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Design Analysis Cover Sheet

Complete only applicable items.

(1.) QA: ~~N~~L Z.C. 03/25/97

2. DESIGN ANALYSIS TITLE Waste Package Support and Pier Static and Seismic Analyses			
3. DOCUMENT IDENTIFIER (Including Rev. No.) BBAB00000-01717-0200-00006 REV 00			4. TOTAL PAGES 32
5. TOTAL ATTACHMENTS 20 Attachments	6. ATTACHMENT NUMBERS - NO. OF PAGES IN EACH 358 Total Pages: See Remarks in Block 12 for Attachment No.s, page counts, and dates.		
	Printed Name	Signature	Date
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12. REMARKS

I-2, II-2, III-2, IV-6 (01/30/97), V-6 (02/20/97), VI-72 (01/30/97), VII-72 (01/30/97), VIII-5 (01/30/97), IX-5 (02/20/97), X-2 (01/31/97), XI-4 (01/31/97), XII-10, XIII-5 (02/12/97), XIV-5 (02/12/97), XV-72 (02/11/97), XVI-72 (02/11/97), XVII-5 (02-12-97), XVIII-5 (02/12/97), XIX-2 (02/11/97), XX-4 (02/11/97).

Design Analysis Revision Record

Complete only applicable items.

(1.)

2. DESIGN ANALYSIS TITLE	
Waste Package Support and Pier Static and Seismic Analyses	
3. DOCUMENT IDENTIFIER (Including Rev. No.)	
BBAB00000-01717-0200-00006 REV 00	
4. Revision No.	**5. Description of Revision**
00	Issued approved.

Table of Contents:

1. PURPOSE

The objective of this analysis is to determine appropriate dimensions and materials for waste package (WP) support and pier based on structural requirements. This document will explore the waste package support and pier resistance to the weight of the WP under static and seismic load conditions. The purpose of this analysis is to provide input for the WP support and pier drawings.

This design analysis first evaluates an original design concept, and then a second design configuration which was evolved from the results of the original analysis. A third design concept is also analyzed which is capable of supporting the maximum WP weight as is specified in Assumption EBDRD 3.7.1.J.2 of the Controlled Design Assumptions (CDA) Document (Ref. 5.1, p. 4-22).

2. QUALITY ASSURANCE

The Quality Assurance (QA) program applies to this analysis. The work reported in this document is part of the preliminary WP support and pier design analysis that will eventually support the License Application Design phase. This activity, when appropriately confirmed, can impact the proper functioning of the Mined Geologic Disposal System (MGDS) waste package; the waste package has been identified as an MGDS Q-List item important to safety and waste isolation (pp. 4, 15, Ref. 5.2). The waste package is on the Q-List by direct inclusion by the Department of Energy (DOE), without conducting a QAP-2-3 evaluation. As determined by an evaluation performed in accordance with QAP-2-0, *Conduct of Activities*, the work performed for this analysis is subject to *Quality Assurance Requirements and Description* (QARD; Ref. 5.3) requirements. As specified in NLP-3-18, the development of this analysis is subject to QA controls. Although a documented evaluation is not required by the current revision of QAP-2-0, the Waste Package Design Development (WPDD) responsible manager has selected the applicable procedural controls for this activity commensurate with the work control activity evaluation entitled "Perform Criticality, Thermal, Structural, and Shielding Analyses" (Ref. 5.4).

All design inputs which are identified in this document are for the preliminary stage of the WP support and pier design process; all of these design inputs, excluding the codes and standards, will require subsequent confirmation (or superseding inputs) as the waste package design proceeds. This document will not directly support any construction, fabrication, or procurement activity and therefore is not required to be procedurally controlled as TBV (to be verified). In addition, the inputs associated with this analysis are not required to be procedurally controlled as TBV. However, use of any data from this analysis for input into documents supporting construction, fabrication, or procurement is required to be controlled as TBV in accordance with the appropriate procedures.

3. METHOD

Finite-element solutions of the problems were performed by making use of the commercially available ANSYS finite-element code. A finite-element model of the waste package support structure was developed and analyzed for static and seismic load conditions. The results of these analyses were plotted in terms of the maximum stress contours to determine at what location the stresses reached a critical magnitude, exceeding the yield strength in the material. Some analytical calculations were also performed by making use of basic relations of strength of materials. The results of the analytical and finite-element method solutions were then compared to the allowable stresses obtained for each component of the WP support and pier. Since the maximum stresses were determined to be less than the allowables, assumed dimensions were verified and recommended in Section 8 of the design analysis.

4. DESIGN INPUTS

All design inputs are for conceptual or preliminary designs; these design inputs, excluding codes and standards, will require subsequent qualification (or superseding inputs) as the waste package support and pier design proceeds to the final design.

4.1 Design Parameters

A three-dimensional (3-D) finite-element model of the support and pier was developed in order to evaluate the effect of the WP static weight on the support structure. Waste Package Development (WPD) design sketches were used to develop the solid finite-element model. These sketches are included in Attachments I, II, and XII.

Material Properties (see Assumption 4.3.1):

ASTM A500 Grade B (Tube material, see Assumption 4.3.2):
Density = 7859 kg/m^3 (Ref. 5.5, p. 145) (see Assumption 4.3.3)
Poisson's ratio = 0.28 (Ref. 5.5, p. 339) (see Assumption 4.3.3)
Since the carbon content of A500 is less than 0.30% (Ref. 5.5, p. 326),
Modulus of elasticity = 203.4 GPa (calculated from English Unit, 29.5*10^6 psi * 6895*10^{-9} GPa/psi, Ref. 5.6, p. 646) (Ref. 5.7, p. 614)
Yield strength = 317 MPa (46 ksi) (Ref. 5.8)
Compressive yield strength = 700 MPa (Ref. 5.5, p. 536) (see Assumption 4.3.4)

ASTM A501 (Pipe material, see Assumption 4.3.2):
Density = 7859 kg/m^3 (Ref. 5.5, p. 145) (see Assumption 4.3.3)
Poisson's ratio = 0.28 (Ref. 5.5, p. 339) (see Assumption 4.3.3)
Since the carbon content of A501 is less than 0.30% (Ref. 5.5, p. 326),
Modulus of elasticity = 203.4 GPa (Ref. 5.7, p. 614)
Yield strength = 248 MPa (36 ksi) (Ref. 5.8)

Compressive yield strength = 700 MPa (Ref. 5.5, p. 536) (see Assumption 4.3.4)

ASTM A36 (Plate and round bar material, see Assumption 4.3.2):
Density = 7859 kg/m^3 (Ref. 5.5, p. 145) (see Assumption 4.3.3)
Poisson's ratio = 0.28 (Ref. 5.5, p. 339) (see Assumption 4.3.3)
Since the carbon content of A36 is less than 0.30% (Ref. 5.5, p. 136),
Modulus of elasticity = 203.4 GPa (Ref. 5.7, p. 614)
Yield strength = 248 MPa (36 ksi) (Ref. 5.8)
Compressive yield strength = 700 MPa (Ref. 5.5, p. 536) (see Assumption 4.3.4)

ASTM A615 Grade 40, (reinforcing bar, see Assumption 4.3.2):
Yield strength = 276 MPa (40 ksi) (Ref. 5.11, pp. 18,19)

Concrete (Pier material, see Assumption 4.3.2):
Density = 2300 kg/m^3 (Ref. 5.9, p. A13)
Poisson's ratio = 0.17 (Ref. 5.10)
Modulus of elasticity = 3.6×10^6 psi = 24.8 GPa (Ref. 5.10)
Concrete ultimate strength = 5000 psi = 34.5 MPa (prestressed concrete, Ref. 5.11, p. 11)

Although there is no significant lateral displacement between the surfaces of the tube and the plate, the following approximate values of coefficients of friction are obtained from Ref. 5.12, p. 441 as inputs to the analysis:
Coefficient of static friction = 0.6
Coefficient of kinetic friction = 0.4

A seismic load factor was applied to the static solution of the finite-element analysis. The acceleration of the waste package in the y-direction (vertical) is selected as the critical component for the finite-element solutions and a peak ground acceleration (PGA) of 0.66*g* is used (Ref. 5.13, Assumption 4.3.5).

A seismic load factor for the horizontal PGA, which is the same as the vertical component, was also obtained from Ref. 5.13 to be used in analytical evaluations (see Assumption 4.3.5).

4.2 Criteria

The following criteria are applicable to the design subject; however, it is not the intent of these analyses to show direct compliance with the following requirements from the Engineered Barrier Design Requirements Document (EBDRD) (Ref. 5.14). Rather, they are used as guidelines and design goals for the preliminary design. Each requirement from the EBDRD is followed by a statement of its use or relevance to the preliminary design. Similar requirements are listed together.

4.2.1.1 "The Repository Segment design will prevent free-liquid-phase water from contacting the waste package during the period from package insertion until repository closure."

[EBDRD 3.2.3.3.A.8.b]

4.2.1.2 "The Repository Segment layout will be designed so that a combination of characteristics will assist in keeping liquid water from contacting the waste packages for the first 300 to 1000 (TBV) years after closure."

[EBDRD 3.2.3.3.A.8.c]

The preliminary waste package support and pier designs presented in this document have been designed to support the WPs above the drift floor where water may collect. Therefore, the support and pier may assist the Repository Segment in meeting these requirements. However, the length of time that the supports will be functional has not yet been determined. These requirements are addressed in Section 7.

4.2.2 "All construction materials or substances to be used underground will first be reviewed for potential effects on engineered barriers, waste isolation, and on site characterization or other testing. They may be used only following review and approval and only in those areas where use has been approved, subject to whatever controls are established. Such materials or substances include, but are not limited to, the following (TBD).

a. Concrete and other cementitious materials, such as shotcrete and grout."

[EBDRD 3.2.3.3.A.12.a]

This requirement is identified because the preliminary design of the pier includes the use of concrete. Before concrete can be used in construction, it must be reviewed and approved. However, this document does not support construction, fabrication, or procurement. If the final design of the waste package pier includes concrete, the process of review and approval of its use in the pier will be initiated. This requirement is addressed in Sections 7 and 8.

4.2.3 "Reliability of the Engineered Barrier Segment shall be as follows:

...

Emplacement hardware (TBD)."

[EBDRD 3.2.5.1.2.B.3]

The reliability of the emplacement hardware is evaluated throughout the design analysis by using the failure criteria for each structural component of the waste package support system.

4.2.4.1 "TESTING AND MAINTENANCE

Engineered Barrier Segment systems, structures and components that are important to safety shall be designed to permit inspection, maintenance, and testing as necessary to ensure their continued functioning and readiness during the operational period until permanent closure of the repository."

[EBDRD 3.2.5.2.1]

4.2.4.2 "Replaceability shall be addressed during design for all equipment."

[EBDRD 3.2.5.2.4.C]

4.2.4.3 "The Engineered Barrier Segment shall be designed and constructed so that facilities are easily and economically maintained. Maintainability considerations include:

...

2. Ease of replacement of installed equipment (i.e., without structure modification)."

[EBDRD 3.2.5.2.8.A.2]

The waste package support and pier designs presented in this document have been developed as modular designs to address these maintenance requirements. The modular design is intended to be economical to manufacture, replace, and maintain. These requirements are addressed in Section 7. The specific requirement for testing of design in EBDRD requirement 3.2.5.2.1 is not addressed in this document.

4.2.5 "PORTABILITY AND LOAD CARRYING

Equipment and components that are developed for the Engineered Barrier Segment and that must be moved over short distances for maintenance or other purposes shall be designed to facilitate movement by taking into consideration such things as weight, hand grips, lifting aids, etc."

[EBDRD 3.2.9]

The waste package support and pier will both have to be moved into the drift and possibly removed from the drift and replaced in the event that they are damaged. The weights of the support and pier are each more than can be lifted by hand, but are far less than the weights of the waste packages. Therefore, the support and pier can be lifted with a gantry. In order to facilitate lifting, lifting aids are included in the design of both the support, lifting holes, and the pier, lifting hooks. This requirement is addressed in Section 7.

4.2.6 "ENGINEERED BARRIER SEGMENT MAJOR COMPONENT CHARACTERISTICS/REQUIREMENTS

The major components of the Engineered Barrier Segment are the waste packages, the underground facility, any backfill placed in emplacement drifts, and any emplacement hardware provided to support and protect the emplaced waste package. (The underground facility portion of the Engineered Barrier Segment and the associated requirements allocated to the EB-DRD by the MGDS-RD are identified as interfaces with the Repository Segment in Section 3.2.3.3.) These major components shall be capable of contributing to the assigned function. Isolate Waste (1.4.3), by containing waste in the waste package during the containment period of 300 to 1,000 years (TBR), and then by limiting the release of radionuclides during the post-containment period."

[EBDRD 3.7]

The waste package support and pier are emplacement hardware provided to support the emplaced waste package. The contributions made by the support and pier to isolating waste are keeping the waste from contacting water on the drift floor as previously discussed, and reducing detrimental effects of contact with the outer barrier. Contact with the outer barrier may potentially cause accelerated corrosion of the outer barrier if stresses are high or if the outer barrier acts as a sacrificial metal to the support. Therefore, the material selected for the preliminary design of the support is a carbon steel similar to that selected for outer barrier in preliminary designs of the waste package. The thickness of the material in the support is far less than the thickness of the outer barrier, thus resulting in a relatively soft interface for the outer barrier. The soft interface will result in a larger contact area between the waste package and support, helping to reduce outer barrier stresses at the interface. This requirement is addressed in Section 7.

4.2.7 "EMPLACEMENT HARDWARE REQUIREMENTS

The emplacement hardware requirements (TBD) are for hardware used to support and protect the emplaced waste packages. Examples of emplacement hardware are a pedestal under the waste package for the in-drift emplacement concept and a carriage and rail system for the horizontal opening concept. Emplacement hardware does not include ground support hardware which is part of the Repository Segment. Emplacement hardware requirements will be added during and after ACD."

[EBDRD 3.7.3]

This requirement is listed to acknowledge that additional requirements may be placed on emplacement hardware which includes the waste package support and pier.

The notation "TBD" in EBDRD requirements 3.2.3.3.A.12.a, 3.2.5.1.2.B.3, and 3.7.3, "TBR" in EBDRD requirement 3.7, and "TBV" in EBDRD requirement 3.2.3.3.A.8.c will not be carried to the conclusions of this analysis based on the rationale that the conclusions derived by this analysis are for conceptual or preliminary design that will not be used as input into documents supporting construction, fabrication, or procurement.

4.3 Assumptions

In the course of developing this document, several assumptions were made regarding the WP support structure analysis. These assumptions along with the assumptions contained in the Controlled Design Assumptions (CDA) Document (Ref. 5.1) are identified below.

The relevant assumptions from the CDA (Ref. 5.1) are as follows:

"**Assumption Identifier:** Key 011 **Subject:** Horizontal In-Drift Emplacement

Waste packages will be emplaced in-drift in a horizontal mode."

"**Assumption Identifier:** Key 046 **Subject:** Backfill in Emplacement Drifts

Backfill in emplacement drifts is not required. However, the repository design should not preclude the use of emplacement drift backfill at the end of the preclosure period. The specifications for the emplacement drift envelope to accommodate are: 1) level single layer backfill (quartz sand, crushed tuff, or other material of similar favorable thermohydrologic properties), and 2) waste packages should initially be covered with at least 0.6 meters of material."

"**Assumption Identifier:** Key 066 **Subject:** Gantry Emplacement and Pedestal Support

Waste packages will be placed center in-drift, on pedestals, using gantry emplacement."

"**Assumption Identifier:** EBDRD 3.7.1.J.2 **Subject:** Waste Package Maximum Weight

The waste package shall meet the following criteria
1. Weight shall not exceed 69,000 kg"

"**Assumption Identifier:** EBDRD 3.7.3 **Subject:** Emplacement Hardware Requirements

The emplacement hardware is used to support and protect the emplaced waste packages. Examples of emplacement hardware are a pedestal under the waste package for the in-drift emplacement concept and a carriage and rail system for the horizontal opening concept. Emplacement hardware does not include ground support hardware, which is part of the Repository Segment. Emplacement hardware requirements will be added during Advanced Conceptual Design (ACD) and Viability Assessment (VA)."

All assumptions are for conceptual or preliminary designs; all of these assumptions will require qualification/confirmation as the waste package design proceeds.

4.3.1 Temperature dependent material properties for ASTM A500 cold formed steel, ASTM

A501 hot formed steel, and ASTM A36 carbon steel were not available for structural analyses. For this reason, room temperature (20°C) material properties were used in these analyses. The properties of carbon steels for which temperature dependence is known change little for the temperature range of interest. Therefore, for this initial set of calculations, use of room temperature properties is adequate. This assumption is used in Section 4.1.

4.3.2 The following materials were assumed for corresponding structural members:
Tube: ASTM A500 Grade B cold formed steel
Pipe: ASTM A501 hot formed steel
Plate and round bar: ASTM A36 carbon steel
Reinforcing bar: ASTM A615 Grade 40, bar number 4
Pier: Concrete
This assumption is used in Section 4.1.

4.3.3 The density, modulus of elasticity, and Poisson's ratio were not available for ASTM A36, A500, and A501 carbon steels. Since the carbon contents are nearly the same (see Ref. 5.5, p. 136 and p. 326), the density of AISI-SAE grade 1024 carbon steel (7859 kg/m^3) is used for these materials (Ref. 5.5, p. 145). The density and modulus of elasticity for AISI-SAE grade 1024 carbon steel and the steel provided in Ref. 5.5, p. 339, Table 6 are approximately the same. Therefore, Poisson's ratio for ASTM A36, A500, and A501 carbon steels is assumed to be 0.28. This assumption is used in Section 4.1.

4.3.4 The compressive mechanical properties of ASTM A36, A500, and A501 carbon steels were not available in the literature. Thus, the compressive yield strength of 86XX steel (700 MPa) with 0.20% carbon content lowest available tempering temperature is conservatively assumed for ASTM A36, A500, and A501 carbon steels (Ref. 5.5, p. 536). This is an acceptable assumption since the carbon contents are close in all four materials considered. This assumption is used in Section 4.1.

4.3.5 A dynamic load factor of 1.66 is assumed to represent the effect of a PGA of 0.66*g*. This assumption is consistent with CDA Key 064 since the PGA was obtained from Ref. 5.13. The duration of an earthquake is short compared to a repeated vibrational load from continuously operating machinery. The effect of any dynamic amplification or fatigue of the material is anticipated to be small for the WP support structure under seismic loading. The vertical and horizontal components of the PGA are also assumed to be the same for lower exceedance probabilities given in Ref. 5.13. This assumption is used throughout.

4.3.6 The maximum-normal-stress theory is assumed to be applicable in determining when material failure will occur. Thus, material failure will occur when the first principal stress, S_1, exceeds the ultimate tensile strength, S_{ut}, or when the third principal stress,

S_3, exceeds the ultimate compressive strength, S_{uc}. This assumption is used in Section 7.1.

4.3.7 The pier is modeled as if it is one piece; a structural component made of concrete. The steel plate shell around the concrete is not modeled. Thus, credit for the strength of the steel shell is not taken. This assumption is used in Section 7.2.

4.3.8 The WP weight is assumed to be uniformly distributed over four nodes on the steel tube. The location of these nodes were determined by considering approximate points of contact between the WP and the structural tube. The reason for selecting the subject nodes is that the tube side walls will deflect as a result of the WP weight, which will eventually increase the load on the tube vertical side walls rather than the face tangent to the WP. Thus, the nearest four nodes to the tube vertical side walls were used as the points of application for vertical forces. This assumption is used in Section 7.2.

4.3.9 A constant thickness for the pier is assumed for simplification of the finite-element-model. The smaller dimension at the top is selected for the thickness in order to perform conservative calculations. This assumption is used in Section 7.2.

4.3.10 One of the parameters in the ANSYS model is the contact stiffness between the tube and the plate. A very high stiffness value will cause stiffness matrix ill-conditioning and divergence. Similarly, an extremely small stiffness value will result in compatibility violations. Therefore, an optimum value for the contact stiffness is one that is between and is arrived at iteratively. The result of iterations revealed that the contact stiffness between the tube and the plate that works best is $1.5*10^8$ N/m. This assumption is used in Section 7.2.

4.3.11 Tube outer width = 203.2 mm (Attachment I-1). This assumption is used in Section 7.

4.3.12 Tube thickness = 14.3 mm (Attachment I-1). This assumption is used in Section 7.

4.3.13 Tube height = 101.6 mm (Attachment I-1). This assumption is used in Section 7.

4.3.14 Projection of individual tube length on horizontal = 830 mm (Attachment I-1). This assumption is used in Section 7.

4.3.15 Tube angle from vertical = 60° (Attachment I-1). This assumption is used in Section 7.

4.3.16 Pier height = 450 mm (Attachment I-2). This assumption is used in Section 7.

4.3.17 Pier bottom width = 1500 mm (Attachment I-2). This assumption is used in Section 7.

4.3.18 Pier top length along the repository = Support plate length = 300 mm (Attachment I-2). This assumption is used in Section 7.

4.3.19 Pier side angle from horizontal = 56.3° (Attachment I-2). This assumption is used in Section 7.

4.3.20 Distance between two pipe centerlines = 1000 mm (Attachment I-1). This assumption is used in Section 7.

4.3.21 Pipe outer diameter = 114.3 mm (Attachment I-1). This assumption is used in Section 7.

4.3.22 Pipe inner diameter = 80.1 mm (Attachment I-1). This assumption is used in Section 7.

4.3.23 Pipe length below the top surface of the plate = 200 mm (Attachment I-1). This assumption is used in Section 7.

4.3.24 Support plate thickness = 20 mm (Attachment I-1). This assumption is used in Section 7.

4.3.25 Support plate width = 1660 mm (Attachment I-1). This assumption is used in Section 7.

4.3.26 Diameter of large round bar = 114.3 mm (Attachment II-1). This assumption is used in Section 7.

4.3.27 Diameter of small round bar = 80 mm (Attachment II-1). This assumption is used in Section 7.

4.3.28 Mass of one waste package support = 174.3 kg (Attachment II-1). The mass value in Attachment II-1 was calculated by Pro/Engineer Version 17.0 used for drafting the sketches. This assumption is used in Section 7.

4.3.29 Mass of the heaviest waste package currently under consideration (21 PWR UCF) = 50,423 kg (see Ref. 5.20 and Attachment XII-1). This assumption is used in Section 7.

4.3.30 The area of contact between the pipe and the plate is assumed to be the bearing stress area between the plate and the concrete pier. The load will be distributed through the plate onto the pier over an area larger than the assumed one since the plate is an elastic material. However, as a preliminary design approach, this assumption is made for conservatism. This assumption is used in Section 7.5.

4.3.31 It is assumed that the WP will be in contact with the WP support system at all times and the vertical component will be the source of the most critical seismic load. The support design allows the WP to align itself on the steel tubes. For preliminary analysis of the seismic effects, only the vertical component of dynamic load is considered in the finite-element solutions. This assumption is used throughout.

4.3.32 The gap between the bottom of the pier hole and the bottom of the pipe = 23 mm. This assumption has no effect on the results since the contact between the round bar and the pier concrete is not modeled. This assumption is provided for the WP support third design concept and used in Section 7.7.

4.3.33 Pier top length along the repository = 316 mm (Attachment XII-5). This assumption is provided for the WP support third design concept and used in Section 7.7.

4.3.34 Support plate thickness = 19.05 mm (Attachment XII-5). This assumption is provided for the WP support third design concept and used in Section 7.7.

4.3.35 Hole depth in the pier = 168 mm (Attachment XII-4). This assumption is provided for the WP support third design concept and used in Section 7.7.

4.3.36 Mass of one WP support = 205 kg (Attachment XII-3). The mass value in Attachment XII-3 was calculated by Pro/Engineer Version 17.0 used for drafting the sketches. This assumption is provided for the WP support third design concept and used in Section 7.7.

4.3.37 Pipe outer diameter = 168.3 mm (Attachment XII-3). This assumption is provided for the WP support third design concept and used in Section 7.7.

4.3.38 Pipe inner diameter = 124.4 mm (Attachment XII-3). This assumption is provided for the WP support third design concept and used in Section 7.7.

4.3.39 Diameter of the round bar = 123.8 mm (Attachment XII-3). This assumption is provided for the WP support third design concept and used in Section 7.7.

4.3.40 Pier mass = 947 kg (Attachment XII-4). The mass value in Attachment XII-4 was calculated by Pro/Engineer Version 17.0 used for drafting the sketches. This assumption is used in Section 7.7.

4.3.41 Lifting hook diameter = 12.7 mm (Attachment XII-10). This assumption is used in Section 7.7.

4.3.42 Support height = 477 mm (Attachment XII-3). This assumption is provided for the WP support third design concept and used in Section 7.7.

4.3.43 Extension of the round bar below the pipe = 140 mm (Attachment XII-3). This assumption is provided for the WP support third design concept and used in Section 7.7.

4.4 Codes and Standards

The use of codes and standards for the design of the waste package is restricted to being a source for material properties, specifically for A36, A500, and A501 carbon steel (American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code).

5. REFERENCES

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5.19 *Shock and Vibration Handbook,* Second Edition, C. M. Harris and C. E. Crede, Eds., McGraw-Hill Book Company, New York, NY, 1976.

5.20 *Update of Waste Package Spreadsheet for Sizing and Masses,* W. E. Wallin, Interoffice Correspondence, LV.WP.WEW.09/96-227, September 30, 1996, CRWMS/M&O.

6. USE OF COMPUTER SOFTWARE

The finite-element-analysis (FEA) computer code used for this analysis is ANSYS version (V) 5.1 which is identified with the Computer Software Configuration Item (CSCI) 30003 V5.1HP and was obtained from Software Configuration Management in accordance with appropriate procedures. ANSYS is a commercially available finite-element analysis code and is appropriate for structural analysis of waste packages as performed in this analysis. The analyses using the ANSYS software were executed on a Hewlett-Packard 9000 Series 735 workstation. The software qualification of the ANSYS software, including problems of the type analyzed in this report, is summarized in the Software Qualification Report for ANSYS Version 5.1HP (Ref. 5.15). The ANSYS evaluations performed for this design are fully within the range of the validation performed for the ANSYS V5.1 code. Access to and use of the code for the analysis were granted and performed in accordance with the Life Cycle Plan for ANSYS Version 5.1HP (Ref. 5.16) and the QAP-SI series procedures.

The computational support software used in this analysis is Pro/Engineer Version 17.0. Pro/Engineer was executed on a Hewlett-Packard 9000 Series 735 workstation. Pro/Engineer Version 17.0 is not a controlled computer software and has not been qualified under the QAP-SI series of M&O procedures and will not be qualified under the M&O procedures. The densities given in Section 4.1 were used as inputs to Pro/Engineer Version 17.0 and the corresponding masses of solid components were obtained for use in the analytical evaluations.

The input/output files, figures, and results for all computer analyses performed in this report are presented in Attachments III through XI and XIII through XX.

7. DESIGN ANALYSIS

This design analysis first evaluates an original design concept using loads based on the mass of the 21 PWR UCF (see Attachment I), and then a second design configuration (see Attachment II) which was evolved from the results of the original analysis. A third design concept is also analyzed using the maximum WP mass as listed in Assumption EBDRD 3.7.1.J.2 of the Controlled Design Assumptions (CDA) Document (see Attachment XII). The dimensions given in Section 4.3 have been assumed for these three design concepts.

7.1 Failure Criteria

Two different failure criteria are incorporated in this analysis. Maximum-distortion-energy theory (von Mises criterion) is used to predict the beginning of yield in ductile materials (carbon steels). The ANSYS computer code is capable of including von Mises theory in the finite-element solution. According to this criterion, a given structural component is in the elastic region as long as the maximum value of the distortion energy per unit volume in that material remains smaller than the distortion energy per unit volume required to cause yield in a tensile-test specimen of the same material. Figure 7-1 shows this theory for triaxial stress states. Any given state of stress is represented in that figure by a point of coordinates S_1, S_2, and S_3 which are the three principal stress magnitudes. If this point falls within the volume shown in the figure, the structural component experiences elastic deformation only. If it falls outside this volume, the component plastically deforms (Ref. 5.6 and Ref. 5.17).

The von Mises stress is referred to as equivalent stress in the ANSYS user's manuals (Ref. 5.17). When the equivalent stress (S_{eqv}) is equal to a material yield parameter S_y, the material will develop plastic strains. Therefore, the elastic limit of the materials will not be exceeded as long as S_{eqv} is below S_y. A comparison of the maximum stresses and allowables will be presented in Section 8.

The maximum-normal-stress theory (see Assumption 4.3.6) will be used to determine the beginning of compressive failure in the brittle material which is concrete in the pier. This theory states that failure occurs whenever one of the three principal stresses equals the strength. If the three principal stresses are arranged in the following form:

$$S_1 > S_2 > S_3$$

Then failure occurs whenever

$$S_1 \geq S_{ut} \quad \text{or} \quad S_3 \leq S_{uc}$$

where S_{ut} and S_{uc} are ultimate tensile and compressive strengths, respectively.

The concrete pier is under compressive load due to the weight of the WP and WP support structure. Therefore, the tensile strength part of the maximum-normal-stress theory is not applicable for determining failure in concrete.

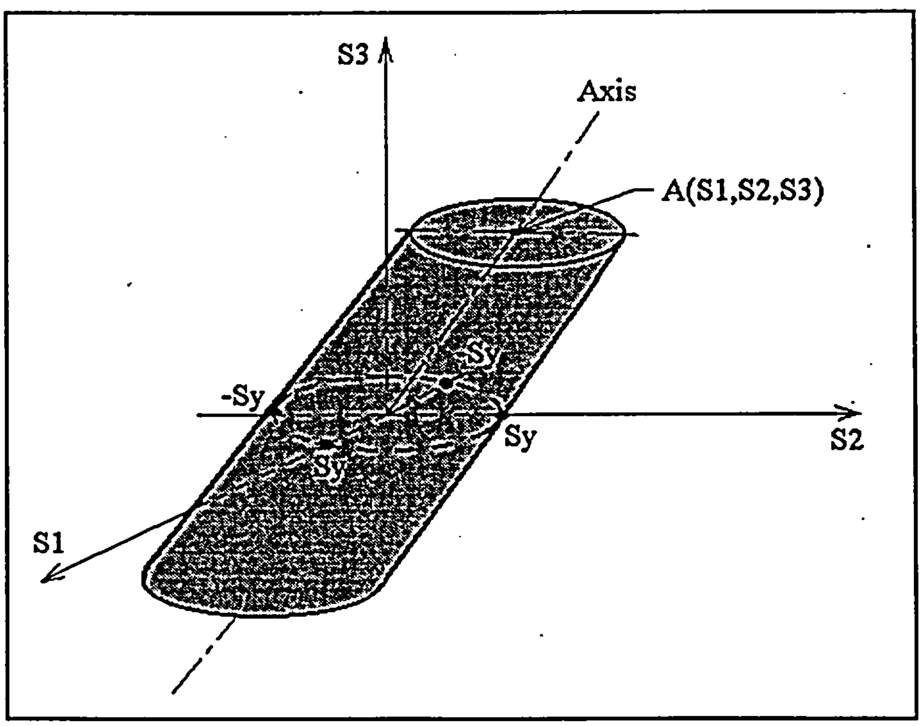


Figure 7-1. The von Mises theory in three dimensions. The oblique elliptical cylinder encloses all values of stress resulting in elastic deformation given by S_1, S_2, and S_3. Cylinder axis is the line $S_1 = S_2 = S_3$.

7.2 Model Development

A three-dimensional half-symmetry finite-element model of the WP support and pier structure has been developed in order to perform a static analysis on the system (see Figure III-1). The WP support consists of the tube, pipe, and the plate. The tube is placed on the pipe with an angle to provide a two-point contact with the waste package. The pipe is welded to the tube at the top and to the plate at the bottom. The WP support structure sits on top of the pier with no rigid connection. Although the pier contains a shell constructed of steel plates, the shell is omitted from the finite-element model which includes the pier as a uniform solid structure made of concrete (Assumption 4.3.7). The pier provides a wide, stable structural base for the WP support.

A static finite-element solution is obtained under two loads applied to the system. The first load is the weight of the structural components and the second is the vertical force applied to the tube to represent the WP weight. The force is uniformly distributed over four nodes on the structural tube. The locations of these nodes were determined by considering approximate points of contact between the WP and the structural tube. The reason for selecting the subject nodes is that the tube side walls will deflect as a result of the WP weight, which will eventually increase the load on the tube vertical side walls rather than the face tangent to the WP. Thus, the nearest four nodes to the tube vertical side walls were used as the points of application for vertical forces (Assumption 4.3.8).

A constant thickness for the pier is assumed for simplification of the finite-element-model. The smaller dimension at the top is selected for the thickness in order to perform conservative calculations (Assumption 4.3.9).

Displacement constraints are placed on the symmetry plane and at the bottom flat surface of the pier, perpendicular to the component surfaces. The constraints on the oblique surface of the pier are horizontal. These constraints prevent the support and the pier from moving along the three cartesian coordinate system directions.

The constraints on the oblique surface of the pier were intended to be perpendicular to the surface; however, the specific ANSYS command to define these boundary conditions was issued in the solution phase of the FEA software. Therefore, the warning messages on page 55 of Attachments VI, VII, XV, and XVI were caused by this attempt. Since this command is only valid in the preprocessor phase of the program, the software has ignored the command. However, this has no effect on the results of the FEA because it does not make any difference whether the constraints on the oblique surface of the pier are perpendicular to the surface or horizontal. This is justified by the fact that the pier has no significant displacement or any resulting stress magnitudes in the region of the oblique side surfaces.

The eight node brick element (Solid45) is commonly used for the three dimensional modeling of solid structures. This element has three degrees of freedom at each node (translations in the nodal x, y, z directions) (Ref. 5.18). Solid45 also has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. Since the stress magnitudes are not expected to exceed the yield strengths of the materials, an elastic analysis is performed. However, the analysis performed is nonlinear due to contact elements used between the tube and the plate.

One of the parameters in the ANSYS model is the contact stiffness between the tube and the plate. A very high stiffness value will cause stiffness matrix ill-conditioning and divergence. Similarly, an extremely small stiffness value will result in compatibility violations. Therefore, an optimum value for the contact stiffness is one that is between and is arrived at iteratively. The result of iterations revealed that the contact stiffness between the tube and the plate that works best is $1.5*10^8$ N/m (Assumption 4.3.10).

Some of the input parameters for the finite-element model were calculated using the list of assumptions provided in Section 4.3 (Assumptions 4.3.11 through 4.3.28). These calculations are given below:
The tube length is calculated using the horizontal projection length and the angle between the tube and the vertical. Therefore,
Tube length = 830 / (sin 60°) = 958.4 mm (see Section 4.3)
Pier bottom width (half) = 1500 / 2 = 750 mm (see Section 4.3)
Pier angle from vertical = 90° - 56.3° = 33.7° (see Section 4.3)
Pipe center from the symmetry plane = 1000 / 2 = 500 mm (see Section 4.3)
Pipe outer radius = 114.3 / 2 = 57.15 mm (see Section 4.3)
Pipe thickness = (pipe outer diameter - pipe inner diameter) / 2
= (114.3 - 80.1) / 2 = 17.1 mm (see Section 4.3)
Gap height below the pipe = 220 + 20 - 200 = 40 mm (see Section 4.3)
Support plate width (half) = 1660 / 2 = 830 mm (see Section 4.3)

Due to possible irregularities in pedestal heights, the waste package is considered to be resting on two pedestals instead of three.

The WP weight is distributed over four nodes on the tube. Therefore,
the force applied vertically on each node = WP weight / (number of nodes * number of supports * 2)
= (9.81 * 50423) / (4 * 2 * 2)
= 30915.6 N (see Assumption 4.3.29 for WP mass)

7.3 General Design Description - First Design Concept

Two design concepts have been considered which have small differences in their structures. This section includes a general description of the first design (see Attachment I) and common aspects with the second design for the WP support and pier.

A modular design was developed for the waste package support assembly. The assembly consists of a waste package pier and a waste package support. A modular design is desirable because it allows flexibility in waste package placement in the drifts and individual component replacement in the event that the support structure is damaged in a handling accident. In the event of a handling accident, it is less critical for the support structure to be damaged than for the waste package to be breached. Therefore, the support structure is not designed to withstand handling accidents.

7.3.1 Waste Package Support

The waste package support is constructed entirely of carbon steel. Steel was chosen over concrete as the material for its strength and ductility. The strength is required to support the weight of the waste package while the ductility provides a softer interface which allows loads to distribute. This is important because the initial interfaces between the supports and the waste package are line contacts. This is also beneficial if there is misalignment of the supports due to tolerances. The use of steel also allows the support to be designed with a lower stiffness than that of a concrete design. This will reduce damage to the waste package in the event that a waste package is dropped onto the support.

The waste package support is fabricated from 2 pieces of rectangular steel tubing and 2 pipes. The 2 pieces of rectangular steel tubing are welded together to form a vee shape. Then the two pipes are welded to the tubes and to the steel plate. The lower sections of the pipes engaging the pier serve as pins to position the supports on the pier and prevent tipping of the support. The upper sections of the pipes serve as columns to transmit load from the tubes to the plate and ultimately into the concrete of the pier. A standard size of rectangular tubing was selected to reduce manufacturing costs. The steel types chosen are ASTM A500 Grade B for the tube and ASTM A501 for the pipe. This carbon steel is a standard material for these shapes. The sizing of the support was dependent on the required strength, the available space in the drift, and the desired spacing between the invert and the bottom of the waste package.

7.3.2 Waste Package Pier

Concrete was chosen as the main structural material for the waste package pier. Concrete was chosen because it is relatively inexpensive and performs well under compression loading.

7.4 General Design Description - Second Design Concept

This section includes an evaluation of a slightly modified design concept by comparison with the results obtained from the previous design. This concept is shown in sketches provided in Attachment II. There are only a few differences between the two designs and the rest of the structures are the same as discussed in Section 7.3. In the second design, the waste package support includes 2 stepped circular steel bars instead of 2 pipes. The narrow sections of the bars serve as pins to position the supports on the pier and prevent tipping of the support. The wider stepped sections of the bars serve as columns to transmit load from the support to the top plate of the pier. The steel type chosen for the bar is ASTM A36.

In the second design concept, the waste package pier is fabricated from steel plates, steel pipe, steel bars, concrete, and rebar. Steel is added to the pier mainly to improve interfaces with other components in the drift. The steel plates are welded to form the waste package pier shell. The steel chosen is ASTM A36 for the plates. This carbon steel is readily available in the shapes specified. The shell serves as the form for the concrete which is cast in the shell. The shell prevents chipping of the concrete and slows drying out of the concrete which could be caused by relatively high temperatures in the emplacement drift. The steel shell also provides a better interface between the pier and the concrete invert. The rebar design has not yet been developed, but small rebar sections have been included in the design sketches as lifting hooks. Holes on the top surface of the concrete and the top plate allow the attachment of the waste package support. The bars on the bottom of the pier are used for positioning on the invert, and the half section of pipe on the bottom of the pier is to allow for drainage of any water before it contacts the waste package.

Although the material yield strength is lower for ASTM A36, having a solid round bar instead of a pipe increases the strength of the support structure. Since the equivalent stresses are significantly below the yield strength of the pipe in the analysis of the first design, the results obtained for the first design concept are bounding, indicating that the second design is also acceptable.

7.5 Bearing Stress Calculations for the Pier and the Plate - Second Design Concept

The pier design is evaluated for the bearing stress caused by the weight of the WP. Since the upper sections of the pipes serve as columns to transmit load from the support to the top plate of the pier, the maximum bearing stress on the pier must be compared to the allowable compressive strength of the concrete. A conservative assumption is made by using the area of contact between the pipe and the plate in order to determine the bearing stress (Assumption 4.3.30). Since the area of contact and the load are the same for the plate and the pier as a result of this assumption, the resulting stresses are also the same. The compressive strength of the steel is higher than that of the concrete. Therefore, the following calculations were performed to determine the bearing stress in the pier:

Mass of the heaviest waste package currently under consideration (21 PWR UCF) = 50,423 kg (see Assumption 4.3.29)
Mass of one waste package support = 174.3 kg (see Section 4.3)
Therefore, weight on one WP support structure = ((50423 / 2) + 174.3) * 9.81 = 249035 N.

Diameter of large round bar = 0.1143 m (see Section 4.3)
Diameter of small round bar = 0.08 m (see Section 4.3)

Bearing area between the large round bar and the steel plate $= \pi * (0.1143^2 - 0.08^2) / 4$
$= 5.234 * 10^{-3}$ m^2

Bearing stress = $(249035 / 2) / 5.234 * 10^{-3} = 23.8$ MPa

This stress will be used to determine the bounding stress value in the next section.

7.6 Seismic Design Evaluations - Second Design Concept

When the WP support and pier structure is subject to a seismic input, the deflection of the structural members are caused by the dynamic load. This dynamic load is the force required to cause the support structure to deflect in response to the motion imposed by the ground surface. For practical purposes, as a preliminary design approach, the dynamic load may be considered as the static or dead-weight load multiplied by a dynamic load factor (Ref. 5.19). The structural members of the support system must be designed to withstand, without failure, the stress imposed by the dynamic load. In general, the stress in the member subject to a dynamic load is equal to that caused by a static load of the same magnitude. It does not necessarily follow, however, that the same design stress can be used for both static and dynamic conditions. Since a structure may fail under repeated occurrences of the stress, a lower value of acceptable stress must be used to recognize the effect of fatigue of the material.

A peak ground acceleration of 0.66*g* was provided in Section 4.1. The duration of an earthquake is short compared to a repeated vibrational load from continuously operating machinery. Therefore, the effect of any dynamic amplification or fatigue of the material is anticipated to be small for the WP support structure under seismic loading. Assuming that the WP will be in contact with the WP support system at all times and the vertical component will be source of the most critical seismic load (Assumption 4.3.31), a dynamic load factor of 1.66 can be used to obtain preliminary results for this problem (Assumption 4.3.5).

Using the bearing stress calculated in Section 7.5 and the seismic load factor, the bearing stress due to seismic load is determined as follows:
Bearing stress due to seismic load $= 1.66 * 23.8 = 39.5$ MPa
$= 5729$ psi

This is the bounding ultimate strength for the concrete pier for the second design concept. However, as it will be seen in Section 7.7, a modified design (third design) will result in a lower value of the bearing stress and will be used as a basis to recommend a design strength for the pier concrete.

The results obtained for the static and seismic analyses of the first and second design concepts are given in Tables 7-1 and 7-2.

Table 7-1. WP Support and Pier Static Analysis Results (first and second design concepts)

WP Support and Pier Structural Components	Maximum Equivalent Stress (Seqv)	Tensile Yield Strength (Sy) (see Section 4.1)	Compressive Yield Strength (Syc) (see Section 4.1)
Tube	176.6 (IV-2)	317.0	700.0
Pipe	81.6 (IV-3)	248.0	700.0
Plate	29.5 (IV-4)	248.0	700.0

*All stress magnitudes are in MPa

Table 7-2. WP Support and Pier Seismic Analysis Results (first and second design concepts)

WP Support and Pier Structural Components	Maximum Equivalent Stress (Seqv)	Tensile Yield Strength (Sy) (see Section 4.1)	Compressive Yield Strength (Syc) (see Section 4.1)
Tube	293.3 (V-2)	317.0	700.0
Pipe	135.3 (V-3)	248.0	700.0
Plate	48.9 (V-4)	248.0	700.0

*All stress magnitudes are in MPa

7.7 General Design Description and Evaluations - Third Design Concept

The CDA document includes an assumption that the maximum WP mass will not exceed 69,000 kg (see Section 4.3). As a result of the increase in the WP mass, the dimensions of the second design concept are modified in order to meet the strength requirements of the WP support and pier design which can hold a WP mass of 69,000 kg. The modified design sketches are given in Attachment XII).

A larger pipe diameter is used in the modified design compared to the previous two concepts. The thickness of the pipe is also larger than that of the pipe described in Section 7.3 as a first design concept. The lower pipe is replaced by a round bar in order to increase the structural strength against horizontal seismic loads. The pier length, plate thickness, and the gap length between the pier hole bottom surface and the pipe bottom surface are also modified in this design concept (Assumptions 4.3.32 through 4.3.38). Since the finite-element-model does not include a rigid contact between the pipe and the pier, the gap dimension has no effect in the results. Some of the analytical stress calculations and FEA results for this design are given in Sections 7.7.1 and 7.7.2.

7.7.1 Bearing Stress Calculations - Third Design Concept

The bounding waste package mass = 69,000 kg (see Section 4.3)
Mass of one waste package support = 205 kg (Assumption 4.3.36)
Therefore, weight on one WP support structure = ((69000 / 2) + 205) * 9.81 = 340456 N.

Pipe outer diameter = 0.1683 m (Assumption 4.3.37)
Pipe inner diameter = 0.1244 m (Assumption 4.3.38)

Bearing area between the pipe and the steel plate $= \pi * (0.1683^2 - 0.1244^2) / 4$
$= 0.01009\ m^2$

Bearing stress = (340456 / 2) / 0.01009 = 16.87 MPa = 2447 psi

Therefore, a comparison of the concrete ultimate strength of 34.5 MPa (5000 psi) (see Section 4.1) with this bearing stress magnitude shows that the bearing stress is below the allowable stress for the pier.

The bearing stress on the steel plate is the same as above. Since the allowable compressive strength (700 MPa, see Section 4.1) is more than the one specified for the concrete, it is determined that the steel plate design is acceptable.

7.7.2 Seismic Design Calculations - Third Design Concept

Using the bearing stress and the seismic load factor, the bearing stress due to seismic load is determined as follows:
Bearing stress due to seismic load = 1.66 * 16.87 = 28 MPa
= 4062 psi

A comparison of this bearing stress with concrete ultimate strength also suggests that the bearing stress is smaller than the allowable. A similar observation is made for the steel plate since the bearing area is the same in both cases.

The shear and bending stress calculations on the modified design are also provided in this section. The second concept included solid bars in the support structure. Therefore, it was not evaluated for horizontal loads because of larger area moments of inertia and lower WP load. Since no sliding between the WP and the support is assumed, the calculations for the horizontal seismic load are conservatively performed as follows (see Section 4.1 for the horizontal PGA which is the same as the vertical component):

Shear force on each round bar = 0.66 * (340456 / 2) = 112350 N

Diameter of the round bar = 0.1238 m (Assumption 4.3.39)
Shear stress = Shear force at the top surface of the plate / cross-sectional area of the round bar
= 112350 / (π $(0.1238)^2$ / 4) = 9.3 MPa

Bending stress on the round bar due to horizontal seismic input is calculated below:
Moment arm is the height from the contact point between the WP and the tube to the top surface of the plate. The contact point between the WP and the tube is assumed to be on a line normal to the tube surface which passes through the centerline of the pipe-tube interface.
Therefore,
moment arm = pipe height on centerline + vertical distance of the contact point from the pipe-tube interface on the centerline = [0.477 - 0.14 - (0.1683 * (tan30) / 2)] + [0.1016 * (sin60)] = 0.3764 m (see Attachment XII, page 3 for geometry and dimensions) (Assumptions 4.3.42 and 4.3.43)

Bending stress = bending moment * radius of the round bar / area moment of inertia of the round bar = (112350 * 0.3764) * (0.1238 / 2) / (π $(0.1238)^4$ / 64) = 227 MPa

The magnitudes of stresses determined for the shear and bending are acceptable since they are less than the yield strength of the material (248 MPa, see Section 4.1).

7.7.3 Handling Load Evaluations

A preliminary stress calculation for the lifting hook in the pier is performed to determine if the pier can be lifted using the material and dimensions assumed for this component. The calculation is provided for the normal stress in the hook as follows:
Pier mass = 947 kg (Assumption 4.3.40)
Pier weight = 947 * 9.81 = 9290 N
Lifting hook diameter = 0.5 in. = 0.0127 m (Assumption 4.3.41)
Normal stress on the lifting hook = (Pier weight / number of rebars engaged into concrete) / (rebar cross-sectional area)
Therefore,
normal stress on the lifting hook = (9290 / 4) / (π * $(0.0127)^2$ / 4) = 18.3 MPa

This magnitude of stress is significantly less than the allowable yield strength of the material (276 MPa, see Section 4.1) without any consideration of a dynamic load factor. However, this stress is so low that even if a load factor of 15 is applied, the normal stress would still be lower than the material yield strength. Since the handling load factor is anticipated to be significantly less than 15, the lifting hook design meets the structural requirement of lifting the pier.

The results obtained for the static and seismic analyses of the modified design are given in Tables 7-3 and 7-4.

Table 7-3. WP Support and Pier Static Analysis Results (third design concept)

WP Support and Pier Structural Components	Maximum Equivalent Stress (Seqv)	Tensile Yield Strength (Sy) (see Section 4.1)	Bearing Stress (compression) (see Section 7.7)	Compressive Yield Strength (Syc) (see Section 4.1)	Compressive Ultimate Strength (Suc) (see Section 4.1)
Tube	172.5 (XIII-2)	317.0	N/A	700.0	N/A
Pipe	89.0 (XIII-3)	248.0	N/A	700.0	N/A
Plate	40.3 (XIII-4)	248.0	N/A	700.0	N/A
Pier	N/A	N/A	16.87	N/A	34.5

*All stress magnitudes are in MPa

Table 7-4. WP Support and Pier Seismic Analysis Results (third design concept)

WP Support and Pier Structural Components	Maximum Equivalent Stress (Seqv)	Tensile Yield Strength (Sy) (see Section 4.1)	Bearing Stress (compression) (see Section 7.7)	Compressive Yield Strength (Syc) (see Section 4.1)	Compressive Ultimate Strength (Suc) (see Section 4.1)
Tube	286.7 (XIV-2)	317.0	N/A	700.0	N/A
Pipe	147.8 (XIV-3)	248.0	N/A	700.0	N/A
Plate	66.9 (XIV-4)	248.0	N/A	700.0	N/A
Pier	N/A	N/A	28.0	N/A	34.5

*All stress magnitudes are in MPa

8. CONCLUSIONS

As identified in Sections 2 and 4, this analysis is based on unqualified/unconfirmed input data, and use of any data from this analysis for input into documents supporting construction, fabrication, or procurement is required to be controlled as TBV in accordance with the appropriate procedures.

The failure criteria were explained in Section 7.1. Thus, the equivalent stresses from the ANSYS solution are compared to the stress allowables in order to evaluate the WP support and pier structure for any permanent deformation due to the WP static load. Tables 7-1 through 7-4 give the maximum values of the equivalent stress and allowable stress magnitudes.

A second failure criterion is used to determine any permanent deformation or crack in the concrete pier. The maximum-normal-stress theory requires the maximum compressive stress magnitude to be less than the compressive strength. This comparison is also provided in Tables 7-3 and 7-4. The attachment and page number where each stress magnitude can be found are shown in parentheses in Tables 7-1 through 7-4.

8.1 Tube Response to WP Static Load

Maximum-distortion-energy theory is based on a comparison of the material yield strength with the maximum equivalent stress (von Mises stress) observed in the material. The maximum equivalent stress magnitude occurs on the inner surface of the tube side wall. The maximum equivalent stress magnitude in the tube is 172.5 MPa, see Figure III-2 and Attachment XIII, page 2. When the yield strength of the tube (317 MPa) is compared to the equivalent stress value (172.5 MPa), it can be concluded that the elastic limit is not exceeded in the tube.

Having evaluated the results of the finite-element analysis of the tube in accordance with the maximum-distortion-energy theory, it is determined that the tube is able to withstand the static WP load without permanent deformation.

8.2 Pipe Response to WP Static Load

The maximum equivalent stress magnitude occurs on the outer surface of the pipe, in the region of contact with the tube. The maximum equivalent stress magnitude in the pipe is 89 MPa, see Attachment XIII, page 3. When the yield strength of the pipe (248 MPa) is compared to the equivalent stress value (89 MPa), it can be concluded that there is no permanent deformation in the pipe.

Having evaluated the results of the finite-element analysis of the pipe in accordance with the maximum-distortion-energy theory, it is determined that the pipe is able to withstand the static WP load without permanent deformation.

8.3 Plate Response to WP Static Load

The maximum equivalent stress magnitude occurs on the top surface of the plate in the region of contact with the pipe. The maximum equivalent stress magnitude in the plate is 40.3 MPa, see Attachment XIII, page 4. When the yield strength of the plate (248 MPa) is compared to the equivalent stress value (40.3 MPa), it is concluded that there is no permanent deformation in the plate.

8.4 Pier Response to WP Static Load

The results of the modified WP support design are also carried to the conclusions in terms of the pier response and maximum compressive stresses. Since the modified design has more strength and area of contact between the pipe and the plate, the resulting bearing stress in the pier is smaller despite a higher load from the WP (69,000 kg). Hence, the structural analyses of this concept revealed that the maximum bearing stress magnitude in the pier is 16.87 MPa, see Section 7.7. When the ultimate strength of concrete (34.5 MPa, see Section 4.1) is compared to the bearing stress (16.87 MPa), it is concluded that the concrete strength is not exceeded in the pier.

Having evaluated the results of the finite-element analysis of the pier in accordance with the maximum-normal-stress theory, it is determined that the pier is able to withstand the static WP load without failure.

8.5 Conclusions Drawn from Seismic Evaluations

A seismic factor of 1.66 was applied to the load of the static finite-element analysis in order to obtain a preliminary result for the seismic design of the support and pier structure (see Sections 7.6 and 7.7). The results are provided in Tables 7-2 and 7-4 and compared to the allowables. It has been concluded that the structural waste package support and pier design is acceptable for the seismic loads considered.

8.6 Maximum Deflection in the Support Structure

The maximum displacement in the system is determined to be 0.4 mm (Attachment XIX, page 2) and is in the region of contact between the tube and the pipe. (It should be noted that the results obtained from the finite-element model with the seismic load factor is reported for the maximum displacements in order to present the limiting case.) Since the maximum bending occurs in the tube lower plate due to the reaction force from the pipe, this is an expected result from the finite-element solution. The results also show that all stresses are in the elastic range of the stress-strain curve. This is why the maximum displacement in the support system is small.

8.7 Conclusions Drawn from Analyses of the WP Support Structure Designed to Hold the Maximum WP Weight as Specified in the CDA

The results of the structural analyses (see Tables 7-3 and 7-4) show that all stress magnitudes including the results of the seismic evaluations are below the stress allowables. Thus, it is determined that the design is structurally capable of withstanding the loads described in this document.

Structural evaluations of the WP support and pier design presented in this document show that the dimensions and material properties listed in Section 4.3 are acceptable and can be used to develop technical drawings of the subject structural components. Based on the results of this analysis, the assumed dimensions and materials for the third design concept are recommended for developing technical drawings for the WP support and pier design (Attachment XII).

The 600 mm Gantry Wheel design sketches are included in Attachment XII, pages 6 through 9. This design has a smaller pier thickness and larger width at the top. The most critical stress on the pier is the bearing stress due to load transfer from the pipe through the steel plate (see Section 7.7). Since the magnitude of the bearing stress is independent of the pier thickness and the width, the 600 mm Gantry Wheel design will experience a similar stress distribution with the 300 mm Gantry Wheel design concept. Thus, the dimensions provided for the 600 mm design concept in Attachment XII are recommended as an alternative for the WP support and pier design.

9. ATTACHMENTS

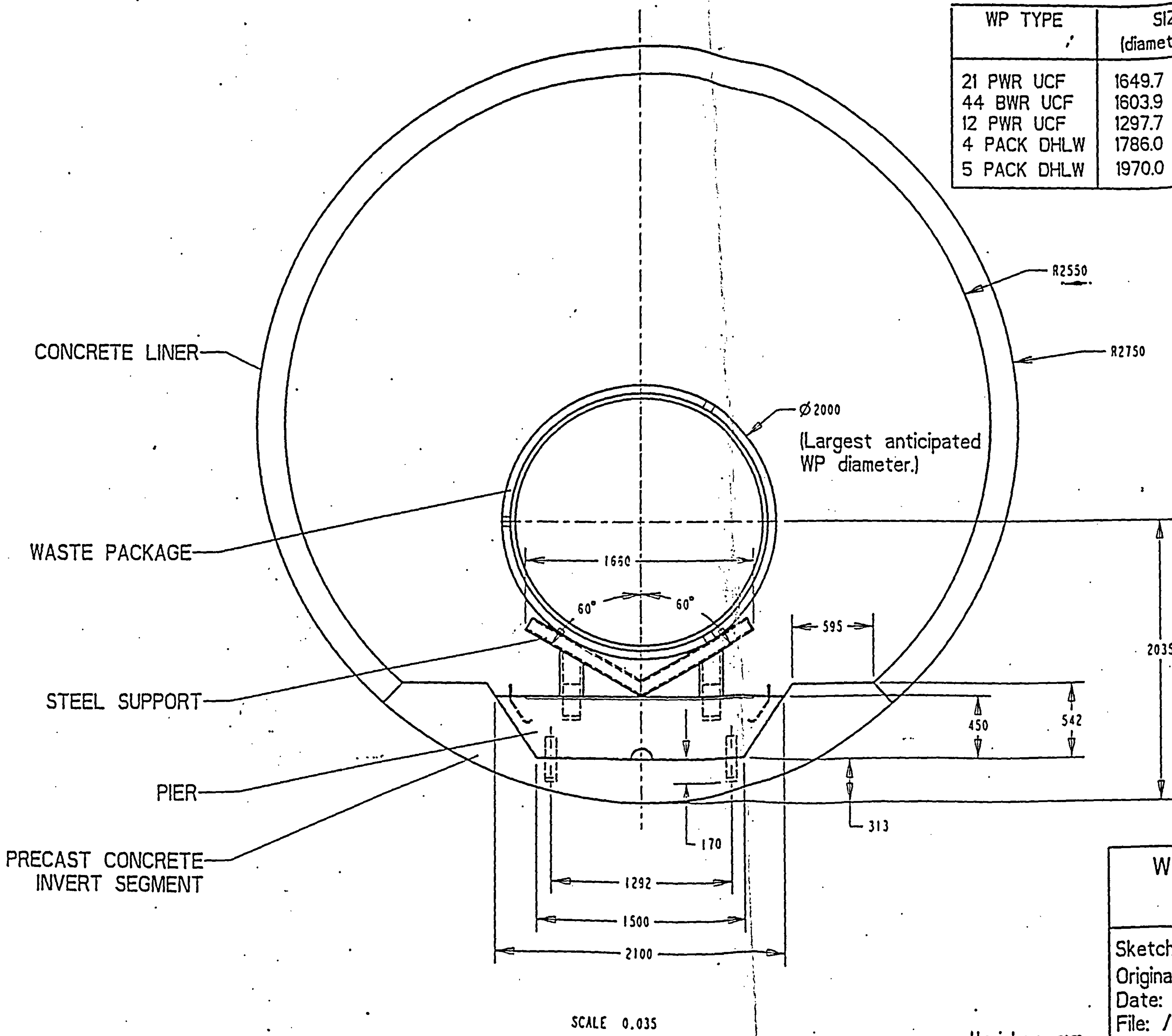
The following attachments are provided in this section :

Attachment I (2 pages):	WP support structure sketches provided for the first design concept
Attachment II (2 pages):	WP support structure sketches provided for the second design concept
Attachment III (2 pages):	Figures obtained from ANSYS V5.1 (third design concept)
Attachment IV (6 pages):	Equivalent and principal stresses for the support structure (static analysis results): eqvstrs.res: Jan 30 1997
Attachment V (6 pages):	Equivalent and principal stresses for the support structure (static analysis with a seismic load factor): eqvstrs1.res: Feb 20 1997
Attachment VI (72 pages):	Input/output files for static analysis: invert2.old1.out: Jan 30 1997
Attachment VII (72 pages):	Input/output files for static analysis performed with a seismic load factor: invert3.old1.out: Jan 30 1997
Attachment VIII (5 pages):	Postprocessing input/output files for static analysis: post2.old1.out: Jan 30 1997 (i/o files for Attachment IV)
Attachment IX (5 pages):	Postprocessing input/output files for static analysis performed with a seismic load factor: post2.old1.out: Feb 20 1997 (I/o files for Attachment V)
Attachment X (2 pages):	Maximum displacement in the waste package support and pier structure (static analysis with a seismic load factor): displ.res: Jan 31 1997
Attachment XI (4 pages):	Postprocessing input/output files for static analysis performed with a seismic load factor: post3.old1.out: Jan 31 1997 (I/o files for Attachment X)
Attachment XII (10 pages):	WP support structure sketches provided for the third design concept

Attachment XIII (5 pages):	Equivalent and principal stresses for the support structure (static analysis results) (for the third design concept): eqvstrsc.res: Feb 12 1997
Attachment XIV (5 pages):	Equivalent and principal stresses for the support structure (static analysis with a seismic load factor) (for the third design concept): eqvstrss.res: Feb 12 1997
Attachment XV (72 pages):	Input/output files for static analysis (for the third design concept): ingp2.old1.out: Feb 11 1997
Attachment XVI (72 pages):	Input/output files for static analysis performed with a seismic load factor (for the third design concept): ingp3.old1.out: Feb 11 1997
Attachment XVII (5 pages):	Postprocessing input/output files for static analysis (for the third design concept): post2gp.old1.out: Feb 12 1997 (I/o files for Attachment XIII)
Attachment XVIII (5 pages):	Postprocessing input/output files for static analysis performed with a seismic load factor (for the third design concept): post2s.old1.out: Feb 12 1997 (I/o files for Attachment XIV)
Attachment XIX (2 pages):	Maximum displacement in the waste package support and pier structure (static analysis with a seismic load factor) (for the third design concept): displsc.res: Feb 11 1997
Attachment XX (4 pages):	Postprocessing input/output files for static analysis performed with a seismic load factor (for the third design concept): post3s.old1.out: Feb 11 1997 (I/o files for Attachment XIX)

Table 1

WP TYPE	SIZE (diameter x length)	DISTANCE	WP LOADED MASS (kg)
21 PWR UCF	1649.7 x 5335	1833	50,423 est.
44 BWR UCF	1603.9 x 5335	1806	46,424 est.
12 PWR UCF	1297.7 x 5335	1629	32,236 est.
4 PACK DHLW	1786.0 x 3790 est.	1911	30,511 est.
5 PACK DHLW	1970.0 x 3790 est.	2018	35,692 est.



Units: mm

" For Information Only "

Waste Package Support Layout

(300 mm Gantry Wheel)

Sketch Number: SK-0004.Rev05

Originator: H. Wang HW 2/24/97 SNB 02/24/97 TWD 2-24-97

Date: 2/20/97

File: /users/wang/proe/supprt1_invert/sk0004_r5.drw