DRESSER® STYLE 38,

24-1/2 INCH COUPLING

CYCLIC DISPLACEMENT

QUALIFICATION TEST

DIABLO CANYON POWER PLANT

ASW BYPASS PROJECT

ES Test Director/Preparer Robert LaPointe Date 11-22-96

Independent Technical Reviewer Erban L Green Date 11-22-96

Civil/Engineering Projects Eric Fujlin Date 11/25/96

Project Manager [signature] Date 11/22/96

9702030196 970127
PDR ADOCK 05000275
P PDR

I. ABSTRACT

PG&E is installing a bypass around portions of the original piping of the Auxiliary Salt Water System because of potential corrosion. The bypass uses conventional buried pipe design. The pipe is subject to large soil displacements. Dresser Couplings® are used to absorb the movement and to limit the stress in the pipe. The bypass piping and couplings will be fully lined and/or coated, both internally and externally. The piping, but not the couplings, will be cathodically protected to minimize degradation from corrosion. Couplings, not encased in concrete, will be doubly coated and encased in a geomembrane to preclude corrosion.

The Dresser coupling requirements are modified from the original-equipment-manufacture (OEM) design and have been verified, by test, to be capable of substantially greater longitudinal displacement with corresponding retained sealing capability when exposed to Hosgri Earthquake design basis input motions. In addition, the coupling was subjected to input motions up to 2.5 times greater than the DCPP Long Term Seismic Program (LTSP) 84% probability of nonexceedence displacements to demonstrate its seismic margin. To achieve the necessary displacement, the coupling must be lubricated; whereas the OEM design was a dry rubber-to-metal seal. Compatibility of the lubricant with all materials was addressed.

II. INTRODUCTION

Diablo Canyon Power Plant (DCPP) is installing over 1700 feet of 24 inch diameter, lined pipe to bypass portions of the existing saltwater system piping that may be degraded due to corrosion. The existing and replacement piping is fabricated from ASME A106, Grade B material with a plasticized polyvinyl chloride (PVC) liner. The liner was applied using a proprietary process by Barber-Webb Company of Los Angeles, California called Paraline®. The Paraline® covers the inside of the pipe, the flange faces, and portions of the pipe exterior at the plain end connections. On the plain ends, the Paraline® is wrapped back on the outside of the pipe for a distance of 12 to 16 inches so that the wetted surfaces under the mechanical coupling are protected from the seawater. Devoe Coatings' Devguard™ 238, an abrasion resistant epoxy coating, is applied to the remaining exterior portions of the pipe spools for abrasion and corrosion protection.

A 24 1/2 inch Dresser® Style 38, mechanical coupling (Attachments 1 and 2) is used to accommodate axial motion resulting from settlement and/or earthquake motion. The carbon steel middle ring of the coupling is coated, on the inside, with Paraline® to preclude corrosion by contact with sea water. Styrene butadiene rubber (SBR) gaskets seal the middle ring to the Paraline® surfaces on the outside of the pipe, completing the saltwater envelope.

DCPP's bypass design requires that the couplings accommodate up to +/- 3/4 inch axial pipe seismic displacement and remain leak tight. The possibility exists that the 3/4 inch of travel would be reached more than once. The Dresser® Coupling gasket design is such that it can absorb one event of 3/16 inch (3/8 inch per coupling) axial motion and not leak. Beyond 3/8 inch movement, the vendor will not assume the gaskets will reseat. The standard installation for this coupling seats the gasket on an uncoated carbon steel pipe surface and, as a result, the gasket adheres to the smooth pipe surface. During axial motion, each gasket would deform and absorb up to 3/16 inch and not lose its bond with the pipe metal surface. The manufacturer stated that should the gasket-to-pipe seal be upset, it might reseat after a single event but may not reseal when more than one event is involved at that displacement (for example, multiple earthquakes). Repeated upsets of the gasket-to-pipe interface may cause the gasket to roll under the follower ring and lose its seal resulting in a coupling leak.

Previous testing, performed by the manufacturer, on a 14 inch diameter pipe coupling subjected to high-cycle displacements demonstrated that the coupling has the capability to maintain integrity following peak-to-peak displacements of up to about one inch. However, these tests differed from DCPP's design in some important aspects, including the use of Paraline®, magnitude of the imposed displacements, and the number of earthquakes to which the coupling should be subjected.

The DCPP piping design requires that the coupling be able to accommodate pipe displacements at least four times the Dresser® design. In order to be able to function beyond the 3/8 inch limitation and still maintain the water tight seal, the coupling would have to slide along the Paraline® surface and, in the process, maintain its water tight seal. Because of this need for the coupling gaskets to slip at the gasket-to-Paraline® interface, DCPP's design includes the use of lubricants.

III. PROGRAM OBJECTIVES

The testing program had the following objectives:

- Find a lubricant that would substantially reduce friction between the Dresser® coupling gaskets and the Paralined® pipe and also be compatible with the interface materials.
- Establish the level of friction reduction attained by using the lubricant.
- Perform a seismic test that simulates the design basis seismic event at DCPP, preceded by a number of smaller seismic events.
- If the tests are successful at safe shutdown earthquake (SSE/Hosgri) levels, then establish a margin of safety in support of the DCPP LTSP.

IV. LUBRICANT

1. Basis

Selection of a lubricant centered on choosing a material that was chemically inert to the interfacing materials and had a wide service range of service temperature. Silicones were selected because of a long history of successful use with the generic materials involved. Dow Corning, a major manufacturer of silicones, was contacted and Dow agreed to perform tests on the actual production formulations to establish positive compatibility for the specific materials in the PG&E application. R&DS Design Basis EQ Lead helped establish the test parameters for the compatibility tests.

2. Results

Three Dow Corning® products were tested for compatibility with the Dresser coupling gasket material and the Paraline material. Accelerated aging tests were performed which simulated 20 years of contact between the lubricants and both the SBR Dresser® gaskets and PVC Paraline® materials. The tests were performed based on an activation energy of .7 eV. The temperature (198° F) was selected to be at a level below the phase change of the Dow Corning lubricants. Baseline values for hardness(durometer), tensile strength, and elongation were performed on both aged and un-aged material. Specimens were placed in an oven, and aged for 10 days and then tested for hardness, tensile strength, and elongation.

The Dow Corning® lubricants used in these tests were DC 111, DC 112, and DC 3452, all silicone-based. Testing was conducted in April and May, 1996 by Dow Corning Corporation, Midland, Michigan. Results from the Dow Corning® tests are recorded in RMS on Reel 6731, Frames 0065-0074 (Attachment 3).

In general, the aging tests suggest no negative effect of the lubricants with regard to tensile and elongation. However, modulus values were off for SBR for all samples except that coated with DC 3452 because these samples failed to reach 100% elongation. This included the sample with no lubricant which suggests the coated samples were at least no worst.

Dow Corning® DC 3452 had the least effect on both the Dresser® Coupling gasket and Paraline® materials and was chosen as the lubricant for mechanical testing of an assembled coupling.

V. FRICTIONAL FORCES

1. Basis

The second objective was achieved by determining the magnitude of frictional forces that exist when using the lubricant between the coupling gaskets and Paraline® versus the forces encountered after assembling the Dresser® Coupling using soapy water as directed by Dresser Manufacturing Division in their coupling installation instructions (Attachment 4 - DC 6014453-68-1). The level of reduction of frictional forces would be key to successfully completing a seismic test of the coupling at the design displacements required for DCPP.

2. Results

The test assembly consisted of two production spool pieces (1-6158-SP5 and 1-6159-SP5) held in the horizontal plane on rollers with a production Dresser® coupling connecting the two spools (Attachment 5). The spool pieces were filled with water and pressurized by a hydrostatic pump.

This test established that approximately 45 psig was required to overcome initial gasket-to-Paraline® friction, when the coupling is assembled using soapy water and allowed to sit for 48 hours. Approximately 23 psig was required to keep it moving once the gasket-to-Paraline seal was upset.

Note: Manufacturer's rule of thumb is that a maximum of 1 kip/inch of diameter would be the force required to overcome coupling friction, after the gasket has set, when the coupling has been assembled using soapy water. With a cross-sectional area of 424.56 sq. in., the 45 psig value, from the DCPP soapy water test, yields 19,105 pounds, somewhat less than the maximum 24,000 pounds derived by rule of thumb.

The test using Dow Corning DC 3452 never developed as a hydrostatic test. The pipe spools started to move apart during the water-fill stage, prior to external application of hydrostatic pressure. It took less than one psig to create/maintain pipe movement.

For the lubricated coupling, a one psi pressure yields a 425 pound frictional force. This 45 to 1 reduction in frictional force would aid in the success of the seismic tests that follow. Test results, from the adhesion tests, are documented in A/R A0396347 (Attachment 6) and in RMS on Reel 6731, Frames 0085-0089 (Attachment 7). The test was conducted under Mechanical Maintenance Work Order M0005579, Activity 1 (Attachment 8).

VI. SEISMIC TESTING

1. Seismic Criteria

PG&E Civil/Engineering Projects(C/EP), in San Francisco, developed the seismic criteria based on an analysis of design basis seismic events, and those seismic events based upon the DCPP LTSP. The largest design basis seismic displacements would originate from a Hosgri earthquake. Requirements for the fragility tests, whose displacements exceeded those of the Hosgri earthquake, were also developed to determine the safety margin for the coupling. Attachment 9 contains the seismic test requirements, which are presented as two alternatives. Alternative 2, below was selected for the test program.

Alternative 2:

- Sinusoidal cyclic test starting with low amplitude slip, progressively increasing, ending with 5 cycles of peak slip displacement. Run five tests to simulate OBE input, one test for Hosgri input, and three fragility tests at progressively increasing peak displacements to demonstrate the reserve margin that the coupling has.
- Frequency: 4.5 Hz. minimum (Note: Input motions with higher frequencies will increase the severity of loading on the coupling. Input motion frequencies in the range of 4.5 to approximately 5.5 Hz are acceptable.)
- Duration of each test: approximately. 25 sec., adjusted as needed to achieve the displacement cycles as summarized below.

Test	Series 1 80 cycles	Series 2 20 cycles	Series 3 20 cycles	Series 4 5 cycles	Comments
1	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri
2	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri
3	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri
4	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri
5	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri.
6	0.5 in.	0.75 in.	1 in.	1.5 in.	Hosgri
7	0.67 in.	1 in.	1.33 in.	2 in.	Fragility
8	0.83 in.	1.25 in.	1.67 in.	2.5 in.	Fragility
9	1 in.	1.5 in.	2 in.	3 in.	Fragility

Displacements, listed in the table, are peak-to-peak values.

In order to simulate earthquake response, Series 1 through 4 inputs should be imposed continuously, with one series commencing immediately after completion of the preceding series.

Because of the concern about the capacity of the coupling to maintain its integrity following multiple seismic events, the coupling would be subjected to five OBE-level input motions preceding the Hosgri input. This approach also was intended to

demonstrate that the coupling can accommodate smaller earthquakes which have a higher likelihood for occurrence than the SSE.

2. Testing Considerations

Testing of a full size coupling and piping was selected to verify the function of the joint. Testing a full size specimen, would eliminate the need for scaling results on a smaller diameter pipe test assembly. Production spool pieces and a production coupling would be used. Field coupling installation instructions would be used to reflect production conditions as closely as possible.

PG&E C/EP determined that the installed piping would be subject to predominantly axial motion. Off-axis motion was determined to be less than 1 degree and would not have to be simulated in the tests. The test rig was designed around one plane-of-motion.

Initially, testing was to be performed with the test assembly internally pressurized to 150 psig. This required an extremely large hydraulic piston, servo valve control module, pump and motor beyond the capabilities of equipment available. The motion of the piping would also create a shock absorber effect which would significantly increase the required input forces. Additionally, maintaining 150 psig internal pressure on the assembly would require either an external accumulator and two 4" diameter supply and return lines or a pressurized bladder inserted inside the stationary pipe. These requirements were difficult to achieve and always resulted in an increased capacity of the hydraulic system.

The decision was made to eliminate the water (and hydrostatic pressure) on the inside of the pipe. The test would provide a more conservative result due to the lack of lubrication (from the water) on the inside frictional interfaces. The forces required to perform the test are greatly reduced allowing the use of a commercially available shaker head and servo control valve system and the test rig could be of more reasonable size. This would also reduce the hazards to personnel during the test.

It was postulated that the coupling could adhere to one pipe more than the other, i.e. "walk" off to one side uncovering the gap between the pipes. A Dresser® Coupling gasket would be backed-off from the coupling follower ring, by 1" and held in place using stainless steel banding to prevent the coupling from going too far in one direction. The gasket and banding are referred to in the test procedure as the bumper. During the preliminary tests, this arrangement proved to have insufficient frictional force to restrain the coupling and was subsequently replaced by 24" pipe clamps.

All testing was performed under the DCPP Quality Program.

3. Test Apparatus Description

Basic design concept was to subject the pipes and coupling to vibratory motion that conservatively simulates that postulated for the inground piping during an earthquake. This would be accomplished by holding two production pipe spools in alignment with a Dresser® coupling installed between the spools. One spool would move and the other spool would be stationary. Coupling "walking" would not be restricted unless the coupling moved to one side more than two inches.

To the maximum extent possible, production materials, procedures, and practices were used to approximate field conditions. The mounting details were made as close to an inground configuration as possible. The use of casters and structural supports, to maintain alignment, were devised to simulate an installed condition.

After preliminary tests, the test rig was stiffened. Square tubing was utilized to reinforce the anchor points to the concrete pad. See Attachment 10 for details of the final configuration of the test rig. Attachment 11 shows details of the shaker (hydraulic piston/cylinder/servo) mounting details.

Alignment of the test rig, pipe spools, and shaker was performed by TES Electrical/Mechanical using a precision optical level measuring unit and a horizontal precision measuring unit; both having a +/- 2 mil accuracy.

The large casters, used to maintain alignment of the moving pipe, were prone to developing flat spots when forced against the pipe for more than a day. These casters were faced with plastic and the plastic would deform at the point of contact with the pipe. To compensate, the caster would be turned just before the test. Not turning the caster created a thump and misalignment when the spool attached to the shaker was moved. The casters were marked to ensure that they were not turned to a previous flat spot.

There was concern that the lubricant would heat up during the tests, both from the sun heating the black external coating and from friction, making the lubricant more lubricious; thereby invalidating the test results. A water hose with a small spray nozzle was trained on the coupling during the test to simulate the in-ground heat sink and eliminate heat build-up.

The test rig was designed by PG&E Engineering Services/Support Engineering, Piping Engineering Group and fabricated by PG&E DCPP Outage Services. The test rig, test assembly, and associated hydraulic pump, servo controls, shaker head, and instrumentation were assembled in Area 10 at DCPP.

The hydraulics, shaker head, and instrumentation were supplied by PG&E Technical and Environmental Services (TES).

4. Seismic Tests

The qualifying seismic tests were performed on August 27 and 28, 1996 using the Seismic Qualification Test Procedure For Dresser Style 38, etc.(see Attachment 12) and Work Order CO146487 (Attachment 13).

The first three tests were exploratory in nature and not part of the seismic qualification tests. They were performed to establish the dynamic characteristics of the test assembly, test rig, servo control system, hydraulic pump unit, and shaker head.

The order in which the tests were conducted was modified from the PG&E C/EP "Dresser Coupling Testing Guidelines" (Attachment 9) criteria of five operating basis earthquakes (OBEs) followed by a safe shutdown earthquake (SSE) (Hosgri). The change of testing sequence was approved in a meeting with the Lead C/EP Engineer the day of the test. The original sequence was based on IEEE 344-87 and considered the 5 OBEs as aging/conditioning tests which simulated the system having been in operation for a period of time prior to experiencing a SSE. The test sequence consisted of one OBE followed by one Hosgri, a hydrostatic test, then 4 more OBEs, another hydrostatic test, then 3 fragility tests (beyond Hosgri displacement) and the final hydrostatic test. No leakage was observed during any hydrostatic test. For purposes of meeting the intent of IEEE 344-87 the first 6 tests will be considered as OBEs and the first fragility test will more than satisfy the SSE (Hosgri) test requirement. PG&E performed the tests out of sequence to ensure that a Hosgri level event would pass the hydrostatic test after the first OBE was performed. Since this was the first time that a Dresser Style 38 coupling had been taken to these seismic levels, there was some doubt whether the coupling would remain leak tight, so the test sequence was rearranged to check leakage after one OBE and one Hosgri test. Once the test assembly passed the hydrostatic test the remainder of tests were performed. Although the original test plan permitted replacement of the pipe and coupling components prior to beginning the fragility test series, the entire series of tests, including OBE's, Hosgri, and all fragility tests were performed using the same hardware, Paraline®, and gaskets.

Fragility tests were not limited by the design of the piping-coupling system; but were limited by the input displacement capabilities of the testing apparatus and the maximum gap, that can exist, between the pipes before the coupling would no longer be leak tight. A maximum displacement of 2.81 inches was achieved in the fragility test series.

The hydrostatic test hold time, specified by C/EP, was changed from a 30 minute hold time. Upon reviewing the hold time specified in DCPP MP M-56.1 "SYSTEM PRESSURE TEST", the hydrostatic test hold time was changed to coincide with the industry recognized minimum of 10 minutes. The 30 minute hold time was originally specified based upon good judgment and not on specific technical criteria.

VII. SUMMARY

The coupling favored one pipe and moved in one direction before that movement stopped. A pipe clamp had been placed on either side of the coupling to prevent the coupling from uncovering the pipe gap. The coupling stopped moving to one side before it would have engaged the pipe clamp on that side and stayed in that spot for the duration of the tests.

One Dresser Style 38, 24 1/2 inch mechanical coupling was tested through 5 Operational Basis Earthquakes (OBE's), 1 Hosgri earthquake, and 3 fragility tests using the same hardware, the same gaskets, and the same Paralined pipe surfaces for all tests. Once the tests started, the coupling was not disassembled for inspection until after the final hydrostatic test. From a cumulative effect standpoint, the tests represented more than 5 consecutive Hosgri events without failure. Because of the lack of any serious damage or degradation observed in the coupling components, and the ability of the coupling to maintain leak tightness after the completion of tests, it is likely that a significant margin exists beyond the tested displacements.

Inspection of the Dresser coupling gaskets and the Paraline surfaces revealed that the materials, although showing some wear, would still perform their design function and did not leak during a hydrostatic test at 150 psig.

VIII. CONCLUSIONS

Dow Corning DC 3452 was selected on the basis of compatibility with the interfacing materials and on the basis of a demonstrated 45-to-1 reduction in frictional forces between Paralined™ pipe and the Dresser® coupling. Field materials and procedures were used to closely represent field conditions.

The DC 3452 lubricant and Dresser® coupling performed satisfactorily during all the qualifying seismic and fragility tests. At the end of testing, the Paraline® showed some signs of deterioration, however; this degradation is understandable in light of the fact that those same surfaces experienced the cumulative effects of approximately five complete simulated Hosgri events (all preliminary testing plus the qualifying OBEs, Hosgri, and fragility tests) without losing the ability to maintain a watertight seal. Additionally, only one set of Dresser® coupling gaskets were used for all the qualifying (OBE and Hosgri tests) and fragility tests. The gaskets were subjected to the cumulative effects of approximately four Hosgri events without leaking when hydrostatically tested at 150 psig.

The Dresser® coupling and the Paraline® surfaces of the 24" diameter ASW pipe are capable of performing the required design function during or after the postulated

seismic requirements of the ASW Piping Bypass Project. The design is conservative enough to support at least five consecutive worst case operating events without failure.

IX. RECORDS

The tests were recorded using video tape and 35 mm film. A VHS video has been assembled to show the entire set of qualifying seismic tests. Another video shows the preliminary testing program where the testing apparatus (test rig, test assembly, shaker head, etc.) was subjected to trial runs and pretest adjustments.

TES recorded the data from their accelerometers and their equipment. These records are included in Attachment 14 (RMS Reel No. 06874, Frames 0292 to 0469).

X. REFERENCES

1. U.S. Nuclear Regulatory Commission Regulatory Guide 1.100, Revision 2, June 1988, Seismic Qualification of Electric and Mechanical Equipment for Nuclear Power Plants.

2. IEEE Std 344-1987, IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations.

3. Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation, PVP-34, The American Society of Mechanical Engineers, presented at The Third National Congress on Pressure Vessels and Piping, San Francisco, California, June 25-29, 1979.

4. Piping Handbook, Sixth Edition, 1992, McGraw-Hill, Inc.

5. Dynamics of Structures - Theories and Applications to Earthquake Engineering, 1995, Prentice-Hall, Inc.

6. The Civil Engineering Handbook, 1995, CRC Press, Inc.

7. Seismic Effects in PVP Components, PVP - Vol. 88, The American Society of Mechanical Engineers, presented at The 1984 Pressure Vessel and Piping Conference and Exhibition, San Antonio, Texas, June 17-21, 1984.

8. Dynamics and Seismic Issues in Primary and Secondary Systems, PVP - Vol. 137, The American Society of Mechanical Engineers, presented at The 1988

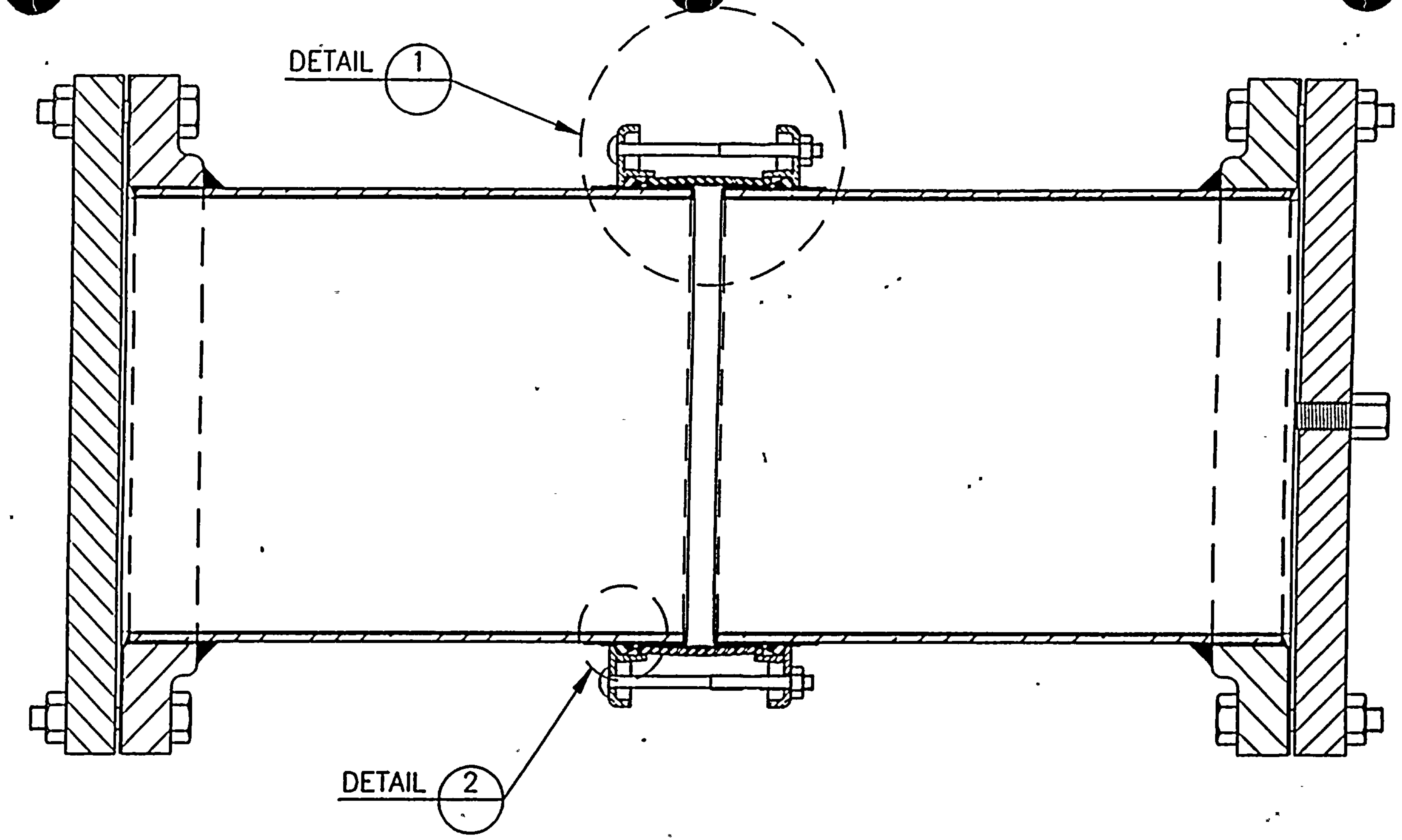
ASME Pressure Vessels and Piping Conference, Pittsburgh, Pennsylvania, June 19-23, 1988.

9. Seismic Engineering , 1994, Volume 1, PVP - Vol. 275-1, The American Society of Mechanical Engineers, presented at The 1994 Pressure Vessels and Piping Conference, Minneapolis, Minnesota, June 19-23, 1994.

XI. ATTACHMENTS

1. Dresser Coupling Test Configuration
2. Dresser Coupling Details
3. Dow Corning Lubricant Test Report
4. Dresser Coupling Installation Instructions
5. Photograph of Frictional Force Setup
6. A/R A0396347 - Dresser Coupling Test Program
7. Dresser Coupling Adhesion Test Results and Conclusions
8. Maintenance Work Order M0005579, Activity 01, Perform Coupling Test
9. PG&E Civil/Engineering Projects Dresser Coupling Testing Guidelines
10. DCPP Dresser Coupling Seismic Test Rig
11. Test Rig Shaker Mounting Detail
12. Seismic Qualification Test Procedure for Dresser Style 38, 24 1/2 Inch Coupling to be used in DCPP Auxiliary Saltwater Bypass Piping Project, signed 8-13-96.
13. DCPP Work Order C0146487
14. Chapters 1 through 3 of TES Dresser Coupling Cyclic Displacement Slip Capacity Test Report - 420DC-96.183, RMS Reel No. 06874, Frames 0292 to 0469.

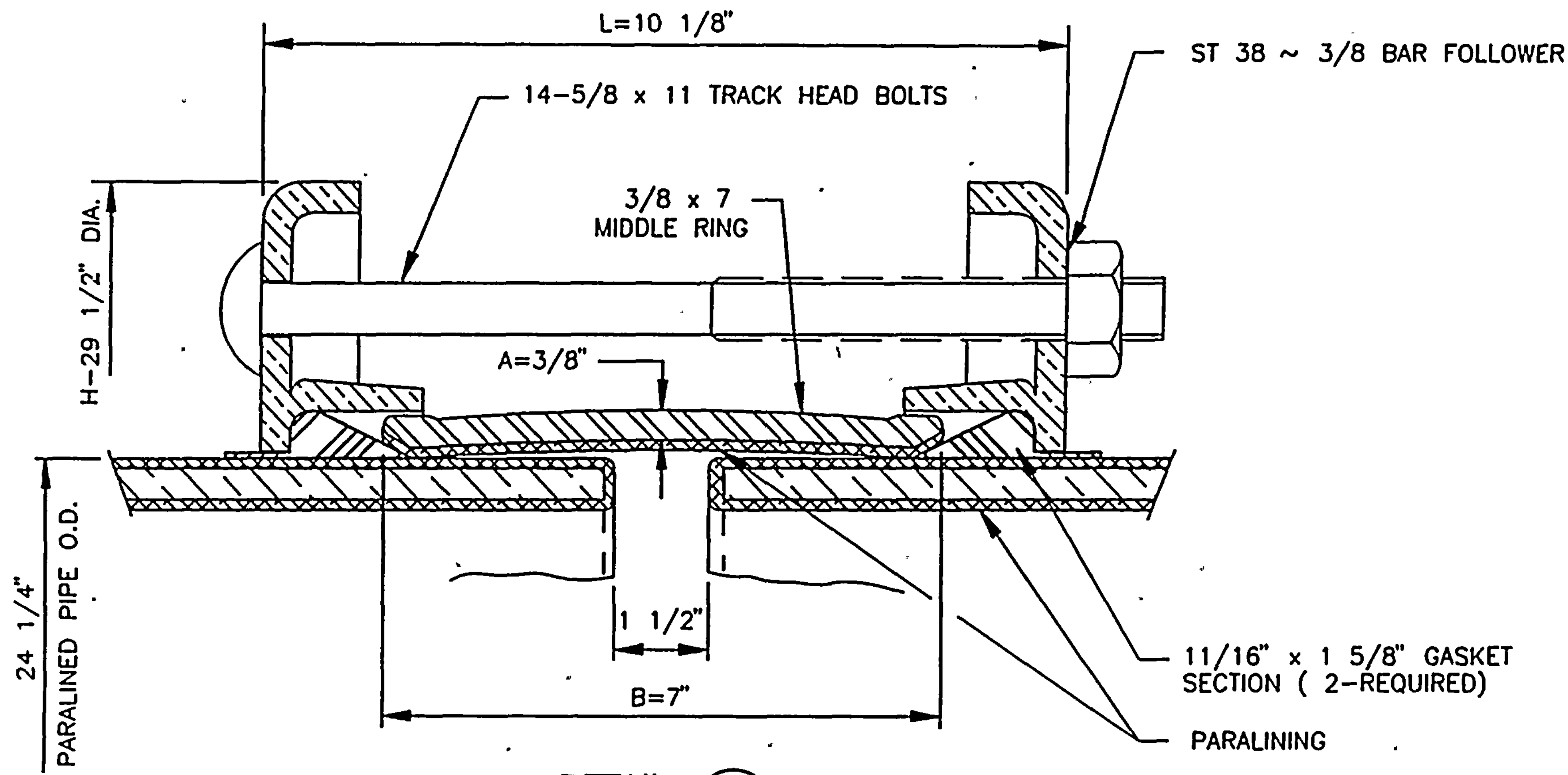
ATTACHMENT 1



TEST CONFIGURATION
24 1/2" O.D. STYLE 38 COUPLING
(SCALE: 1 1/2" = 1'-0")
ATTACHMENT 1

Figure 6
DCL-97-010

ATTACHMENT 2



DETAIL 1

24 1/2" O.D. STYLE 38 COUPLING

(SCALE: 1/2"=1")

ATTACHMENT 2

DRESSER® STYLE 38,

24-1/2 INCH COUPLING

CYCLIC DISPLACEMENT

QUALIFICATION TEST

DIABLO CANYON POWER PLANT

ASW BYPASS PROJECT

ES Test Director/Preparer Robert LaPointe Date 11-22-96

Independent Technical Reviewer Orlan L Green Date 11-22-96

Civil/Engineering Projects ______ Date 11/20/96

Project Manager ______ Date 11/22/96

~~9702~~030196

I. ABSTRACT

PG&E is installing a bypass around portions of the original piping of the Auxiliary Salt Water System because of potential corrosion. The bypass uses conventional buried pipe design. The pipe is subject to large soil displacements. Dresser Couplings® are used to absorb the movement and to limit the stress in the pipe. The bypass piping and couplings will be fully lined and/or coated, both internally and externally. The piping, but not the couplings, will be cathodically protected to minimize degradation from corrosion. Couplings, not encased in concrete, will be doubly coated and encased in a geomembrane to preclude corrosion.

The Dresser coupling requirements are modified from the original-equipment-manufacture (OEM) design and have been verified, by test, to be capable of substantially greater longitudinal displacement with corresponding retained sealing capability when exposed to Hosgri Earthquake design basis input motions. In addition, the coupling was subjected to input motions up to 2.5 times greater than the DCPP Long Term Seismic Program (LTSP) 84% probability of nonexceedence displacements to demonstrate its seismic margin. To achieve the necessary displacement, the coupling must be lubricated; whereas the OEM design was a dry rubber-to-metal seal. Compatibility of the lubricant with all materials was addressed.

II. INTRODUCTION

Diablo Canyon Power Plant (DCPP) is installing over 1700 feet of 24 inch diameter, lined pipe to bypass portions of the existing saltwater system piping that may be degraded due to corrosion. The existing and replacement piping is fabricated from ASME A106, Grade B material with a plasticized polyvinyl chloride (PVC) liner. The liner was applied using a proprietary process by Barber-Webb Company of Los Angeles, California called Paraline®. The Paraline® covers the inside of the pipe, the flange faces, and portions of the pipe exterior at the plain end connections. On the plain ends, the Paraline® is wrapped back on the outside of the pipe for a distance of 12 to 16 inches so that the wetted surfaces under the mechanical coupling are protected from the seawater. Devoe Coatings' Devguard™ 238, an abrasion resistant epoxy coating, is applied to the remaining exterior portions of the pipe spools for abrasion and corrosion protection.

A 24 1/2 inch Dresser® Style 38, mechanical coupling (Attachments 1 and 2) is used to accommodate axial motion resulting from settlement and/or earthquake motion. The carbon steel middle ring of the coupling is coated, on the inside, with Paraline® to preclude corrosion by contact with sea water. Styrene butadiene rubber (SBR) gaskets seal the middle ring to the Paraline® surfaces on the outside of the pipe, completing the saltwater envelope.

Enclosure 6

DRESSER® STYLE 38,

24-1/2 INCH COUPLING

CYCLIC DISPLACEMENT

QUALIFICATION TEST

DIABLO CANYON POWER PLANT

ASW BYPASS PROJECT

ES Test Director/Preparer Robert LaPointe Date 11-22-96

Independent Technical Reviewer Erban L Green Date 11-22-96

Civil/Engineering Projects [illegible] Date 11/20/96

Project Manager [illegible] Date 11/22/96

~~9702~~030196

I. ABSTRACT

PG&E is installing a bypass around portions of the original piping of the Auxiliary Salt Water System because of potential corrosion. The bypass uses conventional buried pipe design. The pipe is subject to large soil displacements. Dresser Couplings® are used to absorb the movement and to limit the stress in the pipe. The bypass piping and couplings will be fully lined and/or coated, both internally and externally. The piping, but not the couplings, will be cathodically protected to minimize degradation from corrosion. Couplings, not encased in concrete, will be doubly coated and encased in a geomembrane to preclude corrosion.

The Dresser coupling requirements are modified from the original-equipment-manufacture (OEM) design and have been verified, by test, to be capable of substantially greater longitudinal displacement with corresponding retained sealing capability when exposed to Hosgri Earthquake design basis input motions. In addition, the coupling was subjected to input motions up to 2.5 times greater than the DCPP Long Term Seismic Program (LTSP) 84% probability of nonexceedence displacements to demonstrate its seismic margin. To achieve the necessary displacement, the coupling must be lubricated; whereas the OEM design was a dry rubber-to-metal seal. Compatibility of the lubricant with all materials was addressed.

II. INTRODUCTION

Diablo Canyon Power Plant (DCPP) is installing over 1700 feet of 24 inch diameter, lined pipe to bypass portions of the existing saltwater system piping that may be degraded due to corrosion. The existing and replacement piping is fabricated from ASME A106, Grade B material with a plasticized polyvinyl chloride (PVC) liner. The liner was applied using a proprietary process by Barber-Webb Company of Los Angeles, California called Paraline®. The Paraline® covers the inside of the pipe, the flange faces, and portions of the pipe exterior at the plain end connections. On the plain ends, the Paraline® is wrapped back on the outside of the pipe for a distance of 12 to 16 inches so that the wetted surfaces under the mechanical coupling are protected from the seawater. Devoe Coatings' Devguard™ 238, an abrasion resistant epoxy coating, is applied to the remaining exterior portions of the pipe spools for abrasion and corrosion protection.

A 24 1/2 inch Dresser® Style 38, mechanical coupling (Attachments 1 and 2) is used to accommodate axial motion resulting from settlement and/or earthquake motion. The carbon steel middle ring of the coupling is coated, on the inside, with Paraline® to preclude corrosion by contact with sea water. Styrene butadiene rubber (SBR) gaskets seal the middle ring to the Paraline® surfaces on the outside of the pipe, completing the saltwater envelope.

DCPP's bypass design requires that the couplings accommodate up to +/- 3/4 inch axial pipe seismic displacement and remain leak tight. The possibility exists that the 3/4 inch of travel would be reached more than once. The Dresser® Coupling gasket design is such that it can absorb one event of 3/16 inch (3/8 inch per coupling) axial motion and not leak. Beyond 3/8 inch movement, the vendor will not assume the gaskets will reseat. The standard installation for this coupling seats the gasket on an uncoated carbon steel pipe surface and, as a result, the gasket adheres to the smooth pipe surface. During axial motion, each gasket would deform and absorb up to 3/16 inch and not lose its bond with the pipe metal surface. The manufacturer stated that should the gasket-to-pipe seal be upset, it might reseat after a single event but may not reseal when more than one event is involved at that displacement (for example, multiple earthquakes). Repeated upsets of the gasket-to-pipe interface may cause the gasket to roll under the follower ring and lose its seal resulting in a coupling leak.

Previous testing, performed by the manufacturer, on a 14 inch diameter pipe coupling subjected to high-cycle displacements demonstrated that the coupling has the capability to maintain integrity following peak-to-peak displacements of up to about one inch. However, these tests differed from DCPP's design in some important aspects, including the use of Paraline®, magnitude of the imposed displacements, and the number of earthquakes to which the coupling should be subjected.

The DCPP piping design requires that the coupling be able to accommodate pipe displacements at least four times the Dresser® design. In order to be able to function beyond the 3/8 inch limitation and still maintain the water tight seal, the coupling would have to slide along the Paraline® surface and, in the process, maintain its water tight seal. Because of this need for the coupling gaskets to slip at the gasket-to-Paraline® interface, DCPP's design includes the use of lubricants.

III. PROGRAM OBJECTIVES

The testing program had the following objectives:

- Find a lubricant that would substantially reduce friction between the Dresser® coupling gaskets and the Paralined® pipe and also be compatible with the interface materials.
- Establish the level of friction reduction attained by using the lubricant.
- Perform a seismic test that simulates the design basis seismic event at DCPP, preceded by a number of smaller seismic events.
- If the tests are successful at safe shutdown earthquake (SSE/Hosgri) levels, then establish a margin of safety in support of the DCPP LTSP.

IV. LUBRICANT

1. Basis

Selection of a lubricant centered on choosing a material that was chemically inert to the interfacing materials and had a wide service range of service temperature. Silicones were selected because of a long history of successful use with the generic materials involved. Dow Corning, a major manufacturer of silicones, was contacted and Dow agreed to perform tests on the actual production formulations to establish positive compatibility for the specific materials in the PG&E application. R&DS Design Basis EQ Lead helped establish the test parameters for the compatibility tests.

2. Results

Three Dow Corning® products were tested for compatibility with the Dresser coupling gasket material and the Paraline material. Accelerated aging tests were performed which simulated 20 years of contact between the lubricants and both the SBR Dresser® gaskets and PVC Paraline® materials. The tests were performed based on an activation energy of .7 eV. The temperature (198° F) was selected to be at a level below the phase change of the Dow Corning lubricants. Baseline values for hardness(durometer), tensile strength, and elongation were performed on both aged and un-aged material. Specimens were placed in an oven, and aged for 10 days and then tested for hardness, tensile strength, and elongation.

The Dow Corning® lubricants used in these tests were DC 111, DC 112, and DC 3452, all silicone-based. Testing was conducted in April and May, 1996 by Dow Corning Corporation, Midland, Michigan. Results from the Dow Corning® tests are recorded in RMS on Reel 6731, Frames 0065-0074 (Attachment 3).

In general, the aging tests suggest no negative effect of the lubricants with regard to tensile and elongation. However, modulus values were off for SBR for all samples except that coated with DC 3452 because these samples failed to reach 100% elongation. This included the sample with no lubricant which suggests the coated samples were at least no worst.

Dow Corning® DC 3452 had the least effect on both the Dresser® Coupling gasket and Paraline® materials and was chosen as the lubricant for mechanical testing of an assembled coupling.

V. FRICTIONAL FORCES

1. Basis

The second objective was achieved by determining the magnitude of frictional forces that exist when using the lubricant between the coupling gaskets and Paraline® versus the forces encountered after assembling the Dresser® Coupling using soapy water as directed by Dresser Manufacturing Division in their coupling installation instructions (Attachment 4 - DC 6014453-68-1). The level of reduction of frictional forces would be key to successfully completing a seismic test of the coupling at the design displacements required for DCPP.

2. Results

The test assembly consisted of two production spool pieces (1-6158-SP5 and 1-6159-SP5) held in the horizontal plane on rollers with a production Dresser® coupling connecting the two spools (Attachment 5). The spool pieces were filled with water and pressurized by a hydrostatic pump.

This test established that approximately 45 psig was required to overcome initial gasket-to-Paraline® friction, when the coupling is assembled using soapy water and allowed to sit for 48 hours. Approximately 23 psig was required to keep it moving once the gasket-to-Paraline seal was upset.

Note: Manufacturer's rule of thumb is that a maximum of 1 kip/inch of diameter would be the force required to overcome coupling friction, after the gasket has set, when the coupling has been assembled using soapy water. With a cross-sectional area of 424.56 sq. in., the 45 psig value, from the DCPP soapy water test, yields 19,105 pounds, somewhat less than the maximum 24,000 pounds derived by rule of thumb.

The test using Dow Corning DC 3452 never developed as a hydrostatic test. The pipe spools started to move apart during the water-fill stage, prior to external application of hydrostatic pressure. It took less than one psig to create/maintain pipe movement.

For the lubricated coupling, a one psi pressure yields a 425 pound frictional force. This 45 to 1 reduction in frictional force would aid in the success of the seismic tests that follow. Test results, from the adhesion tests, are documented in A/R A0396347 (Attachment 6) and in RMS on Reel 6731, Frames 0085-0089 (Attachment 7). The test was conducted under Mechanical Maintenance Work Order M0005579, Activity 1 (Attachment 8).

VI. SEISMIC TESTING

1. Seismic Criteria

PG&E Civil/Engineering Projects(C/EP), in San Francisco, developed the seismic criteria based on an analysis of design basis seismic events, and those seismic events based upon the DCPP LTSP. The largest design basis seismic displacements would originate from a Hosgri earthquake. Requirements for the fragility tests, whose displacements exceeded those of the Hosgri earthquake, were also developed to determine the safety margin for the coupling. Attachment 9 contains the seismic test requirements, which are presented as two alternatives. Alternative 2, below was selected for the test program.

Alternative 2:

- Sinusoidal cyclic test starting with low amplitude slip, progressively increasing, ending with 5 cycles of peak slip displacement. Run five tests to simulate OBE input, one test for Hosgri input, and three fragility tests at progressively increasing peak displacements to demonstrate the reserve margin that the coupling has.

- Frequency: 4.5 Hz. minimum (Note: Input motions with higher frequencies will increase the severity of loading on the coupling. Input motion frequencies in the range of 4.5 to approximately 5.5 Hz are acceptable.)

- Duration of each test: approximately. 25 sec., adjusted as needed to achieve the displacement cycles as summarized below.

Test	Series 1 80 cycles	Series 2 20 cycles	Series 3 20 cycles	Series 4 5 cycles	Comments
1	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri
2	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri
3	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri
4	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri
5	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri
6	0.5 in.	0.75 in.	1 in.	1.5 in.	Hosgri
7	0.67 in.	1 in.	1.33 in.	2 in.	Fragility
8	0.83 in.	1.25 in.	1.67 in.	2.5 in.	Fragility
9	1 in.	1.5 in.	2 in.	3 in.	Fragility

Displacements, listed in the table, are peak-to-peak values.

In order to simulate earthquake response, Series 1 through 4 inputs should be imposed continuously, with one series commencing immediately after completion of the preceding series.

Because of the concern about the capacity of the coupling to maintain its integrity following multiple seismic events, the coupling would be subjected to five OBE-level input motions preceding the Hosgri input. This approach also was intended to

demonstrate that the coupling can accommodate smaller earthquakes which have a higher likelihood for occurrence than the SSE.

2. Testing Considerations

Testing of a full size coupling and piping was selected to verify the function of the joint. Testing a full size specimen, would eliminate the need for scaling results on a smaller diameter pipe test assembly. Production spool pieces and a production coupling would be used. Field coupling installation instructions would be used to reflect production conditions as closely as possible.

PG&E C/EP determined that the installed piping would be subject to predominantly axial motion. Off-axis motion was determined to be less than 1 degree and would not have to be simulated in the tests. The test rig was designed around one plane-of-motion.

Initially, testing was to be performed with the test assembly internally pressurized to 150 psig. This required an extremely large hydraulic piston, servo valve control module, pump and motor beyond the capabilities of equipment available. The motion of the piping would also create a shock absorber effect which would significantly increase the required input forces. Additionally, maintaining 150 psig internal pressure on the assembly would require either an external accumulator and two 4" diameter supply and return lines or a pressurized bladder inserted inside the stationary pipe. These requirements were difficult to achieve and always resulted in an increased capacity of the hydraulic system.

The decision was made to eliminate the water (and hydrostatic pressure) on the inside of the pipe. The test would provide a more conservative result due to the lack of lubrication (from the water) on the inside frictional interfaces. The forces required to perform the test are greatly reduced allowing the use of a commercially available shaker head and servo control valve system and the test rig could be of more reasonable size. This would also reduce the hazards to personnel during the test.

It was postulated that the coupling could adhere to one pipe more than the other, i.e. "walk" off to one side uncovering the gap between the pipes. A Dresser® Coupling gasket would be backed-off from the coupling follower ring, by 1" and held in place using stainless steel banding to prevent the coupling from going too far in one direction. The gasket and banding are referred to in the test procedure as the bumper. During the preliminary tests, this arrangement proved to have insufficient frictional force to restrain the coupling and was subsequently replaced by 24" pipe clamps.

All testing was performed under the DCPP Quality Program.

3. Test Apparatus Description

Basic design concept was to subject the pipes and coupling to vibratory motion that conservatively simulates that postulated for the inground piping during an earthquake. This would be accomplished by holding two production pipe spools in alignment with a Dresser® coupling installed between the spools. One spool would move and the other spool would be stationary. Coupling "walking" would not be restricted unless the coupling moved to one side more than two inches.

To the maximum extent possible, production materials, procedures, and practices were used to approximate field conditions. The mounting details were made as close to an inground configuration as possible. The use of casters and structural supports, to maintain alignment, were devised to simulate an installed condition.

After preliminary tests, the test rig was stiffened. Square tubing was utilized to reinforce the anchor points to the concrete pad. See Attachment 10 for details of the final configuration of the test rig. Attachment 11 shows details of the shaker (hydraulic piston/cylinder/servo) mounting details.

Alignment of the test rig, pipe spools, and shaker was performed by TES Electrical/Mechanical using a precision optical level measuring unit and a horizontal precision measuring unit; both having a +/- 2 mil accuracy.

The large casters, used to maintain alignment of the moving pipe, were prone to developing flat spots when forced against the pipe for more than a day. These casters were faced with plastic and the plastic would deform at the point of contact with the pipe. To compensate, the caster would be turned just before the test. Not turning the caster created a thump and misalignment when the spool attached to the shaker was moved. The casters were marked to ensure that they were not turned to a previous flat spot.

There was concern that the lubricant would heat up during the tests, both from the sun heating the black external coating and from friction, making the lubricant more lubricious; thereby invalidating the test results. A water hose with a small spray nozzle was trained on the coupling during the test to simulate the in-ground heat sink and eliminate heat build-up.

The test rig was designed by PG&E Engineering Services/Support Engineering, Piping Engineering Group and fabricated by PG&E DCPP Outage Services. The test rig, test assembly, and associated hydraulic pump, servo controls, shaker head, and instrumentation were assembled in Area 10 at DCPP.

The hydraulics, shaker head, and instrumentation were supplied by PG&E Technical and Environmental Services (TES).

4. Seismic Tests

The qualifying seismic tests were performed on August 27 and 28, 1996 using the Seismic Qualification Test Procedure For Dresser Style 38, etc.(see Attachment 12) and Work Order CO146487 (Attachment 13).

The first three tests were exploratory in nature and not part of the seismic qualification tests. They were performed to establish the dynamic characteristics of the test assembly, test rig, servo control system, hydraulic pump unit, and shaker head.

The order in which the tests were conducted was modified from the PG&E C/EP "Dresser Coupling Testing Guidelines" (Attachment 9) criteria of five operating basis earthquakes (OBEs) followed by a safe shutdown earthquake (SSE) (Hosgri). The change of testing sequence was approved in a meeting with the Lead C/EP Engineer the day of the test. The original sequence was based on IEEE 344-87 and considered the 5 OBEs as aging/conditioning tests which simulated the system having been in operation for a period of time prior to experiencing a SSE. The test sequence consisted of one OBE followed by one Hosgri, a hydrostatic test, then 4 more OBEs, another hydrostatic test, then 3 fragility tests (beyond Hosgri displacement) and the final hydrostatic test. No leakage was observed during any hydrostatic test. For purposes of meeting the intent of IEEE 344-87 the first 6 tests will be considered as OBEs and the first fragility test will more than satisfy the SSE (Hosgri) test requirement. PG&E performed the tests out of sequence to ensure that a Hosgri level event would pass the hydrostatic test after the first OBE was performed. Since this was the first time that a Dresser Style 38 coupling had been taken to these seismic levels, there was some doubt whether the coupling would remain leak tight, so the test sequence was rearranged to check leakage after one OBE and one Hosgri test. Once the test assembly passed the hydrostatic test the remainder of tests were performed. Although the original test plan permitted replacement of the pipe and coupling components prior to beginning the fragility test series, the entire series of tests, including OBE's, Hosgri, and all fragility tests were performed using the same hardware, Paraline®, and gaskets.

Fragility tests were not limited by the design of the piping-coupling system; but were limited by the input displacement capabilities of the testing apparatus and the maximum gap, that can exist, between the pipes before the coupling would no longer be leak tight. A maximum displacement of 2.81 inches was achieved in the fragility test series.

The hydrostatic test hold time, specified by C/EP, was changed from a 30 minute hold time. Upon reviewing the hold time specified in DCPP MP M-56.1 "SYSTEM PRESSURE TEST", the hydrostatic test hold time was changed to coincide with the industry recognized minimum of 10 minutes. The 30 minute hold time was originally specified based upon good judgment and not on specific technical criteria.

VII. SUMMARY

The coupling favored one pipe and moved in one direction before that movement stopped. A pipe clamp had been placed on either side of the coupling to prevent the coupling from uncovering the pipe gap. The coupling stopped moving to one side before it would have engaged the pipe clamp on that side and stayed in that spot for the duration of the tests.

One Dresser Style 38, 24 1/2 inch mechanical coupling was tested through 5 Operational Basis Earthquakes (OBE's), 1 Hosgri earthquake, and 3 fragility tests using the same hardware, the same gaskets, and the same Paralined pipe surfaces for all tests. Once the tests started, the coupling was not disassembled for inspection until after the final hydrostatic test. From a cumulative effect standpoint, the tests represented more than 5 consecutive Hosgri events without failure. Because of the lack of any serious damage or degradation observed in the coupling components, and the ability of the coupling to maintain leak tightness after the completion of tests, it is likely that a significant margin exists beyond the tested displacements.

Inspection of the Dresser coupling gaskets and the Paraline surfaces revealed that the materials, although showing some wear, would still perform their design function and did not leak during a hydrostatic test at 150 psig.

VIII. CONCLUSIONS

Dow Corning DC 3452 was selected on the basis of compatibility with the interfacing materials and on the basis of a demonstrated 45-to-1 reduction in frictional forces between Paralined™ pipe and the Dresser® coupling. Field materials and procedures were used to closely represent field conditions.

The DC 3452 lubricant and Dresser® coupling performed satisfactorily during all the qualifying seismic and fragility tests. At the end of testing, the Paraline® showed some signs of deterioration, however; this degradation is understandable in light of the fact that those same surfaces experienced the cumulative effects of approximately five complete simulated Hosgri events (all preliminary testing plus the qualifying OBEs, Hosgri, and fragility tests) without losing the ability to maintain a watertight seal. Additionally, only one set of Dresser® coupling gaskets were used for all the qualifying (OBE and Hosgri tests) and fragility tests. The gaskets were subjected to the cumulative effects of approximately four Hosgri events without leaking when hydrostatically tested at 150 psig.

The Dresser® coupling and the Paraline® surfaces of the 24" diameter ASW pipe are capable of performing the required design function during or after the postulated

seismic requirements of the ASW Piping Bypass Project. The design is conservative enough to support at least five consecutive worst case operating events without failure.

IX. RECORDS

The tests were recorded using video tape and 35 mm film. A VHS video has been assembled to show the entire set of qualifying seismic tests. Another video shows the preliminary testing program where the testing apparatus (test rig, test assembly, shaker head, etc.) was subjected to trial runs and pretest adjustments.

TES recorded the data from their accelerometers and their equipment. These records are included in Attachment 14 (RMS Reel No. 06874, Frames 0292 to 0469).

X. REFERENCES

1. U.S. Nuclear Regulatory Commission Regulatory Guide 1.100, Revision 2, June 1988, Seismic Qualification of Electric and Mechanical Equipment for Nuclear Power Plants.

2. IEEE Std 344-1987, IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations.

3. Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation, PVP-34, The American Society of Mechanical Engineers, presented at The Third National Congress on Pressure Vessels and Piping, San Francisco, California, June 25-29, 1979.

4. Piping Handbook, Sixth Edition, 1992, McGraw-Hill, Inc.

5. Dynamics of Structures - Theories and Applications to Earthquake Engineering, 1995, Prentice-Hall, Inc.

6. The Civil Engineering Handbook, 1995, CRC Press, Inc.

7. Seismic Effects in PVP Components, PVP - Vol. 88, The American Society of Mechanical Engineers, presented at The 1984 Pressure Vessel and Piping Conference and Exhibition, San Antonio, Texas, June 17-21, 1984.

8. Dynamics and Seismic Issues in Primary and Secondary Systems, PVP - Vol. 137, The American Society of Mechanical Engineers, presented at The 1988

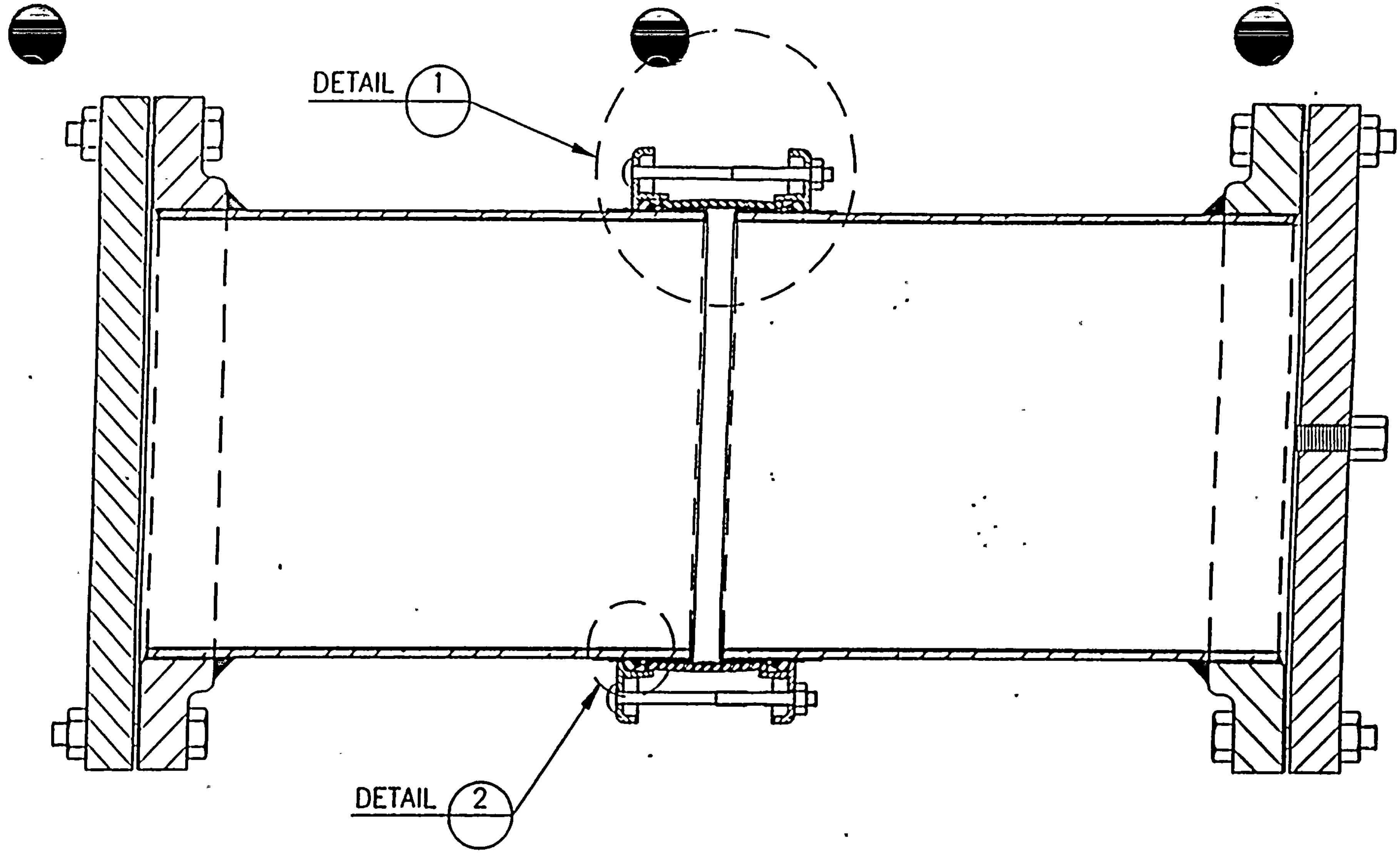
ASME Pressure Vessels and Piping Conference, Pittsburgh, Pennsylvania, June 19-23, 1988.

9. Seismic Engineering , 1994, Volume 1, PVP - Vol. 275-1, The American Society of Mechanical Engineers, presented at The 1994 Pressure Vessels and Piping Conference, Minneapolis, Minnesota, June 19-23, 1994.

XI. ATTACHMENTS

1. Dresser Coupling Test Configuration
2. Dresser Coupling Details
3. Dow Corning Lubricant Test Report
4. Dresser Coupling Installation Instructions
5. Photograph of Frictional Force Setup
6. A/R A0396347 - Dresser Coupling Test Program
7. Dresser Coupling Adhesion Test Results and Conclusions
8. Maintenance Work Order M0005579, Activity 01, Perform Coupling Test
9. PG&E Civil/Engineering Projects Dresser Coupling Testing Guidelines
10. DCPP Dresser Coupling Seismic Test Rig
11. Test Rig Shaker Mounting Detail
12. Seismic Qualification Test Procedure for Dresser Style 38, 24 1/2 Inch Coupling to be used in DCPP Auxiliary Saltwater Bypass Piping Project, signed 8-13-96.
13. DCPP Work Order C0146487
14. Chapters 1 through 3 of TES Dresser Coupling Cyclic Displacement Slip Capacity Test Report - 420DC-96.183, RMS Reel No. 06874, Frames 0292 to 0469.

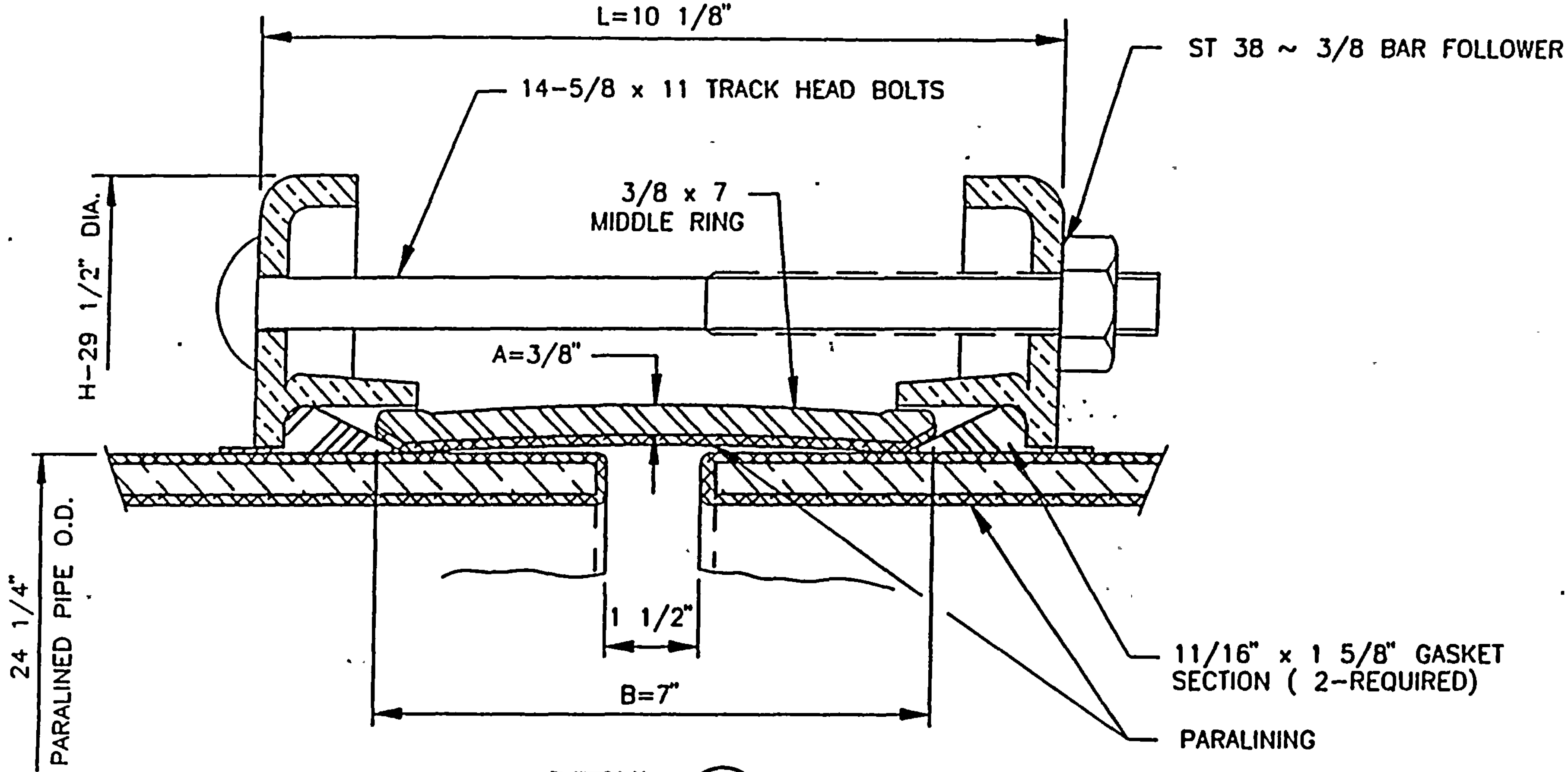
ATTACHMENT 1



TEST CONFIGURATION
24 1/2" O.D. STYLE 38 COUPLING
(SCALE: 1 1/2" = 1'-0")
ATTACHMENT 1

S:\ 6 MECH\RPE64550.DWG

ATTACHMENT 2



DETAIL 1

24 1/2" O.D. STYLE 38 COUPLING

(SCALE: 1/2"=1")

ATTACHMENT 2

August 23, 1996

10183-ASWCALC

Mr. Eric Fujisaki
Pacific Gas & Electric Company
245 Market Street, Mail Code N9B
San Francisco, California 94177

Revised Report
Liquefaction Evaluation
Proposed ASW Bypass
Diablo Canyon Power Plant
San Luis Obispo County, California

Dear Mr. Fujisaki:

This letter report presents the results of Harding Lawson Associates' (HLA's) evaluation of the liquefaction potential[1] of the existing backfill in the vicinity of the proposed ASW Bypass at Diablo Canyon Power Plant in San Luis Obispo County, California. This evaluation was undertaken following our recent field investigation (presented in our May 8, 1996 report, HLA Project No. 10183-005) that revealed the existence of medium dense sands below the water table northeast of the existing Intake Structure (IS). Plate 1 presents a site plan of the subject area. This report was previously issued on July 8, 1996 and is now being revised to address the variations in the definition of the design earthquake magnitudes. The conclusions presented in this report have not been modified.

We obtained information regarding the previous excavations and backfilling operations through 1) review of Mr. Al Tafoya's (of PG&E) draft memorandum entitled *Background Information of Soil Near the I.S. and for Liquefaction Issue*, dated May 31, 1996, 2) a meeting with you on June 14, 1996, and 3) review of a PG&E plan entitled *Rock Topography near ASW Bypass Piping Routing (SK-C-ASWBROCK), Revision A.*

BACKGROUND AND SUBSURFACE CONDITIONS

During the 1970s, the IS and the Circulating Water Intake (CWI) conduits were constructed. The CWI conduits are founded at a depth of 40 to 45 feet below existing grades adjacent to

---

1 Soil liquefaction is a phenomenon which saturated (submerged), cohensionless soils experience a temporary loss of strength because of the buildup of excess pore water pressure, especially during cyclic loadings, such as those induced by earthquakes. Soils most expectable to liquefaction are loose, clean, saturated, uniformly graded, fine-grained sands.

the IS (Elevation -20 feet[2]). To construct the CWI conduits and the IS, deep cuts were made in the existing native soils and rock. The excavation sides were sloped as shown on Plate 1. Following CWI and IS construction, the excavation was backfilled with compacted fill. The specifications required that the backfill be granular material below Elevation 6 feet and that it be compacted to at least 95 percent relative compaction[3]. The field density tests performed during backfilling indicate that the materials were essentially compacted in accordance with the specifications.

In 1978, HLA performed a geotechnical investigation adjacent to the IS which included drilling 5 borings at the locations shown on Plate 1. These borings encountered 25 to 35 feet of fill consisting of stiff clay and dense to very dense sand and gravel. Groundwater was encountered near Elevation 0 feet. Based on the material types and blow counts observed during sampling, the fill encountered was not considered to be potentially liquefiable.

In 1980 and 1981, an excavation was made to repair electrical conduits which were damaged from settlement. The lateral extent of the excavation is shown on Plate 1 and the depth of the excavation extended down to the top of the CWI conduits. The conduits were repaired and the excavation was backfilled with compacted fill. The field density test results indicate that the backfill was compacted to at least 95 percent relative compaction.

In December of 1995, HLA drilled 4 additional borings to characterize the backfill for purposes of the dynamic analyses of the proposed ASW Bypass being conducted by others and the slope stability evaluation being conducted by HLA. The borings encountered fill that ranged in depth from 6 feet at Boring B-2 to 31-1/3 feet (the depth explored) at Boring B-4. The fill generally consisted of stiff clays and dense to very dense sands and gravel which is consistent with the 1978 borings; these materials are not believed to be susceptible to liquefaction. Unexpectedly however, two of the borings encountered medium dense sands below Mean Sea Level (Borings B-1 and B-4, Plates 2 and 3) as indicated by relatively low blow counts obtained during soil sampling. The relatively low blow counts occurred at a depth of 25 feet (Elevation -1 feet), as shown on Plates 2 and 3, and are in what is believed to be the original backfill placed during the CWI conduit construction. The blow count of 18 at 25 feet in Boring B-1 represents a Standard Penetration Test (SPT) N-Value[4] and the blow count of 15 at 25 feet in Boring B-4 represents a pseudo-SPT N-value that was obtained by multiplying the field blow count by 0.7 to account for the larger sampler size (3-inch outside

---

2 Elevations referenced to Mean Sea Level

3 Relative compaction refers to the in-place dry density of soil expressed as a percentage of the maximum dry density of the same soil determined by ASTM D1557 laboratory test procedure. Optimum moisture is the water content that corresponds to the maximum dry density.

4 The SPT N-value is defined as the number of blows of a 140-pound hammer, falling freely through a height of 30 inches, required to drive a standard split-barrel sampler (2-inch outside diameter and a 1-3/8-inch inside diameter) the final 12 inches of an 18-inch drive. For SPT procedures, see ASTM D1586.

diameter and 2.43-inch inside diameter). Additional details regarding the field investigation are presented in HLA's May 8, 1996 report. The groundwater was encountered only in Boring B-4 at a depth of 24 feet (Elevation 0 feet). Because of the proximity of the site to the ocean, the groundwater level is likely influenced by tidal effects.

The zone of the medium dense sands that are located below the water table are believed to be confined to an area that is approximately 10 to 20 feet wide and 100 feet long, as shown on Plate 1. This zone is defined by the following boundaries: the edge of the original excavation for the CWI conduit construction on the north and east, the 1980 backfill placed during repair of the electrical conduits on the west, and the clayey backfill placed during the CWI conduit and IS construction that was encountered by the 1978 Borings 4 and 5 on the south. Based on the recent Boring B-4, we have assumed that this zone is 5 feet thick, from Elevation 0 to -5 feet, throughout the zone described above. This is a conservative assumption, given that the fill was reportedly compacted to at least 95 percent relative compaction. It is more likely that the sands range from being medium dense to dense within the zone defined above.

Because of the relatively low blow counts encountered in the 1995 borings and the potential for relatively high seismic ground shaking, the evaluation discussed in this report was undertaken to assess the liquefaction potential of the medium dense backfill and the likely consequences of liquefaction if it were to occur.

LIQUEFACTION POTENTIAL AND SEISMICALLY-INDUCED SETTLEMENT

In our analyses, we evaluated the liquefaction potential for two levels of ground motion: one for a Magnitude (M) 7.5 event with a peak ground acceleration (PGA) of 0.83 gravity (g) and one for a M6 event with a PGA of 0.35g. The larger magnitude event is believe to represent a conservative upper bound of the design ground motions for the plant. The actual design ground motions for the plant include the Hosgri record, which is for an M7.5 event with a PGA of 0.75g, and the Long Term Seismic Program records, which are for an M7.2 event with a PGA of 0.83g. The smaller event is representative of an earthquake with a higher probability of occurrence.

We evaluated the potential for liquefaction using the procedure developed by Seed et al. (1985)[5]. In this procedure, the physical properties of the soil are characterized by laboratory grain-size tests to determine the percent finer than the number 200 sieve and by field SPTs. We visually observed that there was not a significant amount of fines in the sands ; therefore, laboratory grain-size tests were not performed. The SPT N-Values (15 and 18)

---

5 Seed, H. B., K. Tokimatsu, L.F. Harder, and R.M. Chung, 1985. *Influence of SPT Procedures and Liquefaction Resistance Evaluations*. American Society of Civil Engineers, Journal of Geotechnical Engineering, Vol. 111, No. 12, December.

were converted to $N_{1(60)}$ valuess (15 and 19, respectively) in accordance with the procedures recommended by Seed, et al. (1985). Our analyses indicates that there is a high probability of liquefaction for the medium dense sands located below the water table during the M7-1/2 event. For the M6 event, the data points plot near the boarder between "liquefaction" and "no liquefaction" indicating that there is a much lower chance of liquefaction occurring during the smaller event.

If liquefaction does occur, we judge that its most likely effects will be as follows:

- A reduction of in the strength of the sand during the seismic event
- Seismically-induced settlement of the sands following the seismic event.

We judge the risk of lateral movements due to liquefaction to be very low because of the discontinuous nature of the medium dense sands and the fact that they are confined on all sides.

During our slope stability analyses, we conservatively assumed that the entire 5-foot-thick zone of the medium dense sands would liquefy during the M7-1/2 event and assigned a reduced strength to the zone.

In evaluating seismically-induced settlement, we utilized a procedure developed by Tokimatsu and Seed (1987)7. For the M7-1/2 event (PGA of 0.83g), the computed maximum settlement of the 5-foot layer that liquefies is approximately 1 inch. Because of the depth of this layer and the limited extent of the medium dense sands, we judged that the maximum ground surface settlements could be up to approximately 50 percent of the computed settlements. This would result in a maximum ground surface settlement on the order of 1/2 inch during the M7-1/2 event. For the M6 event (PGA of 0.35g), the computed maximum settlement of the 5-foot layer that liquefies is approximately 1/2 inch. As with the larger event, we judge that the maximum ground surface settlement will be approximately 50 percent of the computed value; approximately 1/4 inch.

Differential settlement of the proposed ASW Bypass could occur during an earthquake because the proposed pipelines will cross over the zone of medium dense sands. We judge that the magnitude of the maximum differential settlement will be approximately equal to the maximum ground surface settlements mentioned above. Because of the depth of the sands below the bypass pipeline, the differential settlement will not occur abruptly in a short distance, but will occur gradually along the pipeline. For design purposes, we

---

6 $N_{1(60)}$ values are the SPT N-values normalized to an effective overburden pressure of 1 ton per square foot and to an effective energy delivered to the drill rods equal to 60 percent of the theoretical free-fall energy.

7 Tokimatsu, K. And Seed, H.B., 1987, *Evaluation of Settlement of Sands Due to Earthquake Shaking*, American Society of Civil Engineers, Journal of Geotechnical Engineering, Volume 113, No. 8, August.

recommend assuming that the estimated maximum differential settlement occurs over a distance of 25 feet.

The settlements mentioned above are the result of densification of the sands following dissipation of pore water pressures developed as a result of seismic shaking. Therefore, the settlements will take place following the earthquake as pore water pressures dissipate. As a result, these settlements should not be added to the transient displacements that are predicted for the pipelines during the earthquake shaking.

These estimated settlements are maximum values that could occur during a single event. It is possible for liquefaction to occur during an earthquake, but to have little or no observable settlement; this does not mean that settlement will not occur during future earthquakes. While liquefaction has been observed to occur repeatedly at the same site during multiple earthquake, the settlement estimates represent the upper bound of accumulative settlement during repeated events at any given point at the site.

COMMENTS REGARDING PREDICTED SETTLEMENTS

The preceding discussion presents settlement estimates that are based on calculations performed using commonly accepted methods of analyses in the geotechnical practice in California that were developed in the 1970s and 1980s. For the following reasons, we believe that the settlement estimates presented above represent conservative upper bound values and that actual settlements will be less:

- Case histories from recent earthquakes[8] suggest that there have not been significant effects from liquefaction observed in soils that have $N_{1(60)}$ values greater than 15. In developing the methodology for the analyses discussed above, the number of data points where liquefaction was observed and the $N_{1(60)}$ values were above 15 was limited and the observations were generally not detailed. During recent earthquakes, the database for materials with $N_{1(60)}$ values greater than 15 has increased significantly.

---

8 Bartlett, S.F. and Youd, T.L., 1995, *Empirical Prediction of Liquefaction-Induced Lateral Spread*, American Society of Civil Engineers, Journal of Geotechnical Engineering, Volume 121, No. 4, April.

Baziar, M.H. and Dobry, R., 1995, *Residual Strength and Large-Deformation Potential of Loose Silty Sands*, American Society of Civil Engineers, Journal of Geotechnical Engineering, Volume 121, No. 12, December.

Fear, C.E. and McRoberts, E.C., 1995, *Reconsideration of Initiation of Liquefaction in Sandy Soils*, American Society of Civil Engineers, Journal of Geotechnical Engineering, Volume 121, No. 3, March.

Pyke, R., 1995, *Practical Aspects of the Evaluation of Liquefaction Potential*, First International Conference on Earthquake Geotechnical Engineering, Tokyo, Japan, November 14 through 16.

- The zone of medium dense sands is confined by stiffer backfill and natural soil and rock. During ground shaking, the stresses and strains in the medium dense sands will be controlled by the deformations of the stiffer materials. In general, the stiffer the deposit, the lower the induced shear strains during the earthquake. Because the settlement of the medium dense sands is a function of the induced shear strains, the settlement of the inclusion of medium dense sands will likely be smaller than the settlement of a large mass of medium dense sands, as assumed in the analyses.

- The water table is located near the top of the medium dense sands and the sands extend above the water table. Because of fluctuation of the water table resulting from tidal effects, the upper portion of the sands is likely not 100 percent saturated. It is more difficult to develop large seismically-induced pore pressures in partially saturated soils. In addition, because the water table is near the top of the sand zone, there is a very short drainage path for the pore water pressures to dissipate. This will also result in lower maximum pore water pressure generation than would be expected for cases with longer drain paths. In general, the smaller the generated pore water pressures, the smaller the seismically-induced settlements.

For the preceding reasons, we believe that the previously reported settlement estimates represent a conservative upper bound. We judge that a more realistic estimate of settlements would be on the order of one-half of those predicted using the referenced methods of analyses. This results in maximum likely ground surface settlements of 1/4 inch for the M7-1/2 event and less than 1/4 inch for the M6 event.

We trust that this provides the information you require at this time. If you have any questions, please call.

Yours very truly,

HARDING LAWSON ASSOCIATES

W. Andrew Herlache

W. Andrew Herlache, G.E.
Associate Engineer

Robert Pyke

Robert Pyke, G.E.
Consulting Engineer

REGISTERED PROFESSIONAL ENGINEER
WARD ANDREW HERLACHE
No. GE 002149
Exp. 3/31/99
GEOTECHNICAL
STATE OF CALIFORNIA

WAH\RP\HTT\mlw 10183\020461L.DOC

Attachments: Plate 1 - Site Plan
Plates 2 and 3 - Log of Borings B-1 and B-4

DCPP's bypass design requires that the couplings accommodate up to +/- 3/4 inch axial pipe seismic displacement and remain leak tight. The possibility exists that the 3/4 inch of travel would be reached more than once. The Dresser® Coupling gasket design is such that it can absorb one event of 3/16 inch (3/8 inch per coupling) axial motion and not leak. Beyond 3/8 inch movement, the vendor will not assume the gaskets will reseat. The standard installation for this coupling seats the gasket on an uncoated carbon steel pipe surface and, as a result, the gasket adheres to the smooth pipe surface. During axial motion, each gasket would deform and absorb up to 3/16 inch and not lose its bond with the pipe metal surface. The manufacturer stated that should the gasket-to-pipe seal be upset, it might reseat after a single event but may not reseal when more than one event is involved at that displacement (for example, multiple earthquakes). Repeated upsets of the gasket-to-pipe interface may cause the gasket to roll under the follower ring and lose its seal resulting in a coupling leak.

Previous testing, performed by the manufacturer, on a 14 inch diameter pipe coupling subjected to high-cycle displacements demonstrated that the coupling has the capability to maintain integrity following peak-to-peak displacements of up to about one inch. However, these tests differed from DCPP's design in some important aspects, including the use of Paraline®, magnitude of the imposed displacements, and the number of earthquakes to which the coupling should be subjected.

The DCPP piping design requires that the coupling be able to accommodate pipe displacements at least four times the Dresser® design. In order to be able to function beyond the 3/8 inch limitation and still maintain the water tight seal, the coupling would have to slide along the Paraline® surface and, in the process, maintain its water tight seal. Because of this need for the coupling gaskets to slip at the gasket-to-Paraline® interface, DCPP's design includes the use of lubricants.

III. PROGRAM OBJECTIVES

The testing program had the following objectives:

- Find a lubricant that would substantially reduce friction between the Dresser® coupling gaskets and the Paralined® pipe and also be compatible with the interface materials.
- Establish the level of friction reduction attained by using the lubricant.
- Perform a seismic test that simulates the design basis seismic event at DCPP, preceded by a number of smaller seismic events.
- If the tests are successful at safe shutdown earthquake (SSE/Hosgri) levels, then establish a margin of safety in support of the DCPP LTSP.

IV. LUBRICANT

1. Basis

Selection of a lubricant centered on choosing a material that was chemically inert to the interfacing materials and had a wide service range of service temperature. Silicones were selected because of a long history of successful use with the generic materials involved. Dow Corning, a major manufacturer of silicones, was contacted and Dow agreed to perform tests on the actual production formulations to establish positive compatibility for the specific materials in the PG&E application. R&DS Design Basis EQ Lead helped establish the test parameters for the compatibility tests.

2. Results

Three Dow Corning® products were tested for compatibility with the Dresser coupling gasket material and the Paraline material. Accelerated aging tests were performed which simulated 20 years of contact between the lubricants and both the SBR Dresser® gaskets and PVC Paraline® materials. The tests were performed based on an activation energy of .7 eV. The temperature (198° F) was selected to be at a level below the phase change of the Dow Corning lubricants. Baseline values for hardness(durometer), tensile strength, and elongation were performed on both aged and un-aged material. Specimens were placed in an oven, and aged for 10 days and then tested for hardness, tensile strength, and elongation.

The Dow Corning® lubricants used in these tests were DC 111, DC 112, and DC 3452, all silicone-based. Testing was conducted in April and May, 1996 by Dow Corning Corporation, Midland, Michigan. Results from the Dow Corning® tests are recorded in RMS on Reel 6731, Frames 0065-0074 (Attachment 3).

In general, the aging tests suggest no negative effect of the lubricants with regard to tensile and elongation. However, modulus values were off for SBR for all samples except that coated with DC 3452 because these samples failed to reach 100% elongation. This included the sample with no lubricant which suggests the coated samples were at least no worst.

Dow Corning® DC 3452 had the least effect on both the Dresser® Coupling gasket and Paraline® materials and was chosen as the lubricant for mechanical testing of an assembled coupling.

V. FRICTIONAL FORCES

1. Basis

The second objective was achieved by determining the magnitude of frictional forces that exist when using the lubricant between the coupling gaskets and Paraline® versus the forces encountered after assembling the Dresser® Coupling using soapy water as directed by Dresser Manufacturing Division in their coupling installation instructions (Attachment 4 - DC 6014453-68-1). The level of reduction of frictional forces would be key to successfully completing a seismic test of the coupling at the design displacements required for DCPP.

2. Results

The test assembly consisted of two production spool pieces (1-6158-SP5 and 1-6159-SP5) held in the horizontal plane on rollers with a production Dresser® coupling connecting the two spools (Attachment 5). The spool pieces were filled with water and pressurized by a hydrostatic pump.

This test established that approximately 45 psig was required to overcome initial gasket-to-Paraline® friction, when the coupling is assembled using soapy water and allowed to sit for 48 hours. Approximately 23 psig was required to keep it moving once the gasket-to-Paraline seal was upset.

Note: Manufacturer's rule of thumb is that a maximum of 1 kip/inch of diameter would be the force required to overcome coupling friction, after the gasket has set, when the coupling has been assembled using soapy water. With a cross-sectional area of 424.56 sq. in., the 45 psig value, from the DCPP soapy water test, yields 19,105 pounds, somewhat less than the maximum 24,000 pounds derived by rule of thumb.

The test using Dow Corning DC 3452 never developed as a hydrostatic test. The pipe spools started to move apart during the water-fill stage, prior to external application of hydrostatic pressure. It took less than one psig to create/maintain pipe movement.

For the lubricated coupling, a one psi pressure yields a 425 pound frictional force. This 45 to 1 reduction in frictional force would aid in the success of the seismic tests that follow. Test results, from the adhesion tests, are documented in A/R A0396347 (Attachment 6) and in RMS on Reel 6731, Frames 0085-0089 (Attachment 7). The test was conducted under Mechanical Maintenance Work Order M0005579, Activity 1 (Attachment 8).

VI. SEISMIC TESTING

1. Seismic Criteria

PG&E Civil/Engineering Projects(C/EP), in San Francisco, developed the seismic criteria based on an analysis of design basis seismic events, and those seismic events based upon the DCPP LTSP. The largest design basis seismic displacements would originate from a Hosgri earthquake. Requirements for the fragility tests, whose displacements exceeded those of the Hosgri earthquake, were also developed to determine the safety margin for the coupling. Attachment 9 contains the seismic test requirements, which are presented as two alternatives. Alternative 2, below was selected for the test program.

Alternative 2:

- Sinusoidal cyclic test starting with low amplitude slip, progressively increasing, ending with 5 cycles of peak slip displacement. Run five tests to simulate OBE input, one test for Hosgri input, and three fragility tests at progressively increasing peak displacements to demonstrate the reserve margin that the coupling has.
- Frequency: 4.5 Hz. minimum (Note: Input motions with higher frequencies will increase the severity of loading on the coupling. Input motion frequencies in the range of 4.5 to approximately 5.5 Hz are acceptable.)
- Duration of each test: approximately. 25 sec., adjusted as needed to achieve the displacement cycles as summarized below.

Test	Series 1 80 cycles	Series 2 20 cycles	Series 3 20 cycles	Series 4 5 cycles	Comments
1	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri
2	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri
3	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri
4	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri
5	0.25 in.	0.38 in.	0.5 in.	0.75 in	OBE--taken as 50% of Hosgri
6	0.5 in.	0.75 in.	1 in.	1.5 in.	Hosgri
7	0.67 in.	1 in.	1.33 in.	2 in.	Fragility
8	0.83 in.	1.25 in.	1.67 in.	2.5 in.	Fragility
9	1 in.	1.5 in.	2 in.	3 in.	Fragility

Displacements, listed in the table, are peak-to-peak values.

In order to simulate earthquake response, Series 1 through 4 inputs should be imposed continuously, with one series commencing immediately after completion of the preceding series.

Because of the concern about the capacity of the coupling to maintain its integrity following multiple seismic events, the coupling would be subjected to five OBE-level input motions preceding the Hosgri input. This approach also was intended to

demonstrate that the coupling can accommodate smaller earthquakes which have a higher likelihood for occurrence than the SSE.

2. Testing Considerations

Testing of a full size coupling and piping was selected to verify the function of the joint. Testing a full size specimen, would eliminate the need for scaling results on a smaller diameter pipe test assembly. Production spool pieces and a production coupling would be used. Field coupling installation instructions would be used to reflect production conditions as closely as possible.

PG&E C/EP determined that the installed piping would be subject to predominantly axial motion. Off-axis motion was determined to be less than 1 degree and would not have to be simulated in the tests. The test rig was designed around one plane-of-motion.

Initially, testing was to be performed with the test assembly internally pressurized to 150 psig. This required an extremely large hydraulic piston, servo valve control module, pump and motor beyond the capabilities of equipment available. The motion of the piping would also create a shock absorber effect which would significantly increase the required input forces. Additionally, maintaining 150 psig internal pressure on the assembly would require either an external accumulator and two 4" diameter supply and return lines or a pressurized bladder inserted inside the stationary pipe. These requirements were difficult to achieve and always resulted in an increased capacity of the hydraulic system.

The decision was made to eliminate the water (and hydrostatic pressure) on the inside of the pipe. The test would provide a more conservative result due to the lack of lubrication (from the water) on the inside frictional interfaces. The forces required to perform the test are greatly reduced allowing the use of a commercially available shaker head and servo control valve system and the test rig could be of more reasonable size. This would also reduce the hazards to personnel during the test.

It was postulated that the coupling could adhere to one pipe more than the other, i.e. "walk" off to one side uncovering the gap between the pipes. A Dresser® Coupling gasket would be backed-off from the coupling follower ring, by 1" and held in place using stainless steel banding to prevent the coupling from going too far in one direction. The gasket and banding are referred to in the test procedure as the bumper. During the preliminary tests, this arrangement proved to have insufficient frictional force to restrain the coupling and was subsequently replaced by 24" pipe clamps.

All testing was performed under the DCPP Quality Program.

3. Test Apparatus Description

Basic design concept was to subject the pipes and coupling to vibratory motion that conservatively simulates that postulated for the inground piping during an earthquake. This would be accomplished by holding two production pipe spools in alignment with a Dresser® coupling installed between the spools. One spool would move and the other spool would be stationary. Coupling "walking" would not be restricted unless the coupling moved to one side more than two inches.

To the maximum extent possible, production materials, procedures, and practices were used to approximate field conditions. The mounting details were made as close to an inground configuration as possible. The use of casters and structural supports, to maintain alignment, were devised to simulate an installed condition.

After preliminary tests, the test rig was stiffened. Square tubing was utilized to reinforce the anchor points to the concrete pad. See Attachment 10 for details of the final configuration of the test rig. Attachment 11 shows details of the shaker (hydraulic piston/cylinder/servo) mounting details.

Alignment of the test rig, pipe spools, and shaker was performed by TES Electrical/Mechanical using a precision optical level measuring unit and a horizontal precision measuring unit; both having a +/- 2 mil accuracy.

The large casters, used to maintain alignment of the moving pipe, were prone to developing flat spots when forced against the pipe for more than a day. These casters were faced with plastic and the plastic would deform at the point of contact with the pipe. To compensate, the caster would be turned just before the test. Not turning the caster created a thump and misalignment when the spool attached to the shaker was moved. The casters were marked to ensure that they were not turned to a previous flat spot.

There was concern that the lubricant would heat up during the tests, both from the sun heating the black external coating and from friction, making the lubricant more lubricious; thereby invalidating the test results. A water hose with a small spray nozzle was trained on the coupling during the test to simulate the in-ground heat sink and eliminate heat build-up.

The test rig was designed by PG&E Engineering Services/Support Engineering, Piping Engineering Group and fabricated by PG&E DCPP Outage Services. The test rig, test assembly, and associated hydraulic pump, servo controls, shaker head, and instrumentation were assembled in Area 10 at DCPP.

The hydraulics, shaker head, and instrumentation were supplied by PG&E Technical and Environmental Services (TES).

4. Seismic Tests

The qualifying seismic tests were performed on August 27 and 28, 1996 using the Seismic Qualification Test Procedure For Dresser Style 38, etc.(see Attachment 12) and Work Order CO146487 (Attachment 13).

The first three tests were exploratory in nature and not part of the seismic qualification tests. They were performed to establish the dynamic characteristics of the test assembly, test rig, servo control system, hydraulic pump unit, and shaker head.

The order in which the tests were conducted was modified from the PG&E C/EP "Dresser Coupling Testing Guidelines" (Attachment 9) criteria of five operating basis earthquakes (OBEs) followed by a safe shutdown earthquake (SSE) (Hosgri). The change of testing sequence was approved in a meeting with the Lead C/EP Engineer the day of the test. The original sequence was based on IEEE 344-87 and considered the 5 OBEs as aging/conditioning tests which simulated the system having been in operation for a period of time prior to experiencing a SSE. The test sequence consisted of one OBE followed by one Hosgri, a hydrostatic test, then 4 more OBEs, another hydrostatic test, then 3 fragility tests (beyond Hosgri displacement) and the final hydrostatic test. No leakage was observed during any hydrostatic test. For purposes of meeting the intent of IEEE 344-87 the first 6 tests will be considered as OBEs and the first fragility test will more than satisfy the SSE (Hosgri) test requirement. PG&E performed the tests out of sequence to ensure that a Hosgri level event would pass the hydrostatic test after the first OBE was performed. Since this was the first time that a Dresser Style 38 coupling had been taken to these seismic levels, there was some doubt whether the coupling would remain leak tight, so the test sequence was rearranged to check leakage after one OBE and one Hosgri test. Once the test assembly passed the hydrostatic test the remainder of tests were performed. Although the original test plan permitted replacement of the pipe and coupling components prior to beginning the fragility test series, the entire series of tests, including OBE's, Hosgri, and all fragility tests were performed using the same hardware, Paraline®, and gaskets.

Fragility tests were not limited by the design of the piping-coupling system; but were limited by the input displacement capabilities of the testing apparatus and the maximum gap, that can exist, between the pipes before the coupling would no longer be leak tight. A maximum displacement of 2.81 inches was achieved in the fragility test series.

The hydrostatic test hold time, specified by C/EP, was changed from a 30 minute hold time. Upon reviewing the hold time specified in DCPP MP M-56.1 "SYSTEM PRESSURE TEST", the hydrostatic test hold time was changed to coincide with the industry recognized minimum of 10 minutes. The 30 minute hold time was originally specified based upon good judgment and not on specific technical criteria.

VII. SUMMARY

The coupling favored one pipe and moved in one direction before that movement stopped. A pipe clamp had been placed on either side of the coupling to prevent the coupling from uncovering the pipe gap. The coupling stopped moving to one side before it would have engaged the pipe clamp on that side and stayed in that spot for the duration of the tests.

One Dresser Style 38, 24 1/2 inch mechanical coupling was tested through 5 Operational Basis Earthquakes (OBE's), 1 Hosgri earthquake, and 3 fragility tests using the same hardware, the same gaskets, and the same Paralined pipe surfaces for all tests. Once the tests started, the coupling was not disassembled for inspection until after the final hydrostatic test. From a cumulative effect standpoint, the tests represented more than 5 consecutive Hosgri events without failure. Because of the lack of any serious damage or degradation observed in the coupling components, and the ability of the coupling to maintain leak tightness after the completion of tests, it is likely that a significant margin exists beyond the tested displacements.

Inspection of the Dresser coupling gaskets and the Paraline surfaces revealed that the materials, although showing some wear, would still perform their design function and did not leak during a hydrostatic test at 150 psig.

VIII. CONCLUSIONS

Dow Corning DC 3452 was selected on the basis of compatibility with the interfacing materials and on the basis of a demonstrated 45-to-1 reduction in frictional forces between Paralined™ pipe and the Dresser® coupling. Field materials and procedures were used to closely represent field conditions.

The DC 3452 lubricant and Dresser® coupling performed satisfactorily during all the qualifying seismic and fragility tests. At the end of testing, the Paraline® showed some signs of deterioration, however; this degradation is understandable in light of the fact that those same surfaces experienced the cumulative effects of approximately five complete simulated Hosgri events (all preliminary testing plus the qualifying OBEs, Hosgri, and fragility tests) without losing the ability to maintain a watertight seal. Additionally, only one set of Dresser® coupling gaskets were used for all the qualifying (OBE and Hosgri tests) and fragility tests. The gaskets were subjected to the cumulative effects of approximately four Hosgri events without leaking when hydrostatically tested at 150 psig.

The Dresser® coupling and the Paraline® surfaces of the 24" diameter ASW pipe are capable of performing the required design function during or after the postulated

seismic requirements of the ASW Piping Bypass Project. The design is conservative enough to support at least five consecutive worst case operating events without failure.

IX. RECORDS

The tests were recorded using video tape and 35 mm film. A VHS video has been assembled to show the entire set of qualifying seismic tests. Another video shows the preliminary testing program where the testing apparatus (test rig, test assembly, shaker head, etc.) was subjected to trial runs and pretest adjustments.

TES recorded the data from their accelerometers and their equipment. These records are included in Attachment 14 (RMS Reel No. 06874, Frames 0292 to 0469).

X. REFERENCES

1. U.S. Nuclear Regulatory Commission Regulatory Guide 1.100, Revision 2, June 1988, Seismic Qualification of Electric and Mechanical Equipment for Nuclear Power Plants.

2. IEEE Std 344-1987, IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations.

3. Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk, and Instrumentation, PVP-34, The American Society of Mechanical Engineers, presented at The Third National Congress on Pressure Vessels and Piping, San Francisco, California, June 25-29, 1979.

4. Piping Handbook, Sixth Edition, 1992, McGraw-Hill, Inc.

5. Dynamics of Structures - Theories and Applications to Earthquake Engineering, 1995, Prentice-Hall, Inc.

6. The Civil Engineering Handbook, 1995, CRC Press, Inc.

7. Seismic Effects in PVP Components, PVP - Vol. 88, The American Society of Mechanical Engineers, presented at The 1984 Pressure Vessel and Piping Conference and Exhibition, San Antonio, Texas, June 17-21, 1984.

8. Dynamics and Seismic Issues in Primary and Secondary Systems, PVP - Vol. 137, The American Society of Mechanical Engineers, presented at The 1988

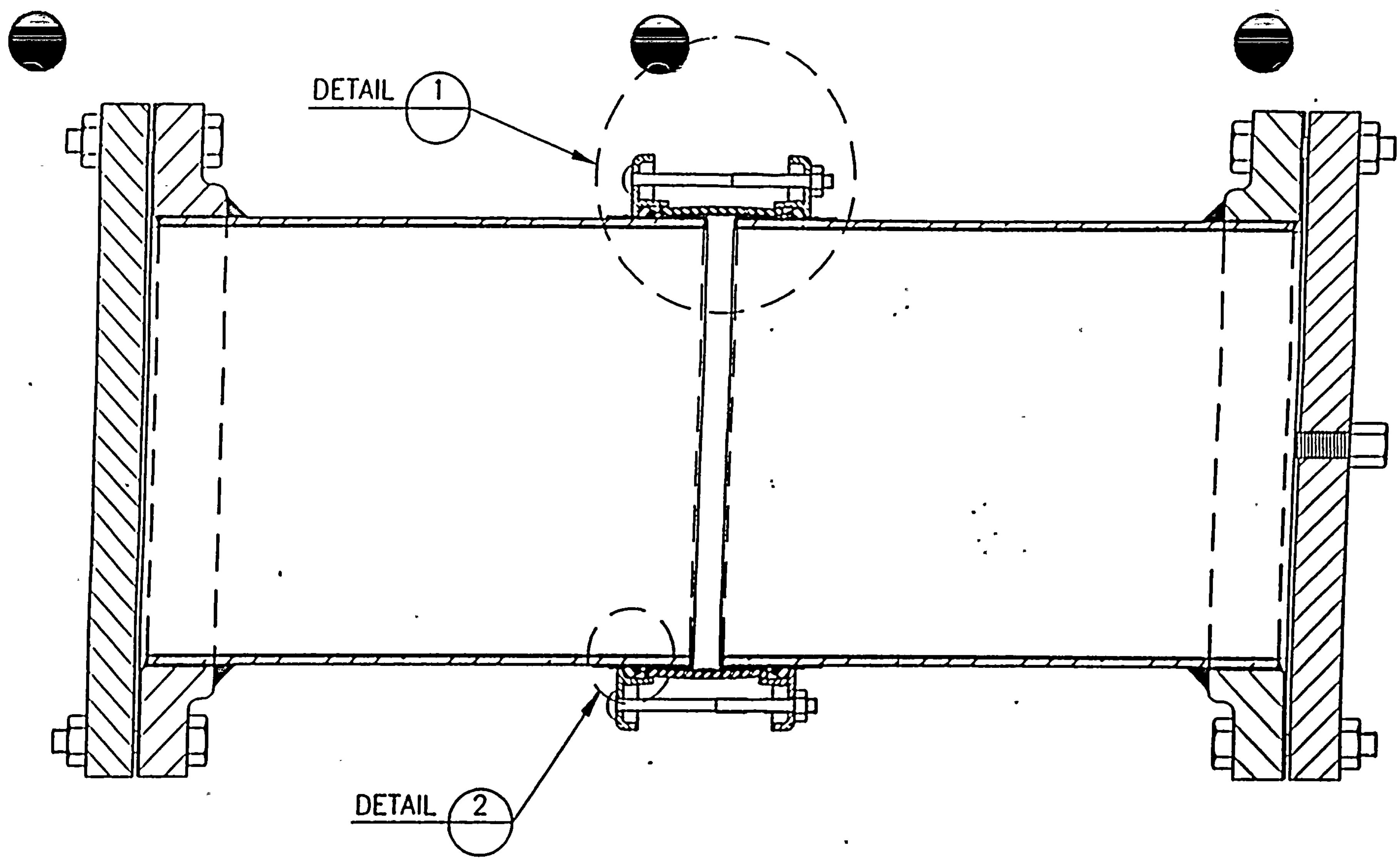
ASME Pressure Vessels and Piping Conference, Pittsburgh, Pennsylvania, June 19-23, 1988.

9. Seismic Engineering , 1994, Volume 1, PVP - Vol. 275-1, The American Society of Mechanical Engineers, presented at The 1994 Pressure Vessels and Piping Conference, Minneapolis, Minnesota, June 19-23, 1994.

XI. ATTACHMENTS

1. Dresser Coupling Test Configuration
2. Dresser Coupling Details
3. Dow Corning Lubricant Test Report
4. Dresser Coupling Installation Instructions
5. Photograph of Frictional Force Setup
6. A/R A0396347 - Dresser Coupling Test Program
7. Dresser Coupling Adhesion Test Results and Conclusions
8. Maintenance Work Order M0005579, Activity 01, Perform Coupling Test
9. PG&E Civil/Engineering Projects Dresser Coupling Testing Guidelines
10. DCPP Dresser Coupling Seismic Test Rig
11. Test Rig Shaker Mounting Detail
12. Seismic Qualification Test Procedure for Dresser Style 38, 24 1/2 Inch Coupling to be used in DCPP Auxiliary Saltwater Bypass Piping Project, signed 8-13-96.
13. DCPP Work Order C0146487
14. Chapters 1 through 3 of TES Dresser Coupling Cyclic Displacement Slip Capacity Test Report - 420DC-96.183, RMS Reel No. 06874, Frames 0292 to 0469.

ATTACHMENT 1



TEST CONFIGURATION

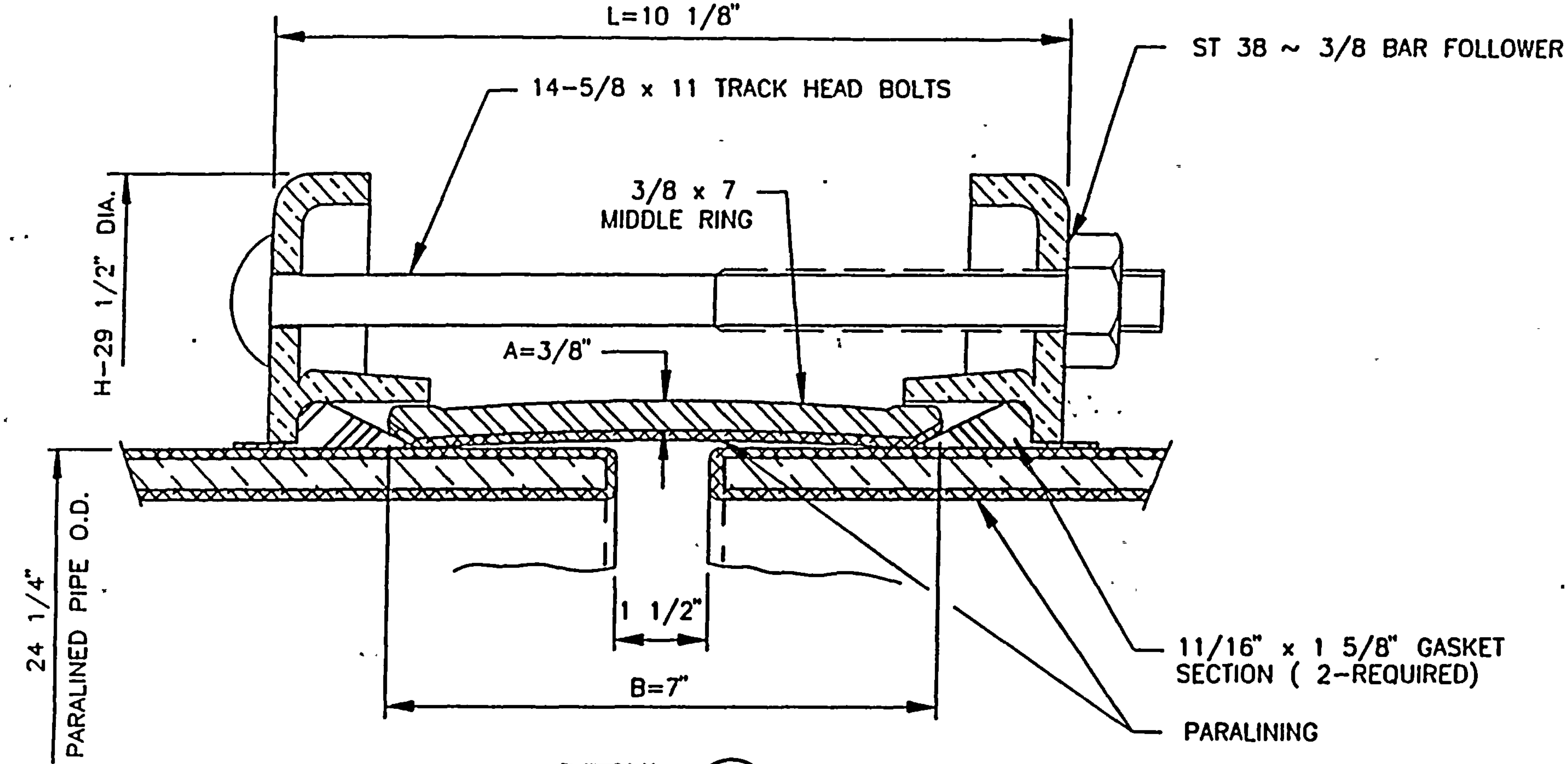
24 1/2" O.D. STYLE 38 COUPLING

(SCALE: 1 1/2" = 1'-0")

ATTACHMENT 1

S\ 6 MECH\RPE6455o.DWG

ATTACHMENT 2



DETAIL 1

24 1/2" O.D. STYLE 38 COUPLING

(SCALE: 1/2"=1")

ATTACHMENT 2

S\ 6 MECH\RPF6455.DWG

August 23, 1996

10183-ASWCALC

Mr. Eric Fujisaki
Pacific Gas & Electric Company
245 Market Street, Mail Code N9B
San Francisco, California 94177

Revised Report
Liquefaction Evaluation
Proposed ASW Bypass
Diablo Canyon Power Plant
San Luis Obispo County, California

Dear Mr. Fujisaki:

This letter report presents the results of Harding Lawson Associates' (HLA's) evaluation of the liquefaction potential[1] of the existing backfill in the vicinity of the proposed ASW Bypass at Diablo Canyon Power Plant in San Luis Obispo County, California. This evaluation was undertaken following our recent field investigation (presented in our May 8, 1996 report, HLA Project No. 10183-005) that revealed the existence of medium dense sands below the water table northeast of the existing Intake Structure (IS). Plate 1 presents a site plan of the subject area. This report was previously issued on July 8, 1996 and is now being revised to address the variations in the definition of the design earthquake magnitudes. The conclusions presented in this report have not been modified.

We obtained information regarding the previous excavations and backfilling operations through 1) review of Mr. Al Tafoya's (of PG&E) draft memorandum entitled *Background Information of Soil Near the I.S. and for Liquefaction Issue,* dated May 31, 1996, 2) a meeting with you on June 14, 1996, and 3) review of a PG&E plan entitled *Rock Topography near ASW Bypass Piping Routing (SK-C-ASWBROCK), Revision A.*

BACKGROUND AND SUBSURFACE CONDITIONS

During the 1970s, the IS and the Circulating Water Intake (CWI) conduits were constructed. The CWI conduits are founded at a depth of 40 to 45 feet below existing grades adjacent to

---

1 Soil liquefaction is a phenomenon which saturated (submerged), cohensionless soils experience a temporary loss of strength because of the buildup of excess pore water pressure, especially during cyclic loadings, such as those induced by earthquakes. Soils most expectable to liquefaction are loose, clean, saturated, uniformly graded, fine-grained sands.

the IS (Elevation -20 feet[2]). To construct the CWI conduits and the IS, deep cuts were made in the existing native soils and rock. The excavation sides were sloped as shown on Plate 1. Following CWI and IS construction, the excavation was backfilled with compacted fill. The specifications required that the backfill be granular material below Elevation 6 feet and that it be compacted to at least 95 percent relative compaction[3]. The field density tests performed during backfilling indicate that the materials were essentially compacted in accordance with the specifications.

In 1978, HLA performed a geotechnical investigation adjacent to the IS which included drilling 5 borings at the locations shown on Plate 1. These borings encountered 25 to 35 feet of fill consisting of stiff clay and dense to very dense sand and gravel. Groundwater was encountered near Elevation 0 feet. Based on the material types and blow counts observed during sampling, the fill encountered was not considered to be potentially liquefiable.

In 1980 and 1981, an excavation was made to repair electrical conduits which were damaged from settlement. The lateral extent of the excavation is shown on Plate 1 and the depth of the excavation extended down to the top of the CWI conduits. The conduits were repaired and the excavation was backfilled with compacted fill. The field density test results indicate that the backfill was compacted to at least 95 percent relative compaction.

In December of 1995, HLA drilled 4 additional borings to characterize the backfill for purposes of the dynamic analyses of the proposed ASW Bypass being conducted by others and the slope stability evaluation being conducted by HLA. The borings encountered fill that ranged in depth from 6 feet at Boring B-2 to 31-1/3 feet (the depth explored) at Boring B-4. The fill generally consisted of stiff clays and dense to very dense sands and gravel which is consistent with the 1978 borings; these materials are not believed to be susceptible to liquefaction. Unexpectedly however, two of the borings encountered medium dense sands below Mean Sea Level (Borings B-1 and B-4, Plates 2 and 3) as indicated by relatively low blow counts obtained during soil sampling. The relatively low blow counts occurred at a depth of 25 feet (Elevation -1 feet), as shown on Plates 2 and 3, and are in what is believed to be the original backfill placed during the CWI conduit construction. The blow count of 18 at 25 feet in Boring B-1 represents a Standard Penetration Test (SPT) N-Value[4] and the blow count of 15 at 25 feet in Boring B-4 represents a pseudo-SPT N-value that was obtained by multiplying the field blow count by 0.7 to account for the larger sampler size (3-inch outside

---

2 Elevations referenced to Mean Sea Level

3 Relative compaction refers to the in-place dry density of soil expressed as a percentage of the maximum dry density of the same soil determined by ASTM D1557 laboratory test procedure. Optimum moisture is the water content that corresponds to the maximum dry density.

4 The SPT N-value is defined as the number of blows of a 140-pound hammer, falling freely through a height of 30 inches, required to drive a standard split-barrel sampler (2-inch outside diameter and a 1-3/8-inch inside diameter) the final 12 inches of an 18-inch drive. For SPT procedures, see ASTM D1586.

diameter and 2.43-inch inside diameter). Additional details regarding the field investigation are presented in HLA's May 8, 1996 report. The groundwater was encountered only in Boring B-4 at a depth of 24 feet (Elevation 0 feet). Because of the proximity of the site to the ocean, the groundwater level is likely influenced by tidal effects.

The zone of the medium dense sands that are located below the water table are believed to be confined to an area that is approximately 10 to 20 feet wide and 100 feet long, as shown on Plate 1. This zone is defined by the following boundaries: the edge of the original excavation for the CWI conduit construction on the north and east, the 1980 backfill placed during repair of the electrical conduits on the west, and the clayey backfill placed during the CWI conduit and IS construction that was encountered by the 1978 Borings 4 and 5 on the south. Based on the recent Boring B-4, we have assumed that this zone is 5 feet thick, from Elevation 0 to -5 feet, throughout the zone described above. This is a conservative assumption, given that the fill was reportedly compacted to at least 95 percent relative compaction. It is more likely that the sands range from being medium dense to dense within the zone defined above.

Because of the relatively low blow counts encountered in the 1995 borings and the potential for relatively high seismic ground shaking, the evaluation discussed in this report was undertaken to assess the liquefaction potential of the medium dense backfill and the likely consequences of liquefaction if it were to occur.

LIQUEFACTION POTENTIAL AND SEISMICALLY-INDUCED SETTLEMENT

In our analyses, we evaluated the liquefaction potential for two levels of ground motion: one for a Magnitude (M) 7.5 event with a peak ground acceleration (PGA) of 0.83 gravity (g) and one for a M6 event with a PGA of 0.35g. The larger magnitude event is believe to represent a conservative upper bound of the design ground motions for the plant. The actual design ground motions for the plant include the Hosgri record, which is for an M7.5 event with a PGA of 0.75g, and the Long Term Seismic Program records, which are for an M7.2 event with a PGA of 0.83g. The smaller event is representative of an earthquake with a higher probability of occurrence.

We evaluated the potential for liquefaction using the procedure developed by Seed et al. (1985)[5]. In this procedure, the physical properties of the soil are characterized by laboratory grain-size tests to determine the percent finer than the number 200 sieve and by field SPTs. We visually observed that there was not a significant amount of fines in the sands ; therefore, laboratory grain-size tests were not performed. The SPT N-Values (15 and 18)

---

5 Seed, H. B., K. Tokimatsu, L.F. Harder, and R.M. Chung, 1985. *Influence of SPT Procedures and Liquefaction Resistance Evaluations*. American Society of Civil Engineers, Journal of Geotechnical Engineering, Vol. 111, No. 12, December.

were converted to $N_{1(60)}$ valuese (15 and 19, respectively) in accordance with the procedures recommended by Seed, et al. (1985). Our analyses indicates that there is a high probability of liquefaction for the medium dense sands located below the water table during the M7-1/2 event. For the M6 event, the data points plot near the boarder between "liquefaction" and "no liquefaction" indicating that there is a much lower chance of liquefaction occurring during the smaller event.

If liquefaction does occur, we judge that its most likely effects will be as follows:

- A reduction of in the strength of the sand during the seismic event
- Seismically-induced settlement of the sands following the seismic event.

We judge the risk of lateral movements due to liquefaction to be very low because of the discontinuous nature of the medium dense sands and the fact that they are confined on all sides.

During our slope stability analyses, we conservatively assumed that the entire 5-foot-thick zone of the medium dense sands would liquefy during the M7-1/2 event and assigned a reduced strength to the zone.

In evaluating seismically-induced settlement, we utilized a procedure developed by Tokimatsu and Seed (1987)[7]. For the M7-1/2 event (PGA of 0.83g), the computed maximum settlement of the 5-foot layer that liquefies is approximately 1 inch. Because of the depth of this layer and the limited extent of the medium dense sands, we judged that the maximum ground surface settlements could be up to approximately 50 percent of the computed settlements. This would result in a maximum ground surface settlement on the order of 1/2 inch during the M7-1/2 event. For the M6 event (PGA of 0.35g), the computed maximum settlement of the 5-foot layer that liquefies is approximately 1/2 inch. As with the larger event, we judge that the maximum ground surface settlement will be approximately 50 percent of the computed value; approximately 1/4 inch.

Differential settlement of the proposed ASW Bypass could occur during an earthquake because the proposed pipelines will cross over the zone of medium dense sands. We judge that the magnitude of the maximum differential settlement will be approximately equal to the maximum ground surface settlements mentioned above. Because of the depth of the sands below the bypass pipeline, the differential settlement will not occur abruptly in a short distance, but will occur gradually along the pipeline. For design purposes, we

---

6 $N_{1(60)}$ values are the SPT N-values normalized to an effective overburden pressure of 1 ton per square foot and to an effective energy delivered to the drill rods equal to 60 percent of the theoretical free-fall energy.

7 Tokimatsu, K. And Seed, H.B., 1987, *Evaluation of Settlement of Sands Due to Earthquake Shaking*, American Society of Civil Engineers, Journal of Geotechnical Engineering, Volume 113, No. 8, August.

recommend assuming that the estimated maximum differential settlement occurs over a distance of 25 feet.

The settlements mentioned above are the result of densification of the sands following dissipation of pore water pressures developed as a result of seismic shaking. Therefore, the settlements will take place following the earthquake as pore water pressures dissipate. As a result, these settlements should not be added to the transient displacements that are predicted for the pipelines during the earthquake shaking.

These estimated settlements are maximum values that could occur during a single event. It is possible for liquefaction to occur during an earthquake, but to have little or no observable settlement; this does not mean that settlement will not occur during future earthquakes. While liquefaction has been observed to occur repeatedly at the same site during multiple earthquake, the settlement estimates represent the upper bound of accumulative settlement during repeated events at any given point at the site.

COMMENTS REGARDING PREDICTED SETTLEMENTS

The preceding discussion presents settlement estimates that are based on calculations performed using commonly accepted methods of analyses in the geotechnical practice in California that were developed in the 1970s and 1980s. For the following reasons, we believe that the settlement estimates presented above represent conservative upper bound values and that actual settlements will be less:

- Case histories from recent earthquakes[8] suggest that there have not been significant effects from liquefaction observed in soils that have $N_{1(60)}$ values greater than 15. In developing the methodology for the analyses discussed above, the number of data points where liquefaction was observed and the $N_{1(60)}$ values were above 15 was limited and the observations were generally not detailed. During recent earthquakes, the database for materials with $N_{1(60)}$ values greater than 15 has increased significantly.

---

8 Bartlett, S.F. and Youd, T.L., 1995, *Empirical Prediction of Liquefaction-Induced Lateral Spread*, American Society of Civil Engineers, Journal of Geotechnical Engineering, Volume 121, No. 4, April.

Baziar, M.H. and Dobry, R., 1995, *Residual Strength and Large-Deformation Potential of Loose Silty Sands*, American Society of Civil Engineers, Journal of Geotechnical Engineering, Volume 121, No. 12, December.

Fear, C.E. and McRoberts, E.C., 1995, *Reconsideration of Initiation of Liquefaction in Sandy Soils*, American Society of Civil Engineers, Journal of Geotechnical Engineering, Volume 121, No. 3, March.

Pyke, R., 1995, *Practical Aspects of the Evaluation of Liquefaction Potential*, First International Conference on Earthquake Geotechnical Engineering, Tokyo, Japan, November 14 through 16.

- The zone of medium dense sands is confined by stiffer backfill and natural soil and rock. During ground shaking, the stresses and strains in the medium dense sands will be controlled by the deformations of the stiffer materials. In general, the stiffer the deposit, the lower the induced shear strains during the earthquake. Because the settlement of the medium dense sands is a function of the induced shear strains, the settlement of the inclusion of medium dense sands will likely be smaller than the settlement of a large mass of medium dense sands, as assumed in the analyses.

- The water table is located near the top of the medium dense sands and the sands extend above the water table. Because of fluctuation of the water table resulting from tidal effects, the upper portion of the sands is likely not 100 percent saturated. It is more difficult to develop large seismically-induced pore pressures in partially saturated soils. In addition, because the water table is near the top of the sand zone, there is a very short drainage path for the pore water pressures to dissipate. This will also result in lower maximum pore water pressure generation than would be expected for cases with longer drain paths. In general, the smaller the generated pore water pressures, the smaller the seismically-induced settlements.

For the preceding reasons, we believe that the previously reported settlement estimates represent a conservative upper bound. We judge that a more realistic estimate of settlements would be on the order of one-half of those predicted using the referenced methods of analyses. This results in maximum likely ground surface settlements of 1/4 inch for the M7-1/2 event and less than 1/4 inch for the M6 event.

We trust that this provides the information you require at this time. If you have any questions, please call.

Yours very truly,

HARDING LAWSON ASSOCIATES

W. Andrew Herlache, G.E.
Associate Engineer

REGISTERED PROFESSIONAL ENGINEER
WARD ANDREW HERLACHE
No. GE 002149
Exp. 3/31/99
GEOTECHNICAL
STATE OF CALIFORNIA

Robert Pyke, G.E.
Consulting Engineer

WAH\RP\HTT\mlw 10183\020461L.DOC

Attachments: Plate 1 - Site Plan
Plates 2 and 3 - Log of Borings B-1 and B-4