Robert L. Cloud and Associates, Inc.

RLCA

Interim Technical Report

DIABLO CANYON UNIT 1
INDEPENDENT DESIGN VERIFICATION PROGRAM
-PUMPS-
ITR #32
REVISION 0

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Project Engineer/Date 2/17/83
Technical Review

Project Manager/Date Edward Denison 2/17/83
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PROGRAM MANAGER'S PREFACE

DIABLO CANYON NUCLEAR POWER PLANT - UNIT 1
INDEPENDENT DESIGN VERIFICATION PROGRAM

INTERIM TECHNICAL REPORT

PUMPS

This is the thirty-second of a series of Interim Technical Reports prepared by the DCNPP IDVP for the purpose of providing a conclusion of the program.

This report provides the analytical results, concerns, recommendations, and conclusions of the IDVP with respect to the initial sample for pumps. All EOI files initiated for the pumps have been closed or identified as an error.

As IDVP Program Manager, Teledyne Engineering Services has approved this ITR-32, including the conclusions and recommendations presented. The methodology followed by TES in performing this review and evaluation is described in Appendix E to this report.

ITR Reviewed and Approved
IDVP Program Manager
Teledyne Engineering Services

R. Wray

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Assistant Project Manager

PUMP REPORT

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1.0 INTRODUCTION

Purpose and Scope

This interim technical report summarizes the independent analysis and verification of the initial sample of pumps at Diablo Canyon Nuclear Power Plant, Unit 1 (DCNPP-1). The pump sample consists of the turbine-driven auxiliary feedwater pump, the auxiliary saltwater pumps, and the component cooling water pumps. The auxiliary feedwater and component cooling water pumps are located in the auxiliary building, while the auxiliary saltwater pump is located in the intake structure.

This report is one of many interim technical reports of the Independent Design Verification Program (IDVP). Interim technical reports include references, sample definitions and descriptions, methodology, a listing of Error and Open Items, an examination of trends and concerns, and a conclusion (Reference 1). This report presents the IDVP results and conclusions of the pump analysis and serves as a vehicle for NRC review. It will also be referenced in the IDVP Phase I Final Report.

Summary

Robert L. Cloud and Associates (RLCA) performed verification analyses for an initial sample of pumps at DCNPP-1. Field verified information was used in both hand and computer calculations to evaluate stresses.

Stresses from the verification analysis were also compared to stresses from the design analysis. In general, design analysis stresses for the auxiliary feedwater and saltwater pumps were found to be lower than those from the verification analyses. The results of this verification effort indicate that stresses for each of the pump samples met the allowables defined by the licensing criteria.

As a result of the comparison, three concerns were noted and recommendations were made.

Background

On September 28, 1981 PGandE reported that a diagram error had been found in a portion of the seismic qualificaion of the Diablo Canyon Nuclear Power Plant Unit 1 (DCNPP-1). This error resulted in an incorrect application of the seismic floor response spectra for sections of the annulus of the Unit I containment building. The error originated when PGandE transmitted a sketch of Unit 2 to a seismic service-related contractor. This sketch contained geometry incorrectly identified as Unit 1 geometry.

As a result of this error, a seismic reverification program was established to determine if the seismic qualification of the plant was adequate for the postulated Hosgri 7.5M earthquake. This program was presented orally to the NRC in a meeting in Bethesda, Maryland on October 9, 1981.

Robert L. Cloud and Associates (RLCA) presented a preliminary report on the seismic reverification program to the NRC on November 12, 1981 (Reference 2). This report dealt with a examination of the interface between URS/Blume and PGandE.

The NRC commissioners met during the next week to review the preliminary report and the overall situation. On November 19, 1981 an Order Suspending License CLI-81-30 was issued which suspended the Diablo Canyon license to load fuel and conduct low power tests up to 5% of rated power at DCNPP-1. This suspending order also specified that an independent design verification program be conducted to ensure that the plant met the licensing criteria.

PGandE retained Robert L. Cloud and Associates as program manager to develop and implement a program that would address the concerns cited in the Order Suspending License CLI-81-30. This program would provide for the independent verification of those buildings, equipment and components which had already been evaluated by PGandE for the Hosgri 7.5M earthquake. The Phase I plan for this program was transmitted to the NRC staff in December 1981 and discussed with the NRC staff in February 1982. Phase I specifically deals with PGandE internal activities and seismic service-related contracts prior to June 1978.

In March 1982, the NRC approved Teledyne Engineering Services as program manager to replace RLCA. However, RLCA continued to perform the independent review of seismic, structural and mechanical aspects of Phase I.

The NRC approved the Independent Design Verification Program Phase I Engineering Program Plan on April 27, 1982 (Reference 3). This plan dictates that a sample of piping, equipment, structures and components be selected for independent analysis. The results of these analyses are to be compared to the design analyses results. If the acceptance criteria are exceeded, an Open Item Report is to be filed. Interim technical reports are to be issued to explain the progress of different segments of the technical work.

2.0 INDEPENDENT DESIGN VERIFICATION METHODS

2.1 PROCEDURES

The IDVP used the following procedure to verify the seismic qualification of the turbine-driven auxiliary feedwater pump, the auxiliary saltwater pumps, and the component cooling water pumps.

First, the equipment's physical dimensions were verified in the field. Next, the equipment was modeled to simulate the mass and stiffness characteristics. From this model, natural frequencies were determined. Seismic accelerations were computed using the natural frequencies together with the Hosgri response spectra selected from the figures listed in Appendix A. Forces, moments and then stresses were calculated for key areas. Computed stresses were compared to the allowables as defined by the licensing criteria. Finally, the computed stresses and methods were compared between both the IDVP and design analyses.

2.2 LICENSING CRITERIA

The IDVP used the Diablo Canyon Nuclear Power Plant Unit I licensing criteria to analyze the turbine-driven auxiliary feedwater pumps, the auxiliary saltwater pumps, and the component cooling water pumps. This criteria is contained in the FSAR and the Hosgri Report (References 4 and 5).

Allowable criteria are those defined in Tables 7-1 and 7-2 of the Hosgri Report (Reference 4) and summarized in Appendix B. Loading combinations and structural criteria from the Hosgri Report are included in Attachment I of the Phase I Engineering Program Plan (Reference 3).

3.0 VERIFICATION ANALYSIS OF PUMPS

3.1 TURBINE-DRIVEN AUXILIARY FEEDWATER PUMP

The turbine-driven auxiliary feedwater pump is located in the Unit 1 auxiliary building, at elevation 100 feet. The pump is a six stage centrifugal pump driven by a steam turbine, which is connected to the pump section through a flexible coupling. Both the turbine and pump sections are mounted on pedestals, which are welded to a base plate assembly. The base plate assembly is attached to the concrete floor slab with six cast-in-place anchor bolts and constructed from a raised plate built on steel members. The area around these channels and under the plate comprises a cavity which is then filled with grout. In effect, the base plate assembly is grouted to the floor slab, embedding the channels in grout.

The total weight of the pump section is 7,250 pounds. The weight of the turbine portion is 2,960 pounds. The axial direction of the pump and turbine corresponds to the plant's North-South axis.

Figure 1 shows the general configuration of the auxiliary feedwater pump. Figure 2 shows the details of the pump and turbine pedestals.

3.1.1 Method of Verification Analysis

The IDVP developed a mathematical model after field verifying the dimensions of the pump, turbine, and supporting structure. Individual stiffnesses were calculated and combined to determine the overall stiffness (Reference 6). The IDVP modeled the pump and turbine as concentrated masses atop springs attached to the base plate. The springs represented the stiffnesses of the pedestals and hold down bolts while the baseplate was considered as a rigid plate attached to the ground by another set of springs representing the anchor bolts.

This representation yielded a more flexible model of the pump-turbine assembly than the actual case because preload in all the bolts was neglected. From a dynamic standpoint, the model was conservative because resulting lower natural frequencies yielded larger seismic responses and, hence, larger seismic loads.

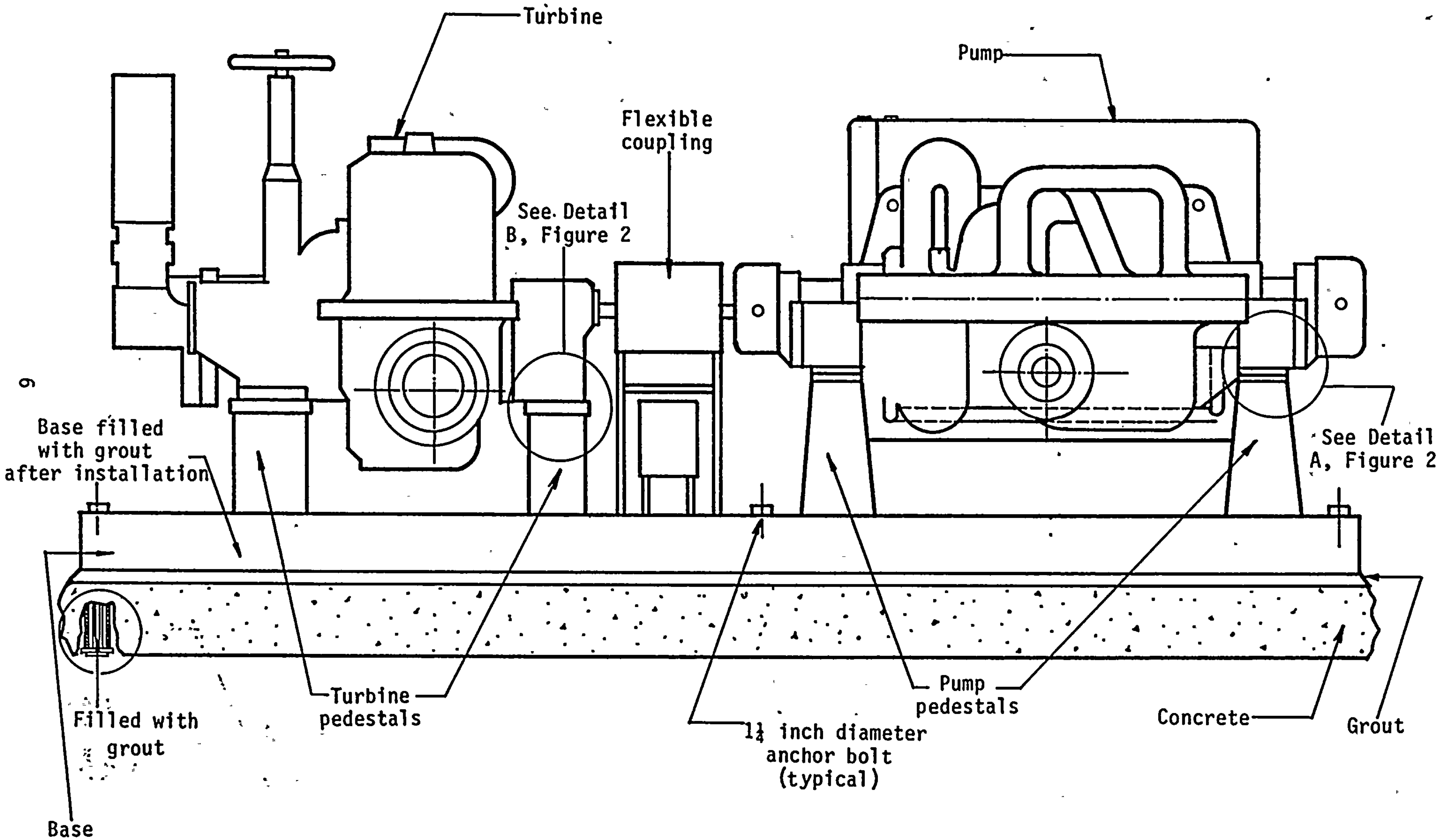


Figure 1

General Configuration of Auxiliary Feedwater Pump

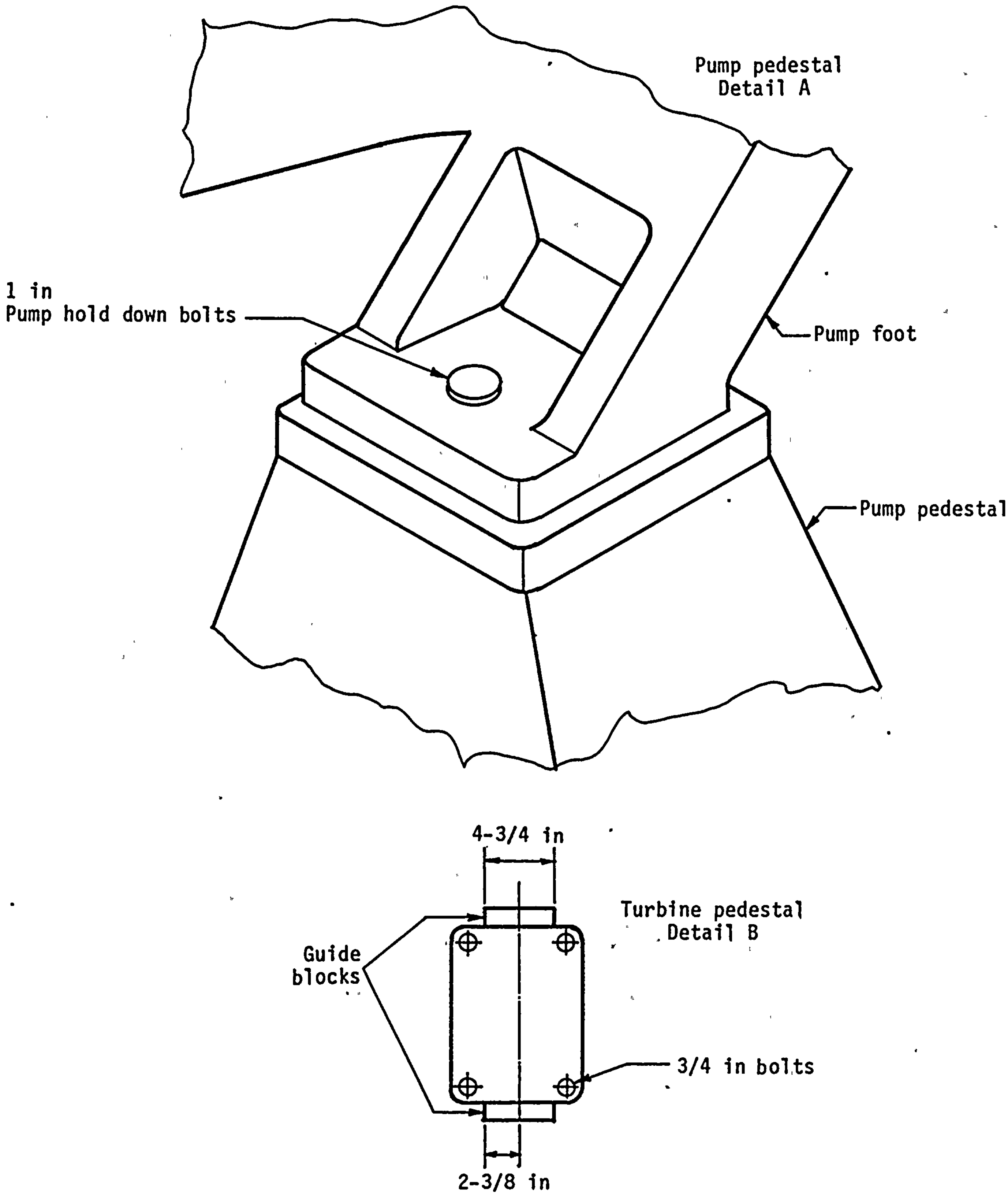


Figure 2

Details of Pump and Turbine Pedestals -
Auxiliary Feedwater Pump

The overall stiffness was combined with the mass of the pump and turbine to determine the overall natural frequency for the horizontal and vertical directions. The model was then reduced to a simplified single degree of freedom model. It was used to develop natural frequencies for the pump alone, the turbine alone, and the pump and turbine combined on the base plate assembly connected to the floor slab by flexible anchor bolts.

The lowest vertical natural frequency was calculated for the combined pump and turbine assembly on the base plate assembly, while the lowest horizontal natural frequency was calculated for the pump on its pedestal alone. The frequencies are given below:

64.8 hertz vertical
17.05 hertz horizontal

As mentioned previously, the frequencies were calculated considering a more flexible representation than the actual case.

From Hosgri response spectra at 4% damping, seismic accelerations were chosen from figures listed in Appendix A to correspond to IDVP natural frequencies. The accelerations are given below:

1.30 g horizontal North-South
1.41 g horizontal East-West
0.70 g vertical

An equivalent static method was used to determine the loads and forces from the seismic accelerations. Nozzle loads due to the attached piping were obtained from PGandE piping analysis results. Nozzle loads consisted of both seismic and normal thermal operating loads. Nozzle, seismic and deadweight loads were combined with the pump torque reaction load to obtain the overall loading and forces at key areas. Because the inclusion of normal thermal operating nozzle loads is not required for a faulted condition evaluation, this approach is conservative.

These loads and forces were then used to calculate seismic stresses at key areas. The calculated stresses were compared to the allowable stresses as defined by the licensing criteria.

3.1.2 Results of Verification Analysis

RLCA computed stresses at the following key areas and compared them to the allowable stresses as defined by the licensing criteria. The results show that the stresses RLCA independently calculated for the key areas are below the allowable stresses.

	Computed (ksi)	Allowable (ksi)
* Pump dowel pin shear stress	14.8	42.0
* Pump hold down bolts tensile stress	9.6	26.7
* Pump feet shear stress	4.6	18.0
Pump pedestal		
tensile stress	1.6	28.8
shear stress	0.8	19.1
Turbine hold down bolt		
tensile stress	10.1	26.7
shear stress	6.3	13.3
Turbine pedestal		
tensile stress	4.3	28.8
shear stress	0.8	19.1
Base plate hold down bolt		
tensile stress	17.0	26.7
shear stress	10.4	13.3
Discharge nozzle stress	17.8	32.4

* Areas that are also explicitly evaluated in the design analysis

Table 1
Verification Analysis- Stresses, Auxiliary Feedwater Pump

3.1.3 Design Analysis Methods

PGandE performed the seismic qualification of the auxiliary feedwater pump for Hosgri conditions using a static analysis method (Reference 7). Based on the manufacturer's pre-Hosgri analysis, PGandE calculated the pump to have a natural frequency greater than 33 hertz, and thus, to be rigid.

In the design analysis, the pump and pedestals were modeled using beam elements from the STRUDL computer program. Four loading conditions were combined: hydraulic torque, pump thrust, thermal nozzle load, and seismic loading. Seismic loading consisted of three directions of seismic induced forces applied at the pump center of gravity. Loads and forces were calculated at key locations for all combinations of loading. Stresses were then calculated by hand for the highest loads at each location.

3.1.4 Comparison of Verification and Design Methods

The design analysis examined only the pump and the pump pedestal. The flexibility of the base plate anchor bolts was not considered in their calculations. In contrast, the verification analysis examined the effects of the pump on its pedestal, the turbine on its pedestal, and the total system. The total system comprised the pump and turbine on their pedestals, and the effects of both these units mounted on the base plate.

The design analysis used a computer model to evaluate the pump and its pedestals, whereas the verification analysis used hand calculations to calculate pump and pedestal loads and forces.

The verification analysis assumed the bolts to have no preload; hence, the bolted joints are represented as more flexible than the actual case (see Section 3.1.1). Consequently, lower natural frequency results were obtained for the verification analysis in both the horizontal and vertical directions. Thus, the verification assumption yielded a more conservative representation of the pump.

3.1.5 Comparison of Verification and Design Results

RLCA compared their results listed in Section 3.1.2 with results from the design analysis as shown below:

	Verification Analysis	Design Analysis
Pump vertical frequency	108 hz	46-58 hz
Pump horizontal frequency	17 hz	36 hz
Pump dowel pins shear stress	14.8 ksi	7.2 ksi
Pump hold down bolts tensile stress	9.6 ksi	2.6 ksi
Pump feet shear stress	4.6 ksi	4.9 ksi

Table 2

Comparison of Stresses - Verification/Design Analyses, Auxiliary Feedwater Pump

The results of both analyses show all stresses to be below allowables. Differences in the frequency results reflect different assumptions concerning anchor bolts and calculation of system frequency (see Sections 3.1.1 and 3.1.4). Stress differences resulted from the higher accelerations in the verification analysis, which are associated with the lower horizontal natural frequencies calculated.

3.1.6 Error and Open Item Report Issued

The IDVP issued one EOI report for the turbine driven auxiliary feedwater pump. Appendix D shows the EOI file number, revision, date and status.

EOI 1072 was issued because the stress results calculated by the IDVP differed from those of the design analysis by more than 15%. As described in Section 3.1.4, the design analysis did not evaluate the pump and turbine system coupled through the base plate, nor did it account for the anchor bolt flexibility. In addition, the spectra referenced in the design qualification summary are spectra other than those listed in Appendix A.

EOI 1072 was resolved as a closed item because the spectra used in the design qualification summary were not contained in a controlled document and were identical to the Hosgri spectra except for identification numbers. In addition, the IDVP determined that the primary reason for the stress differences was the variation in methods used to model the pump-turbine system.

3.2 AUXILIARY SALTWATER PUMP

Two auxiliary saltwater pumps are located in the Unit 1 portion of the intake structure. The overall height of each pump is approximately 33 feet and the total weight of each pump is 10,440 pounds. Pump components consist of an electric motor, a discharge head, pump column and pump bowl. The electric motor and discharge head section are mounted above the floor while the pump column and bowl are submersed in the water below the floor. A vertical shaft connects the electric motor to the impeller at the pump bowl.

Figure 3 shows the general configuration of the auxiliary saltwater pumps.

The primary attachment point of the pump is at a mounting plate attached to the concrete deck at elevation -2.1 feet (see Figure 4). There are additional structural supports at the motor on top and at the pump bowl beneath the water surface. The restraint at the motor permits vertical motion, but prevents translational motion in the horizontal directions. The pump bowl support similarly restrains motion in the translational directions but permits vertical motion. Piping is connected to the pump at the discharge head by a flexible coupling.

3.2.1 Method of Verification Analysis

The IDVP developed a mathematical model after field verifying the dimensions of the pump and supporting structure. Stiffnesses of the pump and components and the supporting structures were individually calculated (Reference 8). The total mass of the pump was divided and lumped at the corresponding centers of gravity for each of the major pump components.

The mass of the water within the pump column and bowl was included in the model as well as the hydrodynamic mass of the water entrained by the column and bowl during pump excitation. The hydrodynamic mass was assumed to be equal to the mass of the water contained in the pump column and bowl. The verification analysis lumped the hydrodynamic mass at the corresponding centers of gravity for the pump column and bowl.

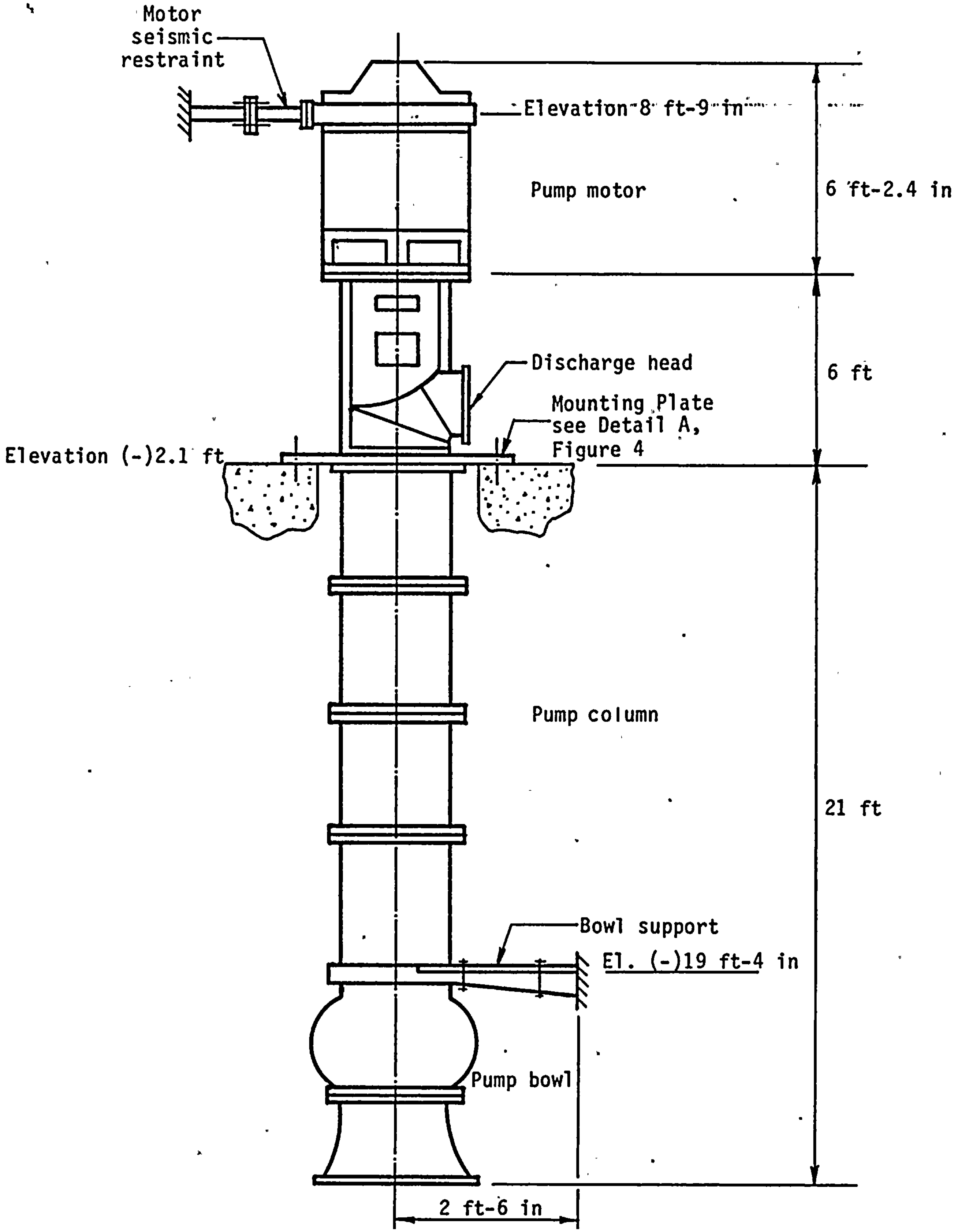
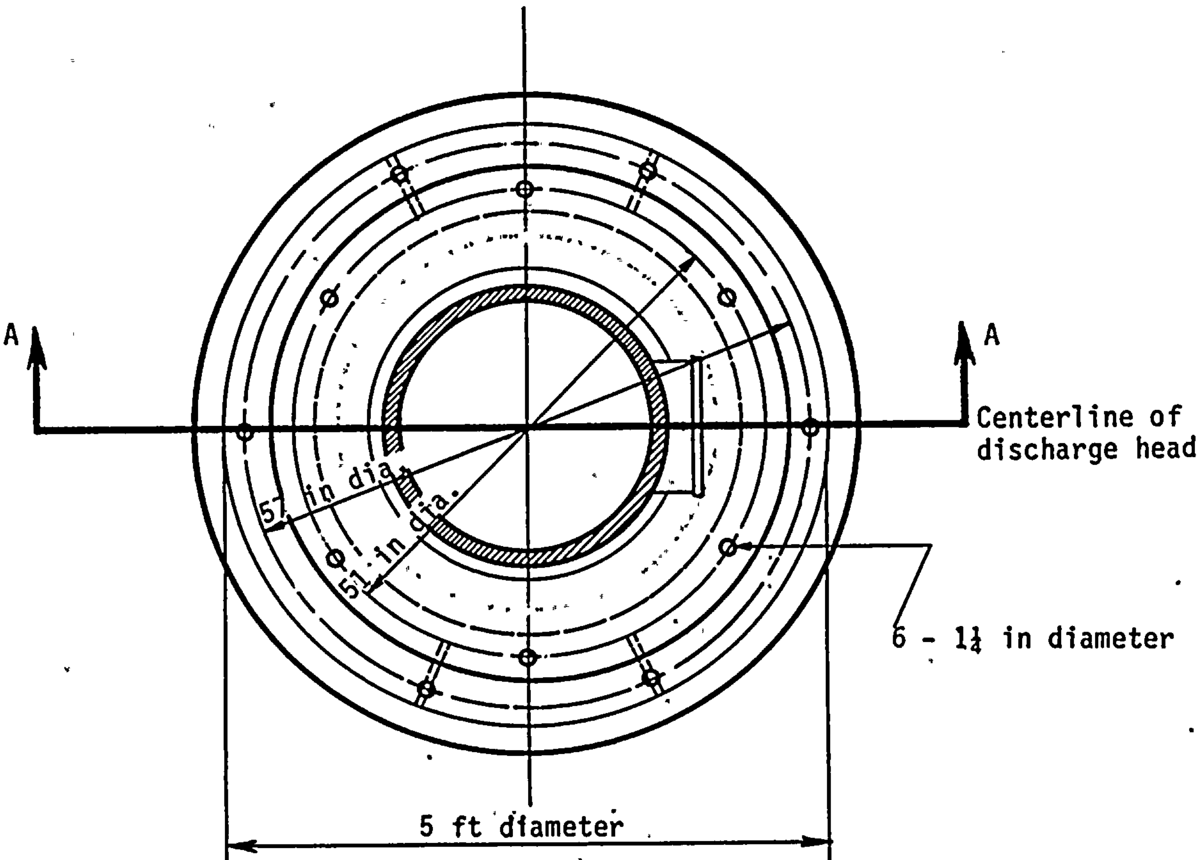
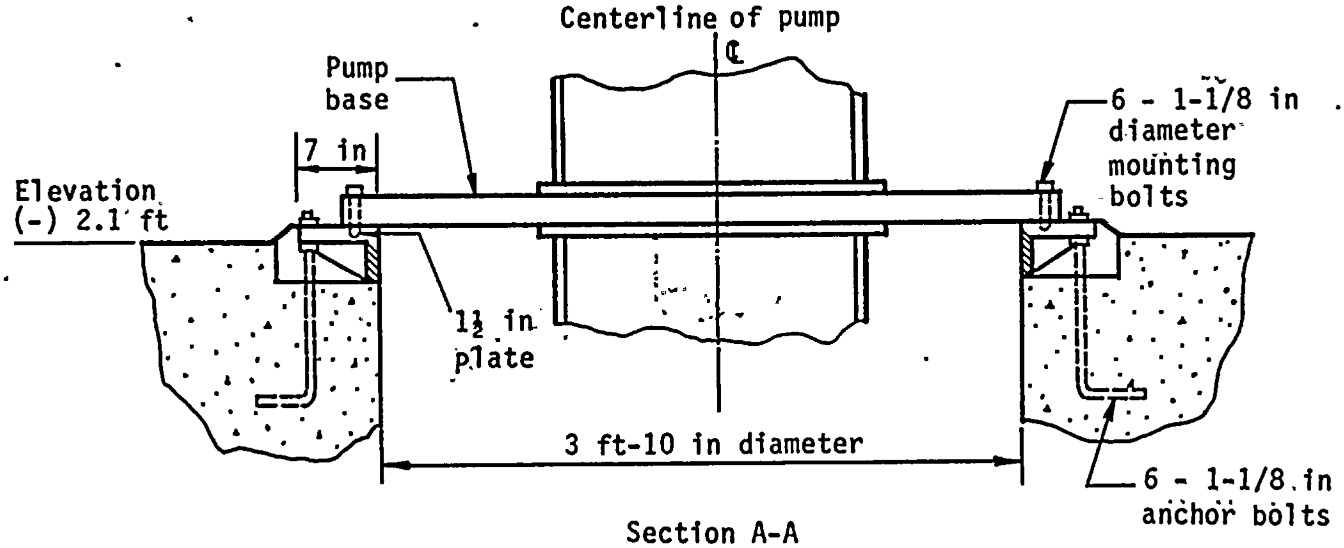


Figure 3

General Configuration of Auxiliary Saltwater Pump



Detail A - Plan View



Section A-A

Figure 4

Mounting Plate Details -
Auxiliary Saltwater Pump

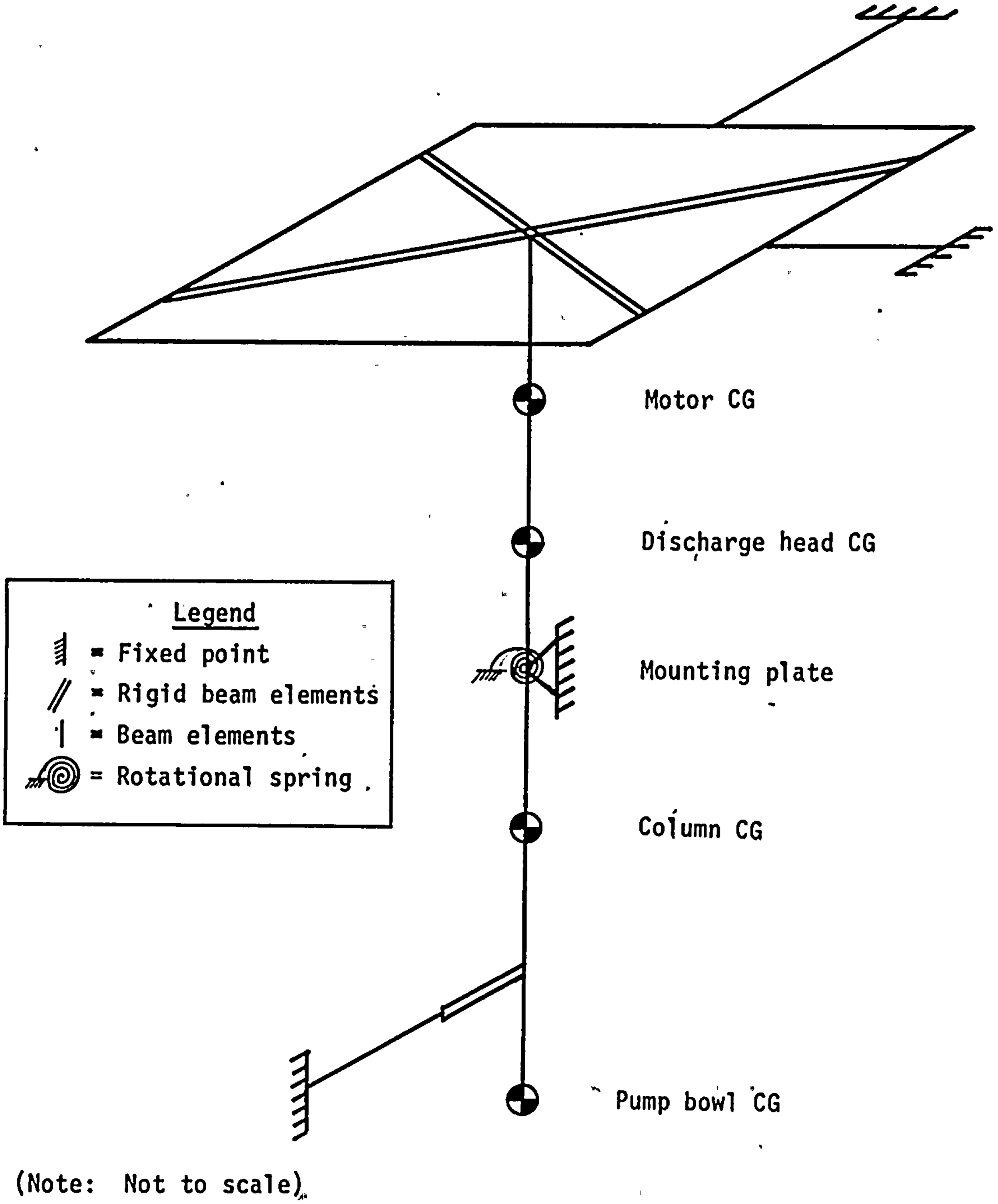


Figure 5
STARDYNE Model - Auxiliary Saltwater Pump

Mounting plate vertical and rotational stiffnesses in the horizontal plane were calculated using the assumption that the edges were simply supported. This assumption gives lower natural frequency results which yield larger seismic responses and, hence, larger seismic loads.

A STARDYNE computer model was developed using the pump mass and stiffness characteristics. The pump was modeled as a series of beam elements and masses to determine the system natural frequencies. Figure 5 shows the STARDYNE model for the auxiliary saltwater pump.

A response spectra modal superposition analysis was used to determine loads and forces at key areas, as the pump was shown to have frequencies less than 33 hertz.

Response spectra were taken from the Hosgri report (see Appendix A). The IDVP used a conservative 3% damping figure because the applicable 4% damping curves were not available.

Using the loads and forces determined from the STARDYNE computer calculations, seismic stresses were calculated for the key areas. Where applicable, the stress calculations included the discharge nozzle pressure reaction load.

3.2.2 Results of Verification Analysis

The IDVP compared the calculated stresses for the auxiliary saltwater pumps to the allowable stresses as defined by the licensing criteria.

The results, presented in Table 3, show that the stresses calculated from the verification analysis are below the allowable stresses.

	Computed (psi)	Allowable (psi)
Motor Support		
8 inch pipe tensile stress	1,276	22,700
Built-up channel box section tensile stress	3,767	22,700
7 inch channel tensile stress	7,509	22,700
Flange bolts	.01 **	1.0
Bowl Support		
Support tensile stress	999	22,700
Strap tensile stress	5,619	22,700
Bolt	.01 **	1.0
Mounting Plate		
* Mounting plate tensile stress	10,799	22,700
Hold down bolt	.08 **	1.0
Pump		
20 inch column tensile stress	5,447	28,300
* Column flange bolt	.08 **	1.0
* Motor anchor bolts	.17 **	1.0
Discharge head bolt	.13 **	1.0

* Areas which are also explicitly evaluated in the design analysis

** Combined shear/tension interaction ratio

Table 3
Verification Analysis - Stresses, Auxiliary Saltwater Pump

3.2.3 Design Analysis Methods

The design analysis of the auxiliary saltwater pump considered the pump as a system of beams with the respective component weights lumped at the component centers of gravity along the pump length (Reference 9). The pump motor, discharge head, column, and bowl were considered as part of the total pump assembly. Not included in the design analysis was the virtual hydrodynamic mass of the water both within the pump and entrained by the pump during motion.

Using the Rayleigh energy method, the design analysis found the pump natural frequency to be greater than 33 hertz. A static analysis approach was then used, applying a seismic load at each respective component mass center of gravity. The IDVP determined that the assumed first mode shape in the design analysis actually approximates the third mode shape and thus, the design result for the horizontal natural frequency was incorrectly calculated. Figure 6 shows the application of the Rayleigh energy method in the design analysis.

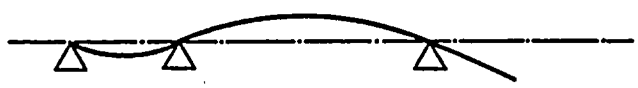
The computer program STRUDL calculated loads and forces at the various support points of the pump. The loads comprised Hosgri seismic loadings, nozzle loads, operating torque, hydraulic thrust and operating pressure.

Hand calculations were used to compute stresses at key locations. Stresses were calculated using the same approach as the manufacturer's analysis except with revised accelerations (Reference 6). Seismic inertia loadings for the various pump components were applied at the component centers of gravity.

3.2.4 Comparison of Verification and Design Methods

The design analysis used hand calculations to calculate natural frequency and support stresses in the vertical direction and a computer method to determine the combined horizontal loadings at key locations. The verification analysis used a computer model to calculate horizontal and vertical natural frequencies as well as loads at key locations.

Design Analysis (Approximate 3rd Mode)



Correct Application (Approximate 1st Mode)

Figure 6

Application of Rayleigh Energy Method-
Design Analysis

The verification analysis computed a lower bound vertical frequency which assumes the bolted mounting plate to have simply supported edges, while the design analysis assumed clamped edges.

The verification analysis considered the spectral accelerations associated with the system's natural frequencies using a response spectra modal superposition analysis. The design analysis used a static method because natural frequencies were calculated to be in the rigid range. However, the design analysis conservatively used seismic accelerations higher than the zero period accelerations.

The design analysis considered all supports to be rigid and modeled the pump as a two-span beam with an additional overhang. The verification analysis included the support flexibilities in the computer model.

From the response spectra modal superposition analysis, the IDVP determined seismic loads in the horizontal and vertical directions using the STARDYNE computer code. Seismic loads and stresses were calculated and then combined with loads and stresses from pump pressure loading, nozzle reaction loading, and deadweight to determine total stress.

In contrast, the design analysis combined seismic loads from the static analyses in the horizontal and vertical directions with the pressure load to calculate net forces.

3.2.5 Comparison of Verification and Design Results

The IDVP compared the results listed in Section 3.2.2 with results from the design analysis as shown below:

	Verification Analysis	Design Analysis
Horizontal natural frequency	28.9 hz	74.3 hz
Vertical natural frequency	25.2 hz	31.0 hz
Main mounting plate stress	9.5 ksi	6.8 ksi
Column flange bolting stress	13.9 ksi	6.3 ksi
Motor anchor bolt stress	18.3 ksi	11.8 ksi

Table 4

Comparison of Stresses - Verification/Design Analyses, Auxiliary Saltwater Pump

The results of both analyses show all stresses to be below allowable.

The IDVP determined that the difference in horizontal frequency results was due to the incorrect application of the Rayleigh energy method in the design analysis (see Section 3.2.3). Differences in vertical natural frequency were due to different boundary conditions used by the analyses to model the mounting plate. The IDVP attributed the higher stresses in the verification analysis to the simply supported edge boundary condition assumed for the mounting plate.

3.2.6 Error and Open Item Reports Issued

The IDVP issued four EOI reports in connection with the auxiliary saltwater pumps. Appendix D shows the EOI number, revision, date and status.

EOI 1020 was issued because the IDVP determined that the Hosgri spectra used in the design analysis were preliminary spectra. However, these spectra are identical to those in the Hosgri report. EOI 1020 was classified as a deviation because of the IDVP concern regarding PGandE control of the design spectra.

EOI 1022 was issued because spectra applicable at the -2.1 feet floor elevation were also used by PGandE as input at the upper auxiliary saltwater pump support, which is located ten feet above -2.1 feet. The IDVP determined that response spectra were not available for this location in the intake structure. Because PGandE is reviewing and reanalyzing the intake structure as part of its internal technical program, EOI 1022 was combined with other intake structure EOIs (967 and 988) and classified as an error Class A or B.

EOI 1073 was issued because the verification analysis showed bolt stresses to exceed the allowable. In addition, a comparison of verification and design analyses stress results differed by more than 15%.

PGandE clarification of the auxiliary saltwater system operating condition showed that the actual pump discharge pressure was less than the value used in the verification analysis. When the actual discharge pressure was used, the verification analysis stresses were below allowable.

The stress differences between the verification and design analyses were caused in part by PGandE's incorrect application of the Rayleigh energy frequency calculation method. (See Section 3.2.3). Approximate third mode shape displacements were assumed rather that the first mode shape displacements, which has a significant contribution to the overall dynamic response (see Figure 6). Different boundary conditions assumed by the analyses also contributed to differences in results. Because of the incorrect application of the Rayleigh energy method, EOI 1073 was classified as a Class C error.

EOI 1114 was issued because the design analysis did not consider the virtual hydrodynamic mass as part of the mass of the submersed portion of the pump. The verification analysis included the hydrodynamic mass and found all stresses to be below allowables. Therefore, EOI 1114 was classified as a Class C error.

3.3 COMPONENT COOLING WATER PUMP

Three component cooling water pumps are located at elevation 73 feet in the Unit 1 portion of the auxiliary building. These pumps are electric motor-driven, single stage, centrifugal pumps. The electric motor driver and pump are mounted on separate pedestals, which are welded to a common base plate structure. Motor and pump shafts are connected by a flexible coupling. The base plate assembly is attached to the concrete floor slab with six cast-in-place anchor bolts and constructed from a raised plate built on steel members. The area around these channels and under the plate comprises a cavity which is then filled with grout. In effect, the base plate assembly is grouted to the floor slab, embedding the channels in grout.

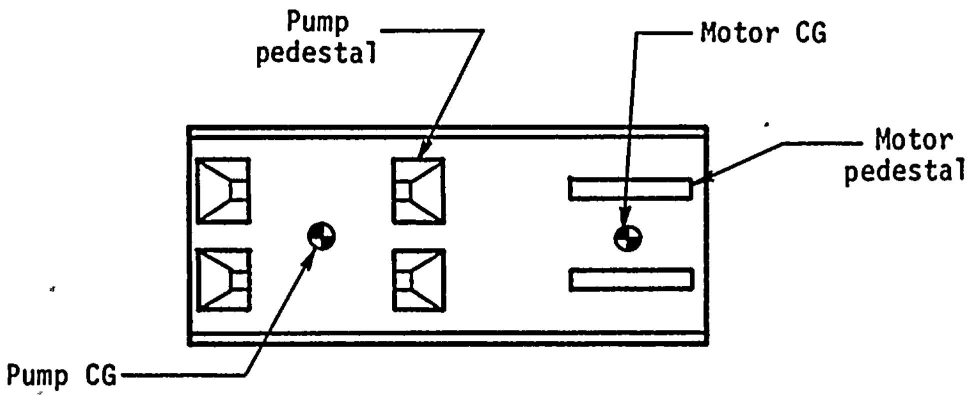
Figure 7 shows the general configuration of the component cooling water pump.

The motor mounting pedestal is constructed from steel plates. A 4300 pound motor is bolted to this pedestal and two jacking dowels are installed at diagonally opposite motor mounting feet.

The 5900 pound pump is mounted on four separate pedestal legs welded to the base plate assembly. Each of the four pump feet is bolted to the pedestals, and dowel pins are installed between the pump feet and the pedestals to withstand shear loads (see Figure 8). The specific configuration of these pins is discussed in Section 3.3.1.

3.3.1 Method of Verification Analysis

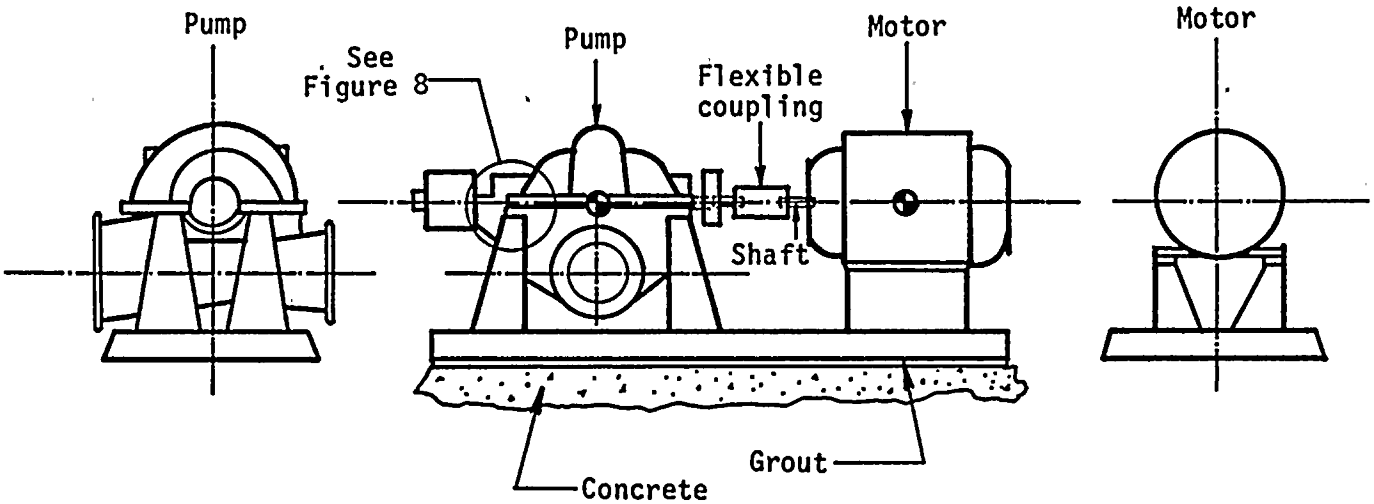
The IDVP developed mathematical models for analysis after field verifying the dimensions of the pump and supporting structure. Since the pump and the motor are connected only by the flexible coupling, each component and supporting structure including the common base plate was analyzed separately (Reference 10). The seismic loads were then combined to analyze the base plate.



Plan View

Base and Pedestals

(Pump and Motor Assemblies Not Shown)



Front View   Side View   Rear View

Figure 7

General Configuration of
Component Cooling Water Pump

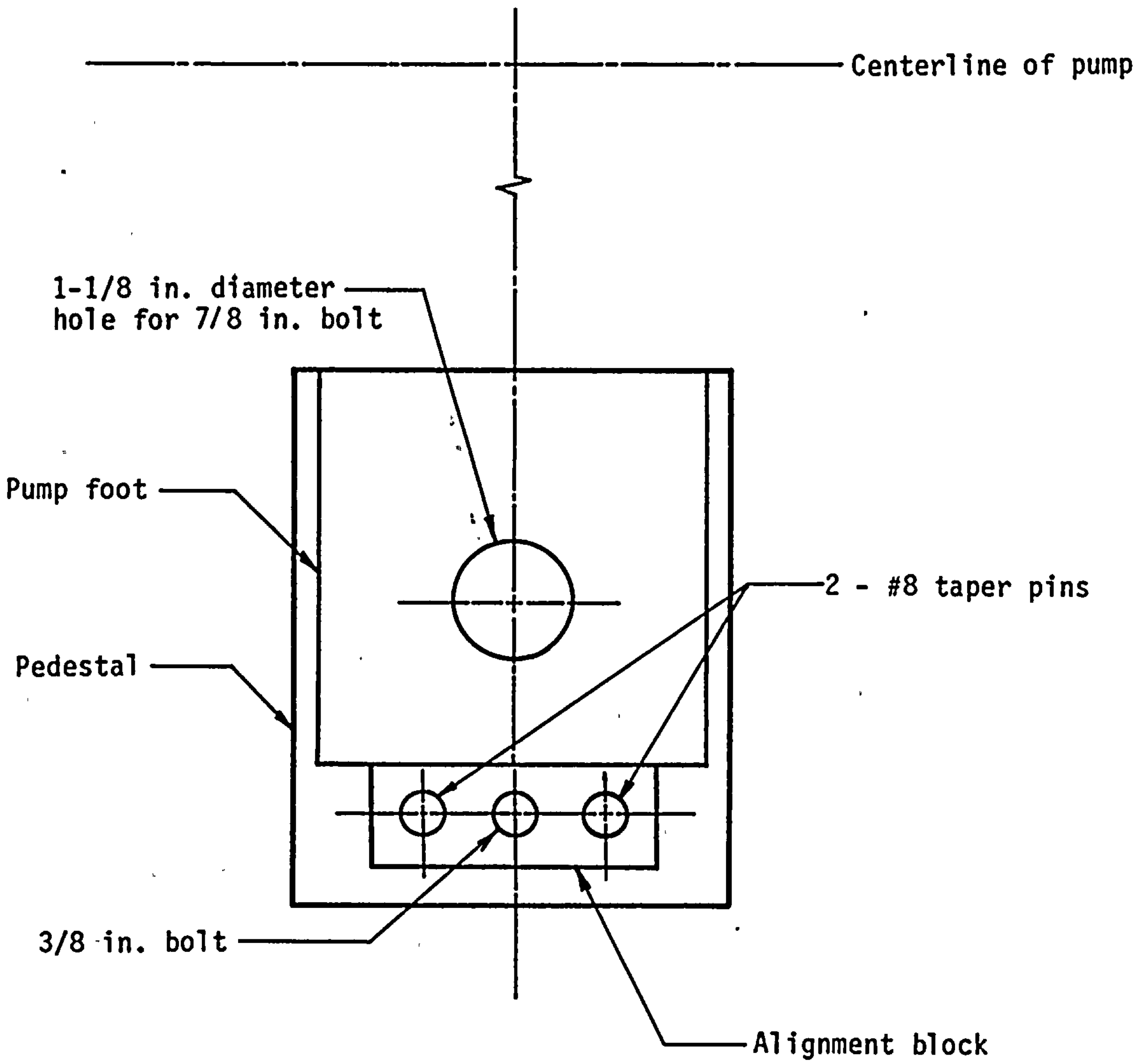


Figure 8
Plan View-Component Cooling Water Pump
Pump Foot / Pedestal

Motor

The motor and its pedestal were included in the model. A computer model of the motor support pedestal was developed using the STARDYNE structural analysis program. The pedestals were modeled using quadrilateral and triangular plate elements. The motor itself was considered rigid relative to the pedestal structure. A concentrated mass representing the total mass of the motor was lumped at the motor's center of gravity and connected by rigid beam elements to the motor mounting points on the pedestal model. The base of the pedestal, which is welded to the base plate assembly, was considered fixed.

From this computer model, the IDVP determined natural frequencies of the supporting structure using the STARDYNE Lanczos modal extraction technique. The first natural frequency result was verified by a closed form hand calculation. All natural frequencies were found to be greater than 33 hertz.

Seismic accelerations were chosen from Hosgri response spectra to correspond to the IDVP natural frequency results (see Appendix A).

The IDVP used the following acceleration values:

0.63 g horizonal
0.50 g vertical

The horizontal acceleration was the same in the North-South and East-West directions, because at elevation 73 feet where the pumps are located, free field Hosgri response spectra are to be used. A 4% damping value was specified; however, the value was irrelevant because all natural frequencies were in the rigid range.

Using these accelerations and the computer model, an equivalent static analysis was performed to determine the loads at key locations. The pump operating torque load was considered in developing the loads. Stresses were then calculated at the key locations and compared to allowable stresses as defined by the licensing criteria.

Pump

To analyze the pump supporting structure includ- the base plate, the pump and its pedestals were considered together. A computer model of the pump and the pedestals was developed using the STARDYNE structural analysis program. The pedestals were modeled using beam elements equivalent to the tapered pedestals' average cross-sectional properties.

The pump itself was considered rigid relative to the supporting structure. A concentrated mass representing the mass of the pump was lumped at the center of gravity. Rigid elements were used to connect the pump mass point to the pump mounting points at the pedestals and to represent the offset of the pump nozzles from the pump center of gravity. The base of the pedestals, which are welded to the base plate assembly, were considered fixed.

Upper and lower boundary condition cases were run to determine the natural frequencies because the exact configuration of the pump feet to pedestal mountings (i.e., dowel pin clearances, alignment block clearances, hold down bolt to mounting hole clearances, hold down bolt preload, etc.) was not precisely known.

The first case considered that no sliding would occur and that the loading would be evenly distributed between each of the four pedestals. The second case did not account for any axial restraint at the two pedestals on the motor side of the pump. It also allowed for sliding in the axial direction between the pump feet and alignment block. Each block was able to resist the lateral load in one direction only. Thus, the lateral load was resisted at three points: each of the two hold down bolts at the pump motor end and one of the alignment blocks.

Nevertheless, for both boundary condition cases, all natural frequencies were found to be greater than 33 hertz.

Seismic accelerations were chosen from Hosgri response spectra to correspond to the IDVP natural frequency results (see Appendix A). Because the pumps are located at elevation 73 feet and all frequencies are in the rigid range, zero period free field accelerations were used.

The acceleration values for the pump analysis, listed below, are the same as those used in the motor analysis.

0.63 g horizontal
0.50 g vertical

Seismic accelerations, deadweight, pump torque loading and pump nozzle loads were used in an equivalent static analysis with each of the two boundary condition cases. The IDVP reviewed loads from each model. Worst case loads from both models were selected for key locations. Stresses were calculated from these loads and compared to the allowable stresses as defined by the licensing criteria.

Pump Shaft

A simple beam model was developed for the pump shaft to calculate the shaft natural frequency, stresses and maximum deflection. Using a closed form solution, the shaft was modeled as a simply supported, uniformly loaded beam with a concentrated load representing the impeller weight. Its natural frequency was found to be greater than 33 hertz.

The shaft was then subjected to the same seismic accelerations and deadweight as the motor and pump. Shaft seismic bending stresses were calculated. Shaft shear stress due to pump torque loading was also determined. Maximum shaft deflection was compared to the existing clearance in the impeller wear ring at the center of the shaft.

Base Plate

The IDVP combined loadings from the separate analyses of the motor and the pump to find the net loading on the base plate assembly. Loads and stresses were calculated at key locations. The results were compared to the allowable stresses as defined by the licensing criteria.

3.3.2 Results of Verification Analysis

The IDVP computed stresses at the following key areas and compared them to the allowable stresses defined by the licensing criteria. The results show that all stresses are below the allowables.

	Computed	Allowable
Motor foot	645 psi	22,700 psi
Motor hold down bolts	.0013 **	1.0 **
Motor shear pin	12,314 psi	17,400 psi
Motor support pedestal	1,966 psi	22,700 psi
Pump nozzle	4,000 psi	31,500 psi
Pump/pedestal mounting pad welding	1,068 lb/in	3,181 lb/in
Pump hold down bolts*	.34 **	1.0 **
Pump shear pins at alignment block	28,692 psi	34,200 psi
Pump support pedestal	6,672 psi	22,700 psi
Pump shaft (bending)*	1,345 psi	36,000 psi
Pump shaft deflection*	0.006 in	0.025 in
Base bolting (tensile)	40,482 psi	40,600 psi
Base plate shear	6,207 psi	22,700 psi

* Areas that are also explicitly evaluated in the design analysis

** Combined shear/tension interaction ratio

Table 5

Verification Analysis - Stresses
Component Cooling Water Pump

3.3.3 Design Analysis Methods

The design analyses for the component cooling water pumps consisted of separate analyses of the pump pedestals, pump shaft, motor foundation and base bolting (Reference 11).

The pump and its pedestals were analyzed in two separate calculations. A STRUDL computer code model was developed in one case and a simplified beam model in the other. The STRUDL analysis calculated a natural frequency greater than 33 hertz, using a pedestal wall thickness of 1/2 inch. The simplified beam analysis conservatively calculated a natural frequency of 26.4 hertz, using a pedestal wall thickness of 1/4 inch. (Information suppled to the IDVP indicates the correct wall thickness is 3/8 inch, Reference 12.) Stresses were also calculated for the pump bolts and the taper pins.

For the pump shaft, the design analysis calculated a natural frequency of 209 hertz using Rayleigh's energy method. This reflects the use of an impeller weight lighter than the actual weight. A later calculation shows a correct impeller weight was used to calculate shaft deflections and stresses.

The design analysis of the motor and its foundation considered the motor support to be rigid and calculated a natural frequency of 503 hertz. This natural frequency result did not include the effects of the pump and motor pedestals. Later, a revised design analysis was performed for the pump that included the pedestals.

3.3.4 Comparison of Verification and Design Methods

In general, different methods were used by the verification and design analyses for each of the major pump components. These methods are discussed in Sections 3.3.1 and 3.3.3. The verification analysis used individual STARDYNE computer models for the pump and motor. Loads were then combined to analyze the base. The design analysis used computer and hand calculations for the pump, while hand calculations were used for the pump shaft, motor foundation and base bolting.

The verification analysis show all frequencies to exceed 33 hertz. Therefore, the simplified modeling assumptions used in the design analysis were found to be acceptable.

The verification and the design analyses of the shaft stresses and deflections compared closely, although the frequency results differed. The design analysis of the pump shaft is discussed in Section 3.3.3.

3.3.5 Comparison of Verification and Design Results

IDVP compared their results listed in Section 3.3.2 with results from the design analysis as shown below:

	Verification Analysis	Design Analysis
Pump horizontal natural frequency	38.8 hz	26.4/88 hz*
Pump shaft natural frequency	54 hz	209 hz*
Motor horizontal natural frequency	71.9 hz	503 hz
Pump shaft deflection	.006 in	.006 in
Pump hold down bolting stress		
shear	10,454 psi	24,570 psi
tension	34,559 psi	36,500 psi
Pump shaft stress		
torsion shear stress	1,396 psi	1,474 psi
bending stress	1,345 psi	2,159 psi

* See Section 3.3.3

Table 6

Comparison of Stresses - Verification/Design Analyses, Component Cooling Water Pump

3.3.6 Error and Open Item Report Issued

The IDVP issued one EOI report in connection with the component cooling water pump. Appendix D shows the EOI number, revision, date and status.

EOI 1113 was issued because the results of the verification analysis differed from those of the design analysis by more than 15%. EOI 1113 was closed because all stresses were below allowable in both analyses. Differences in results were attributed to variations in methods and weights used by the analyses.

4.0 EVALUATION OF PUMP ANALYSIS

4.1 INTERPRETATION

The IDVP performed analyses for three samples of pumps: turbine-driven auxiliary feedwater, auxiliary saltwater and component cooling water. The results were compared to the allowables and design analysis results. All stresses were found to be below the allowables.

Six EOIs have been issued as a result of the comparison of verification and design analyses methods and results (EOIs 1020, 1022, 1072, 1073, 1113 and 1114). Three concerns have been noted:

- Spectra were not available for the upper support arm on the auxiliary saltwater pump. In addition, preliminary spectra (though identical to Hosgri spectra) were used in two of the design analyses.
- In applying the Rayleigh energy method, the design analysis for the auxiliary saltwater pump incorrectly assumed the third mode shape.
- The design analysis did not consider the effects of the virtual hydrodynamic mass on the submerged portion of the auxiliary saltwater pump.

4.2 RECOMMENDATIONS

The following recommendations address the concerns described in the previous section:

- Review all seismic inputs as already set forth in the DCP corrective action program.
- Review the design analyses of the two remaining pumps analyzed by PGandE or its seismic service-related contractors for the Hosgri earthquake (fuel oil transfer and motor driven auxiliary feedwater). The purpose of the review is to assure that the Rayleigh energy method and virtual hydrodynamic mass were applied correctly.

The DCP may opt to include the second recommendation in the corrective action program subject to IDVP verification.

5.0 CONCLUSION

The IDVP performed verification analyses for three samples of pumps. All stresses were found to be below the allowables and therefore, the pumps met the licensing criteria. As a result of comparing the verification results to the design analysis results, three concerns have been noted - seismic inputs, application of the Rayleigh energy method and consideration of virtual hydrodynamic mass. The present DCP corrective action program addresses the first concern. The IDVP has made recommendations to address the second and third.

6.0 REFERENCES

Reference No.	Title	RLCA File No.
1	DCNPP Independent Design Verification Program, Phase I, Revision 1, July 6, 1982 (Revision 0, March 29, 1982).	
2	Preliminary Report, Seismic Reverification Program, Robert L. Cloud Associates, November 12, 1981.	
3	DCNPP Independent Design Verification Program, Program Procedure, Phase I, Engineering Program Plan, Revision 0, March 31, 1982.	
4	Diablo Canyon Site Units 1 and 2 Final Safety Report, USAEC Docket.Nos. 50-275 and 50-323.	P105-4-200-005
5	Seismic Evaluation for Postulated 7.5M Hosgri Earthquake, USNRC Docket Nos. 50-275 and 50-323.	P105-4-200-001
6	RLCA Verification Analysis of the Turbine-Driven Auxiliary Feedwater Pump, Revision 2, January 31, 1983.	P105-4-550-010
7	Tab G from PGandE M&NE File 119.51, Seismic Calculations	P105-4-435-011 P105-4-435-012 P105-4-435-013
8	RLCA Verification Analysis of the Auxiliary Saltwater Pump, Revision 4, February 17, 1983.	P105-4-550-011
9	Seismic Calculations from PGandE M&NE File 116.31.	P105-4-435-001

Reference No.	Title	RLCA File No.
10	RLCA Verification Analysis of the Component Cooling Water Pump, Revision 1, January 25, 1983.	P105-4-550-029
11	Seismic Calculations in Tab G of PGandE M&NE File 140.063.	P105-4-435-008
12	Bingham Pump Company, Drawing D-10885X, Revision A, 9-16-69.	P105-4-435-028
13	Independent Design Verification Program, Program Procedure, Preparation of Open Item Reports, Error Reports, Program Resolution Reports and IDVP Completion Reports DCNPP-IDVP-PP-003, Revision 1, 6/18/82.	

Appendix A
Hosgri Response Spectra Considered
in IDVP Pump Analysis
(1 page)

APPENDIX A

HOSGRI RESPONSE SPECTRA CONSIDERED IN THE IDVP PUMP VERIFICATION ANALYSES

Turbine Driven Auxiliary Feedwater Pump

Horizontal:	Figures*	4-114, 4-119, 4-123, 4-127, 4-132, 4-137, 4-141, 4-145
Vertical:	Figure*	4-150

Auxiliary Saltwater Pump

Horizontal:	Figures*	4-1, 4-4
Vertical:	Figures*	3-4, 3-5

Component Cooling Water Pump

Horizontal:	Figures*	4-2, 4-5
Vertical:	Figures*	3-4, 3-5

* Figure numbers correspond to those from the Hosgri Report (Reference 5).

Appendix B
Licensing Criteria
(2 pages)

Appendix B

Licensing Criteria

Component (1,2)	Loading Combinations (3)	Criteria (4,5,6,7)
Active Pumps	Deadweight + Pressure + Seismic + Nozzle Loads	$\sigma_m \leq 1.2S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$

(1) Active : Mechanical equipment which is needed to go from normal full power operation to cold shutdown following the earthquake and which must perform mechanical motions during the course of accomplishing its design function..

(2) Inactive : Mechanical equipment which is not required to perform mechanical motions in taking the plant from normal full power operation to cold shutdown following the earthquake..

(3) Nozzle loads shall include all piping loads transmitted to the component during the Hosgri earthquake.

(4) σ_m = general membrane stress. This stress is equal to the average stress across the solid section under consideration, excludes discontinuities and concentrations and is produced only by mechanical loads.

(5) σ_L = local membrane stress. This stress is the same as σ_m except that it includes the effect of discontinuities.

(6) σ_b = bending stress. This stress is equal to the linear varying portion of the stress across the solid section under consideration, excludes discontinuities and concentrations, and is produced only by mechanical loads.

(7) S = code allowable stress value. The allowable stress shall correspond to the highest metal temperature at the section under consideration during the condition under consideration.

Note: Taken from the Hosgri Report, Table 7-1, "Hosgri Seismic Evaluations, Loading Combinations and Structural Criteria-Mechanical Equipment"

Support	Loading Combinations(3)	Criteria(4,5,6)
Linear Supports(2)	Deadweight + Seismic + Nozzle Loads	ASME Code Appendix XVII and Appendix F (Stresses not to exceed S_y for active components)
Plate and Shell(1) Active Components	Deadweight + Seismic + Nozzle Loads	$\sigma_m \leq 1.2S$ $(\sigma_m + \sigma_b) \leq 1.8S$
Bolts	Deadweight + Seismic + Nozzle Loads	ASME Code Appendix XVII and/or Code Case 1644 plus Appendix F

(1) Plate and Shell Type Supports: Plate and shell type component supports are supports such as vessel skirts and saddles which are fabricated from plate and shell elements and are normally subjected to a biaxial stress field.

(2) Linear Type Support: A linear type component support is defined as acting under essentially a single component of direct stress. Such elements may also be subjected to shear stresses. Examples of such structural elements are: tension and compression struts, beams and columns subjected to bending, trusses, frames, arches, and cables.

(3) Nozzle loads shall be those nozzle loads acting on the supported component during the Hosgri earthquake.

(4) σ_m = general membrane stress. This stress is equal to the average stress across the solid section under consideration, excludes discontinuities and concentrations and is produced only by mechanical loads.

(5) σ_b = bending stress. This stress is equal to the linear varying portion of the stress across the solid section under consideration, excludes discontinuities and concentrations, and is produced only by mechanical loads.

(6) S = Code allowable stress value. The allowable stress shall correspond to the highest metal temperature at the section under consideration during the condition under consideration.

Note: Taken from the Hosgri Report, Table 7-2, "Hosgri Seismic Evaluation Loading Combinations and Structural Criteria Mechanical Equipment Supports"

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Appendix C
Key Term Definitions
(6 pages)

KEY TERMS AND DEFINITIONS USED IN THE PUMP REPORT

(The definitions in this glossary establish the meanings of words in the context of their use in this document. These meanings in no way replace the specific legal and licensing definitions.)

Acceptance Criteria

- The comparison between the design analysis and the independent analysis where the results must agree within 15% and be below allowable. Failure to meet this acceptance criteria results in the issuance of an Open Item.

Allowable Criteria

- Maximum stress or load provided by the licensing criteria.

Closed Item

- A form of program resolution of an Open Item which indicates that the reported aspect is neither an Error nor a Deviation. No further IDVP action is required (from Reference 13).

Completion Report

- Used to indicate that the IDVP effort related to the Open Item identified by the File Number is complete. It references either a Program Resolution Report which recategorized the item as a Closed Item or a PGandE document which states that no physical modification is to be applied in the case of a Deviation or a Class D Error (from Reference 13).

DCNPP-1

- Diablo Canyon Nuclear Power Plant Unit 1

Design Codes

- Accepted industry standards for design (ex. AISC, AISI, ANSI, ASME, AWWA, IEEE).

EOI

- Error and Open Item Report

Error Report

- An Error is a form of program resolution of an Open Item indicating an incorrect result that has been verified as such. It may be due to a mathematical mistake, use of wrong analytical method, omission of data or use of inapplicable data.

  Each Error shall be classified as one of the following:

- o Class A: An Error is considered Class A if design criteria or operating limits of safety related equipment are exceeded and, as a result, physical modifications or changes in operating procedures are required. Any PGandE corrective action is subject to verification by the IDVP.
- o Class B: An Error is considered Class B if design criteria or operating limits of safety related equipment are exceeded, but are resolvable by means of more realistic calculations or retesting. Any PGandE corrective action is subject to verification by the IDVP.
- o Class C: An Error is considered Class C if incorrect engineering or installation of safety related equipment is found, but no design criteria or operating limits are exceeded. No physical modifications are required, but if any are applied they are subject to verification by the IDVP.
- o Class D: An Error is considered Class D if safety related equipment is not affected. No physical modifications are required, but if any are applied, they are subject to verification by the IDVP (From Reference 13).

Equivalent static method

- Static analyses methodology whereby an acceleration figure is applied to the component configuration.

FSAR

- PGandE's Final Safety Analysis Report

Hosgri Criteria

- Licensing criteria referring specifically to the postulated 7.5M Hosgri earthquake.

Hosgri Report

- A report issued by PGandE that summarizes their evaluation of the DCNPP-1 for the postulated Hosgri 7.5M earthquake. Includes seismic licensing criteria.

Hosgri 7.5M Earthquake

- Maximum intensity earthquake for which the plant is designed to remain functional. Same as Safe Shutdown Earthquake (SSE).

Interim technical report

- Interim technical reports are prepared when a program participant has completed an aspect of their assigned effort in order to provide the completed analysis and conclusions. These may be in support of an Error, Open Item or Program Resolution Report or in support of a portion of the work which verifies acceptability. Since such a report is a conclusion of the program, it is subject to the review of the Program Manager. The report will be transmitted simultaneously to PGandE and to the NRC (From Reference 1).

Licensing Criteria

- Contained in PGandE Licensing Documents, includes allowable criteria (See Hosgri Report definition).

NRC

- Nuclear Regulatory Commission

NRC Order Suspending License CLI-81-30

- The order dated November 19, 1981 that suspended the license to load fuel and operate DCNPP-1 at power levels up to 5% of full power and specified the programs that must be completed prior to lifting of the suspension.

Open Item

- A concern that has not been verified, fully understood and its significance assessed. The forms of program resolution of an Open Item are recategorized as an Error, Deviation, or a Closed Item. (From Reference 13).

PGandE

- Pacific Gas and Electric Company

Phase I Program

- Review performed by RLCA, RFR, and TES restricted to verifying work performed prior to June 1978 related to the Hosgri re-evaluation design activities of PGandE and their service-related contractors.

Potential Program Resolution Report
and Potential Error Report

- Forms used for communication within IDVP.

Program Resolution Report

- Used to indicate that the specific item is no longer active in the IDVP. It indicates whether the resolution is a Closed Item, a Deviation, or that responsibility for an Open Item has been transferred to the PGandE Technical Program. Further IDVP action is required upon completion of the associated PGandE Technical Program Task if the IDVP transfers an Open Item to PGandE or if physical modifications are applied with respect to a deviation (Reference 13).

Rayleigh-Energy Method

- A computational method to find the approximation of a system's frequency.

Response

- The motion resulting from an excitation of a device or system under specified conditions.

Response Spectra

- Graph showing relationship between acceleration and frequency. Used in seismic analysis.

Response Spectra Modal Superposition

- Dynamic analysis methodology whereby responses are calculated separately on a mode by mode basis and then combined.

RLCA

- Robert L. Cloud and Associates, Inc.

RFR

- Roger F. Reedy, Inc.

Sample

- Initial sample stipulated in Phase I Program of equipment, components, and buildings to be design verified by independent analysis.

Sampling Approach

- Method used by the IDVP to determine the initial sample (buildings, piping, equipment and components) for analysis and to provide for sample expansion when required.

SSE

- Safe Shutdown Earthquake: Maximum intensity earthquake for which the plant is designed to remain functional (Hosgri 7.5M).

Seismic

- Refers to earthquake data.

Single Degree of Freedom Model

- Simplified mathematical representation of a structure.

SWEC

- Stone & Webster Engineering Corporation

TES

- Teledyne Engineering Services

Verification Program

- Undertaken by the IDVP to evaluate Diablo Canyon Nuclear Power Plant for compliance with the licensing criteria.

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Appendix D
EOI Status - Pumps
(1 page)

EOI Status - Pumps

EOI File No.	Subject	Rev.	Date	By	Type	Action Required	Physical Mod.
1020	Auxiliary Saltwater Pumps-Preliminary Spectra	0	2/18/82	RLCA	OIR	RLCA	
		1	3/17/82	RLCA	PPRR/DEV	TES	
		2	4/20/82	TES	PRR/DEV	TES	
		3	6/29/82	TES	CR	None	No
1022	Auxiliary Saltwater Pumps-Spectra at upper support	0	2/18/82	RLCA	OIR	RLCA	
		1	4/30/82	RLCA	PPRR/OIP	TES	
		2	5/10/82	TES	PRR/OIP	PGandE	
		3	9/3/82	TES	OIR	RLCA	
		4	9/7/82	RLCA	PER/AorB	TES	
		5	9/10/82	TES	ER/AorB	PGandE	
1072	Turbine Driven Auxiliary Feedwater Pump-Frequency and Spectra Differences	0	3/23/82	RLCA	OIR	RLCA	
		1	6/8/82	RLCA	PPRR/DEV	TES	
		2	7/8/82	TES	PRR/DEV	TES	
		3	9/10/82	TES	CR	None	No
1073	Auxiliary Saltwater Pumps-Stress Differences & Rayleigh-Ritz method	0	3/23/82	RLCA	OIR	RLCA	
		1	6/8/82	RLCA	PER/C	TES	
		2	6/21/82	TES	ER/C	PGandE	
		3	7/8/82	TES	CR	None	No
1113	Component Cooling Water Pump-Stress Differences	0	2/1/83	RLCA	OIR	RLCA	
		1	2/1/83	RLCA	PPRR/CI	TES	
		2	2/4/83	TES	PRR/CI	TES	
		3	2/4/83	TES	CR	None	No
1114	Auxiliary Saltwater Pump-Virtual Mass of Submerged Pump	0	2/15/83	RLCA	OIR	RLCA	
		1	2/15/83	RLCA	PER/C	TES	
		2	2/15/83	TES	ER/C	PGandE	No

STATUS: Status is indicated by the type of classification of latest report received by PGandE:

OIR - Open Item Report
PPRR - Potential Program Resolution Report
PRR - Program Resolution Report
PER - Potential Error Report
OIP - Open Item with future action by PGandE

ER - Error Report
CR - Completion Report
CI - Closed Item
DEV - Deviation

A - Class A Error
B - Class B Error
C - Class C Error
D - Class D Error

PHYSICAL MOD: Physical modification required to resolve the issue. Blank entry indicates that modification has not been determined.

Appendix E
Program Manager's Assessment
(1 page)

APPENDIX E

PROGRAM MANAGERS ASSESSMENT

As IDVP Program Manager, TELEDYNE ENGINEERING SERVICES (TES) has established a Review and Evaluation Team, headed by a qualified team leader, as described in Section 7.4 (f) of the Phase I Program Management Plan (Rev.1). The assigned team leader for the area, Pumps, included in this Interim Technical Report, has personally discussed the procedures, approach, field trip files, analyses, calculations, etc. with RLCA personnel. In addition, the TES Team Leader has reviewed the Open Item Files pertaining to this area of responsibility and, in particular, those files for which RLCA has issued Potential Program Resolution Reports or Potential Error Reports, and on the basis of this evaluation, has recommended appropriate resolutions to the IDVP Program Manager.

Based on this review and evaluation process to date, the Team Leader, along with the TES Program Manager Team, has studied and has concurred with the Interpretation and Recommendations outlined in Section 4.0 of this report.