WOLF CREEK GENERATING STATION
ESSENTIAL SERVICE WATER SYSTEM
PUMP RESTRAINT EMBED REPORT

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Gaithersburg, Maryland
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TABLE OF CONTENTS

* Not included in this transmittal. These appendices are available for review.

1.0 INTRODUCTION

1.1 History

On November 13, 1981, a potentially significant deficiency was reported by E. W. Creel of Kansas Gas and Electric to G. L. Madsen of NRC Region IV in accordance with 10 CFR 50.55(e). The deficiency involved the apparent failure of several embedded plates supporting the Essential Service Water System (E.S.W.S.) Pump seismic restraints. Plate deformations were observed at all plates. Failure of the anchor studs on at least one plate was also observed.

The subject plates are embedded in the west wall of the E.S.W.S. pumphouse forebay structure and are utilized for the attachment of six stainless steel seismic restraints (3 each pump) to the concrete forebay wall. The pump and restraints are illustrated in Figure 1. The restraints are designed to provide lateral support during a seismic event for the pump column extending from the operating floor at elevation 2000'-0" to the forebay intake level at elevation 1958'-0". The supports are located at elevations 1965'-7-3/8", 1975'-7-3/8" and 1990'-7-3/8".

Subsequent investigations at the site on November 19, 1981 by engineering and metallurgical personnel failed to determine the exact cause and extent of the deficiency, since the majority of the plate anchor stud welds could not be visually inspected.

In order to evaluate the significance and cause of the reported deficiency and determine its impact on the safe operation of the E.S.W.S. system, as well as its generic implications throughout the plant, a systematic investigative approach was developed as follows:

a. Remove one of the affected embedded plates (including anchor studs) from the wall and perform material laboratory tests to determine the adequacy of the material utilized and establish the cause of the deficiency.

b. Perform a detailed worst-case analysis of the non-conforming restraint attachments to provide a conservative estimate of their effect on pump operability had the reported deficiency not been detected and corrected.

c. Perform an investigation of typical attachment details throughout the plant to determine whether there exist any generic implications for the reported deficiency.

Material laboratory tests were initiated at Fritz Engineering Laboratories, Lehigh University and completed on January 13, 1982. A test report, including the results of detailed investigations performed on the attachment welds, was completed on February 3, 1982. The engineering analysis was performed based on these test results.

1.2 Action Taken to Correct Deficiency

All E.S.W.S. pump restraint attachments to the concrete wall have been reworked in accordance with a repair procedure designed to transfer pump loads to the wall without utilizing the deficient embedded plates. The repair procedure details are shown in Appendix I. The restraints have therefore been restored to a configuration which satisfies the original design intent.

1.3 Purpose of Report

This report is intended to outline the details and results of the material testing, analyses and investigations carried out to evaluate the reported deficiency and to provide recommendations and conclusions as to its impact on plant safety and operation.

2.0 DESCRIPTION OF DEFICIENCY

2.1 Restraint and Attachment Details

The six affected restraints are identified as hangers No. K-EF11-R001 through and including K-EF11-R006. Two carbon steel embedded plates, 1'-0" wide x 4'-0" long x ½" thick with fourteen 3/4" diameter x 7" long concrete anchor studs are provided at each restraint for attachment to the forebay concrete wall. The restraints are attached to the embedded plates at four locations using 8" wide x 11" long x 1" thick stainless steel plates (Item 16) welded to the embedded plates with 7/16" fillet welds on three sides. Restraint and attachment details are provided in Figure 2.

2.2 Nonconformance Report

Nonconformance report no. 1SN-3884-C dated November 13, 1981 (Appendix I) documented deformations of the twelve carbon steel embedded plates with associated surface spalling of the concrete wall surrounding the plates.

The deformations were identified as curling of the embedded plate edges outward away from the concrete wall, and were discovered after welding of the 1 inch stainless steel plates (Item 16).

Maximum distortions were reported to have occurred at the upper portion of the south embedded plate for restraint no. K-EF11-R003. Inspection of this plate revealed that at least the top three anchor studs had separated from the plate at their welds. This plate was chosen for removal and testing. It was later discovered that actually the uppermost four anchor studs had separated from the plate. In addition to the nonconforming plate, a spare plate, identical to the plates installed in the wall, was also chosen for testing.

3.0 MATERIALS TESTING PROGRAM

3.1 Program Description

In order to determine the adequacy of the embedded plate and anchor stud materials, determine the quality of workmanship provided by the plate supplier and establish the cause of the plate distortions, laboratory investigations conducted at Fritz Engineering Laboratories by Dr. John W. Fisher and Dr. Roger G. Slutter were carried out as follows:

a. Tension tests of the studs remaining on the nonconforming plate and the studs on the spare plate were performed to determine yield and ultimate pull-out capacities.

b. Fractographic and metallographic examinations at the fracture surfaces of the nonconforming plate studs and the spare plate studs were performed to obtain a comparison of failure mode characteristics between the failed studs and the spare plate studs.

c. Stainless steel to carbon steel plate welds were cross-sectioned and plate deformations were measured to identify the cause of the distortions.

Appendix II outlines detail procedures developed for the testing program. Appendix III, the final report prepared by Dr. Fisher and Dr. Slutter, provides detailed descriptions, tabulates the results of the tension tests and provides conclusions regarding their findings.

3.2 Summary of Test Program Results

With the exception of one anchor stud on the nonconforming plate (Specimen A3), which had visible extensive weld damage, the ten remaining studs on the nonconforming plate and the fourteen studs on the spare plate achieved ultimate capacities above the ultimate capacities recommended by the stud manufacturer as a basis for design (23.8 kips).

Appendix III tabulates the results of all anchor studs tension tests conducted and outlines the procedures, methodology and results for the fractographic and metallographic investigations as well as the cross-sectional studies.

3.3 Test Program Conclusions and Cause of Nonconformance

The results of the testing program indicate that no supplier deficiencies exist regarding the material of the carbon steel plates and the anchor studs or the installation (machine welding) of the studs on the plates.

The cross-sectional studies of the stainless steel attachment plate and the carbon steel plate clearly indicate that the plate deformations are the result of transverse shrinkage due to excessive weld material deposited at the connection of the stainless steel restraint attachment plate (Figure 2, Item 16). Examination of the cross-sectional photographs (Appendix III, Figure 75 through 78, and 85) indicates the stainless steel attachment weld size (leg size) is in the range of 1/2" to 3/4"; this is apparent by visual comparison of the weld to the 1" thick stainless steel plate.

Since the required weld size is 7/16", the attachment weld exceeds design requirements. Due to the fact that the amount of weld metal in a fillet weld increases as the square of the leg size, increasing the fillet weld leg size increases the corresponding transverse shrinkage force considerably. Although this shrinkage force increase may not be a factor in connections free to tolerate the corresponding deformations, it becomes critical in cases where the connection is restrained, such as embedded plates using large concrete anchor studs coupled with thick attachments and large welds.

The deformations of the free edge of the carbon steel plate caused by transverse shrinkage, apparently introduced excessive prying forces at the anchor studs, leading to the formation of cracks within the stud weld profile. These cracks can clearly be seen in Figures 43, 44 and 45 of Appendix III (Specimens A3, A1 and A5 respectively) and represent the direct cause of the anchor stud failures documented, as well as the low tension test value of specimen A3.

4.0 ENGINEERING ANALYSIS

4.1 Methodology

In order to determine the effects of the non-conforming restraint attachments on the capability of the pump to withstand a seismic event, a seismic analysis of the pump/restraint system was performed assuming a worst-case condition for all restraint attachments as reported for restraint K-EF11-R003. The analysis utilized the pump material and geometric properties provided in the vendor's seismic qualification report using Bechtel standard computer programs CE-917 "MODAL PROPERTIES OF STRUCTURES" and CE-918 "SPECTRAL RESPONSE."

In general, the analysis approach was as follows:

a. The vendor's pump/restraint system lumped mass model was duplicated for the CE-917 and CE-918 analyses (See Figures 3 and 4).

b. The vendor's original seismic input (floor response spectra) was duplicated in the CE-917 and CE-918 analyses and the results were compared to verify the accuracy of the analysis results.

c. The CE-917 and CE-918 lumped mass model in the East-West direction was adjusted to account for the effects of reduced spring constants at the pump support points due to the nonconforming condition of the restraints. The North-South restraint characteristics are not affected due to the pipe struts provided to the forebay concrete walls (See Figure 2).

d. The CE-917 and CE-918 analysis was performed for the adjusted model using floor response spectra input corresponding to a 0.15g level SSE.

e. The resulting stress levels in the pump components were evaluated against allowable stress criteria used for the original qualification of the pump.

f. The resulting stress levels in the restraints and non-conforming attachments were evaluated for structural integrity.

g. The resulting deformations of the pump column and restraints were evaluated for its effects on pump operability.

4.2 Seismic Analysis Considerations

A seismic input level to the pump associated with a 0.15g SSE was chosen in light of recent NRC concerns with respect to seismicity at the Wolf Creek site. The floor response spectra used for the analysis is identical to that used for the evaluation of other E.S.W.S. pumphouse components.

In adjusting the CE-917 and CE-918 model to account for the nonconforming restraint attachments, the restraint spring constants were calculated assuming all studs located under the upper and lower stainless steel plate attachment welds (Figure 2, Item 16) were failed anchor studs. This assumption accounts for uncertainties associated with the unknown extent of damage to the anchor studs on the embedded plates which were not removed from the wall, and provides a reasonable worst-case failure mechanism for analytical purposes. The analysis therefore is based on only six active studs of the original fourteen at each restraint attachment location. The active studs are located in the center area of the embedded plates where no welded attachment to the embedded plate exists.

Stress-strain characteristics consistent with the anchor stud laboratory test results were used to calculate the stiffness of the six active studs. The idealized failure mechanism used to represent the nonconforming restraint attachments in the seismic analysis is shown in Figure 2.

The vertical response accelerations for the 0.15g level earthquake are nearly identical to those used by the vendor in the original seismic qualification report. Therefore, vertical forces used to evaluate stress levels in the pump components were obtained directly from the vendor analysis. Vertical forces thus obtained were combined with the results of the North-South and East-West analysis using the SRSS method. Stress levels due to operating pressures, nozzle loads and increased seismic forces were investigated for each pump component listed below and outlined in the vendor's seismic qualification report:

a. Pump motor and discharge head

b. Foundation bolts

c. Column shell and flanges

d. Case bowl and flanges

e. Pump shaft

f. Pump shaft bearings

The nonconforming restraint attachments were investigated for vertical seismic and dead loads due to the weight of the restraint, as well as the horizontal seismic loads induced by the pump.

4.3 Other Considerations

Due to the reduced stiffness of the restraint attachments, the horizontal displacement of the pump column would increase at the restraint locations during a seismic event. Although these displacements do not overstress the pump components, they would cause the pump column to impact the west forebay concrete wall.

Therefore, the pump column was conservatively analyzed for this impactive effect using an energy balance approach equating the work done on the system by a constant maximum impulsive load acting through the displacement gap, to the available strain energy stored in the pump column. No credit was taken for energy absorbed by the concrete wall or the damping effects of the water within the forebay compartments.

5.0 ANALYSIS RESULTS

5.1 Pump

As would be expected, the support stiffness reduction caused by the flexibility of the nonconforming restraints, affects the natural frequencies of the pump. Although the rotating elements would have cycled through two lower modes upon pump start-up and shut-down, vibration problems during pump operation would not have been expected, since all natural frequencies are sufficiently removed from the pump operating speed as follows:

Mode	Frequency Hz
1	3.07
2	9.97
3	23.78
4	28.17
5	55.82
6	77.25

The pump operating speed of 885 RPM (14.75 Hz) is 48% above mode 2 and 38% below mode 3.

In general, the resulting stress levels in the various pump components are higher than the original design stresses due to the greater seismic response associated with the nonconforming condition of the restraint attachments. The increased stress levels, however, remain below the allowable stress criteria used by the vendor in his seismic qualification report. This is due primarily to the following factors:

a. The design stress levels contained in the vendor's seismic qualification report were maintained well below the allowable stress criteria. In some cases, design stresses are in the range of 10% to 20% of allowable.

b. In order to simplify his design analysis, the vendor used a conservative design approach by adding design stresses due to SSE, gravitational and normal operating conditions and comparing them to upset condition allowable stresses (1.5S) rather than faulted condition allowable stresses (1.8S) as allowed by the ASME Code. (S=Allowable stress for the component material)

Maximum shaft bearing loads due to horizontal seismic response occur at the impeller bearings within the case bowl, but were not found to affect bearing operation since the film thickness in the water lubricated bearings is sufficient to prevent metal to metal contact. Shaft stresses were found to be within original design allowables.

Maximum stresses due to impact of the pump column against the forebay concrete wall occur at the case bowl to column flange connection. Although the energy balance analysis indicates local yielding would occur at this flange connection during impact, this condition would not be considered to affect pump operation due to the conservative assumptions inherent in the analysis and the fact that no credit was taken for flange prestress. The analysis results show that ample reserve energy exists in the pump column system to absorb the postulated impact.

5.2 Restraints and Attachments

Maximum stresses and displacements for the restraints would occur at the attachment points to the carbon steel embedded plate. Due to the configuration of the idealized attachment failure mechanism (Figure 2), the plate is capable of tolerating relatively large horizontal deformations without exceeding yield stresses. The plate stresses associated with the calculated horizontal displacements are below the yield point of the plate material.

The maximum calculated loads for the active anchor studs were found to be well below the average ultimate loads obtained from the anchor tests as tabulated in Appendix III.

6.0 GENERIC IMPLICATIONS

In order to determine the possibility of similar occurrences at other hanger or restraint attachments throughout the plant, typical attachment details for pipe anchors, hangers and restraints, as well as other system supports were reviewed for similarity to the nonconforming attachment. Particular attention was given to thick stainless steel weldments on carbon steel embedded plates of ½" or less in thickness. The results of this review indicated that the attachment configuration used for the E.S.W.S. pump restraint is unique in light of the following factors:

a. Unusually high stiffness requirements imposed by the E.S.W.S. pump vendor resulted in a special attachment design in order to achieve restraint stiffness.

b. Typical hanger attachments are normally made by welding hanger members directly to the embedded plates, which minimizes the development of shrinkage forces parallel to the face of the embedded plate.

c. Bimetallic welding is not commonly used for hanger or restraint attachments to embedded plates.

d. Heavily loaded attachments to concrete walls or slabs such as pipe whip restraints or large pipe anchors utilize embedded or grouted anchor bolts and surface mounted base plates. Stiffener plates for these types of attachments are normally oriented perpendicular to the plate.

e. Carbon steel embedded plates ½" or less in thickness are utilized only for attachment of relatively lightly loaded supports, such as conduit and cable tray supports.

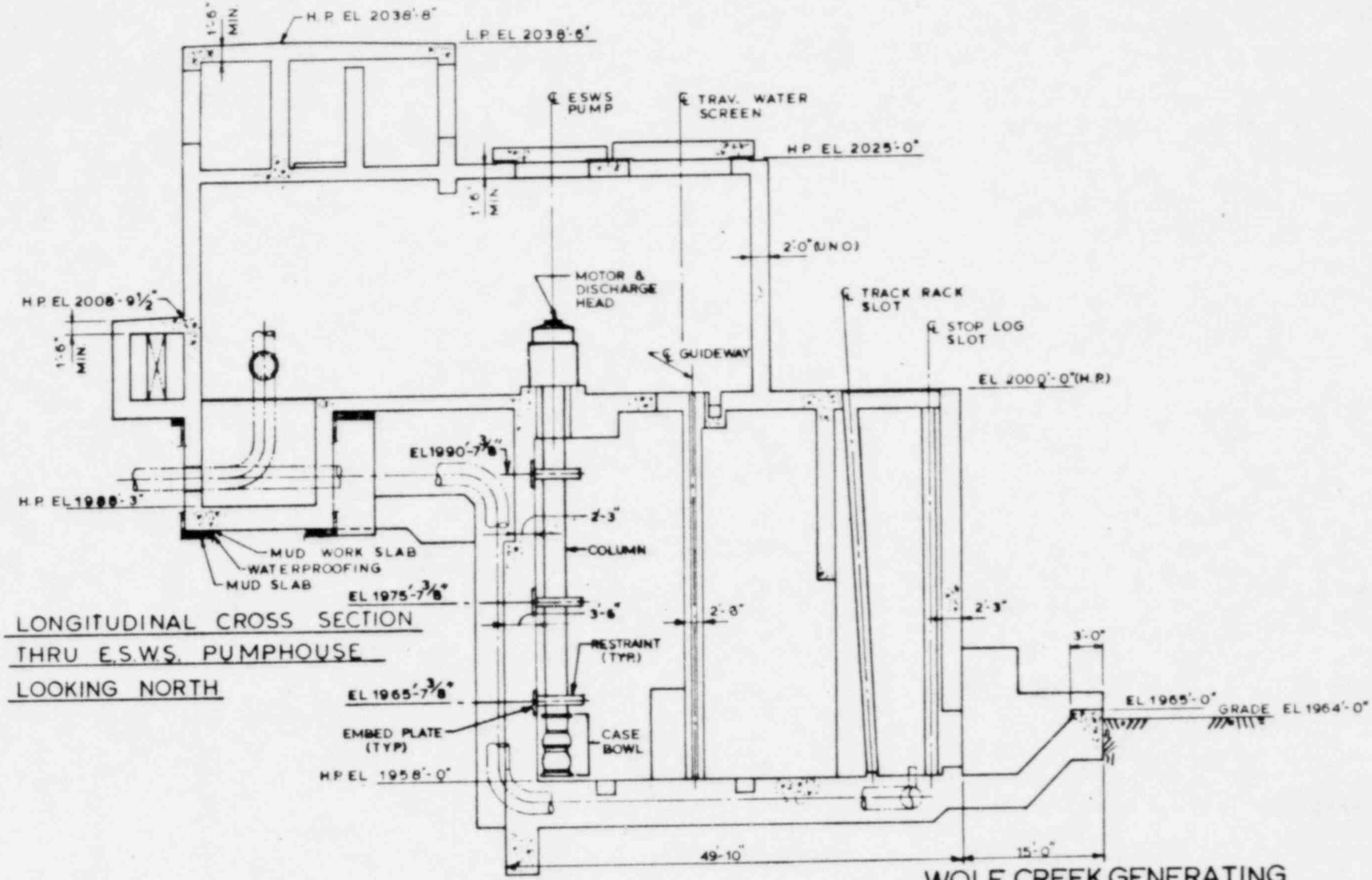
These factors clearly indicate the unique nature of the reported defficiency.

7.0 CONCLUSIONS

The results of the engineering analyses outlined in this report demonstrate that the operability of the E.S.W.S. pumps would not be compromised, and the structural integrity of the seismic restraints would be maintained during a postulated seismic event at the Wolf Creek site. Thus it can be concluded that, had the deficiency not been detected, the operation of the system would not have been adversely affected.

In addition, the results of the materials testing program demonstrate the adequacy of the material provided and preclude generic implications regarding the adequacy of other embedded plates used throughout the plant. Similarly, the review of typical hanger details indicates that the circumstances leading to the reported deficiency are unique in nature and may be considered not applicable to typical hanger attachments.

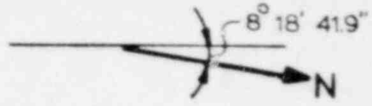
Therefore, the nonconforming conditions relating to the failed anchors and embedded plate deformations do not constitute a significant deficiency as defined by 10CFR 50.55(e).

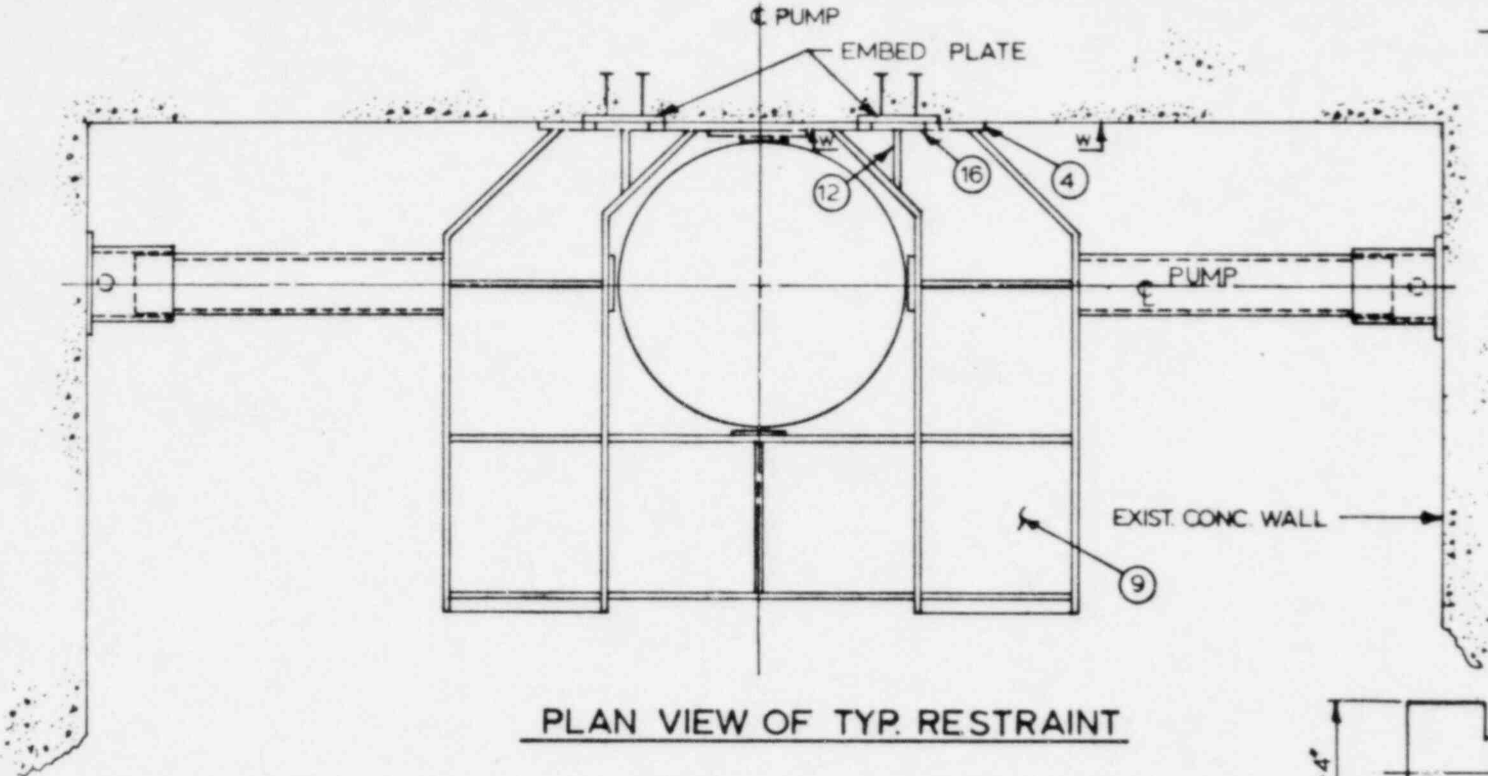


LONGITUDINAL CROSS SECTION
THRU E.S.W.S. PUMPHOUSE
LOOKING NORTH

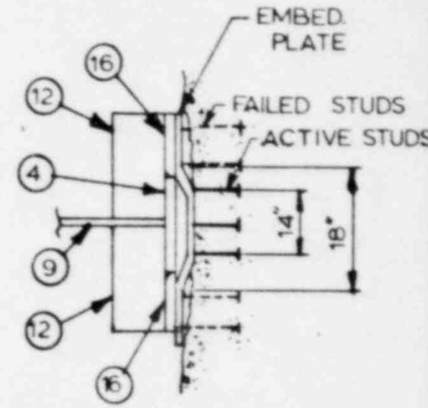
WOLF CREEK GENERATING STATION E.S.W.S. PUMP RESTRAINT EMBED REPORT

FIGURE 1

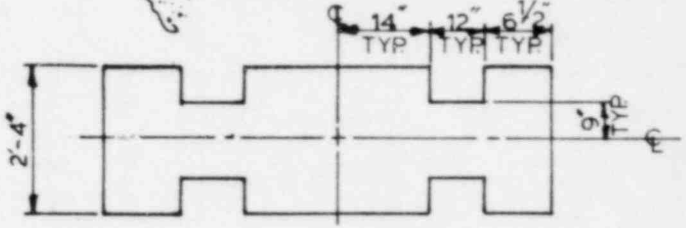




PLAN VIEW OF TYP. RESTRAINT

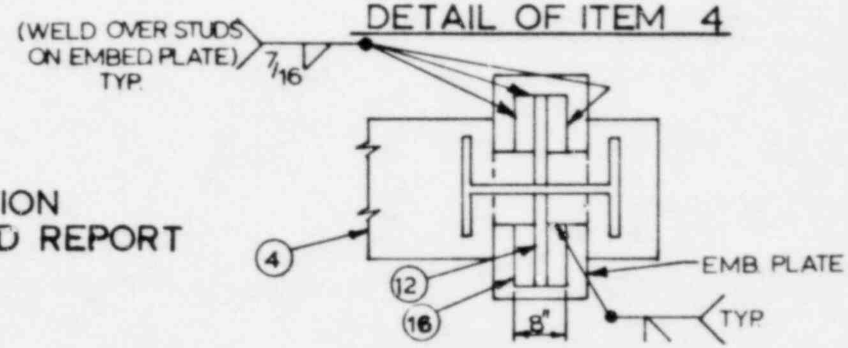


IDEALIZED FAILURE MECHANISM



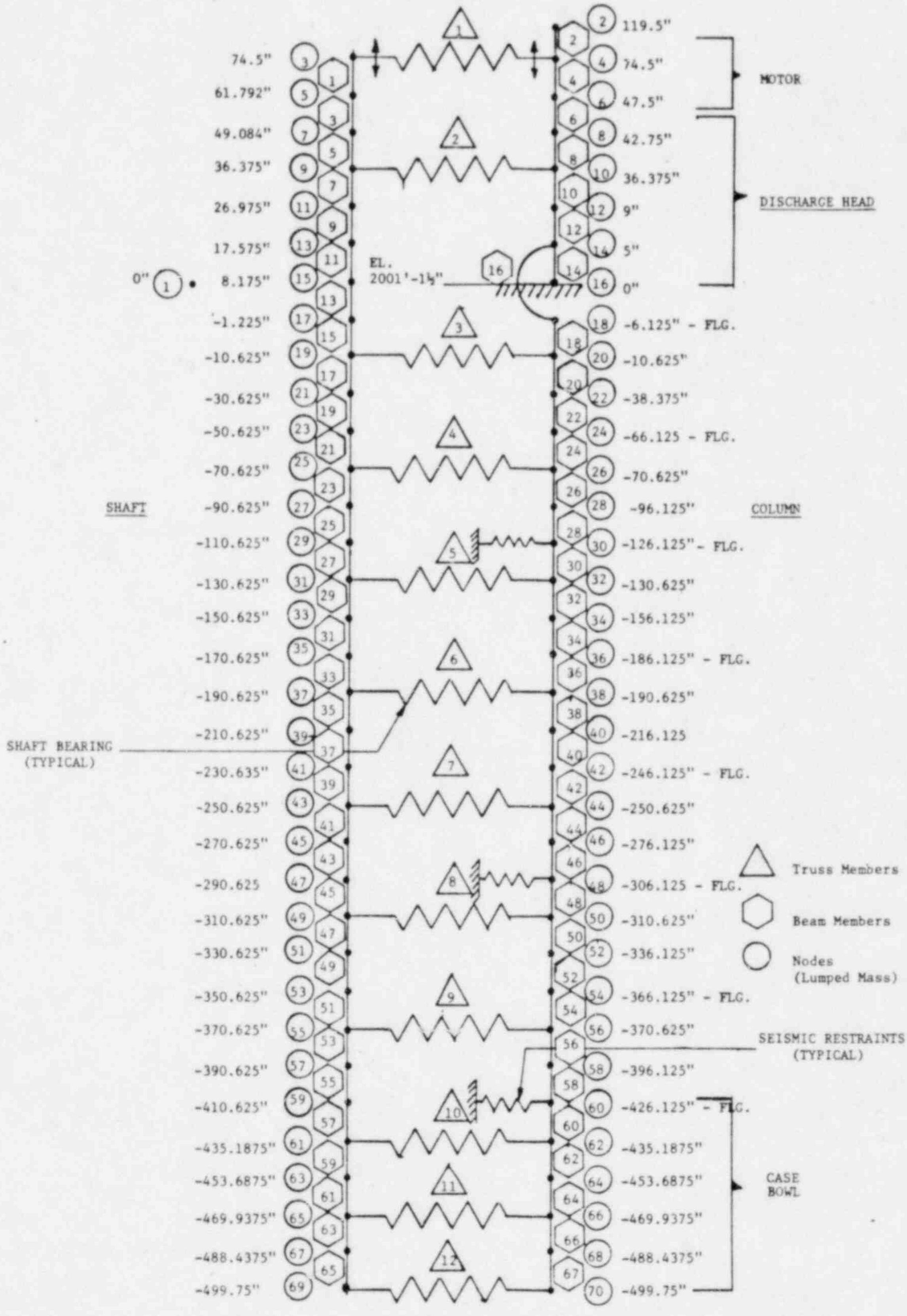
DETAIL OF ITEM 4

NOTE: FOR MORE DETAIL SEE DWG. NO. M-K60111-
HANGER NO. K-EF11-R001/091 TO K-EF11-R006/091



SECTION W-W TYP.

WOLF CREEK GENERATING STATION
E.S.W.S. PUMP RESTRAINT EMBED REPORT
FIGURE 2



VENDOR SAP V MODEL

N-S & E-W

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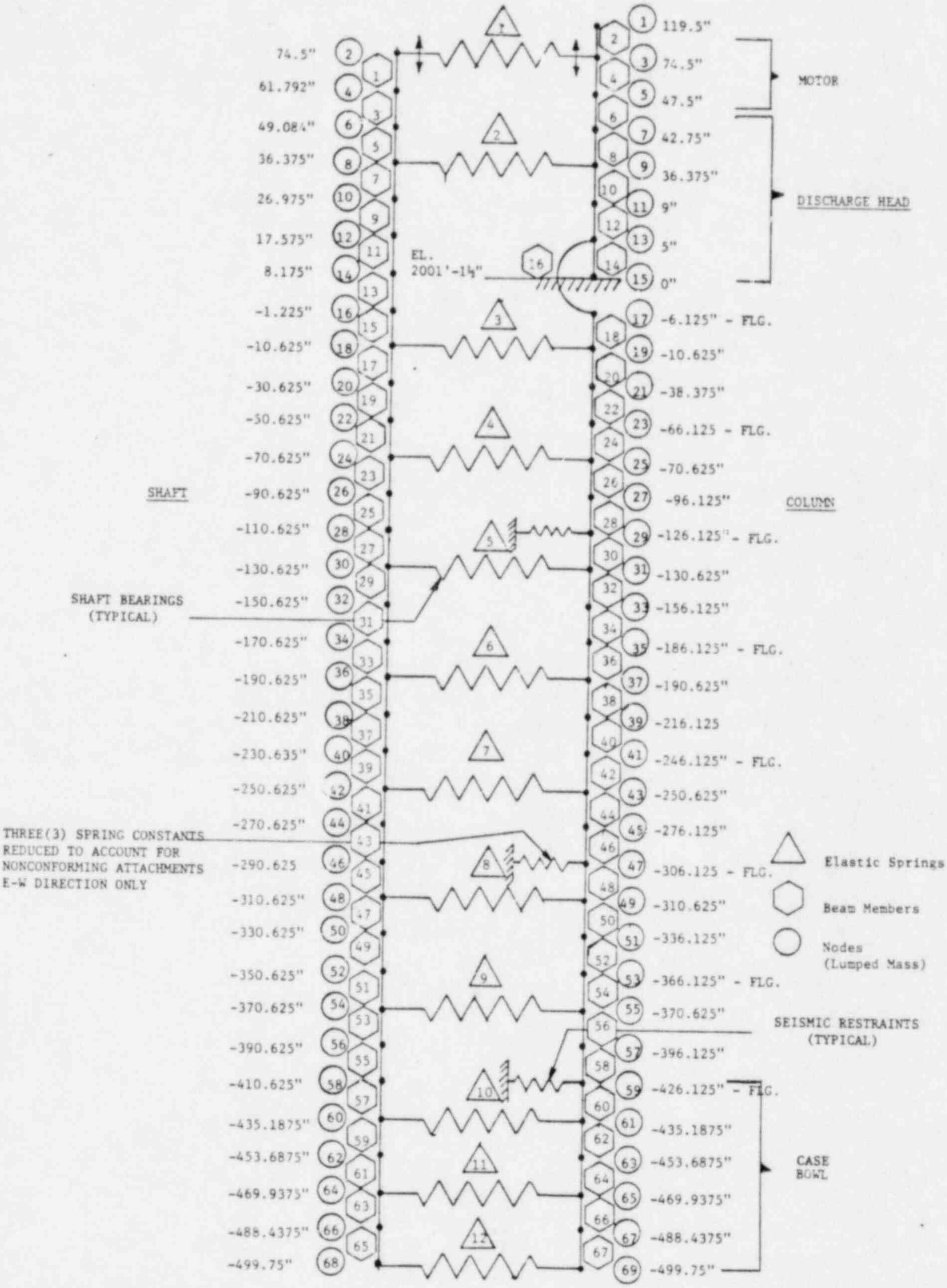
FIGURE 3



CE917 & CE918 MODEL
N-S & E-W

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FIGURE 4