DEIR Appendix S
Seismic Hazard Analysis Workplan

1. INTRODUCTION

The purpose of this workplan is to provide a description of the analytical procedures to be employed by the applicant to implement certain mitigation measures detailed in the Draft Environmental Impact Report for the Wild Goose Storage Inc. Expansion Project in Butte and Colusa Counties, California.

2. NON LINEAR SOIL PIPE MODELING

The computer program FLAC will be used to perform the 2-D and 3-D nonlinear finite difference analysis for the project. FLAC will be used to evaluate permanent ground deformation (PGD) and the response of the pipeline to PGD. A second structural analysis program, ANSYS, will be used to confirm pipeline response. The general approach and details of types of anticipated PGD are as follows:

General Technical Approach

- Develop 3 sets of ground motion time histories but use only one time history in the analysis and final design. The time history judged to be the "most critical" will be used in all model runs.

- Setup a 2-D and 3-D FLAC model for one representative cross-section and one set of material properties to represent the existing site topography and subsurface conditions. The setup will include performing a static analysis and setup of the model for a dynamic analysis or quasi-static analysis. The resulting permanent ground deformations will be used as input for the ANSYS model.

- Use the Mohr-Coulomb constitutive models for soils for all 2-D and 3-D analysis. For the analysis of liquefaction of granular soils the Mohr-Coulomb constitutive model with the residual strength approach will be used.

- The steel pipe will be modeled using 3-D shell elements within FLAC. Since pipe elements are typically used to model the behavior of buried pipes in ANSYS, the results of the shell element in FLAC will be confirmed using pipe elements in ANSYS.

Pipe Properties and Acceptance Criterion

Anticipated Material Parameters

Material parameters for the pipeline are listed below:

Pipe Diameter D=30", API 5L Grade X65, wall thickness t = 0.462-inches

Pipe Diameter D=30", API 5L Grade X65, wall thickness t = 0.562-inches

Acceptance Criterion

The acceptance criterion for the analysis will be based on the criterion set forth in Appendix A, Reference 1. A partial list of the pressure integrity limits was outlined in Appendix A of reference 2 and is summarized below:

Acceptable longitudinal pipeline strain in tension: 4%

Acceptable longitudinal pipeline strain in compression: 1.76 t/D

Ovality of pipe cross-section: 15%

3. PERMANENT GROUND DEFORMATION ANALYSIS

A. Willows Fault Movement & Orientation

The pipeline, within the area of influence of the Willows Fault, will be mitigated to withstand a discrete displacement of 1.1m along dip (reverse; East Side up) with a 50% strike slip component, or 0.55m, at a depth of 1600 feet below the ground surface. The area of influence is defined by creating an envelope that brackets the Willows Fault and propagation from its approximate location at depth through a thick sequence of overlying alluvial and basin deposits. The segment of the pipeline to be mitigated for ground surface rupture or uplift associated with the Willows Fault is shown as a +/- 1 km fault location uncertainty envelope on Figure 7, Reference 8.

B. Revision of Liquefaction & Dynamic Compaction Analysis

A revised liquefaction analyses will be performed using data from previously drilled borings. The revision will account for the fact that some of the borings were drilled using hollow-stem auger methods and soil samples were collected using non-SPT samplers. Appropriate correction factors will be used to account for non-standard testing and/or sampling techniques. The following correction factors will be applied to the measured blow counts for liquefaction analyses.

Correction for overburden pressure	=	C_N	=	$(P_a/\sigma'_{vo})^{0.5} \leq 1.7$
Correction for automatic trip hammer	=	C_E	=	1.25
Correction for borehole diameter	=	C_B	=	1.0
Correction for rod length	=	C_R	=	0.75 for 3m to 4m
				0.85 for 4m to 6m
				0.95 for 6m to 10m
				1.0 for 10m to 30m
Correction for sampler without liners	=	C_S	=	1.2
Correction for Modified California sampler	=	C_{MC}	=	0.67

Correction for hollow stem drilling method = C_{HS} = 0.85

The corrected blow count should be calculated as follows, where N_m is the measured blow count in the field:

$$(N_1)_{60} = N_m C_N C_E C_B C_R C_S C_{MC} C_{HS}$$

The analyses will be performed from boring B-3A to Boring B-6A drilled near the Sacramento River. The result will be used to calculate permanent ground deformation (PGD) associated with liquefaction.

No additional field investigation need be performed as long as the pipeline can be designed to accommodate these conservative estimates of PGD.

C. Liquefaction Potential Rating along Pipeline

The applicant will obtain data in terms of shallow geologic materials from published California Geological Survey, CGS (formerly California Division of Mines and Geology, CDMG) and California Department of Water Resources (DWR) geologic maps along the pipeline alignment. In addition, the applicant will obtain data for the approximate shallow groundwater levels from the State or County files along the pipeline alignment. The combination of shallow groundwater and shallow Holocene geologic materials along with peak ground accelerations will be used to indicate areas of liquefaction susceptibility. The applicant will employ the same techniques as used by CGS in assessing the areas of low, moderate and high liquefaction susceptibility. The results of the analyses will be used in the design of the pipeline.

D. Fault Crossing Analysis

Two approaches will be used to address the fault crossing issue as outlined below:

Step 1:

A 3-dimensional finite difference model using the computer program FLAC will be used to evaluate ground surface rupture or uplift. This model will incorporate the nonlinear behavior of the soil and the linear elastic behavior of the pipe. The estimated maximum vertical and lateral fault displacement will be applied at the base of the model, 1600 feet below the ground surface. The analysis will consider the critical angle of fault displacement. The structural response of the pipeline will be evaluated as described in mitigation measure J and K below.

Step 2:

Pipeline response to faulting or uplift calculated in Step 1, above, will be confirmed using the computer model ANSYS. A 3-D model of the fault will be created using FLAC where the Willows Fault, overburden soils, and pipeline will be modeled in Step 1 above. The permanent ground deformation from the FLAC model will be input into ANSYS to confirm pipeline response.

E. Ground Motion Analysis

The time history developed will be used as input in the numerical modeling. The steps involved in this will be as follows:

1. Perform PSHA to develop Bedrock Spectra

2. Perform Site Response Analysis: Site response analysis will be performed using the computer program SHAKE.

3. Develop Site Specific Design Response Spectra (3 total)

4. Develop Time Histories (matched w/ Spectra) (3 total)

F. Travelling Wave Analysis

This task item will address Mitigation Measure 3.6-2. The objective of this analysis will be to analyze pipeline response to ground shaking and traveling wave effects based on the unique geologic conditions along the pipeline routes (Line 400/401 Connection Pipeline and the Storage Loop Pipeline). Traveling wave and ground shaking effects will be studied using empirical methods and the guidelines set forth in Reference 3.

G. Liquefaction Induced Settlements

This analysis will be carried out to evaluate permanent ground deformation due to liquefaction at the Sacramento River crossing. Standardized penetration values developed as described in section B above will be used to evaluate and quantify settlement due to liquefaction.

H. Liquefaction Induced Lateral Spreading:

The potential for lateral spreading and landslides will be evaluated at this site using semi empirical calculation methods developed by Youd and Garris (1995). If lateral spreading is a concern where the pipeline is above liquefiable soils a more rigorous 2D dynamic model will be setup to estimate the seismically induced slope deformations due to lateral spreading. Time-histories developed in the above sections will be used as input motion for the 2D model. The liquefaction behavior of saturated soils during seismic shaking will be modeled using the Mohr-Coulomb residual strength model. The resulting deformations of the slope will be input into the ANSYS model and the stresses and strains on the pipe will be evaluated as described in mitigation measure J and K below.

I. Pipe Bends

In this analysis a two-stem approach will be used. First, semi-empirical methods will be used to estimate the stresses and strains induced in the pipeline due to bends. If this approach results in pipe stresses and strains that are below tolerable limits of the pipeline then this approach shall be considered sufficient and appropriate. If however the threshold limit states are exceeded, more rigorous analysis will need to be carried out using FLAC and ANSYS.

In this second approach (if required) the stresses and strains induced by shear waves at pipe bends will be analyzed. A single quasi-static seismic excitation will be modeled by displacing the soil grid. There is one single pipe bend location (west of the Willows fault crossing) that requires this analysis. The result of this single pipe bend analysis is assumed to be representative of the bend east of the fault crossing and sufficient for the project mitigation measures at this time. The resulting stresses and strains on the pipe will be evaluated as described in mitigation measure J and K below.

J. PGD Demand Analysis

Where appropriate the above analyses will consider:

1. post wrinkle hinge effects;

2. the onset of incipient wrinkling as well as loss of pressure integrity;

3. a rigorous non-linear soil pipe interaction model;

4. a range of soil block lengths; and

5. load combinations.

A minimum of two additional sets of 3D FLAC/ANSYS analysis may be required to analyze stresses on the pipeline as a result of the two critical combinations of the mentioned PGD hazards.

K. Summary of Pipe Analysis Results

Formal limit states will be provided for each of the PGD scenario mentioned above. The ultimate and serviceability limit states will be defined for each given PGD analysis.

4. FINAL REPORT

The results of the above-mentioned analyses will be provided to the applicant's engineering consultant for incorporation into the final pipeline design.

5. REFERENCED DOCUMENTS:

1. 2001, American Lifelines Alliance, *Guideline for the Design of Buried Steel Pipe, July 2001*, www.americanlifelinesalliance.com.

2. 2001, Kleinfelder Report, *Seismic Hazard Site Investigation and Risk Assessment Wild Goose Natural Gas Storage Pipeline, Colusa and Butte Counties, California,* Project No 23-484855, Report Dated November 7, 2001, Sacramento.

3. 1999, O'Rourke, M.J., and Liu, X., Multi Disciplinary Center for Earthquake Engineering Research, *Response of Buried Pipelines to Earthquake Effects*, MEERC Monograph No. 3, New York.

4. 1995, Youd, T.L. and Garris, C.T., Liquefaction-Induced Ground-Surface Disruption, Journal of Geotechnical Engineering, ASCE, November, Vol., 121, No. 11, pp. 805-809.

5. 1984, American Society of Civil Engineers, *Guidelines for the Seismic Design of Oil and Gas Pipeline Systems*, Prepared by Committee on Gas and Liquid Fuel Lifelines of the ASCE Technical Council on Lifeline Earthquake Engineering, New York.

6. 1983, Wroth W.H., Sweet, J., Goodman, R.E., American Society of Civil Engineers, *Numerical Model Studies of Surface Faulting Hazard*, Houston, Texas, October 17-19, 1983.

7. 1981, Roth, W.H., Scott, R.F., Austin, I*., Centrifuge Modeling of Fault Propagation Through Alluvial Soils*, Geophysical Research Letters, Vol. 8, No. 6, pp. 561-564, May 1981.

8. 2002, Kleinfelder Report, *Willows Fault Rupture Hazard Evaluation, Wild Goose Storage Natural Gas Pipeline, Colusa and Butte Counties, California,* Project No 23-484855, Report Dated April 17, 2002, Sacramento, California, USA

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