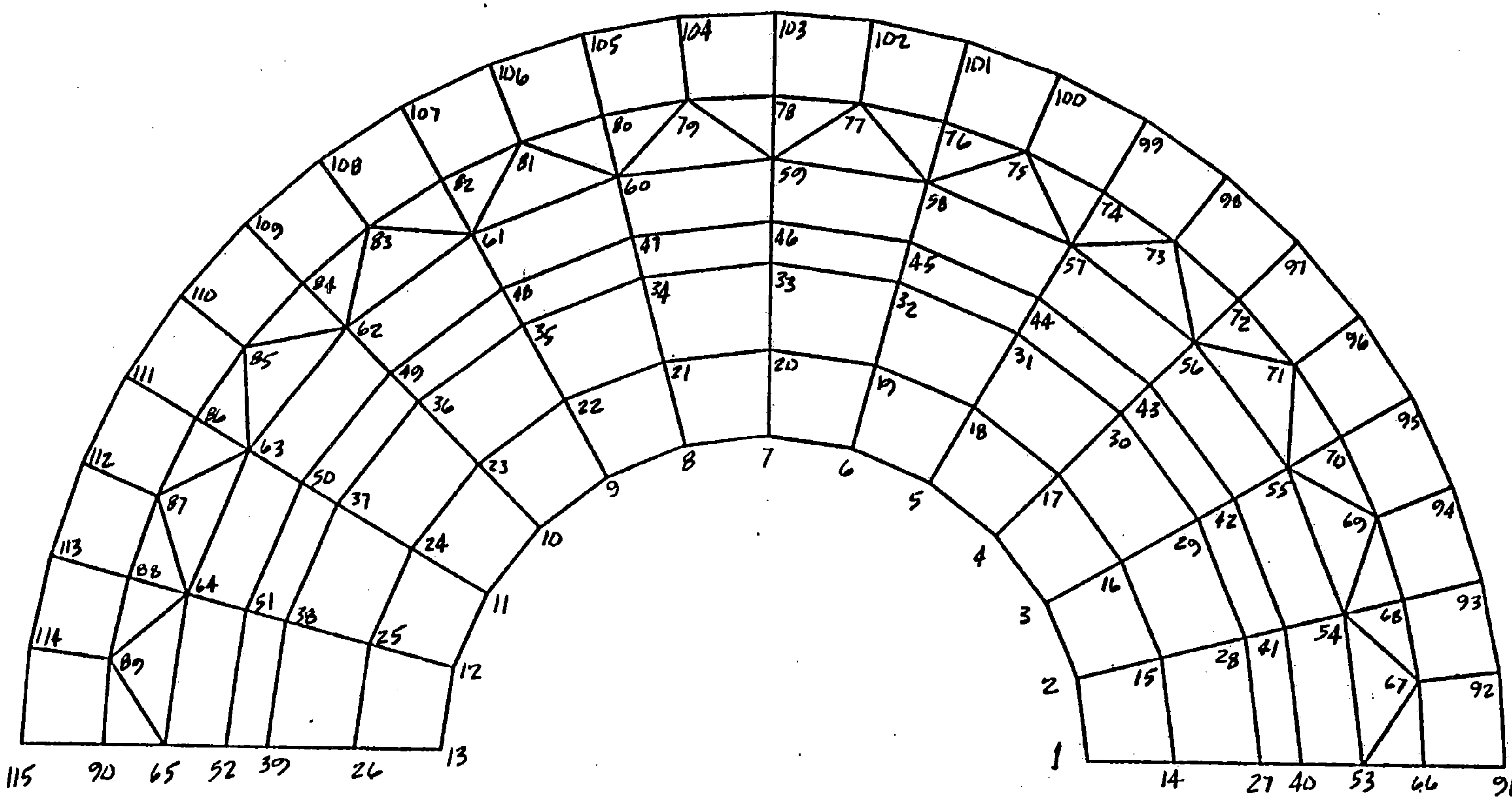


FIGURE 4.3

BASE PLATE - ELEMENTS

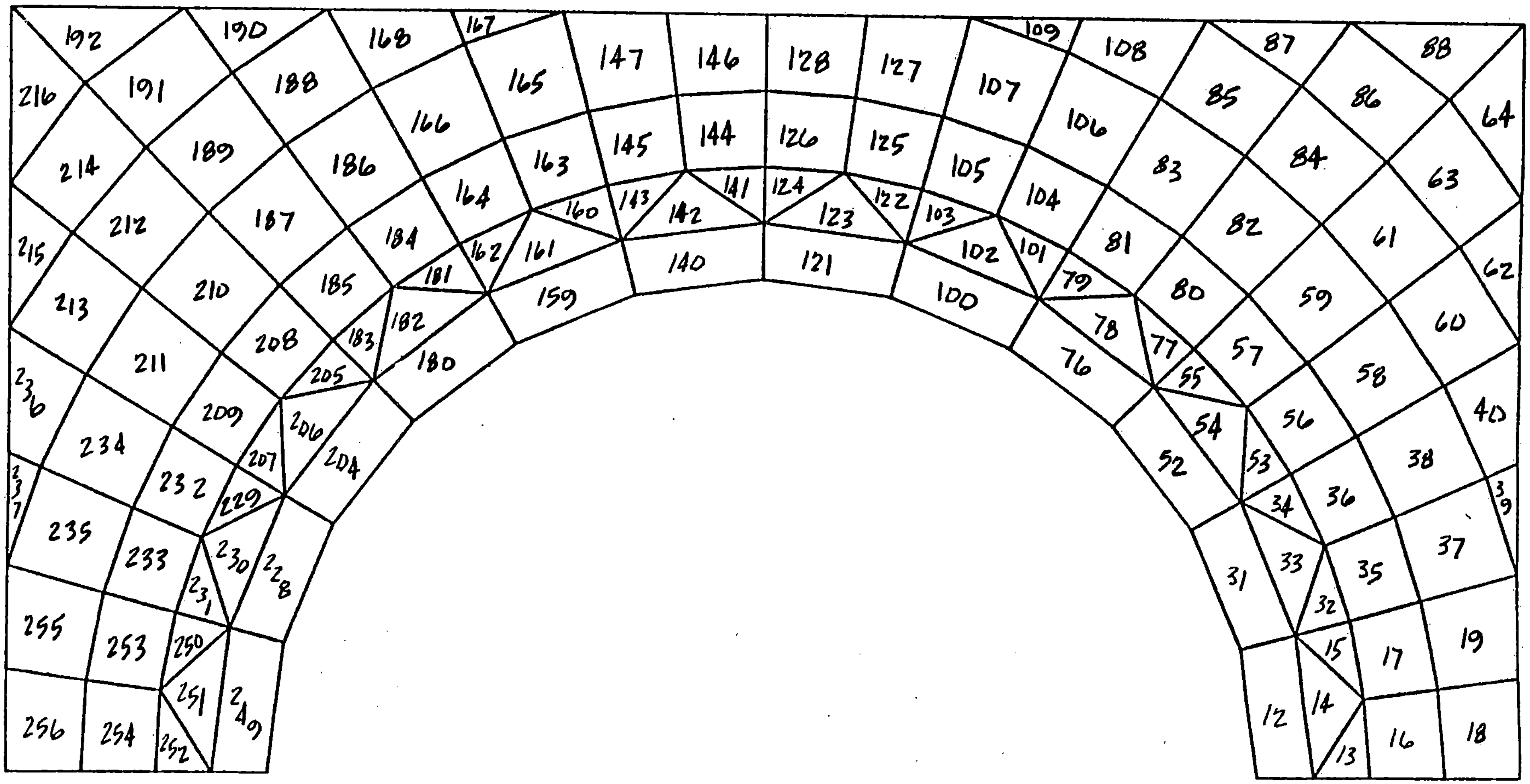


FIGURE 4.4

BASE PLATE - NODES

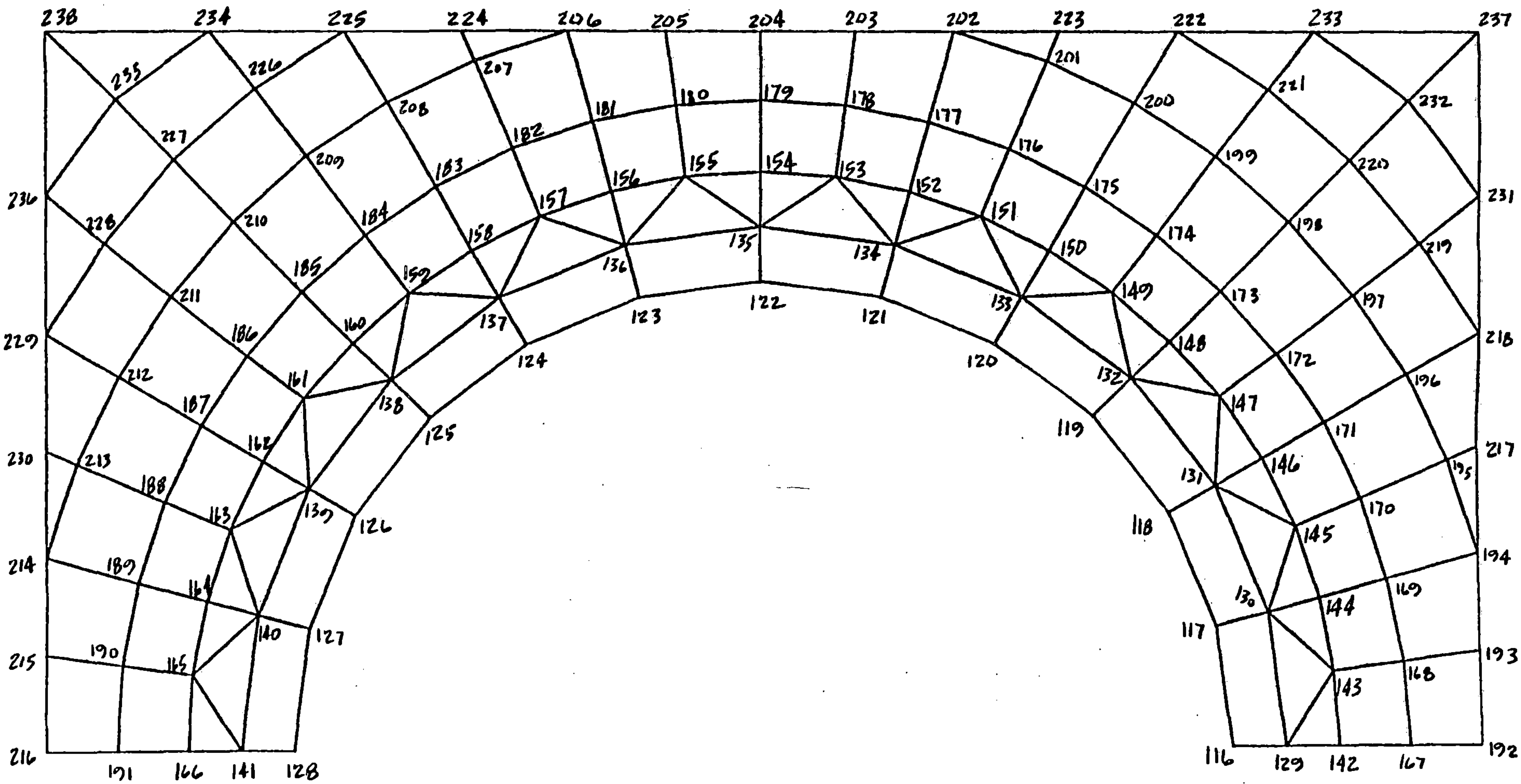


FIGURE 4.5

LOWER PUMP COLUMN - ELEMENTS

239	218	194	170	149	130	111	90	66	42	21	2
238	217	193	169	148	129	110	89	65	41	20	1

LOWER PUMP COLUMN - NODES

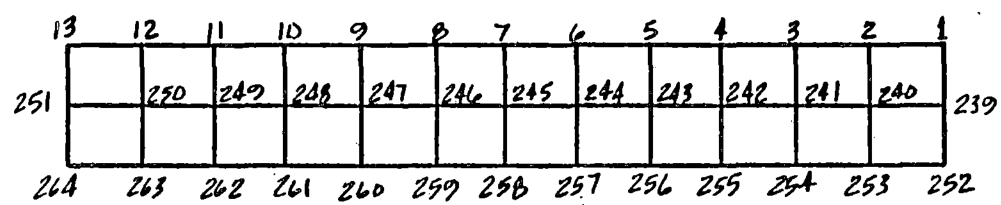


FIGURE 4.6

ASSEMBLED MATHEMATICAL MODEL - PLAN VIEW

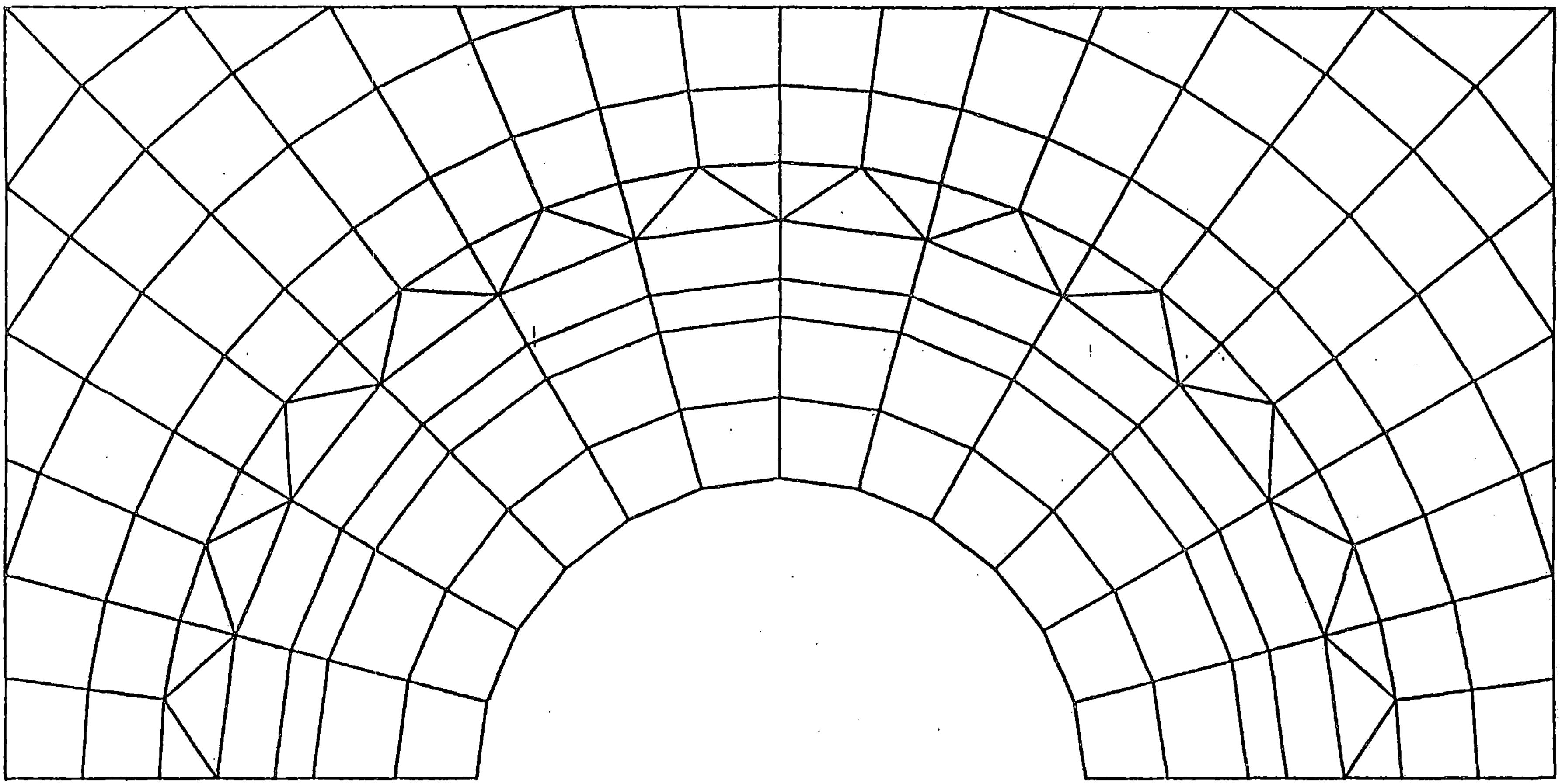


FIGURE 4.7

Section

5.0 ACCEPTANCE CRITERIA AND RESULTS FOR THE .5% DAMPING EVALUATION

02-0660-1089
Revision 0

5.0 ACCEPTANCE CRITERIA AND RESULTS FOR THE .5% DAMPING EVALUATION

5.1 Pump Column

Examination of the SUPERPIPE computer output (References 16, 19, 20 and 21) indicates that the maximum total stress in the Essential Service Water Pump is realized in the 16", standard schedule pump column just above the lower lateral support. Total stress is considered the sum of the stress resulting from the Deadweight, Seismic and Thermal Nozzle loadings. While maximum stress levels do not occur at the same point along the pump in each load case, a conservative but still representative value of total stress can be calculated by summing individual maximum stresses due to each loading regardless of their location. For the Service Water Pump .5% damping evaluation, this results in a total stress of 30024 psi (Reference 22).

The total stress in the Service Water Pump is limited in the Palisades FSAR to 110% of the minimum material yield stress. The specific FSAR eqution for Class I equipment pretaining to the SSE earthquake level is given below.

$$MOL + 2SL \leq 1.10$$

Where:

MOL = Maximum normal operating stress

2SL = Stress resulting from an SSE Earthquake.

Normal operating stress for the Service Water Pump is derived from Deadweight and Thermal Expansion nozzle loads.

The pump column material is ASTM A53 Grade B carbon steel with a minimum yield stress of 35000 psi (Reference 15). Substituting into the FSAR equation

$$1465 \text{ psi} + 28559 \text{ psi} \leq 1.10\ (35000 \text{ psi})$$

$$30024 \text{ psi} \leq 38500 \text{ psi}$$

Thus column stresses are found to be acceptable and consistent with FSAR criteria.

5.2 Pump Shaft

The shaft of the Essential Service Water Pump is stressed primarily due to bending during the SSE Earthquake event and to axial thrust induced by the rotating impellers.

Each of these loadings were evaluated for their impact on the shaft while loads due to Deadweight and Thermal Expansion of the attached piping were considered negligible.

Maximum seismic stress in the shaft was found to occur in the region between the base plate and the lower column supports in the .5% damping evaluation. Bending stress was determined from the relative lateral deflections of the support bearings to be 5902 psi. To obtain a total shaft stress value, the axial stress due to impeller thrust was added. Axial force on the shaft can reach 6856 lbs inducing a stress of 1824 psi. Therefore the total shaft stress was found to be 7726 psi (Reference 26).

The shaft material, in the region of maximum stress, is AISI C-1045 carbon steel with a yield stress of 86,700 psi. Since the maximum total shaft stress is only 9% of the yield stress value, the shaft is considered loaded well within acceptable limits.

5.3 <u>Column Flanges</u>

The Essential Service Water Pump's column flanges were evaluated based on the guidelines of the 1980 ASME Boiler and Pressure Vessel Code as part of the overall investigation into the system's functionality after an SSE earthquake event. Specifically Code Subparagraph NC-3658.1 in conjunction with Code Appendix XI and Appendix L were addressed.

The maximum bending moment acting at a column flanged connection due to an SSE earthquake in addition to normal operating loads was found to be 152476 ft-lb in the .5% damping pump evaluation. This moment occurred at the lower column support level and is equivalent to a flange design pressure of 1414 psi. With this design pressure the radial stress and tangential stress in the flange were computed as 31661 psi and 3626 psi respectively. The flange material, A36 carbon steel, has a minimum yield strength of 36000 psi. Therefore the radial and tangential stress levels in the flange are within the specified allowable limits of the plant FSAR.

The maximum tensile force in any one flange bolt in the .5% damping evaluation was calculated to be 24092 lb (Reference 33). This exceeds the computed preload of 13800 lb. In fact the tensile load in five flange bolts was found to be greater than the applied bolt preload. This however, does not preclude the acceptability of the connection. The maximum shear force in any one bolt was 11843 lb., taken as one-half the axial force in one of the lower lateral supports. Using the maximum shear stress Theory of Failure the flange bolts were found to be capable of withstanding the imposed loads (Reference 33).

5.4 Column Vibration

Below the lower lateral supports at elevation 583'-2 3/4", the Essential Service Water Pump is unrestrained in the horizontal plane for its remaining 30'-5 7/8". Therefore, large lateral deflections were expected at the lower tip of the pump column during an SSE Earthquake event. In the .5% damping evaluation, the maximum lower column horizontal translation was found to be 5.86" for the SSE event in combination with normal operating loads (Reference 22). In discussions with the pump manufacturer, Layne and Bowler, Inc., it was determined that deflection of the bottom end of the pump of as much as 6.00" was acceptable if the stresses in the column flanges and the bolting were within allowable limits (Reference 24).

5.5 Motor Vibration

Above the base plate support at elevation 590'-7", the Essential Service Water Pump is unrestrained in the horizontal plane for the length of the Discharge Head and Motor Unit, some 8'-7 3/4". The Discharge Head Assembly is relatively stiff and lateral deflections for the SSE Earthquake event were lower than in the pump column, reaching only .134" in the .5% damping evaluation. However, the motor unit is sensitive to lateral translation and horizontal vibration during an SSE Earthquake is limited to .020" by the pump manufacturer.

Although the .134" lateral deflection realized at the top end of the motor during the SSE inertia analysis exceeds the 20 mil criteria, it was noted that .129" of this vibration is due to flexible rotation of the sole plate. Since only .005" of the vibration is due to relative bending between the top end of the motor and the sole plate, Layne and Bowler was able to confirm the acceptability of the .134" vibration (Reference 24).

5.6 <u>Discharge Head to Sole Plate Bolts</u>

In addition to determining the stiffness of the sole plate for use in the SUPERPIPE computer analysis, the ANSYS finite element model discussed in Section 4.0 was used to compute loads in the bolts connecting the sole plate to the Discharge Head Assembly. This was accomplished by multiplying the bolt loads from the ANSYS analysis which were caused by a set of "unit loads", by the ratios of the actual sole plate support loads to these unit loads. Actual sole plate support loads were determined in the SUPERPIPE analysis of the Service Water Pump.

The resulting bolt loads for the .5% damping evaluation were thus computed as ± 8029 lb. shear and + 5330 lb. tension (Reference 34). The corresponding shear stress in the bolt was found to be 18174 psi and the tensile stress was found to be 15959 psi. Using an allowable stress specified in the Palisades FSAR for Class I equipment, the subject bolts are found to be inconsistent with the acceptance criteria in combined tension and shear.

5.7 <u>Sole Plate</u>

The ANSYS model used to compute the stiffness of the sole plate to be input into the SUPERPIPE pump analysis was also used to compute sole plate stresses. Utilizing the SUPERPIPE analysis results, which gave the forces and moments acting on the base plate support, the stresses in the sole plate were back-calculated for bending, compression, torsional and shear loads. Tension loads were never realized due to the relative magnitudes of deadweight and seismic contributions. Upon adding absolute maximum principal stresses due to the most severe compressive force, two shear forces, a torsional moment and two bending moments, the total stress level found in the sole plate was 14726 psi (References 28 and 32). This stress value neglected the fact that maximum principal stresses do not occur at the same location for each of the six load applications.

For the sole plate material of ASTM A36 carbon steel the minimum yield stress is 36000 psi. Therefore, stresses in the sole plate for the .5% damping evaluation are of an acceptable magnitude.

5.8 Sole Plate to Concrete Anchor Bolts

In the course of determining the stiffness properties of the sole plate, the loads in the anchor bolts fixing the sole plate to the concrete floor were also determined for applied "unit loads". The analysis performed was elastic and as long as stresses remained in the elastic range, the resulting bolt loads from the ANSYS output (Reference 32) could be multiplied by the ratio of the actual loads on the sole plate to the "unit loads". The actual loads were those forces and moments on the base plate support determined in the SUPERPIPE analysis of the Service Water Pump and summarized in Reference 22.

The resulting anchor bolt design loads for the .5% damping evaluation were thus computed as ± 10911 lb. in shear and + 2353 lb. in tension. The corresponding shear and tensile bolt stresses were 18146 psi and 5094 psi respectively. Using an FSAR based allowable stress as specified for Class I equipment, the anchor bolts are found to be in agreement with the acceptance criteria for combined tension and shear (Reference 28).

Section

6.0 ACCEPTANCE CRITERIA AND RESULTS FOR THE 2% DAMPING EVALUATION

02-0660-1089
Revision 0

6.0 ACCEPTANCE CRITERIA AND RESULTS FOR THE 2% DAMPING EVALUATION

6.1 Pump Column

The SUPERPIPE computer analyses (References 19, 20, 21, and 23) indicate that the maximum total stress in the Essential Service Water Pump occurs in the 16", standard schedule pump column just above the lower lateral support. Utilizing the same procedure for computing total stress in Section 5.1, a total stress value of 20440 psi was calculated for the 2% damping evaluation (Reference 25). This stress level is below the FSAR allowable of 110% yield which is 38500 psi (1.10 x 35000 psi) for the pump column material of ASTM A53 Grade B.

6.2 Pump Shaft

The maximum seismic bending stress in the pump shaft was found to occur between the base plate and the lower column supports. From the relative lateral deflections of the shaft bearings as discussed in Section 2.5, the maximum value of bending stress was found to be 4019 psi in the 2% damping evaluation. Adding to this the axial stress due to an impellar thrust of 6856 lb, the total shaft stress was calculated as 5843 psi (Reference 27).

The shaft material, in the region of maximum stress, is AISI C-1045 Carbon Steel with a yield stress of 86,700 psi. Therefore, shaft stress levels are well within acceptable limits.

6.3 Column Flanges

The maximum bending moment acting at a column flanged connection due to an SSE earthquake in addition to normal operating loads was found to be 96636 ft-lb in the 2% damping pump evaluation. This moment occurred at the lower column support level and is equivalent to a flange design pressure of 896 psi. With this design pressure the radial stress and tangential stress in the flange were computed as 20063 psi and 2298 psi respectively. The flange material, A36 carbon steel, has a minimum yield strength of 36000 psi. Therefore the radial and tangential stress levels in the flange are within the specified allowable limits of the plant FSAR. The maximum bolt tensile force was calculated to be 15269 lb. This load and the tensile load in two adjacent bolts were above the applied preload. The maximum bolt shear force was found to be 7978 lb. Using the Maximum Shear Stress Theory of Failure, the flange bolts are shown acceptable under the applied loads.

6.4 Column Vibration

displacement

In the 2% damping evaluation, the maximum lower column tip horizontal vibration was found to be 3.74" for the SSE event in combination with normal operating loads (Reference 25). Since the pump manufacturer was able to confirm the acceptability of lower column deflections of as much as 6.00" (Reference 24), provided stresses in the column flanges and the bolting are within allowable limits, vibrations of 3.74" are considered acceptable as well. displacement

6.5 Motor Vibration

The maximum lateral deflection of the top end of the motor unit was found to be .088" during the SSE Earthquake event. Although the .088" deflection in the horizontal plane exceeds the 20 mil limit established by the pump manufacturer, it was noted that .083" of this vibration is due to flexible rotation of the sole plate. Since only .005" of the vibration is due to relative bending between the top end of the motor and the sole plate, the pump manufacturer was able to confirm the acceptability of a vibration of this magnitude (Reference 24).

6.6 Discharge Head to Sole Plate Bolts

Following the procedure for determining forces in the bolts connecting the sole plate to the Discharge Head Assembly discussed in Section 5.6, design bolt loads were calculated in the 2% damping evaluation. The resulting bolt loads were computed as $\pm$ 6572 lb. in shear and 4647 lb. in tension. Bolt stresses were determined and compared to the acceptance criteria of the Palisades FSAR specified for Class I pieces of equipment. The shear stress of 14876 psi in combination with the tensile stress of 13914 psi was found to be within the allowable stress levels Reference 34).

6.7 Sole Plate

Utilizing the SUPERPIPE analysis results for the 2% damping evaluation, the forces and moments acting on the base plate support were multiplied by sole plate stress to applied sole plate load ratios determined from the ANSYS computer analysis of the sole plate described in Section 4.0. Upon adding absolute maximum principal stresses due to the most severe compressive force, two shear forces, a torsional moment and two bending moments, the total stress level found in the sole place was computed as 12410 psi (Reference 29). This value of stress was conservatively determined by assuming that the maximum principal stress occured at the same location for all the applied loads.

The maximum sole plate stress is well below the yield stress which for the plate material of ASTM A36 Carbon Steel is 36000 psi. Therefore, the sole plate was found to be consistent with the acceptance criteria of the Palisades FSAR.

6.8 Sole Plate to Concrete Anchor Bolts

Following the procedure for determining anchor bolt loads discussed in Section 5.8, the forces acting on the sole plate to concrete bolts were calculated in the 2% damping pump evaluation. The resulting anchor bolt design loads were found to be ± 8823 lb. in shear and + 2032 lb. in tension. The corresponding shear and tensile bolt stresses were 14674 psi and 4399 psi respectively. Using an FSAR based allowable stress as specified for Class I equipment, the anchor bolts are determined to be consistent with the acceptance criteria for combined tension and shear (Reference 29).

7.0 SUMMARY AND CONCLUSIONS

02-0660-1089
Revision 0

7.0 SUMMARY AND CONCLUSIONS

The investigations of the structural and functional adequacy of the Essential Service Water Pumps discussed in this report were prompted by the need for a documented safety evaluation of this component which was selected by the NRC's Senior Seismic Review Team as having potential seismic fragility. Following the philosophy of the Systematic Evaluation Program, the Safe Shutdown Earthquake was the only earthquake level considered in the pump evalutions. Structural damping ratios of both .5% and 2% were considered in the seismic inertia analysis because the Palisades FSAR does not specifically address the Service Water Pump in this regard. The acceptance criteria to which the pumps were evaluated were based on the Palisades FSAR requirements for Class I Systems and Equipment. Stresses due to normal operation and to the SSE Earthquake event were added and compared to allowable stress levels.

The .5% and 2% damping evaluations found stresses in the pump column and pump shaft to be of acceptable magnitudes. In accordance with the manufacturer's requirements, shaft bearing loads and impeller clearances were not critical. The vibrations experienced at the upper and lower ends of the Service Water Pump during an SSE Earthquake were, however, critical. In both the .5% and 2% damping evaluations, deflections at the top of the motor unit and at the bottom of the suction nozzle were within the limits established by the pump manufacturer for safe operation. The anchor bolts in the sole plate were loaded below allowable levels consistent with the plant FSAR acceptance criteria for loads in conjunction with the SSE Earthquake event.

Certain bolts joining the Discharge Head Assembly to the sole plate were found to be overstressed in the .5% damping pump evaluation. All of these bolts were acceptable in the 2% damping evaluation due to a decrease in seismic acceleration values. The sole plate itself was stressed within the allowables proposed in the plant FSAR. Finally, investigations into the flanged column connections showed that some separation of the flange faces may occur at the elevation of the lower column support. This separation was found possible at only one connection in both evaluations. The extent to which bolt loads exceed their preload value was least in the 2% damping case. These connections are, however, strong enough to carry the imposed loads based on the allowable stress levels of the Palisades FSAR.

In conclusion, there are no modifications to the Essential Service Water Pump necessitated by the investigations of seismic adequacy discussed in this report. The loss of contact at one of the flanged column connections will probably never occur in reality due to the additional force carrying capacity of bolts adjacent to those bolts having tensile loads in excess of their preload. If slight separation occurs it would be only for the short duration of the SSE earthquake. Upon acceptance of the lower lateral supports, to be qualified with the design loads generated by analyses performed for this report, the Service Water Pump is considered capable of maintaining its structural integrity in the event of an SSE earthquake.

It may be important to note that the true structural damping of the system under investigation is thought to be greater than

2% of critical. The fact that thirty feet of pump column is submerged in water lends itself to this conclusion. A detailed examination into this area could lead to the justification of a higher damping value. This would in turn lead to considerably lower inertia forces acting on the pump and consequently lower stresses and smaller pump deflections.

8.0 REFERENCES

02-0660-1089
Revision 0

8.0 REFERENCES

1. Bechtel Company Drawing No. C-221, Revision 10, "Intake Structure Miscellaneous Details," Location C-4 and F-4.

2. Bechtel Company Drawing No. C-226, Revisio 1, "Intake Structure Plans," Location B-7.

3. Palisades Nuclear Power Plant Final Safety Analysis Report, Appendix A, "Design Basis for Structures, Systems and Equipment (Except Containment Structure) for Palisades Plant."

4. C.K. McDonald, "Seismic Analysis of Long Column Vertical Pumps", ASME Publication 74-NE-2.

5. EDS Letter No. 0660-005-NY-011, dated June 18, 1981.

6. EDS Calculation 201, "Determination of Masses," Rev. 0. Job No. 0660-005-643

7. EDS Calculation 202, "Determination of Moments of Inertia," Rev. 0, Job No. 0660-005-643

8. General Electric Drawing No. 992C536, Rev. 3, (Bechtel Company Drawing No. 950x9* M11 Sh. 9-3) Outline - Induction Motor

9. Bechtel Letter No. BEV-EDS-42, dated May 20, 1981. Transmittal of Pump Details, Bill of Materials, etc.

10. EDS Calculation 203, "Mathematical Model," Rev. 2, Job No. 0660-005-643

11. EDS Letter No. 0660-005-NY-011, dated June 18, 1981. Miscellaneous Pump Information

12. Tube Turns Catalog 411 "Welding Fittings and Flanges", 1979.

13. EDS Calcculation 204, "Stiffness Calculation - Loading Conditions", Rev. 1, Job No. 0660-005-643.

14. EDS Calculation 205, "Stiffness Matrix Sole Plate Calculation", Rev. 1, Job No. 0660-005-643.

15. 1980 ASME Boiler and Pressure Vessel Code, Section II, Part A and Section III, Subsection NC.

16. EDS Calculation 210, "Pump Stick Model Computer Analysis", Rev. 1, Computer Run Sequence No. ACGYBMX dated 8/17/81, Job No. 0660-005-643.

17. EDS Letter No. 0660-005-NY-028, dated October 19, 1981. Design Input for ESW Pump Analysis.

18. EDS Calculation 215, "Stick Model-Seismic Analysis - Low Water Level," Rev. 0, Computer Run Sequence No. ACGYGUI, dated 10/20/81, Job No. 0660-005-643.

19. EDS Calculation 216, "Pump 7A - Stick Model - Nozle Loads", Rev. 0, Computer Run Sequence No. ACGYJQR, dated 10/22/81, Job No. 0660-005-643.

20. EDS Calculation 217, "Pump 7B - Stick Model - Nozle Loads", Rev. 0, Computer Run Sequence No. ACGYIUV, dated 10/22/81, Job No. 0660-005-643.

21. EDS Calculation 218, "Pump 7C - Stick Model - Nozle Loads", Rev. 0, Computer Run Sequence No. ACGYJRI, dated 10/22/81, Job No. 0660-005-643.

22. EDS Calculation 213, "Computer Results - .5% Damping", Rev. 1, Job No. 0660-005-643.

23. EDS Calculation 220, "Pump Inertial Analysis - 2% Damping, Rev. 0, Computer Run Sequence No. ACGYPCW, dated 10/20/81, Job No. 0660-005-643.

24. Layne and Bowler, Inc. Letter dated September 11, 1981 from Mr. Chi-Sheng Yang.

25. EDS Calculation 219, "Computer Results -2% Damping", Rev. 0, Job No. 0660-005-643.

26. EDS Calculation 208, "Shaft Stresses - .5% Damping", Rev. 1, Job No. 0660-005-643.

27. EDS Calculation 222, "Shaft Stresses - 2% Damping", Rev. 0, Job No. 0660-005-643.

28. EDS Calculation 214, "Base Plate Stress and Anchor Bolt Load Calculation For The .5% Damping Evaluation", Rev. 1, Job No. 0660-005-643.

29. EDS Calculation 223, "Base Plate Stress and Anchor Bolt Load Calculation For The 2% Damping Evaluation", Rev. 0, Job No. 0660-005-643.

30. EDS Calculation 207, "Spectra Curves", Rev. 0, Job No. 0660-005-643.

31. EDS Calculation 221, "Spectra Curves - 2% Damping", Rev. 0, Job No. 0660-005-643.

32. EDS Calculation 211, "Base Plate Model Computer Analysis", Rev. 1, Computer Run Sequence No.s ACIIZHG dated 8/13/81 and ACIIBAV dated 7/27/81, Job No. 0660-005-643.

33. EDS Calculation 209, "Flange Qualification, Rev. 1, Job No. 0660-005-643.

34. EDS Calculation 224, "Pump Discharge Head Bolt Loads and Stresses, Rev. 0, Job No. 0660-005-643.