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Bureau of Reclamation • Pacific Gas & Electric • Colorado State University

Pit 4 Dam

Slab and Buttress Foundation Scale Model Simulation

By the
Dam Foundation Erosion Study Team

April, 1995

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Dam Foundation Erosion Study Team

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Mr. Doug Morris is the EPRI Project Manager for EPRI Project No. RP3752-01, the Dam Foundation Erosion Study.

Study Team Organizations

The mission of the **Bureau of Reclamation** (Reclamation) is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American Public. Reclamation is responding to the challenge to help develop the West by providing sustained economic growth, improving the environment, and enhancing quality of life. In the future Reclamation will be meeting increasingly complex water demands and resource management needs of the West.

The **Electric Power Research Institute** (EPRI) conducts a far-reaching program of collaborative research and development on behalf of the nation's electric power industry. Today some 350 EPRI scientists and engineers manage nearly 1600 research projects related to the efficient generation, delivery, and use of electricity, with special attention paid to cost-effectiveness and environmental acceptability. Roughly 700 electric utilities fund EPRI research through membership payments and project investments. Research and development, in the form of products, services, and information, contribute directly to the benefit of EPRI members and their customers.

Pacific Gas & Electric Company (PG&E) is a privately owned public utility company providing electric and natural gas service to 6.5 million customers in Northern and Central California. PG&E electric power sources include hydro, geothermal, fossil, and nuclear generation. PG&E's current hydroelectric capability is 3,874 MW from 67 plants, mostly from sites on the western slope of the Sierra Nevada. More than 130 impounding and diversion structures ranging in size from the 335-foot high Salt Springs Dam to small canal diversion structures make up the Hydro sources. The company has a strong research and development program addressing dam safety and other Hydro issues.

Western Area Power Administration (Western) markets hydroelectric power from more than 50 power plants at Federal dams throughout the western United States. The Bureau of Reclamation, the US Army Corps of Engineers, and the International Boundary and Water Commission own and operates the dams and power plants. Western also markets a share of the power from the Navajo Generating Station. Western's mission is to market Federal hydroelectric resources in such a manner as to encourage the most widespread use thereof at the lowest possible rates to consumers consistent with sound business principles.

Colorado State University (CSU), founded in 1870, is the land grant university in Colorado. The Civil Engineering Department enrolls roughly 350 undergraduate and 200 graduate students. Recent research by Civil Engineering faculty includes river mechanics, bank stabilization technology, environmental methods in stream rehabilitation, drop structures, stream monitoring, and embankment overtopping. The Hydraulics Laboratory, Hydromachinery Laboratory, and Outdoor laboratories at the Engineering Research Center are part of the unique research facilities at Colorado State University.

Acknowledgments

The Authors acknowledge the following persons for their assistance with the experimental program. Mr. Tom Brisbane, Colorado State University, supervised the design and construction of the scale model facility. Mr. Russell Dodge, Reclamation, assisted with the procedure for scaling material according to fall velocity. Mr. Jerry Fitzwater, Reclamation, drafted several of the figures in the report, and Mr. Lee Elgin, Reclamation, is the instrumentation consultant for the Dam Foundation Erosion Study.

Pacific Gas & Electric Co. funded this experimental program under Cooperative Research and Development Master Agreement (CRDA) No. Z-19-2-196-91. This agreement is under the authority of the Technology Transfer Act of 1986 (Public Law 99-502). Under the CRDA, Reclamation and PG&E are performing cooperative research in association with Reclamation's Water Technology and Environmental Research (WATER) program and the Department of the Interior Dam Safety Program.

Key Words

Pit 4, Dam Foundation Erosion, Fall Velocity, Erosion, Model, PG&E, EPRI, progressivity

Executive Summary

Reclamation and Pacific Gas & Electric Company (PG&E) entered into Cooperative Research and Development Master Agreement (CRDA) No. Z-19-2-196-91 in December 1991. This agreement is under the authority of the Technology Transfer Act of 1986 (Public Law 99-502). Under the CRDA, Reclamation and PG&E will perform cooperative research in association with Reclamation's Water Technology and Environmental Research (WATER) program and the Department of the Interior Dam Safety Program.

Reclamation received a Request For Proposal (RFP) in September 1992, from Pacific Gas & Electric Co., for a cooperative research study of the Characteristics of Dam Foundation Erosion. In response to the RFP Reclamation invited PG&E, Colorado State University, and Dr. George Annandale to form a study team. The Study Team responded to the RFP in a joint proposal February 1, 1993. PG&E responded favorably to the proposal and the Study Team began preparation of a Survey of Literature and a Pre-Test Report.

Reclamation and Colorado State University entered into Cooperative Agreement #1425-4-FC-81-19700 for completing a Pre-Test Report and seminar, and scale model and prototype model designs. A scope of work for clear water experiments and instrumentation design was part of this agreement. Colorado State University completed the scale model design in December 1993, and completed construction of the 1:3 scale model facility in March 1994. The facility simulates a free-trajectory jet, the type of flow that may occur at a concrete dam during an overtopping event.

In May 1994, at the request of PG&E, the Study Team initiated a change in the scope of work of Cooperative Agreement #1425-4-FC-81-19700. The Study Team postponed the parts of the scope of work referred to as the "clear water experiments" and the instrumentation design tests. In their place the Study Team planned experiments simulating overtopping at the Pit 4 dam, a PG&E owned facility. The documents supplied by PG&E [1][2] describe the parameters of the experiments. PG&E supplied a sample of material from the downstream area of Pit 4 dam. The Pit 4 Material section describes those materials. The experiments include collecting data on extents and temporal changes of erosion only. The clear water experiments, instrumentation design, and remaining experiments were transferred into the scope of work for the new three year cooperative agreement currently being formulated.

Pit 4 Dam is located on the Pit River, in Shasta County, California, about 8 miles northwest of Burney, California. The dam, constructed in 1927, is a composite-type structure, with the right half being a spillway section and the left half a slab-and-buttress structure. Figure 22 (Appendix G - PG&E Pit 4 Figures) presents a plan view and elevation of the dam along with typical sections of the spillway and slab-and-buttress portions.

Experiments on the Pit 4 material satisfied the testing portion of the scale model aspect of Contract No. 1425-4-FC-81-19700. This report presents the results and conclusions of those experiments. The scope of work includes two experiments. The first is a witness test, and the second is a record experiment. The witness test took place on July 26, 1994, with Mr. Ron Adhya, the PG&E Project Manager present. The record experiment took place on August 11-12, 1994.

On July 26, 1994, Colorado State University performed a witness test in the Hydraulics Laboratory. Attendees included Mr. Ron Adhya, PG&E; Dr. Rodney Wittler, Mr. Philip Burgi, and Mr. Brent Mefford, Reclamation; Dr. George Annandale, HDR Inc.; and Dr. James Ruff, Dr. Steven Abt, Mr. Thomas Brisbane, and Mr. Todd Lewis, Colorado State University. The model was prepared with the basin filled with 3 feet of Pit 4 material (scaled) and the jet manifold angle of 30 degrees. The model was operated for approximately a 1-hour period. Data were not taken during the witness test.

Subsequent to the witness test, the model was prepared for a record experiment of the Pit 4 scaled material. Several communications occurred between Colorado State University and Reclamation to determine material depth, jet angle, tailwater depth, discharge, experiment duration, and data collection times. The experimental parameters are:

- Jet/diffuser angle of 10 degrees from vertical
- Pit 4 material depth of 3 feet (Elevation 4 feet)
- Experiment duration of 2 hours
- Bed contouring at 15, 30, 60, and 120 minutes after the beginning of the experiment
- Tailwater sill maintained at 4 inches (model) above the initial bed level
- Discharge of 6.4 ft^3/s. (22% of the PMF)

The Pit 4 material record experiment was conducted by Colorado State University on August 11-12, 1994. Dr. Rodney Wittler witnessed portions of the record experiment. A summary of the experiment results with plots are presented in the results section and also in Appendix F - Three Dimensional Graphs of Erosion Hole.

The Pit 4 material record experiment consisted of four flow periods. After each period of flow, the model was shut down and the surface of the model contoured. The surface was not relevelled. The following time increments (total elapsed time) comprised the four periods: 15 minutes, 30 minutes, 1 hour, and 2 hours.

Results show a maximum erosion depth of roughly 1.98 feet. Scaled, this depth corresponds to a depth of roughly 6 feet. The unit discharge of the model corresponds to a discharge 22% of the PMF discharge.

Conclusions:

- All erosion results in this experimental series correspond to flow that is roughly 22% of the PMF of Pit 4 dam. This is a flow of 10.0 $ft^3/s/ft$ prototype scale or 1.92 $ft^3/s/ft$ model scale.
- The model equations overestimate the erosion for model data by roughly 26% to 36%.
- The prototype Veronese and modified Veronese erosion prediction formulas overestimate the scaled erosion results from the simulation by 32% and 29%. The Mason prototype formula underestimates the scaled erosion results from the simulation by 13%.
- The maximum erosion occurred within the first 12% of the total test time. The time to maximum erosion is undetermined, but progressivity in the simulation is practically nonexistent. The maximum erosion does not substantially change with respect to time.
- Operation of the 1:3 scale model facility with non-cohesive material indicates a high potential for successful simulation of other earth materials. The test basin dimensions facilitate recirculation without constricting the return flow, and the depth of the basin appears adequate.

Pit 4 Dam

Slab and Buttress Foundation Scale Model Simulation

Introduction

The result of basing the Probable Maximum Flood (PMF) on the Probable Maximum Precipitation (PMP) rather than historical statistical predictions of precipitation is an increase in the estimate of the Inflow Design Flood (IDF). Reclamation and PG&E base estimates of the IDF for their dams on the PMF, increasing the estimate of the IDF. The increase in the estimate of the IDF causes recognition of insufficient spillway capacity for passing the flood volume. This recognition creates a need to either upgrade the spillway capacity, allow overtopping of the dam, or remove the dam.

State and Federal Dam Safety regulations require reasonable evidence that an overtopping scheme will not result in destabilization of the dam due to erosion in the foundation and abutment areas. Current methods of predicting and evaluating erosion extents have limited applicability. Existing erosion prediction formulas do not track erosion as a function of time, and have limited application in hard-rock or cohesive foundation materials. The goal of the Dam Foundation Erosion study is to improve technology for predicting and evaluating the progressive erosion extents in the foundation and abutment areas of a dam due to overtopping.

Reclamation received a Request For Proposal (RFP) in September, 1992, from Pacific Gas & Electric Co., for a cooperative research study of the Characteristics of Dam Foundation Erosion. In response to the RFP Reclamation invited PG&E, Colorado State University, and Dr. George Annandale to form a study team. The Study Team responded to the RFP in a joint proposal February 1, 1993. PG&E responded favorably to the proposal and the Study Team began preparation of a Survey of Literature and a Pre-Test Report.

Reclamation and Pacific Gas & Electric Company (PG&E) entered into Cooperative Research and Development Master Agreement (CRDA) No. Z-19-2-196-91 in December 1991. This agreement is under the authority of the Technology Transfer Act of 1986 (Public Law 99-502). Under the CRDA, Reclamation and PG&E will perform cooperative research in association with Reclamation's Water Technology and Environmental Research (WATER) program and the Department of the Interior Dam Safety Program.

Reclamation and Colorado State University entered into Cooperative Agreement #1425-4-FC-81-19700 for completing a Pre-Test Report and seminar, and scale model and prototype model designs. A scope of work for clear water experiments and instrumentation design was part of this agreement. Colorado State University completed the scale model design in December, 1993, and completed construction of the 1:3 scale model facility in March, 1994. The facility simulates a free-trajectory or supported jet, the type of flow that would occur at a dam during an overtopping event. The facility is prepared to experiment a variety of materials while enabling the experimenters to view multiple aspects of material installation. A following section on the scale model presents the plans and capabilities of the facility.

In May, 1994, at the request of PG&E, the Study Team initiated a change in the scope of work of Cooperative Agreement #1425-4-FC-81-19700. The Study Team postponed the parts of the scope of work referred to as the "clear water experiments" and the instrumentation design tests. In their place the Study Team planned experiments simulating overtopping at the Pit 4 dam, a PG&E owned facility. The parameters of the experiments are described in documents supplied by PG&E [1][2]. PG&E supplied a sample of material from the downstream area of Pit 4 dam. Those materials are described in the section Pit 4 Materials. The experiments include collecting data on extents and temporal changes of erosion only. The clear water experiments, instrumentation design, and remaining experiments were transferred into the scope of work for the new three year cooperative agreement currently being formulated.

Experiments on the Pit 4 material satisfied the testing portion of the scale model aspect of Contract No. 1425-4-FC-81-19700. This report presents the results and conclusions of those experiments.

Scale Model Simulation Objective

The objective of the scale model simulation of overtopping Pit 4 dam is to determine potential extents of erosion in the foundation material of Pit 4 dam. Carrying out this objective requires testing the Veronese [5] and Mason [4] formulas estimation of potential erosion. The estimates of erosion extents will be compared with the simulation results, drawing conclusions about the erosion potential of Pit 4 dam foundation material. Finally, the objective is to support the basis for the conclusions regarding foundation stability reached in the PG&E study titled <u>Pit 4 Dam, Stability Under Flood Loading and Dam Break Analysis</u> [1].

In addition, the simulation provides an opportunity to operate the scale model facility, constructed as part of the Dam Foundation Erosion study. Operation of the model facility for tests of a non-cohesive material will indicate the potential for the model to successfully simulate other materials.

Dam Foundation Erosion: Pre-Test Report

PG&E provided separate funds under the Master CRDA to Reclamation for a Survey of Literature, a Pre-Test Report and Pre-Test Report seminar, scale model and prototype model designs, and clear water and instrumentation experiments in the scale model. The purpose of the Survey of Literature and Pre-Test report is to assess the current state of technology. The Pre-Test report presents the Study Team approach for advancing the technology of erosion prediction in dam foundation and abutment areas.

Reclamation published the Survey of Literature [9] on August 6, 1993, and the Pre-Test Report [8] on October 28, 1993. More than seventy officials met at the Pre-Test Report seminar in San Francisco at PG&E Headquarters on October 28, 1993.

Study Team

The Study Team formed to respond to the RFP from PG&E on Characteristics of Dam Foundation Erosion is made up of Government, University, PG&E, and consulting experts in the area of erosion and scour, as well as dam safety. This partnership of private and public presents a unique opportunity for applied research while leveraging scarce resources.

Since the inception of the Study Team, plans have been in formulation for a comprehensive applied research study. The primary product of the research study will be a numerical model for estimating the progressive extents of erosion in the foundation and abutment areas of dams. The Study Team intends to conduct experiments in two physical models at the Hydraulic Laboratories of Colorado State University. The first model, located in the indoor Hydraulics Laboratory has a scale of 1:3 and follows Froude criteria. The second model, to be located at the Outdoor Laboratories, is prototype scale. The 1:3 scale model provides an economy of scale, accurately modeling hydraulics, with scale effects distorting material properties and aeration effects. Accurate simulation of air-water and water-material interaction without scale effects requires a prototype scale model.

The experiments and analysis of these data will be performed by members of the Study Team. The team is made up of the following persons and organizations.

Name	Organization	Role
Dr. Rodney J. Wittler*	Reclamation TSC Water Resources Research Laboratory	Study Team Leader, Reclamation Principal Investigator
Mr. Doug Morris	EPRI	EPRI Project Manager
Mr. Ron Adhya	PG&E	PG&E Project Manager
Professor James Ruff*	Colorado State University	Prototype Model Team Leader, Numerical Modeling Coordinator
Professor Steven Abt*	Colorado State University	Scale Model Team Leader
Dr. George Annandale*	HDR Engineering, Inc.	Erodibility Index consultant
Mr. Greg Scott	Reclamation TSC Geotechnical Group 4	Geotechnical Engineering consultant
Mr. Brent Mefford	Reclamation TSC Water Resources Research Laboratory	Technical Specialist

*Team Leader

Description of Pit 4 Dam

The description of Pit 4 Dam and the surrounding area is from Pit 4 Dam, Stability Under Flood Loading and Dam Break Analysis [1].

Pit 4 Dam is located on the Pit River, in Shasta County, California, about 8 miles northwest of Burney, California. The dam, constructed in 1927, is a composite-type structure, with the right half being a spillway section and the left half a slab-and-buttress structure. Figure 22 (Appendix G - PG&E Pit 4 Figures) presents a plan view and elevation of the dam along with typical sections of the spillway and slab-and-buttress portions.

The spillway section extends from the right abutment and is 213-feet long and a maximum of 78-feet high as measured from foundation bedrock to the crest of the spillway at USGS Elevation 2408, and 108-feet high as measured to the dam's crest at USGS Elevation 2438.5. The upstream face of the spillway section is vertical and the downstream face slopes at 0.7:1. The spillway section supports two drum gates that are controlled by water pressure and, when fully elevated, allow storage to a normal maximum reservoir level of USGS Elevation 2422.5.

The slab-and-buttress section extends from the left abutment and is 202-feet long and has a maximum height of 58 feet as measured to the non-overpour crest of USGS Elevation 2438.5. The upstream slab is from 1.67- to 3.17-feet thick and slopes at 1.8:1. There are 11 buttresses, with a nominal thickness of 2 feet and at 18-foot, center-to-center spacing, that support the upstream slab. These buttresses have a downstream face slope of 9.5:1. A 5-foot-wide concrete cutoff wall is provided at the upstream toe of the slab. The cutoff wall extends to bedrock at Buttress No. 1, but terminates in the overlying unconsolidated materials at the other buttresses sections towards the left abutment. A 4-foot-wide crest walkway with guard rails enables passage across the dam to the left abutment area.

Where the spillway and slab-and-buttress section join near the left side of the river, a massive training wall is provided to prevent spill from scouring the downstream tie of the slab-and-buttress section. The wall is 15-feet thick at the top, 30 feet at its base, and extends 166.5 feet downstream from the dam axis, decreasing in height going downstream. Based on original design records, the wall has a maximum height of 108 feet (50 feet below stream bed) and is founded on competent volcanic rock.

The right abutment of the dam is characterized by relatively steep slopes. The county roadway, that passes about 42 feet above the crest of the dam's axis, cuts though volcanic outcrops in this area. The average slope in the right abutment area is 1.2:1 (H:V); however, the abutment slope is steeper (0.9:1) in the immediate area of the dam. Vegetation is sparse, consisting of pine, oak, and small shrubs.

The slopes in the left abutment area are gentle but hummocky. Ancient landslide deposits, that are several hundred feet wide, cover the area. This ancient landslide, whose source is the left wall of the Pit River canyon, deposited material in the original river channel and caused a redirection of the river towards the southwest about 500 feet upstream of the dam. The average slope in the immediate area downstream of the slab-and-buttress section is 4.7:1; however, the slope steepens to 2.3:1 near the crest-abutment contact. The average slope from the left abutment crest to the base of the wall on the left side of the canyon, located about 400 feet from crest-abutment contact, varies between 3:1 and 4:1. The entire area is covered by a thick growth of mature pine, fir, and oak trees that average about 50 feet in height.

Overview of Experiments

The scope of work includes two experiments. The first is a witness test, and the second is a record experiment. The witness test took place on July 26, 1994 with Mr. Ron Adhya, the PG&E Project Manager present. The record experiment took place on August 11-12, 1994.

Pit 4 Materials:

In early June 1994, a request was forwarded to PG&E through Reclamation to obtain a representative material sample from the PG&E Pit 4 foundation area. A sample of the Pit 4 material was received on or about June 22, 1994. The Colorado State University staff performed a gradation analysis of the material as presented in Table 1. Appendix A - Pit 4 Material Analysis, contains the details of the gradation analysis. Reclamation received the Pit 4 material aggregate gradation curve on June 30, 1994, for review and comment.

On July 7, 1994, Reclamation forwarded a target gradation recommendation for the Pit 4 scale model simulation. The Scale Model Study Team accepted the target gradation and set about accumulating the necessary materials for the model simulation. The model is 1:3 Froude scale while material scale is Froude scale of the fall velocity of the Pit 4 material. Details of the target gradation are in Appendix D - Pit 4 Material Gradation and Target Gradation. The section on Scaling Methodology details the scaling methods.

During July, the target gradation specified by Reclamation was fabricated from materials obtained locally. The model gradation and the fabricated gradation curves are presented in Appendix B - 1:3 Scale Model Gradation and Appendix C - Optimization of Model Gradation.

Witness Test:

On July 26, 1994, a witness test was performed in the Hydraulics Laboratory at Colorado State University. Attendees included Mr. Ron Adhya, PG&E; Dr. Rodney Wittler, Mr. Philip Burgi, and Mr. Brent Mefford, Reclamation; Dr. George Annandale, HDR Inc.; and Dr. James Ruff, Dr. Steven Abt, Mr. Thomas Brisbane, and Mr. Todd Lewis, Colorado State University. The model was prepared with the basin filled with 3 feet of Pit 4 material (scaled) and the jet manifold angle of 30 degrees from horizontal. The staff operated the model for close to one hour. Data were not recorded during the witness test.

Pit 4 Material Record Experiment

Subsequent to the witness test, the model was prepared for a record experiment of the Pit 4 scaled material. Several communications occurred between Colorado State University and Reclamation to determine material depth, jet angle, tailwater depth, discharge, experiment duration, and data collection times. The experimental parameters are:

- Jet/diffuser angle of 10 degrees from vertical.
- Pit 4 material depth of 3 feet. Material surface elevation roughly 2381.00 NGVD.
- Experiment duration of 2 hours.
- Bed contouring at 15, 30, 60, and 120 minutes after the beginning of the experiment.
- Tailwater sill maintained at 4 inches (model) above the initial bed level. Tailwater elevation roughly 2383.00 NGVD.
- Model unit discharge of 1.92 $ft^3/s/ft$, prototype discharge 10.0 $ft^3/s/ft$, 22% of the PMF.

The Pit 4 material experiment was conducted on August 11-12, 1994. Dr. Rodney Wittler witnessed portions of the record experiment. A summary of the experimental results with plots are presented in the results section and also in Appendix F - Three Dimensional Graphs of Erosion Hole.

The Pit 4 material record experiment consisted of four flow periods. After each period, the model was shut down and the surface of the model contoured. The surface was not relevelled. The following time increments (total elapsed time) comprised the four periods: 15 minutes, 30 minutes, 1 hour, and 2 hours.

Results show a maximum model erosion depth of 1.98 feet. Scaled to prototype scale, this depth corresponds to a depth of roughly 6 feet or elevation 2375.00 NGVD.

Material Simulation

In early June 1994, a request was forwarded to PG&E through Reclamation to obtain a representative material sample from the Pit 4 Dam foundation area. A sample of the Pit 4 material was received on June 22, 1994. Colorado State University staff performed a gradation analysis of the material. Table 1 presents the aggregate analysis of the divided sample. Appendix A - Pit 4 Material Analysis, contains the details of the gradation analysis. Reclamation received the Pit 4 material aggregate gradation curve on June 30, 1994, for review and comment.

On July 7, 1994, Reclamation forwarded a target gradation for the model gradation part of the Pit 4 simulation. The model scale is 1:3 while material scales according to Froude scale of the fall velocity. Details of the target gradation are in Appendix D - Pit 4 Material Gradation and Target Gradation. The section on Scaling Methodology details the scaling methods.

Pit 4 Material

According to Pit 4 Dam, Stability Under Flood Loading and Dam Break Analysis [1], Pit 4 Dam is located in the northeastern portion of Shasta County, California, within extensive volcanic terrain of the Cascade Range geomorphic province. This province is bordered on the east by the Modoc Plateau, a province characterized by youthful basaltic terrain interrupted by block-faulting and resulting ridges and basins. To the west, sedimentary and volcanic rocks of the Klamath Mountains province from the basement that the volcanic Cascade rocks cover.

The volcanic and sedimentary rocks of the Cascade Range province range from Pliocene to Holocene in age. The most widespread and continuous rock unit of the Cascade Range province in Shasta County is the Tuscan Formation. This formation, that contains about 330 cubic miles of volcanic debris, is comprised of andesitic, basaltic, and dacitic breccia, tuff breccia, and interlayered flow rock of various compositions.

A succession of basalt and andesite originating from eruptive centers on the crest of the Cascade Range caps the Tuscan rocks. Volcanism has continued into present time with eruptions at Cinder Cone in 1850-1851, located about 35 miles southeast of Pit 4 Dam, and at Lassen Peak in 1914-1917, 38 miles to the southeast.

Bedrock in the dam area mapped by the California Division of Mines and Geology is shown on the Alturas Sheet as Tertiary volcanic rocks [Gay, T. E., Jr., and Aune, Q. A., 1958]. These rocks are described as andesitic flows and pyroclastic rocks. Mapping by Bechtel [1967] for the initial FERC dam safety investigation shows basalt and tuff at the site as well as surficial units of talus and overburden. The present mapping has delineated four bedrock units at the dam site, all at the right abutment. Surficial units have been differentiated into five mapping units.

Relatively sound, blocky basaltic flow rock is exposed at the right abutment area along with underlying tuff. The contact between the flow rock and tuff is well defined although mixed as the underlying tuff appears to fill columnar joint spacing at the base of the flow. This basal zone has been mapped and a dual symbol is shown on the geologic map [2]. Both of these rock types and the basal unit form the foundation materials at the right abutment. Past borings [Bechtel, 1967] indicate the presence of basalt and tuff under the dam foundation. There are no bedrock exposures in the dam's left abutment area. One of the borings performed for this study encountered volcanic agglomerate and tuff at depth downstream of the buttress section. The results of the seismic refraction survey, combined with the known depth to volcanic bedrock at each boring, were used to extrapolate depth to rock in the left abutment area.

The left abutment of the dam is occupied by an ancient landslide deposit comprised of basaltic boulders and cobble-sized fragments set in a silty and sandy matrix. Surface relief of the deposit exhibits hummocky topography, closed depressions, and an abrupt change in slope at its upper end. There are no indications of recent landslide activity. This deposit corresponds to the "overburden and scattered basalt boulder outcrops" described in Bechtel's investigation [1967]. It appears that the major portion of the slab-and-buttress section is founded on these deposits. According to construction records, the left training wall foundation was carried well into bedrock. Based on the results of the geophysical survey, it appears that the highest portion (Buttress No. 1) of the slab-and-buttress section is also founded on rock.

Concrete was found in Boring 1 at a depth of 28.5 to 33.5 feet. Based on the location and depth, this material is probably a portion of the lean concrete back fill placed adjacent to the left abutment side of the training wall during construction. Material found in the boring above the lean concrete probably represents back fill of the foundation excavation required to construct the training wall.

Analysis of Sample Material

Table 1 presents the results of the gradation analysis of the Pit 4 material prepared by the Colorado State University Sediment Laboratory. The sample supplied by PG&E was subdivided into seven parts. Each part was analyzed by mechanical sieving. Appendix A - Pit 4 Material Analysis contains the results of the individual gradations. Table 1 shows the aggregate results of the seven parts. The sample material consists of basaltic boulders and cobble-sized fragments set in a silty and sandy matrix, characteristic of the material below the buttress section of the Pit 4 dam. The material in the sample has an aggregate specific gravity of roughly 2.65.

Scaling Methodology

The basis for the model gradation is a 1:3 Froude scaling of the fall velocity of the Pit 4 material and the corresponding model gradation. Figure 1 shows a fall velocity curve of sand and silt material in water. Follow this procedure to scale the material.

1. Determine the decade size fractions of the Pit 4 material, that is D_{10}, D_{20}, ..., D_{100}.
2. Enter the vertical axis of Figure 1, Particle Diameter, at the first decade size fraction.
3. Read the corresponding fall velocity
4. Scale the fall velocity according to Froude criteria with scale 1:3. Velocity scales according to the square root of the horizontal scale, λ_v=1.732. Reduce the reading from the figure by a factor of 1.732.
5. Reenter Figure 1 on the horizontal axis, at the scaled value of the fall velocity.

6. Read the corresponding particle diameter. This particle diameter is the scaled value of the Pit 4 material for that size fraction.
7. Repeat for all decade size fractions.
8. Create a model gradation that follows the scaled size fractions, the target gradation.

Table 1. Aggregate gradation of Pit 4 material.

Soils Testing: Grain Size Determination (Mechanical Method)
(Aggregate results of samples A-G)

Project # : 531762
Sample Location : Pit 4
Performed by : T.L.
Date : 6 / 28 / 94

* Note: D.S. = Dry Soil

Weight of Dry Soil before sieving: 8998.5 g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of D.S. [g]	Accumulated Weight Ret. [g]	% Finer	
5/8 "	16.000	976.1	976.1	89.13	D_{10} = 0.100 mm
10	2.000	1891.2	2867.3	68.07	D_{30} = 0.346 mm
18	1.000	1347.0	4214.3	53.07	D_{50} = 0.880 mm
45	0.354	1887.6	6101.9	32.04	D_{60} = 1.500 mm
60	0.250	680.3	6782.2	24.47	D_{70} = 2.474 mm
120	0.125	1150.6	7932.8	11.65	D_{90} = 16.000 mm
230	0.063	568.4	8501.2	5.32	
Pan	---------	477.9	8979.1	0.00	

$$C_u = \frac{D_{60}}{D_{10}} = 15.000 \qquad C_c = \frac{D_{30}^2}{D_{10}D_{60}} = 0.798$$

Table 2 shows the results of scaling the Pit 4 material. Every other size decade is shown in the table. The smaller fractions scale at a factor of roughly 2:3 while the larger fractions scale at roughly 1:3. Fall velocity scaling primarily influences the scale applied to the finer fractions. The gradation represented by the scaled size fractions constitutes the "Target Gradation".

Table 2. Material scaling and Target Gradation specification.

	Pit 4 Size (mm)	*Pit 4 Fall Vel. (cm/s)*	*Scaled Fall Vel. (cm/s)*	*Scale Model Size (mm)*
D_0	0.03	0.07	0.04	0.02
D_{20}	0.19	2.10	1.21	0.12
D_{40}	0.54	6.00	3.46	0.30
D_{60}	1.30	12.54	7.24	0.65
D_{80}	5.00	24.60	14.20	1.65
D_{100}	100.00	110.00	63.51	33.07

Available Materials

Colorado State University proposed two sets of materials satisfactory for mixing to match the target gradation. The first set, described in Appendix D - Pit 4 Material Gradation and Target Gradation, includes small amounts of material that Colorado State University had on hand. The experiment requires roughly 600 ft^3 of material, therefore Colorado State University began investigating other sources for sufficient quantities of satisfactory material. The Western Mobile

(WM) gravel pits near Fort Collins, Colorado, provided the necessary materials in sufficient quantities. Appendix B - 1:3 Scale Model Gradation and Appendix C - Optimization of Model Gradation show the properties of the materials available from the Western Mobile pits and the process of mixing them to match the target gradation.

Model Gradation

After gradation analysis on the available materials, portions of each material were added to a scaled gradation, whose parts are the sum of the parts of the additions. The volumetric amounts of the portions are varied until the scaled gradation matches closely the target gradation. Following the target gradation, a test batch of the model gradation was prepared and subjected to gradation analysis. This process and the intermediate results are contained in Appendix B - 1:3 Scale Model Gradation, Appendix C - Optimization of Model Gradation, and Appendix D - Pit 4 Material Gradation and Target Gradation. The gradation analysis of the test batch is presented in Appendix E - Model Gradation Verification. Table 3 shows the results of the gradation analysis of the final model gradation.

Figure 2 shows a comparison of the target gradation, the model gradation, and the results of the verification analysis. The comparison shows that size and fall velocity similitude is acceptable for the experiment.

Table 3. Final model gradation.

Soils Testing: Grain Size Determination (Mechanical Method)

Project # : 531762
Sample : Model Mixture
Performed by : TL
Date : 7/19/94

Weight of Dry Soil before sieving 3911.7 g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of D.S. [g]	Accumulated Weight Ret. [g]	% Retained	% Finer
3/8"	9.510	356	356.0	9.1	90.9
#4	4.760	241.9	597.9	6.2	84.7
#18	1.000	552	1149.9	14.1	70.6
0.0232"	0.589	525.0	1674.9	13.4	57.2
#35	0.500	166.2	1841.1	4.2	52.9
#45	0.354	252.2	2093.3	6.4	46.5
0.0116"	0.295	106.0	2199.3	2.7	43.8
#70	0.210	504.8	2704.1	12.9	30.9
#170	0.088	837	3541.1	21.4	9.5
#230	0.063	112	3653.1	2.9	6.6
Pan	-------	251.5	3904.6	6.4	0.2

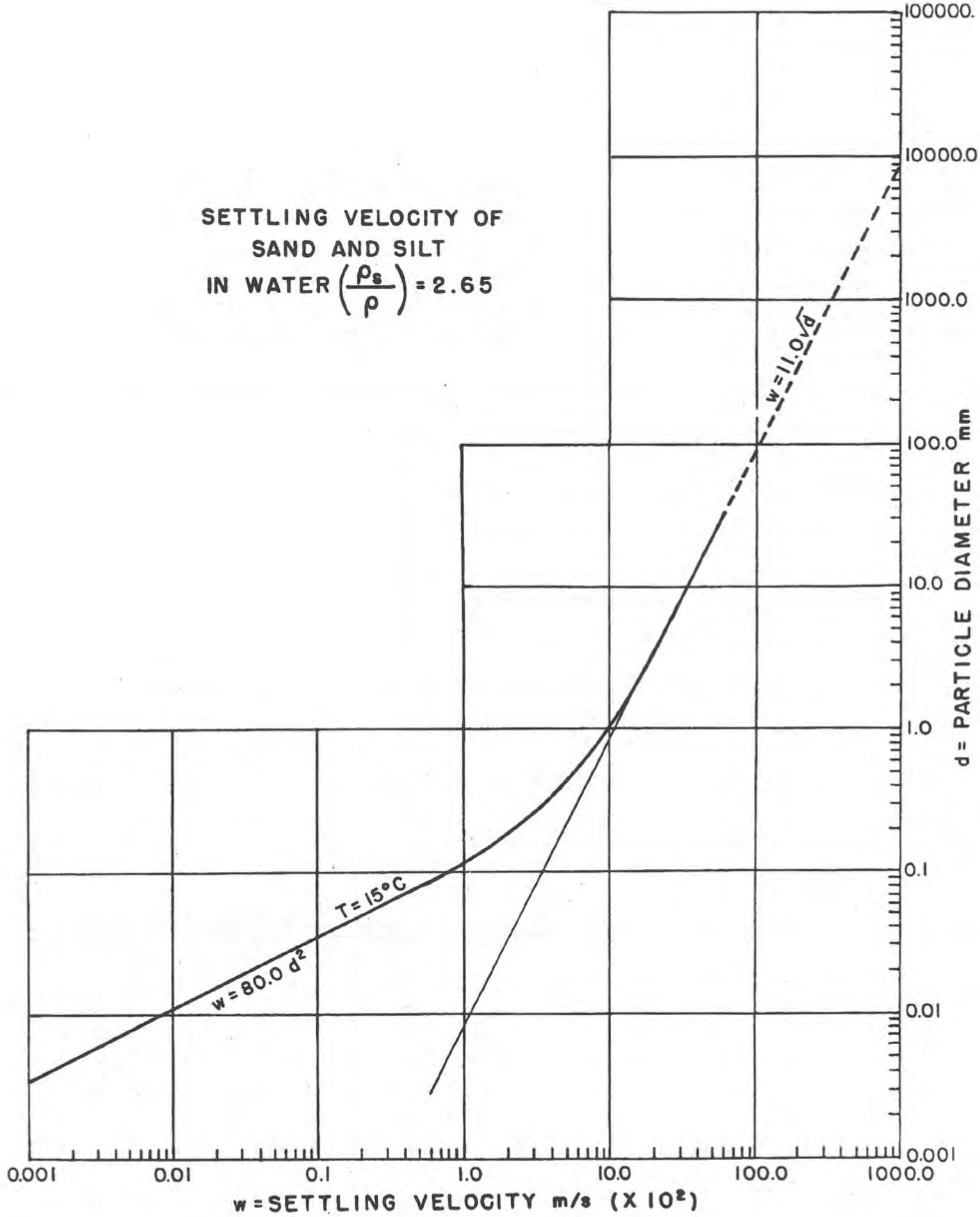

Figure 1. Settling velocity diagram.

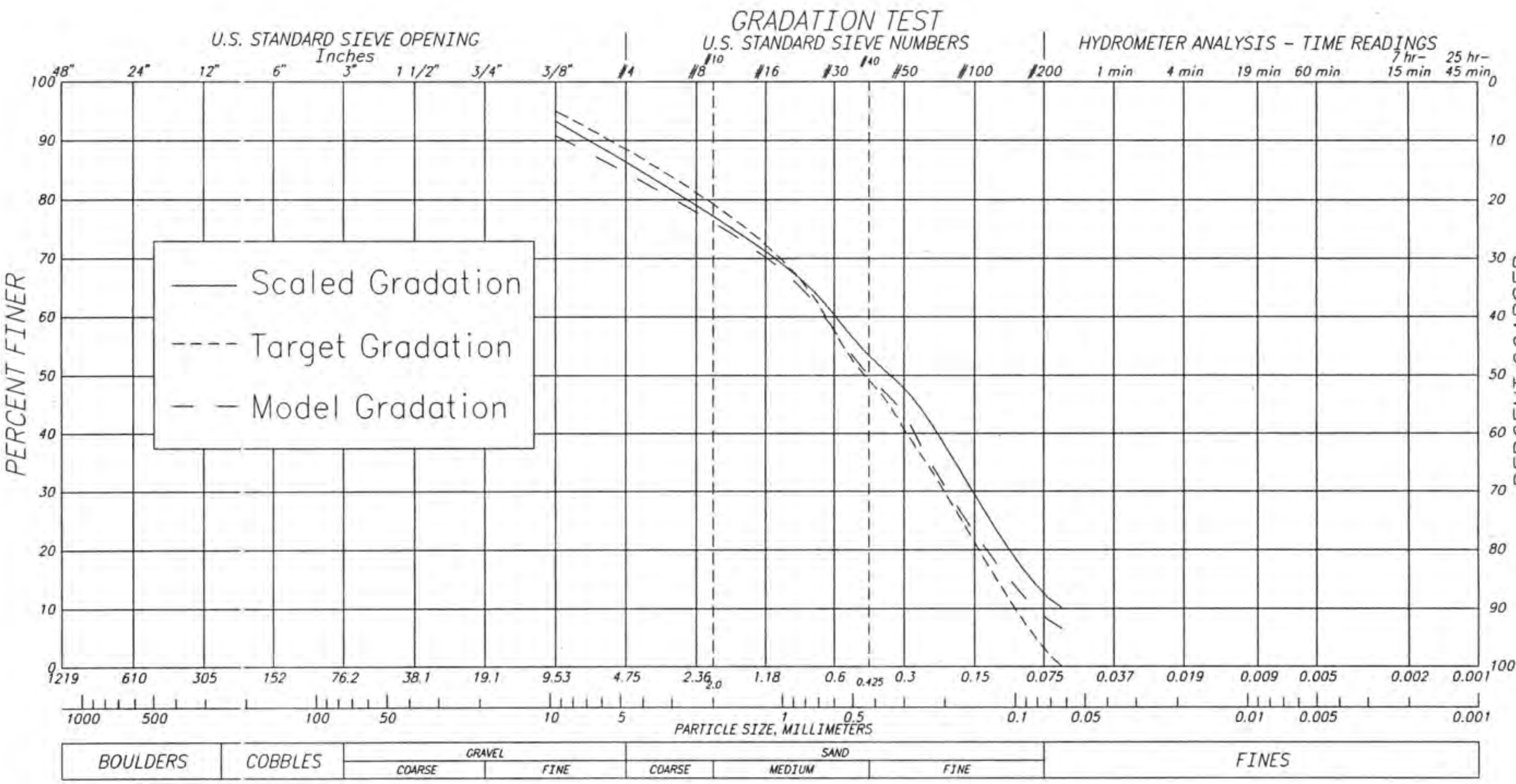

Figure 2. Comparison of gradations: Scaled gradation, Table 2, Target gradation, Appendix B - 1:3 Scale Model Gradation and Appendix D - Pit 4 Material Gradation and Target Gradation, Model gradation, Appendix E - Model Gradation Verification.

Free Trajectory Jet Simulation

Introduction

The basis for similitude of the free trajectory jet is Froude scaling. The calculations in this section show the process that the Study Team followed while establishing similitude. The process includes the following steps:

1. Document existing hydraulics at Pit 4 Dam
2. Document scale factors and model dimensions
3. Determine the capacity of the scale model in terms of the Pit 4 PMF
4. Determine the head corresponding to the simulated fraction of the Pit 4 PMF
5. Calculate the trajectory of the free trajectory jet.
6. Match the model trajectory with the model dimensions and parameter settings.

Scale Model Facility

The Scale Model Facility is located at the Hydraulics Laboratory, Engineering Research Center, Colorado State University. The model scale is 1:3. Material scale is based upon fall velocity Froude similitude. The flow capacity is roughly 6.4 ft^3/s (0.18 m^3/s). The following figures, Figure 3 through Figure 11 show various views of the facility.

Plans

Figure 3 shows an overall plan of the 1:3 scale model facility. The facility includes the water supply and flow measurement system, the orifice assembly, the test basin, wasteway, and walkways and viewing platforms. There is a material recovery system in the wasteway to prevent large amounts of eroded material from entering the laboratory recirculating water supply. Flow is measured with a calibrated orifice plate (not shown) in the 20 inch supply line.

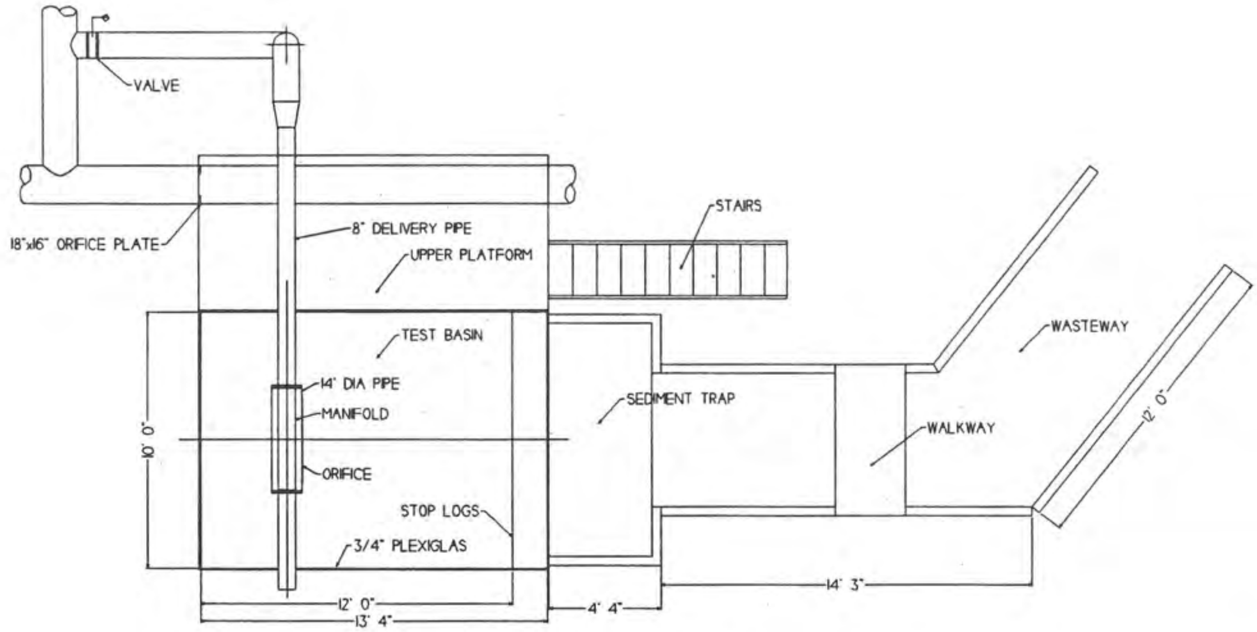

Figure 3. Plan of scale model facility.

Figure 4 shows dimensions of the test basin and orifice and orifice delivery pipe. An 8 inch delivery pipe and manifold along with a 14 inch pipe section and orifice assembly form an annulus. The annulus assembly is 44 inches (1.12 m) wide. All piping is Schedule 40.

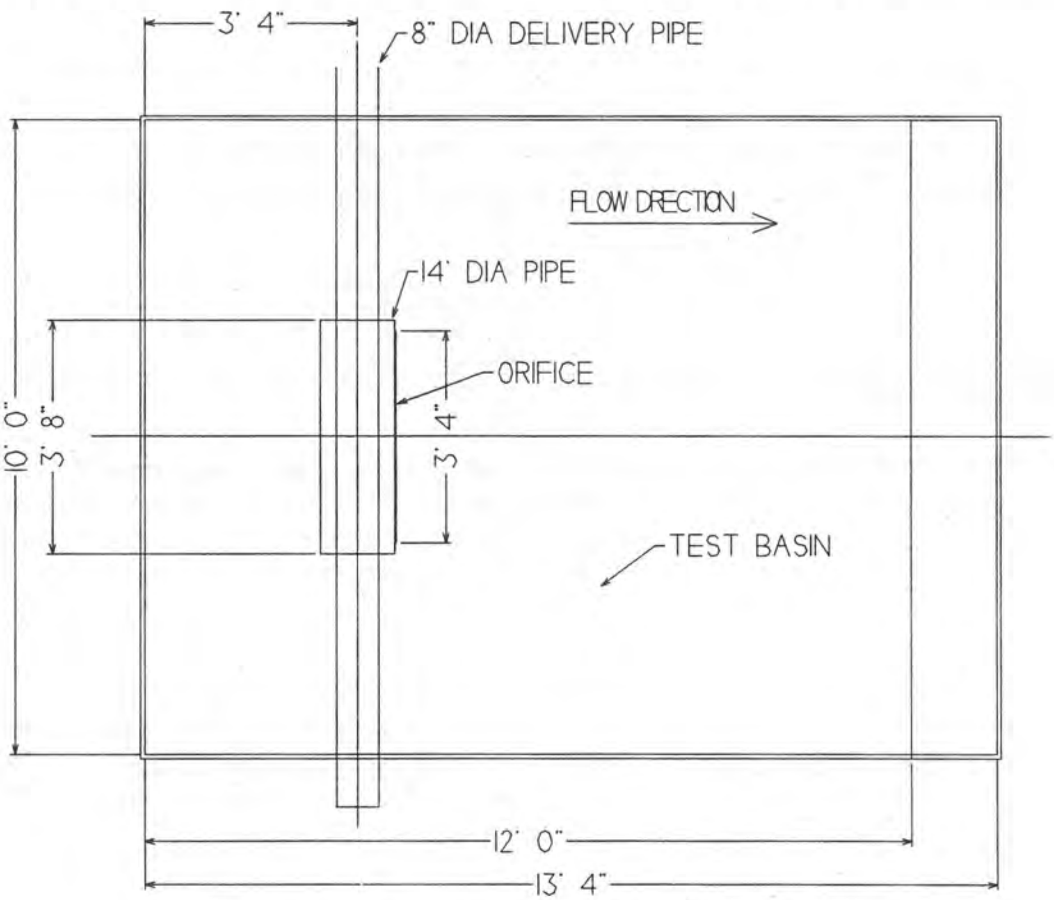

Figure 4. Plan of experimental basin, scale model facility.

Figure 5 shows the downstream aspects of the facility including stop logs that control tailwater level, stairs and upper viewing platform, and the relative position of the 8 inch delivery pipe.

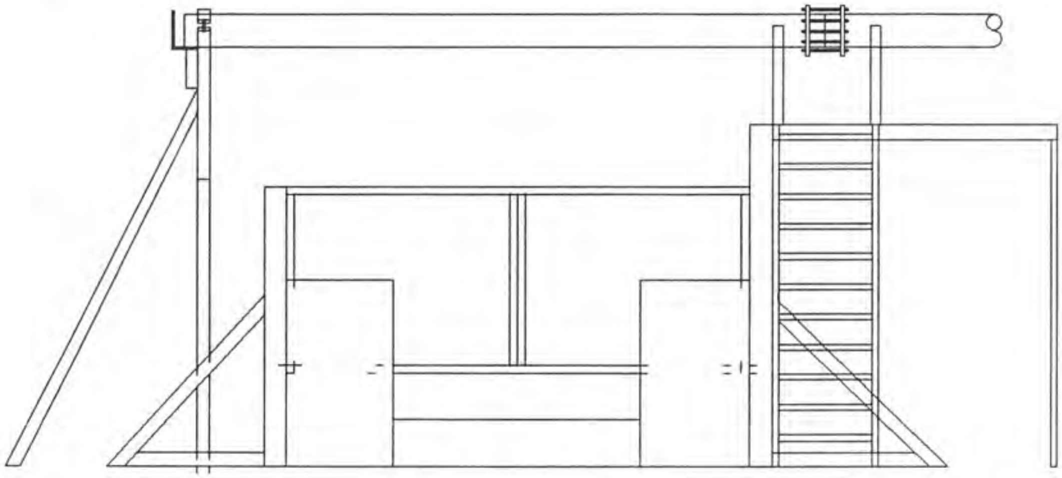

Figure 5. View from downstream of scale model facility. (Orifice not pictured)

Figure 6 shows a profile of the test basin. Water enters through an 8 inch delivery pipe via the manifold, shown in Figure 9, into the 14 inch pipe section. The flow direction through the manifold is towards the head wall of the test basin. The water flows over and under the manifold section, towards the orifice on the downstream facing side wall of the 14 inch pipe section.

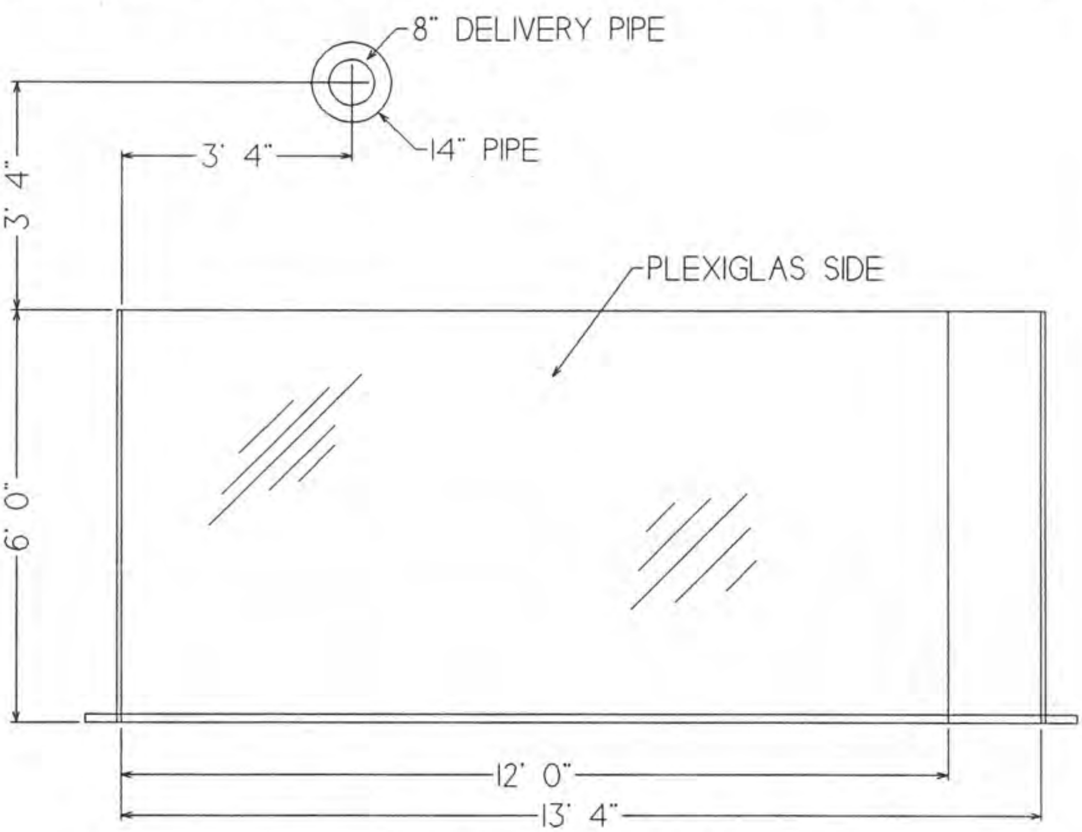

Figure 6. Profile of scale model facility.

Figure 7 details the orifice assembly in the 14 inch pipe section. The orifice width is 40 inches (1.02 m). The entire assembly and 8 inch delivery pipe may rotate about the 1" diameter pin in the end of the assembly. The Dresser coupling allows full rotation of the orifice assembly.

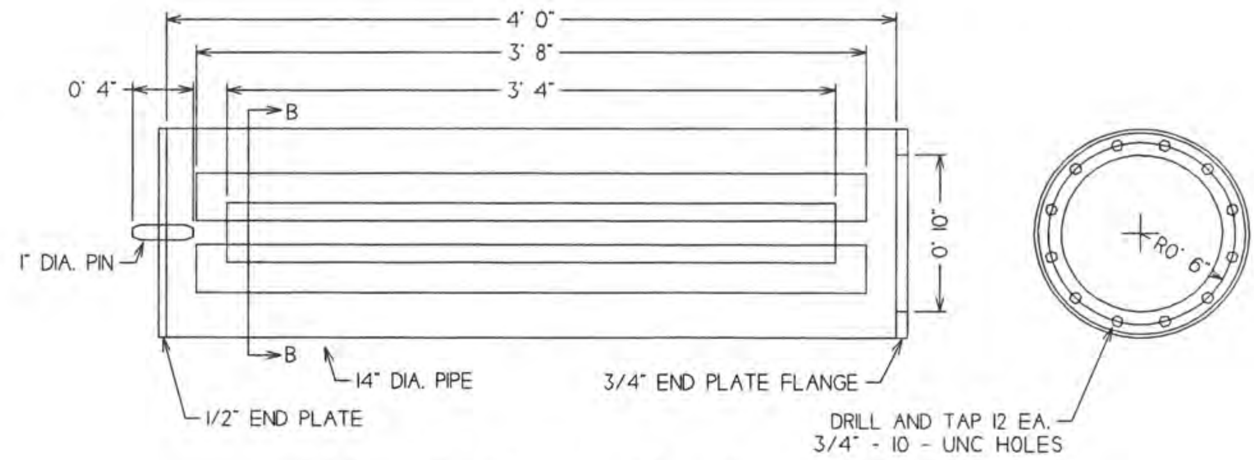

Figure 7. Orifice assembly, scale model orifice.

Figure 8 is a front view of the orifice in the side wall of the 14 inch pipe section. The orifice height is adjustable from 0.4 to 2.8 inches (10–71 cm). The orifice has standard weir knife edges.

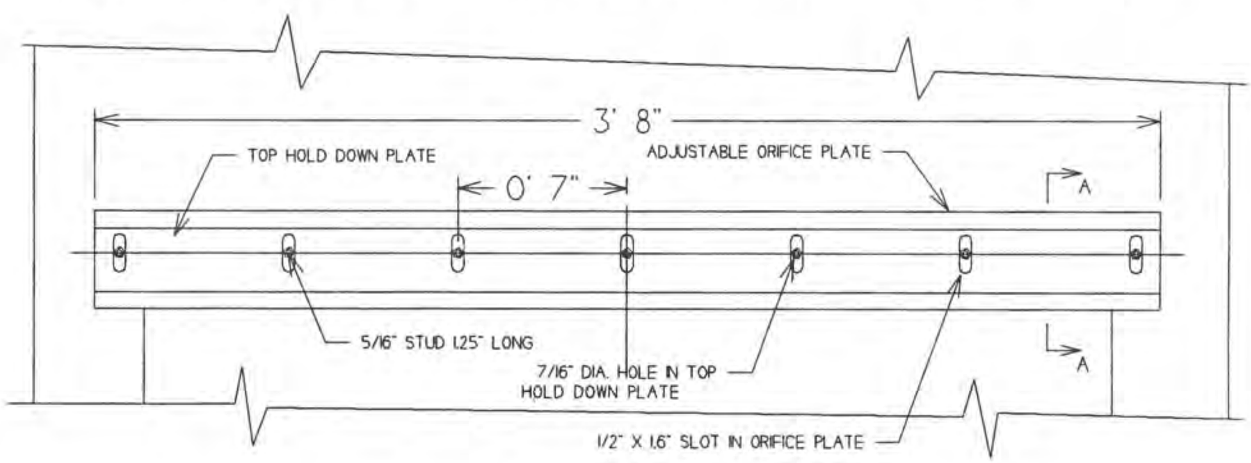

Figure 8. Orifice plate detail, front view.

Figure 9 shows the manifold pattern, developed flat. More than 18 variations of the manifold pattern were tested in the Orifice Design phase of the Dam Foundation Erosion study. The objective of that phase of design was a uniform, coherent jet, issuing perpendicular to the 8" delivery pipe and parallel to the axis of the test basin. Head taps installed at the quarter points of the annulus orifice assembly measure the head distribution in the exterior portion of the annulus, the driving head for the flow through the orifice. A constant head distribution causes a uniform flow distribution across the width of the orifice.

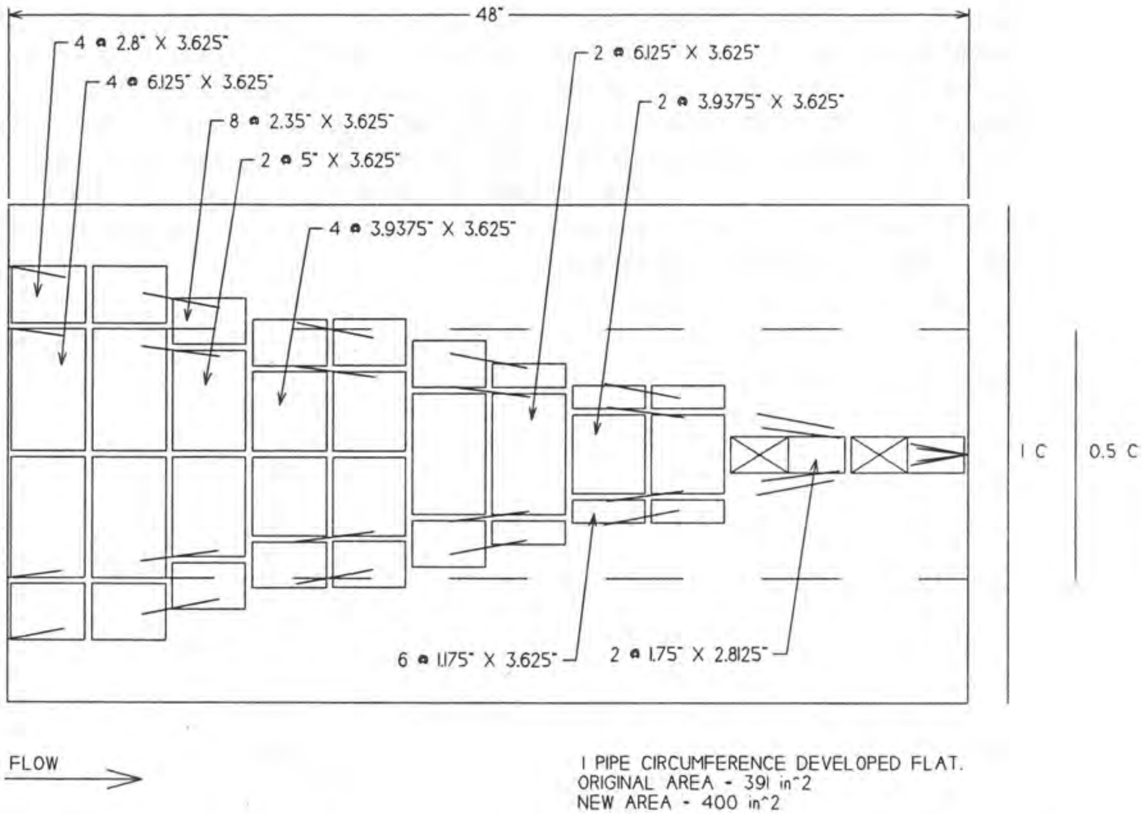

Figure 9. 8" Manifold outlet pattern, developed flat.

Figure 10 shows one half of the orifice section, Section A-A from Figure 8. A fastener holds the orifice plate and holding plate to the wall of the 14 inch pipe section.

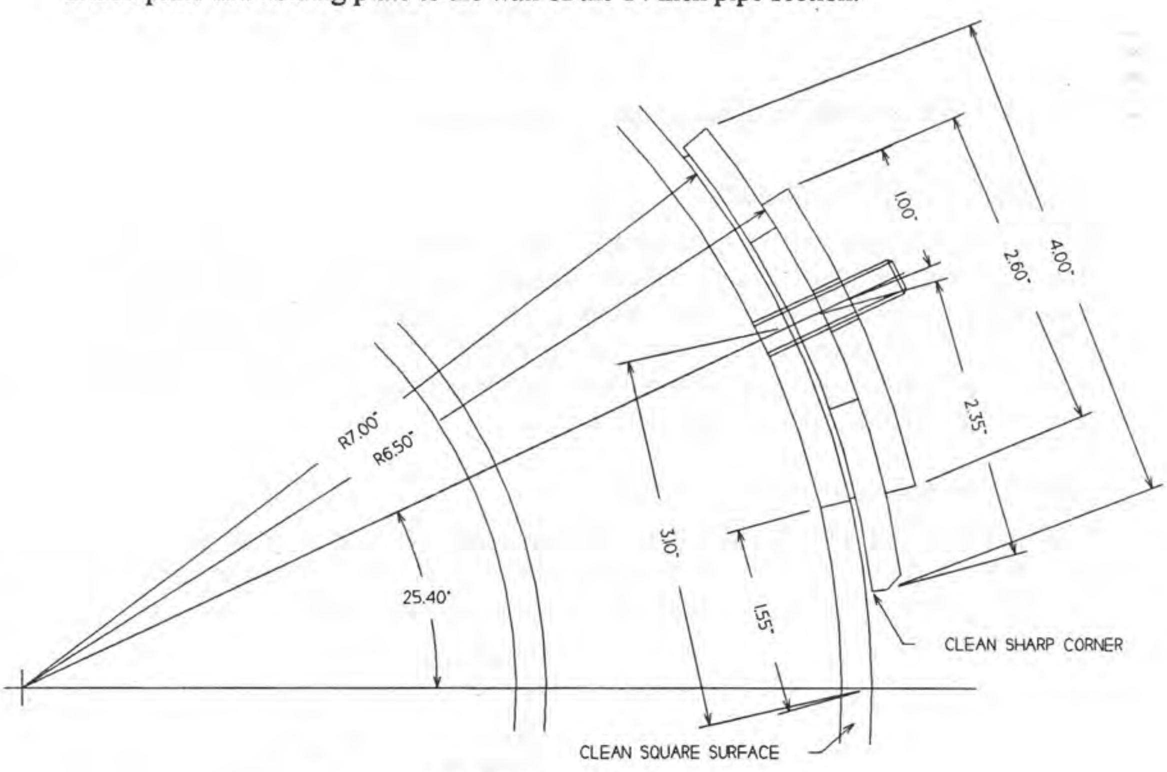

Figure 10. Section A-A, scale model orifice.

Figure 11 shows annulus Section B-B, from Figure 7. Flow enters the interior of the annulus section axially through the 8 inch delivery pipe. The flow passes through the manifold, perpendicular to the axis of the 8 inch delivery pipe. The manifold pattern causes an even distribution of flow and pressure in the exterior of the annulus section. Flow splits into two streams, one flowing over the manifold section and another flowing beneath the manifold section. The two streams meet just upstream of the orifice and exit through the orifice. The orifice assembly may rotate about the axis of the 8 inch delivery pipe so that flow may issue at any vertical angle with respect to the test basin.

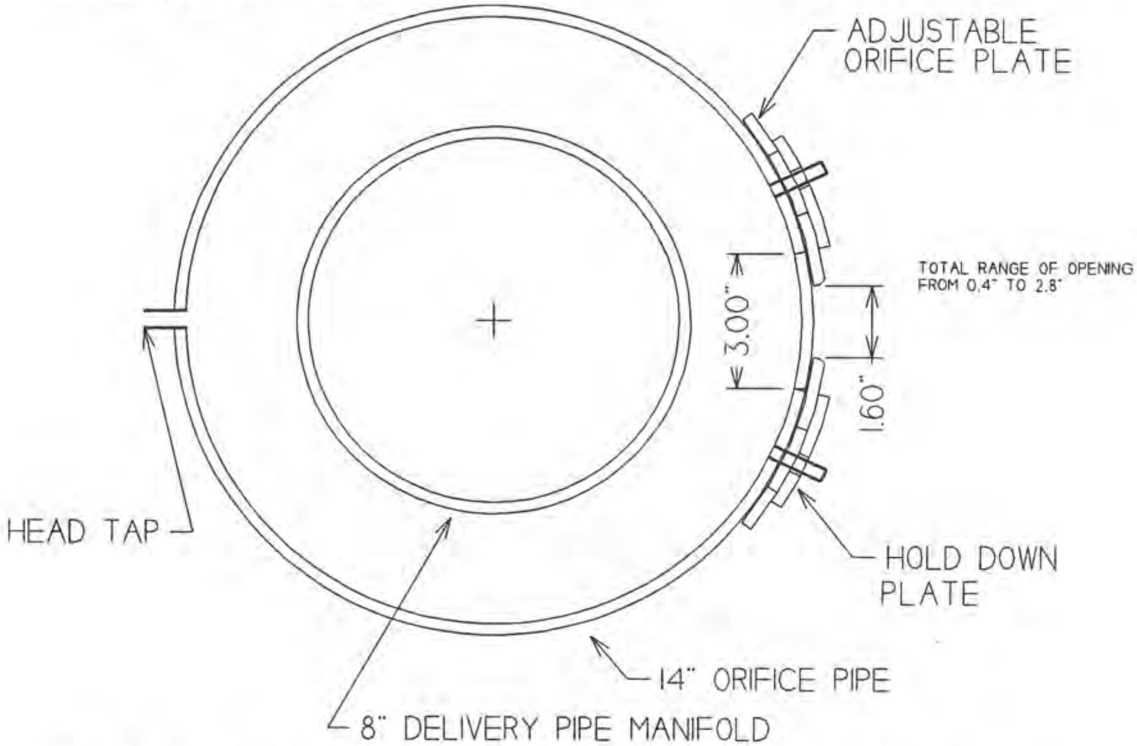

Figure 11. Section B-B, scale model orifice. Note head tap and flow directions.

Capacity & Dimensions

This section describes the 1:3 scale model. The scale factor, λ, is the ratio of the Pit 4 linear dimensions to the model dimensions. Froude scaling causes the unit discharge to scale proportional to the linear scale raised to the three-halves power. Discharge scales proportional to the linear scale raised to the five-halves power. The subscript "m" refers to the model properties, the subscript "p" refers to the prototype or Pit 4 Dam, the subscript "Q" refers to discharge, and the subscript "q" refers to unit discharge.

Model Dimensions and Capacity

The scale model has a false or sub-floor, one foot above the concrete floor of the laboratory. The space beneath the sub-floor facilitates instrumentation for velocity and pressure measurements. The scale, capacity, and dimensions, are listed in the following table.

Scale		**Orifice Dimensions:**	
λ:	3	Width:	3.33 ft
λ_q:	5.2	Height	0.133 ft
λ_Q:	15.6	Elevation:	9.33 ft (From concrete floor)
			2397.00 NGVD

Basin Dimensions:	**Maximum Discharge:**	
Length: 13.33 ft	Q_m	6.4 ft^3/s
Width: 10.00 ft	q_m	1.92 $ft^3/s/ft$
Depth: 6.00 ft (5.00 ft from concrete floor)	q_p	10.0 $ft^3/s/ft$

Orifice Details

The width of the orifice is 40 inches, or 3.33 feet. The height of the orifice for the Pit 4 simulation is 1.6 inches, or 0.133 feet. The area of the orifice is 64 in^2, or 0.444 ft^2. The maximum flow for the experiment is 6.42 ft^3/s. The orifice velocity therefore is 14.445 ft/s. Assuming a contraction coefficient of 0.6, the maximum velocity of the jet is 24.075 ft/s. This velocity corresponds to a head of 9.0 feet. Added to the elevation of the orifice above the tailwater surface, the total calculated head is roughly 13.67 feet, or 4.166 meters. The calculated total head compares favorably to the head tap readings taken during the test, see Table 22. The mean of the head tap readings added to the distance of the orifice above the tailwater results in a total head of 11.65 feet or 3.55 meters. The difference is probably due to the assumption regarding the contraction coefficient. Because of the turbulence of the flow in the diffuser, the orifice is probably not as efficient as a 0.6 contraction coefficient implies. The erosion formula comparisons will use the lower value of total head, 11.65 feet or 3.55 meters.

Pit 4 Dam Hydraulics

Pit 4 Dimensions

The primary source of information regarding Pit 4 dam is two PG&E reports. The first, Pit 4 Dam, Stability Under Flood Loading and Dam Break Analysis [1], contains two figures, Figure 1, and Figure 2-1, that specify elevations. The second, Pit 4 Dam, Geotechnical Investigation for Abutment Erosion Study During Extreme Flood Events [2], contains information on the borings and geotechnical background of Pit 4 dam investigations. The following notes refer to Figures 1 and 2-1 from Pit 4 Dam, Stability Under Flood Loading and Dam Break Analysis.

Notes

1. The simulation is for Section 1-1. This corresponds to the location of the first bore hole, B-1.
2. There are two datum: PG&E and NGVD. See Section 1.2, page 1, of Pit 4 Dam, Stability Under Flood Loading and Dam Break Analysis for an explanation. Note that some figures use the PG&E datum while calculations use the NGVD datum.
3. Crest elevation: 2438.50 (NGVD)
4. Ground surface elevation, B-1: 2381.00 (NGVD)
5. Some of the sample calculations in Appendix A of the Dam break analysis may be incorrect indicating a ground level of 2400.50 NGVD. From Figure 1 - the plan, profile, and cross-sectional drawing of the dam, the ground surface is 2400.50, but the local datum used is PG&E not NGVD (also note the crest elevation of the dam: 2458.00)

PMF Extrapolation

The purpose of this analysis is to extrapolate to the fraction of the PMF corresponding to 10 $ft^3/s/ft$. The flow capacity of the model is 1.92 $ft^3/s/ft$, for a prototype discharge of 10.0 $ft^3/s/ft$. Table 2, pg. 4, Pit 4 Dam, Stability Under Flood Loading and Dam Break Analysis [1] gives three values of unit discharge, q, corresponding to the 45%, 50%, and 65% levels of the PMF. Figure

12 shows these three values. Entering the Y-axis of Figure 12, the unit discharge, at 10 ft³/s/ft, the corresponding X-axis, or %PMF is roughly 22%. All erosion results in this experimental series corresponds to 22% of the PMF.

Table 4. From <u>Pit 4 Dam, Stability Under Flood Loading and Dam Break Analysis</u>, Table 2, pg. 4.

%PMF	q ft³/s/ft	Hydraulic Head ft	Failed Deck Slab ft	h ft	Crest Elevation (NGVD)	Reservoir Elevation (NGVD)	Velocity Head, h_v ft
45	75.5	42.4	4.0	8.4	2434.5	2442.9	1.25
50	152.0	43.4	8.0	13.4	2430.5	2443.9	2.00
65	273.0	46.8	11.0	19.8	2427.5	2447.3	2.95
22	*10.0*	*40.2*	*0.0*	*2.2*	*2438.5*	*2440.7*	*0.32*

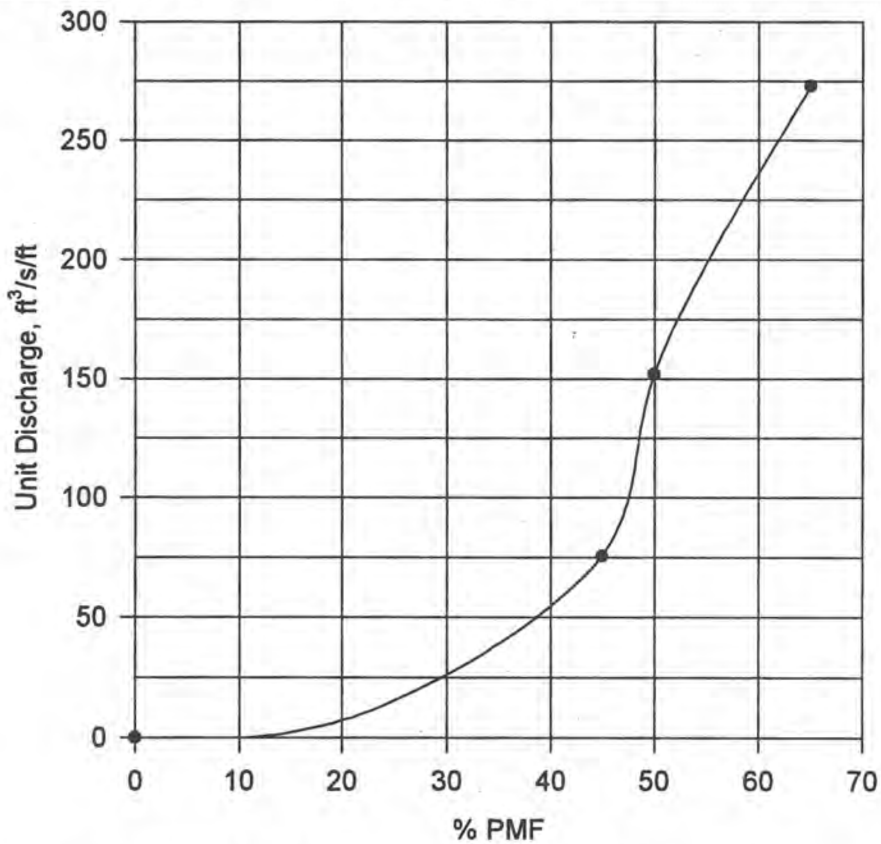

Figure 12. Unit discharge versus % PMF, Pit 4 dam, PG&E.

PMF - Discharge Relationship

This section shows the process the Study Team followed to first match the results of reported in the PG&E report [1] and second specify the values for the experiment and subsequent analysis. There are apparent discrepancies in the PG&E report [1] as the notes stipulate.

The calculations in this section are for comparison with the values reported in the PG&E report [1] and reproduced here in Table 5. The following equations are useful for determining agreement with the Table 5 values of q, h, h_v, crest elevation, computed reservoir elevation, and H'. The hydrostatic head, h, above the dam crest is given by back solving the relationship given in Chow [3], p. 80, for a broad-crested weir, in terms of head and unit discharge, q.

$$q = 3.09h^{1.5} \tag{1}$$

Table 5. From Pit 4 Dam, Stability Under Flood Loading and Dam-Break Analysis, Table 2, pg. 4.

%PMF	q ($ft^3/s/ft$)	h (ft)	h_v (ft)	Crest Elevation (NGVD)	Computed Rsvr Elev. (NGVD)	Table 4 Rsvr Elev. (NGVD)	H' (ft)
45	75.5	8.4	1.44	2434.5	2442.9*	2443.6	61.9
50	152.0	13.4	2.29	2430.5	2443.9*	2445.2	62.9
65	273.0	19.8	3.38	2427.5	2447.3*	2449.1	66.3
22	10.0	2.19	0.37	2438.5	2440.7		59.7

* **NOTE:** Reservoir elevations computed by adding h to the crest elevation **do not** match those reported in Table 4 of [1]

According to Chow [3], p.28, the expression for the velocity head, h_v, upstream of the dam crest is:

$$h_v = \alpha \frac{v^2}{2g}, \ \alpha = 1.15 \tag{2}$$

Mason and Veronese formulae require the total head, H', the difference between the reservoir elevation and ground elevation at the point of jet impact. The following calculations show the results of these equations applied to the 45% PMF discharge at Pit 4 dam.

Sample calculation for the 45% PMF

$$h = \left(\frac{q}{3.09}\right)^{\frac{1}{1.5}} = \left(\frac{75.5}{3.09}\right)^{\frac{1}{1.5}} = 8.42 ft$$

The reservoir elevation is equal to 2434.5 ft + 8.4 ft = 2442.9 ft. Note that the calculated value does not match the value given in Table 4 [1] of 2443.6 ft. The velocity head is 1.436 ft.

$$h_v = \alpha \frac{v^2}{2g} = \alpha \frac{1}{2g}\left(\frac{q}{h}\right)^2 = 1.15 \frac{1}{64.4}\left(\frac{75.5}{8.42}\right)^2 = 1.436 ft$$

The total static head, H', is 2442.9 ft -2381.0 ft =61.9 ft.

Trajectory Similitude

Appendix H - Trajectory Analysis describes the derivation of the kinematic equations of a free-trajectory jet of water. The results of the trajectory analysis in Appendix H - Trajectory Analysis show that the orifice angle should be roughly ten degrees from the vertical, achieving kinematic similitude with Pit 4 dam. The similitude is for flow equivalent to 22% of the PMF. The kinematic equation for the centerline of the nappe is:

$$\frac{y_c}{H} = A\left(\frac{x_c}{H}\right)^2 + B\left(\frac{x_c}{H}\right) + C + \tfrac{1}{2}D \tag{3}$$

Table 6 summarizes the values, from Chow [3], of the coefficients for the 22% of PMF flow. These values and equation 3 result in an expression for the trajectory of the jet over Pit 4 dam.

Table 6. Trajectory Coefficients.

%PMF	h	q	h_v	A	B	C	m	D
22%	2.19	10.00	0.37	-0.38	0.00	0.07	-0.04	0.57

Table 7 is a tabulation of the coordinates of the trajectory according to equation 3, and the tangent angle, θ. The angle θ is the angle from the vertical of the direction of the stream line along the centerline of the nappe. The tangent angle θ is the arctan of the central point derivative.

Trajectory Match Point: Vertical Coordinate

Table 8 presents the corresponding points of Pit 4 and the scale model. Figure 13 shows the centerline of the scaled free trajectory jet superimposed upon the side view of the scale model. The trajectory begins at the crest of Pit 4 dam and according to equation 3 follows the path shown in the figure. The internal and external features of the jet are not shown in the figure. The elevation of the orifice of the model is 2397.00 NGVD. The corresponding trajectory angle, θ, according to Table 7, is 10.42°, or roughly 10°. By setting the model orifice at this angle, there is kinematic similitude. The horizontal coordinate of the impact point of the jet is 18.25 ft, that is the jet impacts roughly 18.25 ft downstream of the crest of the Pit 4 dam.

Table 7. Scale Model Trajectory

x_c	y_c	θ
0.00	2439.28	84.73
1.00	2439.10	70.48
3.00	2437.70	43.51
5.00	2434.89	29.71
7.00	2430.69	22.19
8.00	2428.06	19.64
9.00	2425.08	17.61
10.00	2421.76	15.94
11.00	2418.08	14.56
12.00	2414.06	13.39
13.00	2409.68	12.40
14.00	2404.96	11.54
15.00	2399.89	10.79
15.50	2397.22	10.45
16.00	2394.46	10.13
17.00	2388.69	9.54
18.00	2382.57	9.09
18.25	2380.98	8.90

Table 8. Corresponding points between Pit 4 dam and the model.

Reference Point	Scale Model	Pit 4 (NGVD)
Concrete floor	0.00 ft	2369.0
Sub-floor	1.00 ft	2372.0
Material Elevation	4.00 ft	2381.0
Tail Water Elevation	4.667 ft	2383.0
Orifice Centerline	9.33 ft	2397.0

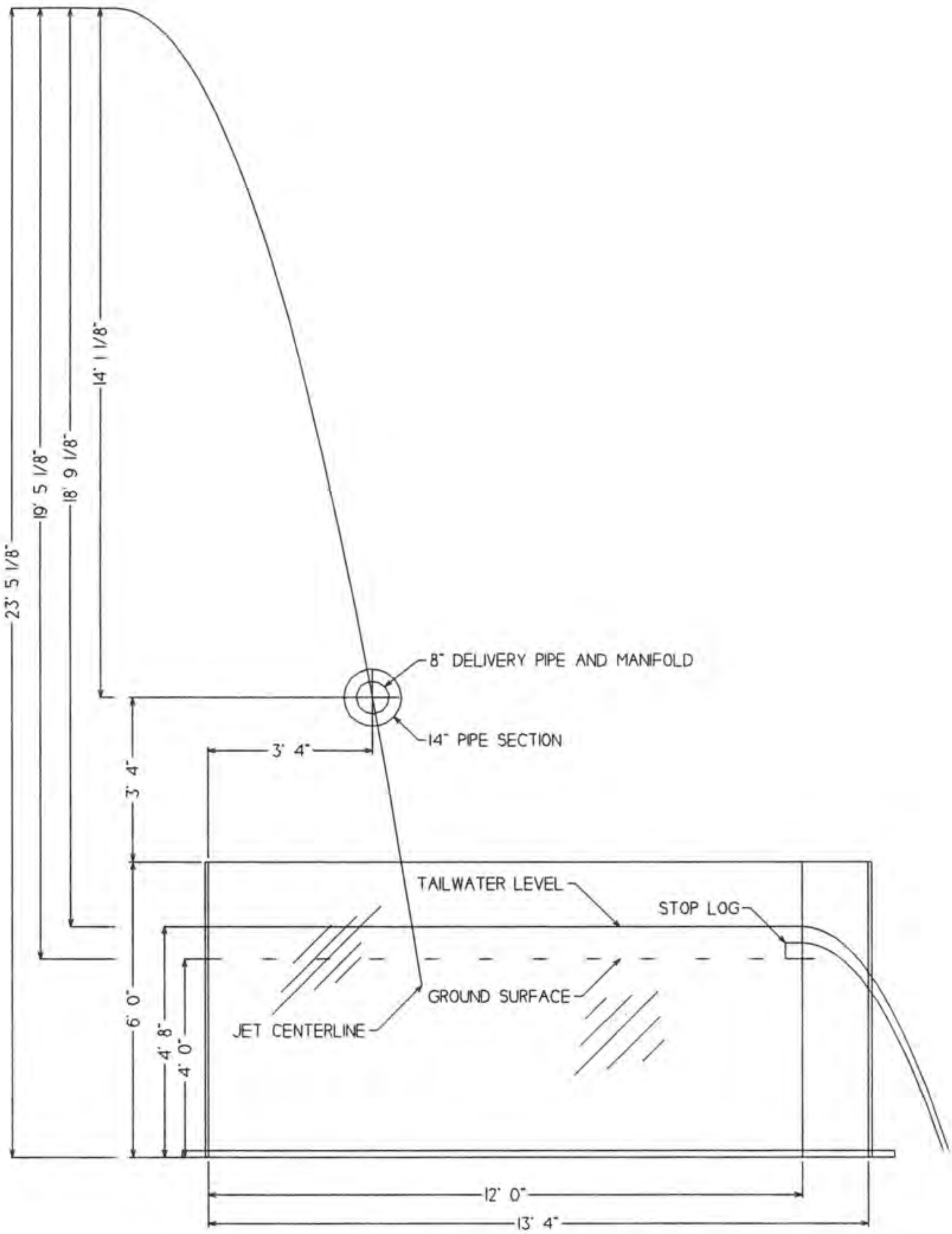

Figure 13. Side view of 1:3 scale model showing trajectory of Pit 4 jet.

Table 9. Experiment parameters with Pit 4 similitude.

Variable	Value
%PMF	22%
Prototype Unit Discharge	10.0 $ft^3/s/ft$
Model Unit Discharge	1.92 $ft^3/s/ft$
Tangent Angle, θ (Orifice angle from Vertical)	10.42°
Total Static Head	59.7 ft
Impact Distance from Dam Crest	18.25 ft

Results

Introduction

The results include a report of data from the experiment and a comparison of the maximum erosion depth with the depth predicted by the Veronese and Mason formulae. The primary data are the XYZ points describing the topography in the test basin at the end of each flow period. Appendix F - Three Dimensional Graphs of Erosion Hole contains graphical and tabular accounts of the data.

The model data compare with four formulas that predict the erosion in plunge pools. The first two are the Veronese and Modified Veronese formulas. The second two are the Mason model formula and the Mason prototype formula. The Veronese formulas are both for prototype application. This section will compare model data, scaled to prototype scale with both Veronese formulas. Model data, unscaled, will compare to the Mason model formula. Then the model data, scaled to prototype, will compare to the Mason prototype formula.

The data show that progressivity, defined as the time rate of change of the maximum erosion, is indistinguishable with the time scale of the experiment. The maximum erosion occurred within the first flow period, and did not significantly change over the remainder of the flow periods. The maximum erosion occurred within twelve percent of the total test time.

Erosion Prediction

Equation 4 is the Veronese [5] equation. Reclamation includes the Veronese formula in Design of Small Dams [6] in English units. The version here is for metric units. The expression yields an estimate of erosion measured from the tailwater surface to the bottom of the scour hole.

$$Y_s = 1.90 H^{0.225} q^{0.54} \tag{4}$$

Y_s = depth of erosion below tailwater (meters)
H = elevation difference between reservoir and tailwater (meters)
q = unit discharge ($m^3/s/m$)

The Veronese equation neglects material properties. Yildiz [7] presents a modified version of the Veronese equation, including the angle, θ, of incidence from the horizontal of the jet.

$$Y_s = 1.90 H^{0.225} q^{0.54} \sin\theta \tag{5}$$

Equation 6 is the Mason [4] equation, based on model data. Note that the Mason model equation is dimensionally homogeneous and includes the median grain size of the foundation material.

$$Y_s = \frac{3.27 q^{0.60} H^{0.05} h^{0.15}}{g^{0.30} d^{0.10}} \tag{6}$$

h = tailwater depth above original ground surface (meters)
d = median grain size of foundation material, d_{50} (meters)
g = acceleration of gravity (m/s^2)

The Mason [4] equation for prototype data is, assuming d is constant for prototypes, and using metric units for the coefficients:

$$D = K \frac{q^x H^y h^w}{g^v d^z} \tag{7}$$

$$K = 6.42 - 3.10 H^{0.10},\ x = 0.6 - \frac{H}{300},\ y = 0.15 + \frac{H}{200}$$
$$v = 0.30,\ w = 0.15, z = 0.10,\ d = 0.25m$$

The Mason formulas do include a material factor, d. However, it is unlikely that this factor adequately represents the wide variety of materials and material properties found in foundation materials. The reasons for endorsing the Mason formulas are the thoroughness of the research, the comprehensive nature of the data, including scale model studies and prototype case studies, and the dimensional analysis and dimensional homogeneity of the formulas.

Pit 4 Erosion Prediction: Veronese and Mason Formulae

Table 10 shows the value of the properties for the Veronese and Mason formulae. Units are metric because the formulae are in metric form. The difference between the head, H, for the model scaled to prototype and the prototype is due to the capacity limitation of the 1:3 scale model facility. The model scaled to prototype head is the sum of the mean of the head tap readings (Table 22) and the distance between the orifice and the tailwater. The prototype head is the sum of the crest elevation plus the depth of the jet overtopping the dam minus the tailwater elevation of Pit 4 dam (Table 5).

Table 10. Variables for erosion formula comparison.

	Model	*Model Scaled to Prototype*	*Pit 4*
H	3.55 m	10.65 m	18.20 m
q	0.18 m^3/s/m	0.93 m^3/s/m	0.93 m^3/s/m
h	0.20 m	0.61 m	3.41 m
d_{50}	4.5E-4 m	4.3E-4 m	8.8E-4 m
g	9.81 m/s^2	9.81 m/s^2	9.81 m/s^2

The tailwater depth differs significantly between the model and the prototype. Calculations from the PG&E report [1] indicate that the tailwater for a flow of 22% of the PMF is roughly 11.2 feet, or elevation 2392.2 NGVD. The tailwater simulated in the model was much less than this due to limitations of the model facility. However, the limitation in this case results in a conservative estimate of the erosion depth because increasing tailwater depth reduces the depth of erosion.

Table 11 presents the exponents for the Mason prototype formula. Each is a function of the prototype dimensions, scaled from the model or directly from the PG&E report [1].

Table 11. Exponents and coefficients for erosion formula comparison.

	Model Scaled to Prototype	*Pit 4*
K	2.49	2.28
v	0.30	0.30
w	0.15	0.15
x	0.565	0.54
y	0.20	0.24
z	0.10	0.10

Table 12 shows the results of applying the Veronese and Mason formulae to the Pit 4 simulation and to Pit 4 Dam. Where a formula is not applicable, the symbol N/A appears. The results are in metric units while Table 13 shows the same results in English units.

Table 12. Formula estimates of erosion below tailwater and model results. (Metric)

	Model Eqtn.	*Model Results*	*Model Scaled to Prototype Eqtn.*	*Results Scaled to Prototype*	*Pit 4 Eqtn.*
Veronese	1.00 m	0.77 m	3.11 m	2.36 m	3.51 m
Modified Veronese	0.99 m	0.77 m	3.06 m	2.36 m	3.46 m
Mason Model	1.07 m	0.77 m	N/A	N/A	N/A
Mason Prototype	N/A	N/A	2.06 m	2.36 m	3.06 m

Table 13. Formula estimates of erosion below tailwater and model results. (English)

	Model Eqtn.	*Model Results*	*Model Scaled to Prototype Eqtn.*	*Results Scaled to Prototype*	*Pit 4 Eqtn.*
Veronese	3.28 ft	2.58 ft	10.2 ft	7.74 ft	11.5 ft
Modified Veronese	3.25 ft	2.58 ft	10.0 ft	7.74 ft	11.4 ft
Mason Model	3.51 ft	2.58 ft	N/A	N/A	N/A
Mason Prototype	N/A	N/A	6.76 ft	7.74 ft	10.0 ft

Erosion Estimates for Various Fractions of the PMF

This section presents estimates of erosion for Pit 4 dam based upon the Veronese (Equation 4), Modified Veronese (Equation 5), and Mason Prototype (Equation 6) formulae. The following tables present the data that form the basis for the calculations. Table 14 shows the estimates from the three equations for various fractions of the PMF flow in English units while Table 15 shows the same results in metric units.

Table 14. Formula estimates of erosion elevation for various fractions of PMF. (English)

%PMF	*Veronese NGVD (ft)*	$Veronese_{Modified}$ *NGVD (ft)*	$Mason_{Prototype}$ *NGVD (ft)*
22	2382.26	2382.43	2383.65
37	2372.24	2372.61	2374.10
41	2369.90	2370.33	2371.61
45	2366.80	2367.29	2368.37
50	2353.38	2354.10	2354.73
65	2339.57	2340.55	2339.24

Table 15. Formula estimates of erosion elevation for various fractions of PMF. (Metric)

%PMF	*Veronese NGVD (m)*	*$Veronese_{Modified}$ NGVD (m)*	*$Mason_{Prototype}$ NGVD (m)*
22	726.11	726.16	726.54
37	723.06	723.17	723.63
41	722.35	722.48	722.87
45	721.40	721.55	721.88
50	717.31	717.53	717.72
65	713.10	713.40	713.00

Table 16 shows the reservoir, tailwater, and ground surface elevations for the various fractions of the PMF in English units while Table 17 shows the same data in metric units. All elevations are NGVD, and some are interpolated from data from Table 2, Page 4, Pit 4 Dam Stability Under Flood Loading and Dam-Break Analysis [1].

Table 16. Reservoir, Tailwater, Ground elevation for various fractions of PMF. (English)

%PMF	*Reservoir Elev. NGVD (ft)*	*Tailwater Elev. NGVD (ft)*	*Ground Elev. NGVD (ft)*
22	2440.90	2393.20	2381.00
37	2442.80	2396.70	2381.00
41	2443.50	2398.00	2381.00
45	2444.20	2399.00	2381.00
50	2445.20	2400.30	2381.00
65	2449.10	2404.00	2381.00

Table 17. Reservoir, Tailwater, Ground elevation for various fractions of PMF. (Metric)

%PMF	*Reservoir Elev. NGVD (m)*	*Tailwater Elev. NGVD (m)*	*Ground Elev. NGVD (m)*
22	743.98632	729.44736	725.7288
37	744.56544	730.51416	725.7288
41	744.7788	730.9104	725.7288
45	744.99216	731.2152	725.7288
50	745.29696	731.61144	725.7288
65	746.48568	732.7392	725.7288

Table 18 shows the hydraulic, material, and kinematic data for the various fractions of the PMF. The total head is H, the tailwater depth is h, the unit discharge is q, the median grain size is d_{50}, and the acceleration of gravity is g.

Table 18. Hydraulic, material, and kinematic data for various fractions of the PMF.

%PMF	H *(m)*	h *(m)*	q *($m^3/s/m$)*	d_{50} *(m)*	g *(m/s^2)*
22	14.54	3.72	0.93	425.0E-6	9.81
37	14.05	4.79	4.18	425.0E-6	9.81
41	13.87	5.18	5.43	425.0E-6	9.81
45	13.78	5.49	7.01	425.0E-6	9.81
50	13.69	5.88	14.12	425.0E-6	9.81
65	13.75	7.01	25.36	425.0E-6	9.81

Table 19 shows the coefficients for the Mason prototype formula for the various fractions of the PMF. The angle θ is the jet impingement angle, in radians, from the horizontal.

Table 19. Formula coefficients for various fractions of the PMF.

%PMF	K	v	w	x	y	z	d (m)	θ (rad)
22	2.37	0.30	0.15	0.55	0.22	0.10	0.25	1.40
37	2.38	0.30	0.15	0.55	0.22	0.10	0.25	1.40
41	2.39	0.30	0.15	0.55	0.22	0.10	0.25	1.40
45	2.39	0.30	0.15	0.55	0.22	0.10	0.25	1.40
50	2.39	0.30	0.15	0.55	0.22	0.10	0.25	1.40
65	2.39	0.30	0.15	0.55	0.22	0.10	0.25	1.40

Figure 14 shows the calculations of erosion elevation by the Veronese and Mason prototype formulae. The single model data point shows how the model data relates to the estimates of the formulae. The model yielded greater erosion than the estimates because the model had lower tailwater than proscribed. Therefore, the model, as operated, yields conservative estimates of erosion. All of the erosion estimation formulae calculate the erosion from the tailwater elevation. Figure 14 shows that below roughly 25% of the PMF, their is no erosion of the native material due to the dampening effect of the tailwater. The "knee" in the plot of the Mason prototype and Veronese formulae is due to the dramatic increase in unit discharge beginning at roughly 45% of the PMF. Figure 12 shows the unit discharge as a function of fractional values of the Pit 4 PMF.

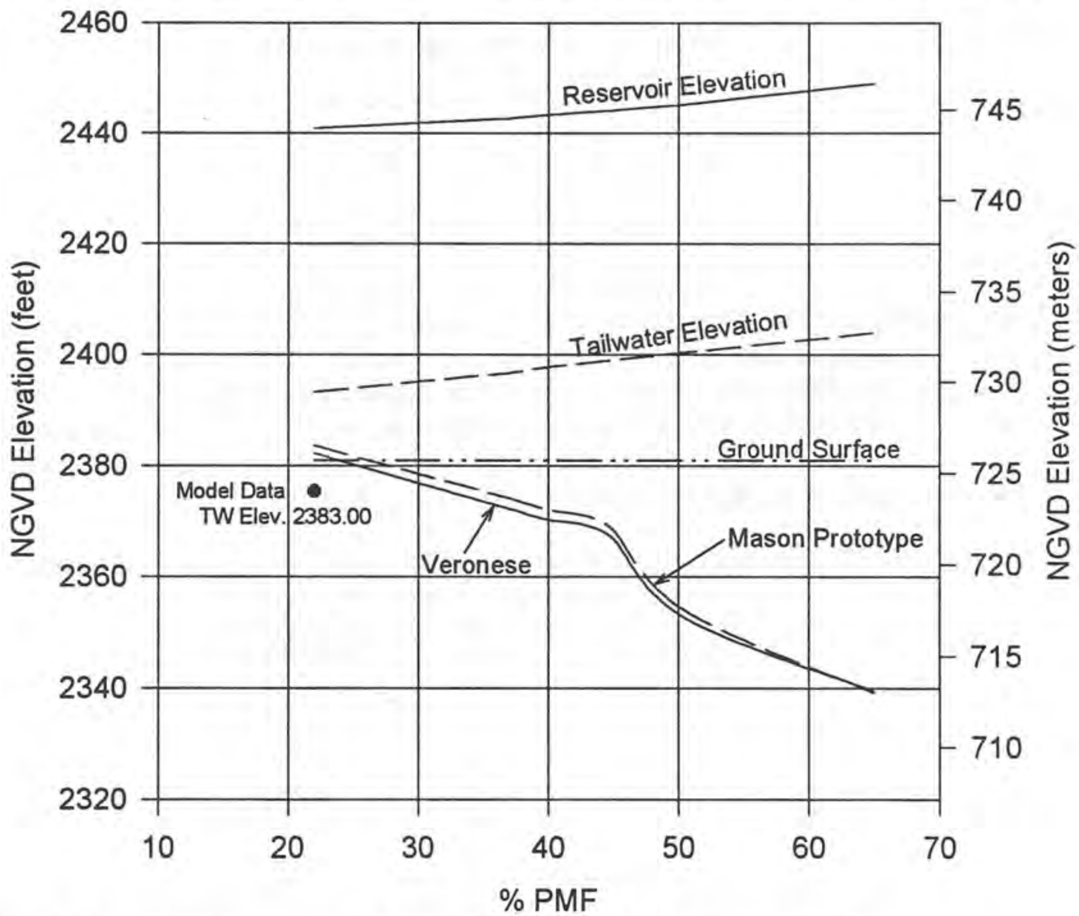

Figure 14. Erosion estimates for various fractions of the Pit 4 PMF flow.

Results

The Pit 4 material record experiment consists of 4 flow periods. After each flow period, the model was shut down and the surface of the model material contoured. The following total elapsed times (total elapsed time) comprise the four periods: 15 minutes, 30 minutes, 1 hour, and 2 hours. Time scales according to the one-half power of the linear scale, or by a factor of 1.732. The elapsed times correspond to prototype times of 26 minutes, 52 minutes, 104 minutes, and 208 minutes.

The initial surface consisted of simulated Pit 4 material placed to a (settled) depth of roughly 3 feet above the sub floor (Y≅4). This elevation corresponds to the ground elevation near boring no. 1, as described in [1] Each progressive flow period in the Pit 4 material record experiment series started at the condition the model was left at in the previous flow period.

During each flow period, the tailwater depth was set by placing stop logs such that one stop log was over the initial Pit 4 material record experiment surface, i.e.: the stop logs were placed such that the top surface was at Y=4.333 ft for <u>each</u> flow period. This elevation corresponds to an elevation one foot greater than the material surface elevation. The stop logs acted as a weir for the flow exiting the test basin. The depth of flow over the weir was less than 0.35 feet. Therefore, the tailwater elevation was roughly 2383.00 NGVD for all flow periods. Table 20 shows the discharges for each flow period.

Table 20. Discharge during each flow period.

Flow period (Elapsed time)	*Discharge* (ft^3/s)
15 minutes	*6.382*
30 minutes	*6.400*
1 hour	*6.420*
2 hours	*6.363*

The maximum depth of erosion for each flow period follows in Table 21. Note that the depth assumes the initial surface was a plane at Y = 4.07 feet. The mean elevation of the material continually declines, indicating net transport of material out of the test basin. The maximum erosion is the difference between the mean elevation at time 0, 4.07 feet, and the maximum depth of scour at a single location in the test basin after each of the flow periods. Add the tailwater depth (~0.60 ft) to the values reported in Table 21 to calculate the total erosion, Y_s.

Table 21. Summary results of erosion of Pit 4 material record experiment.

Elapsed Time Model (minutes)	Mean Elevation Model (feet)	Max. Erosion Model Scale (feet)
0	4.07	0.21*
15	3.65	1.98
30	3.64	1.91
60	3.58	1.78
120	3.39	1.92

*Note: This value reflects the difference between the minimum and maximum elevations of the original surface.

An even pressure distribution in the orifice chamber causes the jet to be uniform. Three head taps were installed through the upstream wall of the 14 inch pipe section detecting the head downstream of the manifold, and upstream of the orifice. Figure 15 is a schematic of the head taps, showing the left (L), middle (M), and right (R) taps while Figure 11 shows the taps in relation to the orifice. The measured static head at three points in the diffuser follow in Table 22. The final column of

Table 22 is the ratio of the root of the maximum head differential along the manifold to the root of the maximum head. The values are nearly constant at roughly 39%. This ratio is an indication of the variability of the flow through the orifice. At most, the unit discharge may vary up to roughly 39% across the length of the orifice. However, because of the placement of the head taps, at the rear of the orifice assembly, further flow distribution occurring as the flow turns through 180° is not reflected in this parameter. Tests on the orifice and the flow distribution are in progress.

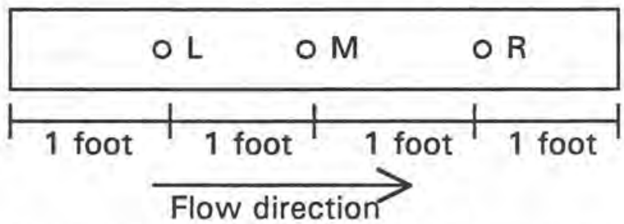

Figure 15. Head tap configuration. Taps are opposite the orifice.

Table 22. Head tap readings.

Flow Period (Elapsed Time)	h_L (ft. H_2O)	h_M (ft. H_2O)	h_R (ft. H_2O)	$\frac{\sqrt{\Delta h}}{\sqrt{h}}$
15 minutes	7.008	7.255	8.205	38%
30 minutes	6.308	6.605	7.455	39%
60 minutes	6.388	6.715	7.555	39%
120 minutes	6.338	6.655	7.405	38%

Topographic Results

The following figures, Figure 16 through Figure 20, present the topography of the Pit 4 scaled material at elapsed times of 0, 15, 30, 60, and 120 minutes. Features of note include the erosion hole, the mound downstream of the erosion hole, and the progression of the hole in the upstream and downstream directions. The hole appears to be symmetrical with respect to the centerline of the orifice and test basin. In each figure, flow direction is from left to right. The orifice occupies vertical coordinates 3.33 feet to 6.67 feet, and horizontal coordinate 3.33 feet. The point of jet impact, with the original material surface, is at coordinate 4.26 feet.

The topographic diagrams are the product of the XYZ triplets tabulated in Appendix F - Three Dimensional Graphs of Erosion Hole. The computer program Surfer™ compiled and plotted the diagrams. The contour interval is 0.2 feet (model scale). The extents of the test basin are 10 feet by 15 feet. The initial material surface elevation was 4.07 feet. Flow exited over 4x4 inch stop logs, spanning the entire width of the test basin, or 10 feet. The mounding extended to the stop logs in the latter flow periods.

$q = Q = ?$ Table 20 6.4 cfs

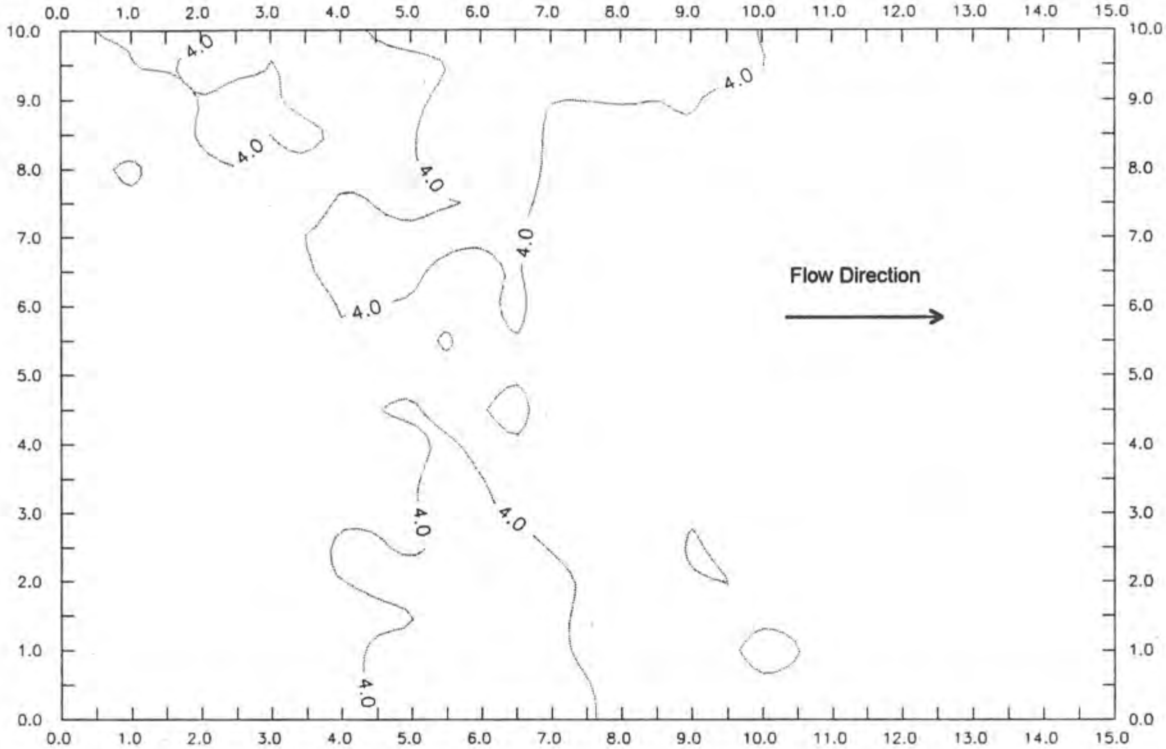

Figure 16. Erosion topography at time t=0. Horizontal and Vertical scales are feet.

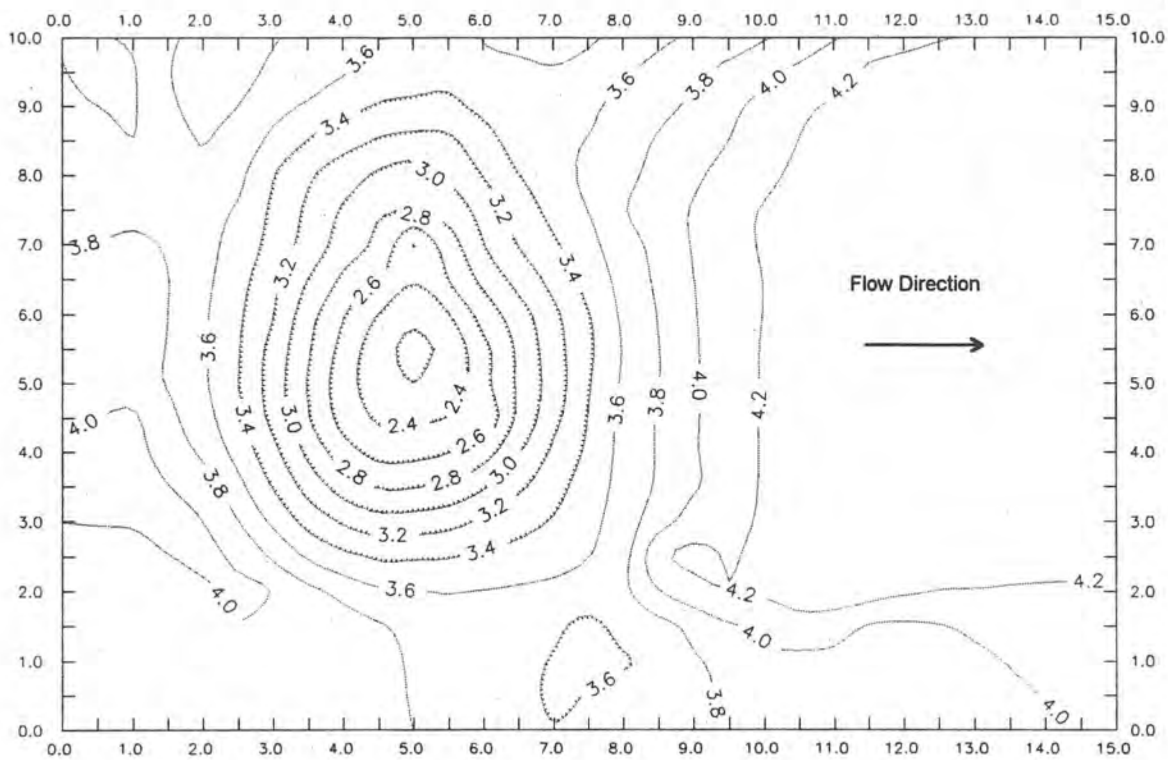

Figure 17. Erosion topography at t=15 minutes. Horizontal and Vertical scales are feet.

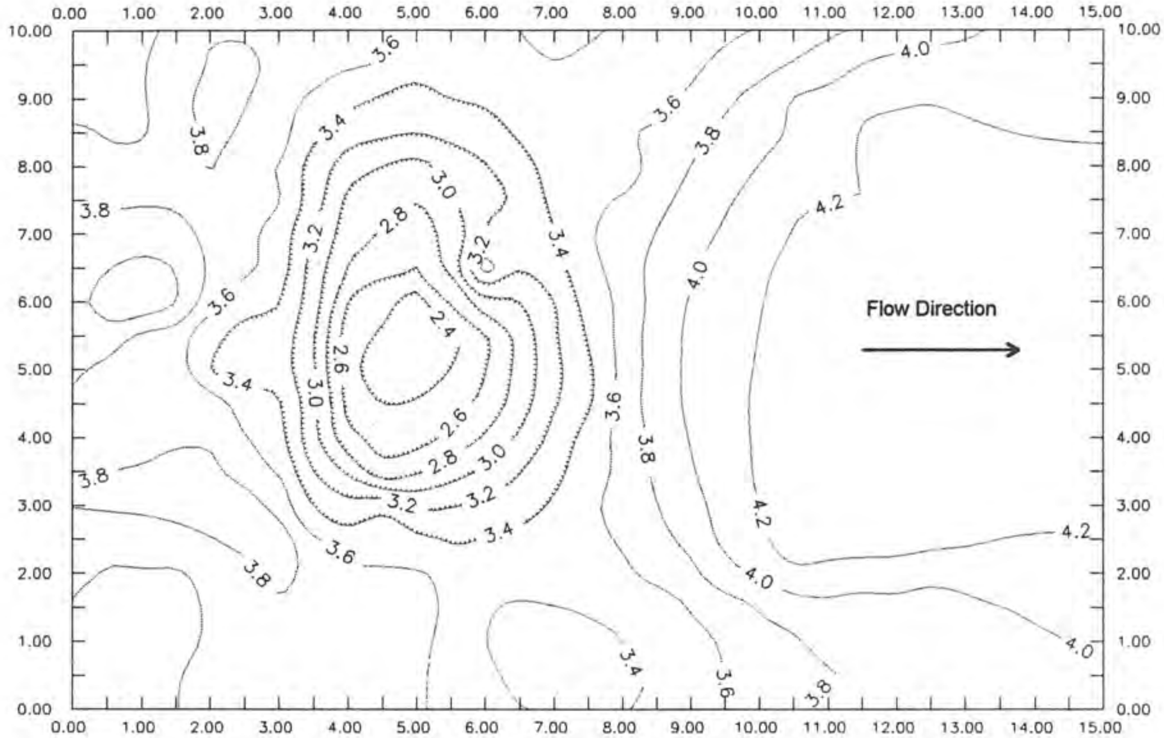

Figure 18. Erosion topography at t=30 minutes. Horizontal and Vertical scales are feet.

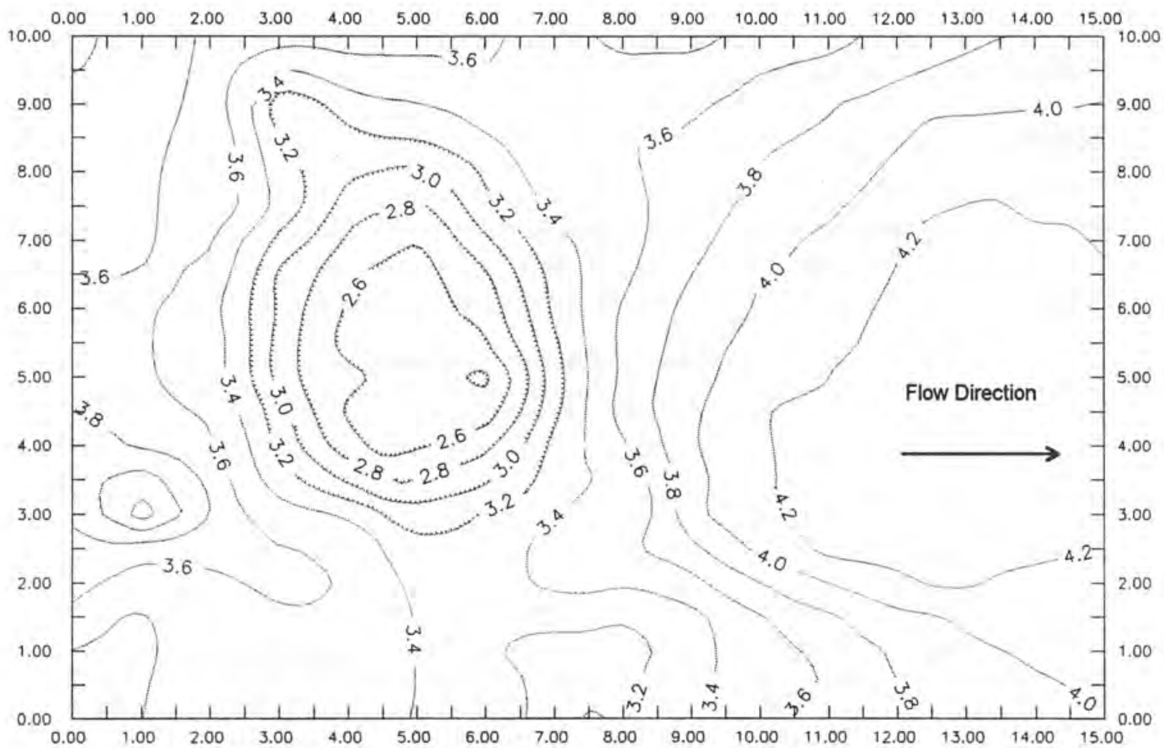

Figure 19. Erosion topography at t=60 minutes. Horizontal and Vertical scales are feet.

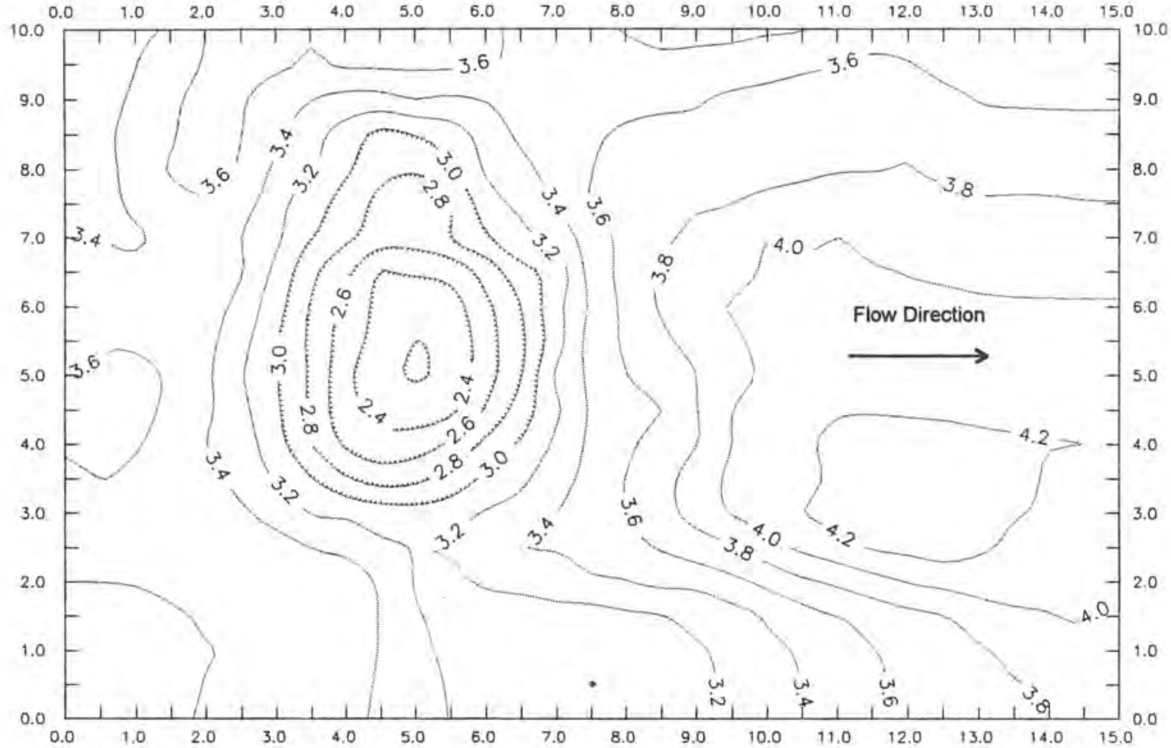

Figure 20. Erosion topography at t=120 minutes. Horizontal and Vertical scales are feet.

Analysis

Table 23and Table 24 present the results of the Veronese and Mason formulae applied to the model, prototype, and Pit 4 data.

Model

The Veronese, modified Veronese, and Mason model estimates are similar, roughly 3.28 feet (1 meter). The equation estimates result from use of the lesser of two estimates of model head, 11.65 ft (3.55 meters). Therefore, the equation estimates of erosion are the least possible reasonable estimates. The model equations overestimate the erosion for model data by roughly 26% to 36%.

Table 23. Formula estimates of erosion and model data results. (Metric)

	Model Eqtn.	*Model Results*	*Model Scaled to Prototype Eqtn.*	*Results Scaled to Prototype*	*Pit 4 Eqtn.*
Veronese	1.00 m	0.77 m	3.11 m	2.36 m	3.51 m
Modified Veronese	0.99 m	0.77 m	3.06 m	2.36 m	3.46 m
Mason Model	1.07 m	0.77 m	N/A	N/A	N/A

Table 24. Formula estimates of erosion and model data results. (English)

	Model Eqtn.	*Model Results*	*Model Scaled to Prototype Eqtn.*	*Results Scaled to Prototype*	*Pit 4 Eqtn.*
Veronese	3.28 ft	2.58 ft	10.2 ft	7.74 ft	11.5 ft
Modified Veronese	3.25 ft	2.58 ft	10.0 ft	7.74 ft	11.4 ft
Mason Model	3.51 ft	2.58 ft	N/A	N/A	N/A

Prototype

Analysis of the prototype data includes two comparisons, the first, model data scaled to prototype, and second, prototype data, compared to model results. Scaling the model data from Table 10 results in erosion estimates of 10.2 ft, 10.0 ft, and 6.76 ft from the Veronese, modified Veronese, and Mason prototype formulas respectively. This compares with the scaled model results of 7.74 feet. The prototype Veronese and modified Veronese erosion prediction formulas overestimate the scaled erosion results from the simulation by 32% and 29%. The Mason prototype formula underestimates the scaled erosion results from the simulation by 13%.

The Mason prototype equation using model data scaled to prototype scale produces an estimate that most nearly matches the simulation results, underestimating by roughly 13%. The reason for the match is the value of head used in the calculation. The model head is 3.55 meters, scaled to 10.65 meters (35 feet) while the prototype head is 18.2 meters (59.7 feet). The smaller head for the model data results in a smaller estimate of erosion, matching the simulation results. Therefore, scaling model data and using the Mason prototype equation results in an erosion estimate that is in good agreement with the scaled model results. Using model data scaled to prototype scale and either of the Veronese equations or the Mason model equation results in erosion estimates that exceed the model results by roughly 30%.

Progressivity

Table 21 shows the progression of erosion during the Pit 4 material record experiment. The total elapsed time of the simulation is 120 minutes. The mean bed elevation before the experiment was 4.07 feet. At the end of the experiment the mean elevation was 3.39 feet, a mean reduction of 0.68 feet. The reduction in mean elevation corresponds to removing a volume of 102.0 cubic feet of material from the test basin during the experiment.

The initial material surface had a deviation (Maximum elevation minus minimum elevation) of 0.21 feet while the mean elevation was 4.07 feet (2381.21 NGVD). At the end of the first flow period, 15 minutes elapsed time, the maximum erosion, tailwater elevation minus maximum scour elevation, was 2.58 feet, scaled to prototype scale 7.74 feet. The maximum erosion was 7.53 feet, 7.14 feet, and 7.56 feet at the end of the second, third and fourth flow periods respectively. After the third flow period, prior to bed contouring, an erroneous flow event occurred for less than 30 seconds, possibly resulting in the lower than average maximum erosion. The erroneous flow occurred before a laboratory valve was finished closing, resulting in some flow washing the sides of the scour hole into the bottom of the hole.

The mean maximum erosion is 1.90 feet, model scale, 5.69 feet, prototype scale. The single maximum erosion was recorded at the end of the first flow period, 15 minutes elapsed time. Thus the maximum erosion occurred within the first 12% of the total test time. The time to maximum erosion is undetermined, but progressivity in the simulation is practically nonexistent. The maximum scour does not substantially change with respect to time. Figure 21 shows plots of model and prototype time versus mean elevation, scale model maximum erosion, and prototype maximum erosion.

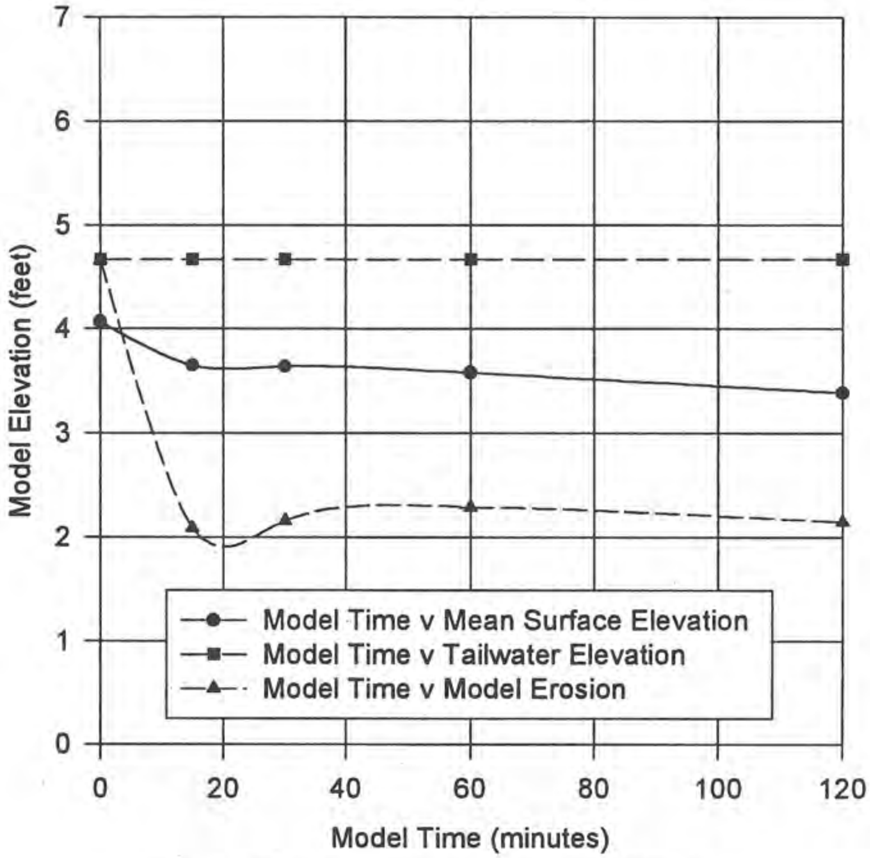

Figure 21. Progressive erosion, model scale.

Conclusions

- All erosion results in this experimental series correspond to flow that is roughly 22% of the PMF of Pit 4 dam. This is a flow of 10.0 $ft^3/s/ft$ prototype scale or 1.92 $ft^3/s/ft$ model scale.
- The model equations overestimate the erosion for model data by roughly 26% to 36%.
- The prototype Veronese and modified Veronese erosion prediction formulas overestimate the scaled erosion results from the simulation by 32% and 29%. The Mason prototype formula underestimates the scaled erosion results from the simulation by 13%.
- The maximum erosion occurred within the first 12% of the total test time. The time to maximum erosion is undetermined, but progressivity in the simulation is practically nonexistent. The maximum erosion does not substantially change with respect to time.
- Operation of the 1:3 scale model facility with non-cohesive material indicates a high potential for successful simulation of other earth materials. The test basin dimensions facilitate recirculation without constricting the return flow, and the depth of the basin appears adequate.

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[7] Yildiz, D., Üzücek, E., "Prediction of Scour Depth From Free Falling Flip Bucket Jets", *Intl. Water Power and Dam Construction*, November, 1994.

[8] Wittler, R.J., et. al., "*Dam Foundation Erosion: Pre-Test Report*", Release Draft, PAP 643, US Bureau of Reclamation Water Resources Research Laboratory, October 1993.

[9] Wittler, R.J., et. al., "*Dam Foundation Erosion Survey of Literature*", Release Draft, PAP 628, US Bureau of Reclamation Water Resources Research Laboratory, August, 1993.

Appendices

Appendix A - Pit 4 Material Analysis

Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)
Sample A

Project # :	531762	* Note: D.S. = Dry Soil, W.S. = Wet Soil, & Cont. = Container.
Sample Location :	pit 4	
Performed by :	T.L.	
Date :	6 / 28 / 94	

Weight of Cont.	683.9 g
Total Sample Weight (W.S. + Cont.)	2411.9 g
Weight of Dry Soil	1728 g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of Seive [g]	Weight of D.S. + Seive [g]	Weight of D.S. [g]	Accumulate Weight Ret. [g]	% Finer
5/8 "	16.000	550.0	864.9	314.9	314.9	81.78
10	2.000	480.0	793.0	313.0	627.9	63.66
18	1.000	452.1	688.6	236.5	864.4	49.98
45	0.354	444.2	799.0	354.8	1219.2	29.44
60	0.250	406.5	544.4	137.9	1357.1	21.46
120	0.125	381.2	584.0	202.8	1559.9	9.73
230	0.063	389.3	483.8	94.5	1654.4	4.26
Pan	---------	370.2	443.5	73.3	1727.7	0.02

Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)
Sample B

Project # : 531762
Sample Location : pit 4
Performed by : T.L.
Date : 6 / 28 / 94

* Note: D.S. = Dry Soil, W.S. = Wet Soil, & Cont. = Container.

Weight of Cont. 678 g
Total Sample Weight (W.S. + Cont.) 2006.5 g
Weight of Dry Soil 1328.5 g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of Seive [g]	Weight of D.S. + Seive [g]	Weight of D.S. [g]	Accumulate Weight Ret. [g]	% Finer
5/8 "	16.000	550.0	727.4	177.4	177.4	86.65
10	2.000	479.8	784.9	305.1	482.5	63.68
18	1.000	451.9	647.1	195.2	677.7	48.99
45	0.354	444.1	707.0	262.9	940.6	29.20
60	0.250	405.9	496.3	90.4	1031.0	22.39
120	0.125	381.1	533.0	151.9	1182.9	10.96
230	0.063	389.2	464.0	74.8	1257.7	5.33
Pan	---------	370.3	436.8	66.5	1324.2	0.32

Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)
Sample C

Project # :	531762	* Note: D.S. = Dry Soil, W.S. = Wet Soil,
Sample Location :	pit 4	& Cont. = Container.
Performed by :	T.L.	
Date :	6 / 28 / 94	

Weight of Cont.	683.2	g
Total Sample Weight (W.S. + Cont.)	2157.2	g
Weight of Dry Soil	1474	g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of Seive [g]	Weight of D.S. + Seive [g]	Weight of D.S. [g]	Accumulate Weight Ret. [g]	% Finer
5/8 "	16.000	550.0	597.4	47.4	47.4	96.78
10	2.000	479.9	772.2	292.3	339.7	76.95
18	1.000	451.9	697.8	245.9	585.6	60.27
45	0.354	444.0	792.6	348.6	934.2	36.62
60	0.250	405.9	529.3	123.4	1057.6	28.25
120	0.125	381.2	611.7	230.5	1288.1	12.61
230	0.063	389.2	494.0	104.8	1392.9	5.50
Pan	---------	370.3	446.3	76.0	1468.9	0.35

Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)
Sample D

Project # : 531762
Sample Location : pit 4
Performed by : T.L.
Date : 6 / 28 / 94

* Note: D.S. = Dry Soil, W.S. = Wet Soil, & Cont. = Container.

Weight of Cont. 677.9 g
Total Sample Weight (W.S. + Cont.) 1656.3 g
Weight of Dry Soil 978.4 g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of Seive [g]	Weight of D.S. + Seive [g]	Weight of D.S. [g]	Accumulate Weight Ret. [g]	% Finer
5/8 "	16.000	550.0	671.4	121.4	121.4	87.59
10	2.000	480.0	677.0	197.0	318.4	67.46
18	1.000	452.1	594.7	142.6	461.0	52.88
45	0.354	444.2	646.7	202.5	663.5	32.19
60	0.250	406.0	477.2	71.2	734.7	24.91
120	0.125	381.1	499.5	118.4	853.1	12.81
230	0.063	389.2	454.9	65.7	918.8	6.09
Pan	---------	370.2	427.0	56.8	975.6	0.29

Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)
Sample E

Project # :	531762	* Note: D.S. = Dry Soil, W.S. = Wet Soil,
Sample Location :	pit 4	& Cont. = Container.
Performed by :	T.L.	
Date :	6 / 28 / 94	

Weight of Cont.	683.9	g
Total Sample Weight (W.S. + Cont.)	1820.2	g
Weight of Dry Soil	1136.3	g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of Seive [g]	Weight of D.S. + Seive [g]	Weight of D.S. [g]	Accumulate Weight Ret. [g]	% Finer
5/8 "	16.000	550.0	717.1	167.1	167.1	85.29
10	2.000	480.0	690.6	210.6	377.7	66.76
18	1.000	452.0	614.0	162.0	539.7	52.50
45	0.354	444.2	676.0	231.8	771.5	32.10
60	0.250	406.0	487.9	81.9	853.4	24.90
120	0.125	381.1	526.0	144.9	998.3	12.14
230	0.063	389.2	460.7	71.5	1069.8	5.85
Pan	---------	370.2	432.8	62.6	1132.4	0.34

Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)
Sample F

Project # : 531762
Sample Location : pit 4
Performed by : T.L.
Date : 6 / 28 / 94

* Note: D.S. = Dry Soil, W.S. = Wet Soil, & Cont. = Container.

Weight of Cont.	678	g
Total Sample Weight (W.S. + Cont.)	1537.2	g
Weight of Dry Soil	859.2	g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of Seive [g]	Weight of D.S. + Seive [g]	Weight of D.S. [g]	Accumulate Weight Ret. [g]	% Finer
5/8 "	16.000	550.0	631.0	81.0	81.0	90.57
10	2.000	480.0	713.9	233.9	314.9	63.35
18	1.000	452.0	585.9	133.9	448.8	47.77
45	0.354	444.2	608.2	164.0	612.8	28.68
60	0.250	406.0	461.3	55.3	668.1	22.24
120	0.125	381.2	467.1	85.9	754.0	12.24
230	0.063	389.2	439.5	50.3	804.3	6.39
Pan	---------	370.6	423.0	52.4	856.7	0.29

Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)
Sample G

Project # :	531762	* Note: D.S. = Dry Soil, W.S. = Wet Soil,
Sample Location :	pit 4	& Cont. = Container.
Performed by :	T.L.	
Date :	6 / 28 / 94	

Weight of Cont.	683.9	g
Total Sample Weight (W.S. + Cont.)	2178	g
Weight of Dry Soil	1494.1	g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of Seive [g]	Weight of D.S. + Seive [g]	Weight of D.S. [g]	Accumulate Weight Ret. [g]	% Finer
5/8 "	16.000	550.0	616.9	66.9	66.9	95.52
10	2.000	480.6	819.9	339.3	406.2	72.81
18	1.000	452.1	683.0	230.9	637.1	57.36
45	0.354	444.1	767.1	323.0	960.1	35.74
60	0.250	406.0	526.2	120.2	1080.3	27.70
120	0.125	381.1	597.3	216.2	1296.5	13.23
230	0.063	389.2	496.0	106.8	1403.3	6.08
Pan	---------	370.4	460.7	90.3	1493.6	0.03

Appendix B - 1:3 Scale Model Gradation

Volume-Based Mixing Calculator

Total Volume (ft^3)	Material Description	
190	Western Mobile Silt	46% of new mixture
	Western Mobile Fill	
	Western Mobile Regular	
160	Western Mobile Masonry	39% of new mixture
	Western Mobile 1/4" Rock	
20	Western Mobile 3/8" Rock	5% of new mixture
40	Western Mobile 3/4" Rock	10% of new mixture
	Western Mobile 1" Rock	
	Western Mobile 1.5" Rock	

Sieve Size (mm)	WM Silt Percent Retained	WM Silt Graded Vol. (ft^3)	WM Fill Percent Retained	WM Fill Graded Vol. (ft^3)	WM Regular Percent Retained	WM Regular Graded Vol. (ft^3)	WM Masonry Percent Retained	WM Masonry Graded Vol. (ft^3)	WM 1/4" Rock Percent Retained	WM 1/4" Rock Graded Vol. (ft^3)	WM 3/8" Rock Percent Retained
####	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
9.510	0.0%	0.0	0.0%	0.0	0.1%	0.0	0.0%	0.0	15.7%	0.0	77.8%
4.760	0.0%	0.0	36.2%	0.0	35.9%	0.0	38.0%	60.8	83.4%	0.0	21.7%
1.000	2.0%	3.8	18.9%	0.0	18.2%	0.0	24.3%	38.9	0.2%	0.0	0.0%
0.589	0.3%	0.6	8.1%	0.0	8.4%	0.0	10.3%	16.5	0.0%	0.0	0.0%
0.500	1.1%	2.1	12.0%	0.0	14.5%	0.0	13.5%	21.6	0.0%	0.0	0.0%
0.354	1.6%	3.0	4.6%	0.0	6.1%	0.0	4.4%	7.0	0.0%	0.0	0.0%
0.295	10.8%	20.5	9.6%	0.0	10.0%	0.0	6.2%	9.9	0.0%	0.0	0.0%
0.210	56.2%	106.8	9.2%	0.0	5.5%	0.0	2.8%	4.5	0.0%	0.0	0.0%
0.088	6.5%	12.4	0.6%	0.0	0.6%	0.0	0.1%	0.2	0.0%	0.0	0.0%
0.063											
Chec	78.5%	149.2	99.1%	0.0	99.3%	0.0	99.6%	159.4	99.3%	0.0	99.5%

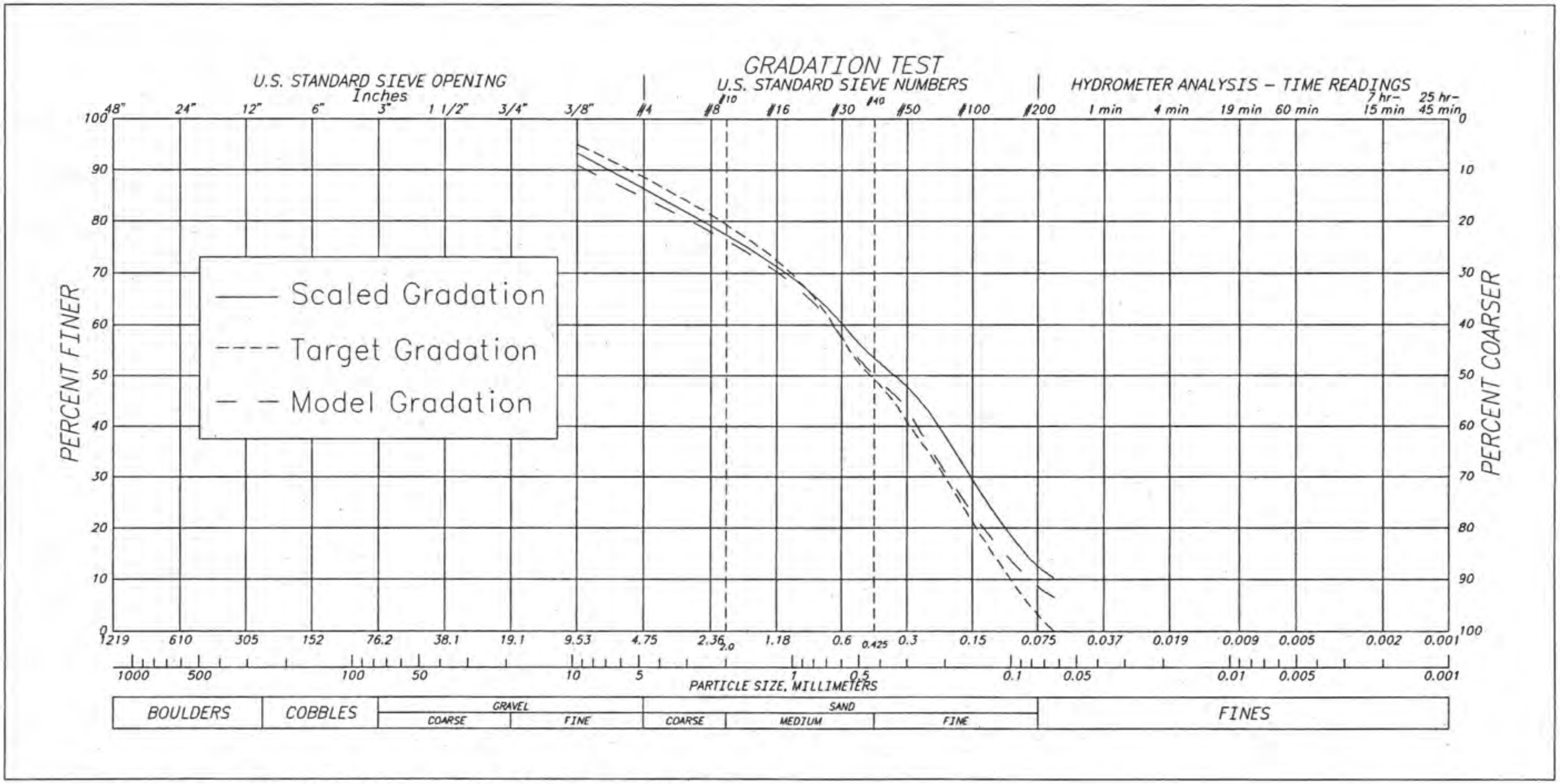
Volume-Based Mixing Calculator

Volume-Based Mixing Calculator

Sieve Size (mm)	WM 3/8" Rock Graded Vol. (ft^3)	WM 3/4" Rock Percent Retained	WM 3/4" Rock Graded Vol. (ft^3)	WM 1.0" Rock Percent Retained	WM 1.0" Rock Graded Vol. (ft^3)	WM 1.5" Rock Percent Retained	WM 1.5" Rock Graded Vol. (ft^3)	New Mixture Total Vol. (ft^3)	New Mixture Percent Retained	Target Percent Retained	ifferenc
38.100											
	0.0	68.9%	27.6	99.7%	0.0	99.5%	0.0	27.6	6.7%	5.0%	1.7%
9.510											
	15.6	30.5%	12.2	0.0%	0.0	0.1%	0.0	27.8	6.8%	6.0%	0.8%
4.760											
	4.3	0.1%	0.0	0.0%	0.0	0.0%	0.0	65.2	15.9%	16.0%	-0.1%
1.000											
	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	42.7	10.4%	16.0%	-5.6%
0.589											
	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	17.1	4.2%	5.0%	-0.8%
0.500											
	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	23.7	5.8%	6.0%	-0.2%
0.354											
	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	10.1	2.5%	6.0%	-3.5%
0.295											
	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	30.4	7.4%	8.0%	-0.6%
0.210											
	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	111.3	27.1%	27.0%	0.1%
0.088											
	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	12.5	3.1%	5.0%	-1.9%
0.063											
Check:	19.9	99.5%	39.8	99.7%	0.0	99.6%	0.0	368.2	90%	100%	

Sieve Size (mm)	New Mixture Percent Finer	Target Percent Finer
38.100		
	93.3%	95.0%
9.510		
	86.5%	89.0%
4.760		
	70.6%	73.0%
1.000		
	60.2%	57.0%
0.589		
	56.0%	52.0%
0.500		
	50.3%	46.0%
0.354		
	47.8%	40.0%
0.295		
	40.4%	32.0%
0.210		
	13.2%	5.0%
0.088		
	10.2%	0.0%
0.063		

Check:



[mm]	Scaled Gradation	Model Gradation	Target Gradation
9.51	93.3%	90.9%	95.0%
4.76	86.5%	84.7%	89.0%
1	70.6%	70.6%	73.0%
0.589	60.2%	57.2%	57.0%
0.5	56.0%	52.9%	52.0%
0.354	50.3%	46.5%	46.0%
0.295	47.8%	43.8%	40.0%
0.21	40.3%	30.9%	32.0%
0.088	13.2%	9.5%	5.0%
0.063	10.2%	6.6%	0.0%

Appendix C - Optimization of Model Gradation

Results from optimization runs using available "WM" materials

Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
Sieve Size (mm)	Difference	Sieve Size (mm)	Difference	Sieve Size (mm)	Difference	Sieve Size (mm)	Difference	Sieve Size (mm)	Difference
38.100		38.100		38.100		38.100		38.100	
	-5.0%		-5.0%		8.3%		-5.0%		6.9%
9.510		9.510		9.510		9.510		9.510	
	-4.0%		4.6%		-0.1%		-0.1%		0.0%
4.760		4.760		4.760		4.760		4.760	
	10.1%		2.2%		-0.4%		6.4%		0.0%
1.000		1.000		1.000		1.000		1.000	
	-5.0%		-5.3%		-5.2%		-5.1%		-7.5%
0.589		0.589		0.589		0.589		0.589	
	-0.6%		-0.7%		-0.7%		-0.6%		-1.7%
0.500		0.500		0.500		0.500		0.500	
	0.1%		-0.1%		0.0%		0.1%		-1.3%
0.354		0.354		0.354		0.354		0.354	
	-3.4%		-3.5%		-3.6%		-3.5%		-3.9%
0.295		0.295		0.295		0.295		0.295	
	-0.4%		-0.5%		-1.2%		-0.5%		-1.0%
0.210		0.210		0.210		0.210		0.210	
	0.1%		0.1%		-3.6%		0.0%		0.1%
0.088		0.088		0.088		0.088		0.088	
	-2.0%		-2.0%		-2.4%		-2.0%		-1.9%
0.063		0.063		0.063		0.063		0.063	
Not selected		Not selected		Not selected		Not selected		Not selected	
Total Volume (ft^3)		Total Volume (ft^3)		Total Volume (ft^3)		Total Volume (ft^3)		Total Volume (ft^3)	
129.7767225	Silt	133.5635617	Silt	117.8757626	Silt	165.0444698	Silt	183.351037	Silt
0	Fill	0	Fill	0	Fill	0	Fill	0	Fill
0	Regular	0	Regular	0	Regular	0	Regular	0	Regular
116.3945076	Masonry	115.8383477	Masonry	122.2519942	Masonry	147.4854078	Masonry	122.2246838	Masonry
34.98583434	1/4" Rock	0	1/4" Rock	0	1/4" Rock	23.12957142	1/4" Rock	19.69528667	1/4" Rock
0	3/8" Rock	39.55084161	3/8" Rock	0	3/8" Rock	22.51593101	3/8" Rock		3/8" Rock
0	3/4" Rock	0	3/4" Rock	57.59620605	3/4" Rock		3/4" Rock	67.68949575	3/4" Rock
0	1" Rock	0	1" Rock	0	1" Rock		1" Rock		1" Rock
0	1.5" Rock	0	1.5" Rock	0	1.5" Rock		1.5" Rock		1.5" Rock

Results from optimization runs using available "WM" materials

Trial 6		Trial 7		Trial 8		Trial 9	
Sieve Size (mm)	Difference	Sieve Size (mm)	Difference	Sieve Size (mm)	Difference	Sieve Size (mm)	Difference
38.100		38.100		38.100		38.100	
	0.1%		2.1%		3.2%		1.7%
9.510		9.510		9.510		9.510	
	-4.8%		-0.1%		0.0%		0.8%
4.760		4.760		4.760		4.760	
	6.0%		0.0%		0.0%		-0.1%
1.000		1.000		1.000		1.000	
	-5.0%		-5.3%		-5.9%		-5.6%
0.589		0.589		0.589		0.589	
	-0.6%		-0.7%		-1.0%		-0.8%
0.500		0.500		0.500		0.500	
	0.1%		-0.1%		-0.4%		-0.2%
0.354		0.354		0.354		0.354	
	-3.4%		-3.5%		-3.6%		-3.5%
0.295		0.295		0.295		0.295	
	-0.5%		-0.5%		-0.7%		-0.6%
0.210		0.210		0.210		0.210	
	0.0%		0.0%		0.1%		0.1%
0.088		0.088		0.088		0.088	
	-2.0%		-2.0%		-2.0%		-1.9%
0.063		0.063		0.063		0.063	
Not selected		Selected		Not selected		Not selected	

Total Volume (ft^3)		Total Volume (ft^3)		Total Volume (ft^3)		Total Volume (ft^3)	
169.1419853	Silt	188.2078252	Silt	185.2196184	Silt	190	Silt
0	Fill	0	Fill	0	Fill	0	Fill
0	Regular	0	Regular	0	Regular	0	Regular
151.8467928	Masonry	163.6650737	Masonry	150.7302832	Masonry	160	Masonry
28.01650905	1/4" Rock		1/4" Rock		1/4" Rock		1/4" Rock
	3/8" Rock	14.42871977	3/8" Rock	30.81253957	3/8" Rock	20	3/8" Rock
	3/4" Rock	42.22876152	3/4" Rock		3/4" Rock	40	3/4" Rock
18.80769835	1" Rock		1" Rock	33.02436677	1" Rock		1" Rock
	1.5" Rock		1.5" Rock		1.5" Rock		1.5" Rock

Appendix D - Pit 4 Material Gradation and Target Gradation

Volume-Based Mixing Calculator

	Total Volume (ft^3)	Material Description
Material #1	190	Western Mobil Silt
Material #2	80	#70 Silica Sand
Material #3	80	#30 Silica Sand
Material #4	90	#20 Silica Sand
Material #5	160	Gravel

Sieve Size (mm)	Material #1 Percent Retained	Material #1 Graded Volume (ft^3)	Material #2 Percent Retained	Material #2 Graded Volume (ft^3)	Material #3 Percent Retained	Material #3 Graded Volume (ft^3)	Material #4 Percent Retained	Material #4 Graded Volume (ft^3)	Material #5 Percent Retained	Material #5 Graded Volume (ft^3)
33.00										
	0%	0.0	0%	0.0	0%	0.0	0%	0.0	19%	30.4
10.00										
	0%	0.0	0%	0.0	0%	0.0	0%	0.0	23%	36.8
5.00										
	0%	0.0	0%	0.0	3%	2.4	3%	2.7	58%	92.8
1.00										
	0%	0.0	0%	0.0	4%	3.2	12%	10.8	0%	0.0
0.90										
	0%	0.0	0%	0.0	11%	8.8	15%	13.5	0%	0.0
0.80										
	0%	0.0	0%	0.0	10%	8.0	17%	15.3	0%	0.0
0.70										
	0%	0.0	0%	0.0	11%	8.8	18%	16.2	0%	0.0
0.60										
	3%	5.7	0%	0.0	15%	12.0	24%	21.6	0%	0.0
0.50										
	11%	20.9	0%	0.0	17%	13.6	3%	2.7	0%	0.0
0.40										
	14%	26.6	0%	0.0	21%	16.8	5%	4.5	0%	0.0
0.30										
	22%	41.8	38%	30.4	8%	6.4	3%	2.7	0%	0.0
0.20										
	35%	66.5	54%	43.2	0%	0.0	0%	0.0	0%	0.0
0.10										
	11%	20.9	8%	6.4	0%	0.0	0%	0.0	0%	0.0
0.05										
	4%	7.6	0%	0.0	0%	0.0	0%	0.0	0%	0.0
0.01										
Check:	100%	190.0	100%	80.0	100%	80.0	100%	90.0	100%	160.0

Volume-Based Mixing Calculator

Sieve Size (mm)	New Mixture Total Volume (ft^3)	New Mixture Percent Retained	New Mixture Percent Finer	Target Percent Retained	Target Percent Finer	% Difference
33.00						
	30.4	5.1%	94.9%	5.0%	95.0%	0.1%
10.00						
	36.8	6.1%	88.8%	6.0%	89.0%	0.1%
5.00						
	97.9	16.3%	72.5%	16.0%	73.0%	0.3%
1.00						
	14.0	2.3%	70.2%	3.0%	70.0%	-0.7%
0.90						
	22.3	3.7%	66.4%	4.0%	66.0%	-0.3%
0.80						
	23.3	3.9%	62.6%	4.0%	62.0%	-0.1%
0.70						
	25.0	4.2%	58.4%	5.0%	57.0%	-0.8%
0.60						
	39.3	6.6%	51.8%	5.0%	52.0%	1.6%
0.50						
	37.2	6.2%	45.6%	6.0%	46.0%	0.2%
0.40						
	47.9	8.0%	37.7%	6.0%	40.0%	2.0%
0.30						
	81.3	13.6%	24.1%	8.0%	32.0%	5.6%
0.20						
	109.7	18.3%	5.8%	16.0%	16.0%	2.3%
0.10						
	27.3	4.6%	1.3%	11.0%	5.0%	-6.5%
0.05						
	7.6	1.3%	0.0%	5.0%	0.0%	-3.7%
0.01						
Check:	600.0	100.0%		100.0%		

Appendix E - Model Gradation Verification

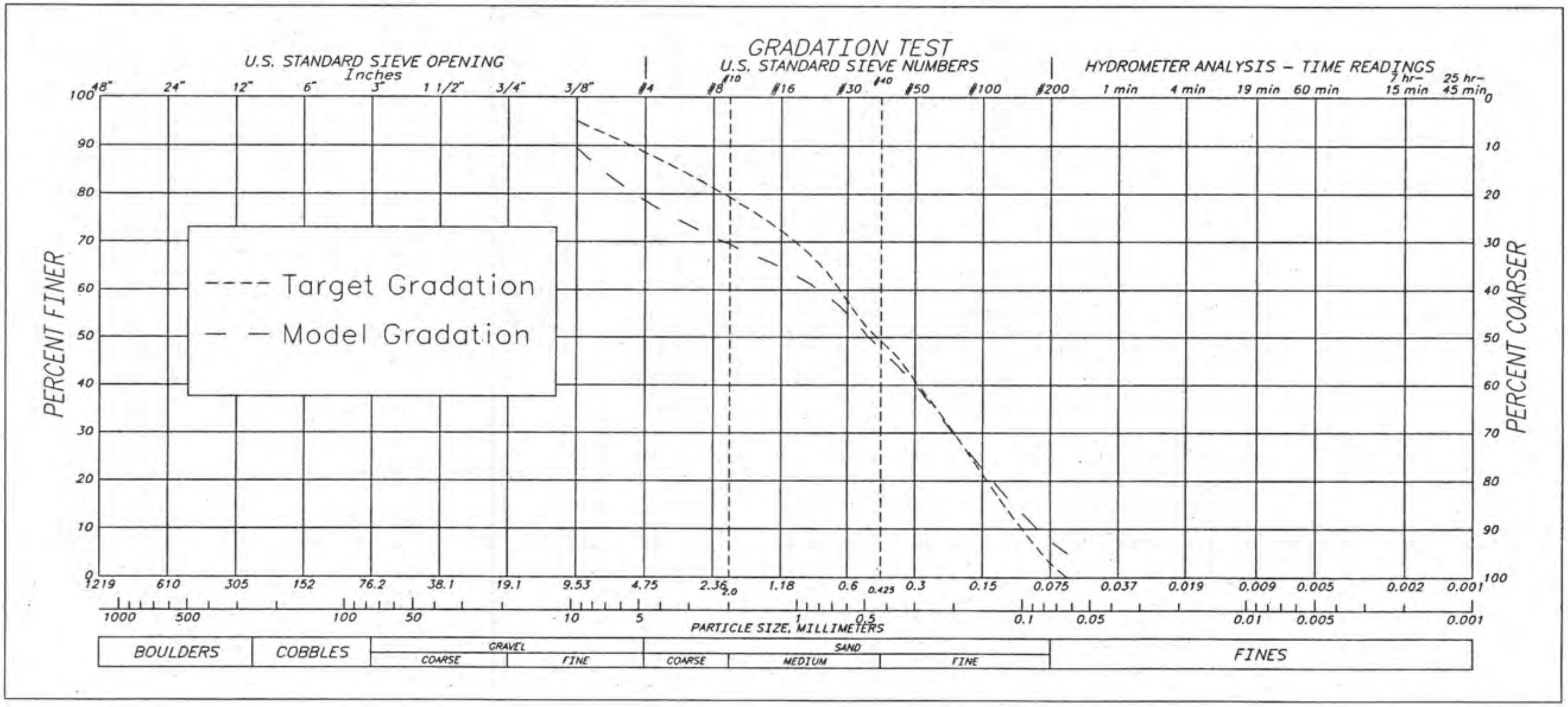
Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)

Project # : 531762
Sample : DFE Sample #1
Site taken from: mix pile
Performed by : K.C.
Date : 7/25/94

Weight of Dry Soil before sieving = 1735.2 g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of D.S. [g]	Accumulated Weight Ret. [g]	% Retained	% Finer	[mm]	Model Gradation	Target Gradation
3/8"	9.510	183.9	183.9	10.6	89.4	9.51	89.4%	95.0%
#4	4.760	228.6	412.5	13.2	76.2	4.76	76.2%	89.0%
#18	1.000	199.5	612.0	11.5	64.7	1	64.7%	73.0%
0.0232"	0.589	174.3	786.3	10.0	54.7	0.589	54.7%	57.0%
#35	0.500	68.7	855.0	4.0	50.7	0.5	50.7%	52.0%
#45	0.354	121.7	976.7	7.0	43.7	0.354	43.7%	46.0%
0.0116"	0.295	66.7	1043.4	3.8	39.9	0.295	39.9%	40.0%
#70	0.210	159.2	1202.6	9.2	30.7	0.21	30.7%	32.0%
#170	0.088	370.8	1573.4	21.4	9.3	0.088	9.3%	5.0%
#230	0.063	74.1	1647.5	4.3	5.1			
Pan	-------	87.6	1735.1	5.0	0.0			


GRADATION TEST
U.S. STANDARD SIEVE OPENING
Inches
U.S. STANDARD SIEVE NUMBERS
HYDROMETER ANALYSIS - TIME READINGS
PERCENT FINER
PERCENT COARSER
Target Gradation
Model Gradation
PARTICLE SIZE, MILLIMETERS
BOULDERS
COBBLES
GRAVEL
COARSE
FINE
SAND
COARSE
MEDIUM
FINE
FINES

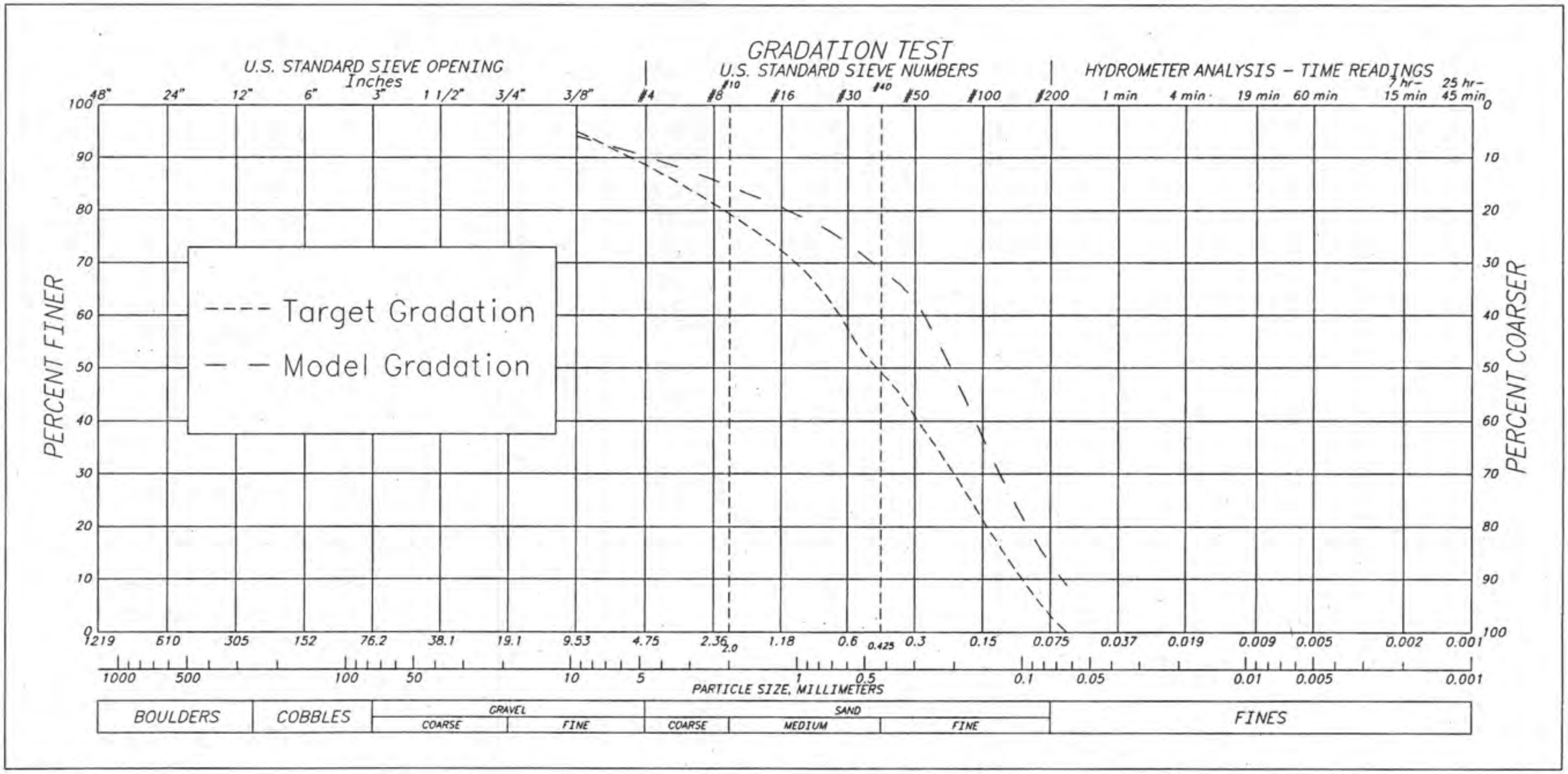
Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)

Project # : 531762
Sample : DFE Sample #2
Site taken from: mix pile
Performed by : B.R.
Date : 7/25/94

Weight of Dry Soil before sieving = 1966.8 g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of D.S. [g]	Accumulated Weight Ret. [g]	% Retained	% Finer	[mm]	Model Gradation	Target Gradation
3/8"	9.510	117.0	117.0	5.9	94.1	9.51	94.1%	95.0%
#4	4.760	66.3	183.3	3.4	90.7	4.76	90.7%	89.0%
#18	1.000	210.2	393.5	10.7	80.0	1	80.0%	73.0%
0.0232"	0.589	123.2	516.7	6.3	73.7	0.589	73.7%	57.0%
#35	0.500	51.4	568.1	2.6	71.1	0.5	71.1%	52.0%
#45	0.354	96.8	664.9	4.9	66.2	0.354	66.2%	46.0%
0.0116"	0.295	63.6	728.5	3.2	63.0	0.295	63.0%	40.0%
#70	0.210	237.3	965.8	12.1	50.9	0.21	50.9%	32.0%
#170	0.088	704.4	1670.2	35.8	15.1	0.088	15.1%	5.0%
#230	0.063	123.8	1794.0	6.3	8.8	0.063	8.8%	0.0%
Pan	-------	171.0	1965.0	8.7	0.1			


GRADATION TEST
U.S. STANDARD SIEVE OPENING Inches
U.S. STANDARD SIEVE NUMBERS
HYDROMETER ANALYSIS – TIME READINGS
PERCENT FINER
PERCENT COARSER
Target Gradation
Model Gradation
PARTICLE SIZE, MILLIMETERS
BOULDERS
COBBLES
GRAVEL
COARSE
FINE
SAND
COARSE
MEDIUM
FINE
FINES

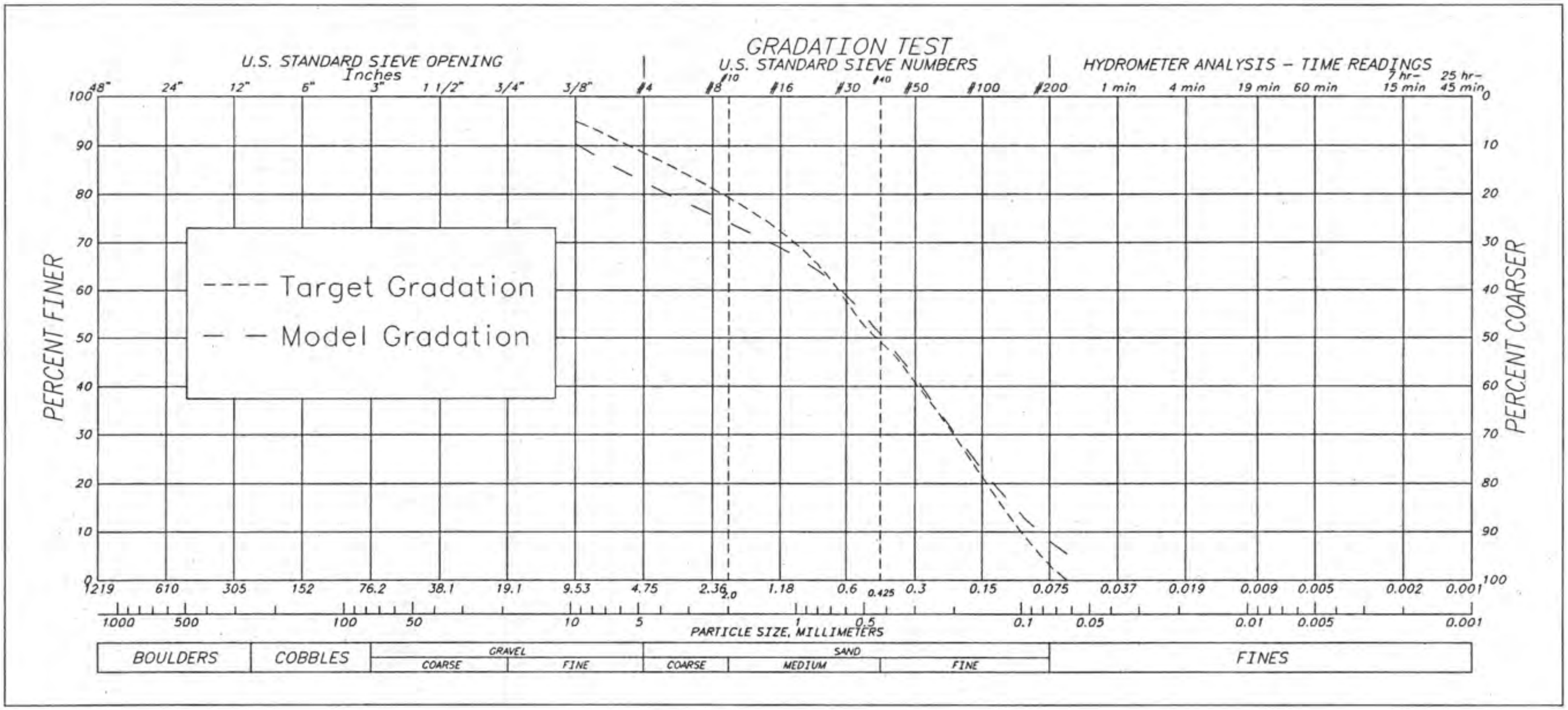
Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)

Project # : 531762
Sample : DFE Sample #3
Site taken from: sediment box
Performed by : B.R.
Date : 7/25/94

Weight of Dry Soil before sieving = 2010.3 g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of D.S. [g]	Accumulated Weight Ret. [g]	% Retained	% Finer	[mm]	Model Gradation	Target Gradation
3/8"	9.510	192.9	192.9	9.6	90.4	9.51	90.4%	95.0%
#4	4.760	177.1	370.0	8.8	81.6	4.76	81.6%	89.0%
#18	1.000	257.1	627.1	12.8	68.8	1	68.8%	73.0%
0.0232"	0.589	200.6	827.7	10.0	58.8	0.589	58.8%	57.0%
#35	0.500	84.6	912.3	4.2	54.6	0.5	54.6%	52.0%
#45	0.354	168.2	1080.5	8.4	46.3	0.354	46.3%	46.0%
0.0116"	0.295	90.3	1170.8	4.5	41.8	0.295	41.8%	40.0%
#70	0.210	217.5	1388.3	10.8	30.9	0.21	30.9%	32.0%
#170	0.088	428.2	1816.5	21.3	9.6	0.088	9.6%	5.0%
#230	0.063	83.5	1900.0	4.2	5.5	0.063	5.5%	0.0%
Pan	-------	111.2	2011.2	5.5	0.0			


GRADATION TEST
U.S. STANDARD SIEVE OPENING
Inches
U.S. STANDARD SIEVE NUMBERS
HYDROMETER ANALYSIS - TIME READINGS
PERCENT FINER
PERCENT COARSER
---- Target Gradation
— — Model Gradation
PARTICLE SIZE, MILLIMETERS
BOULDERS
COBBLES
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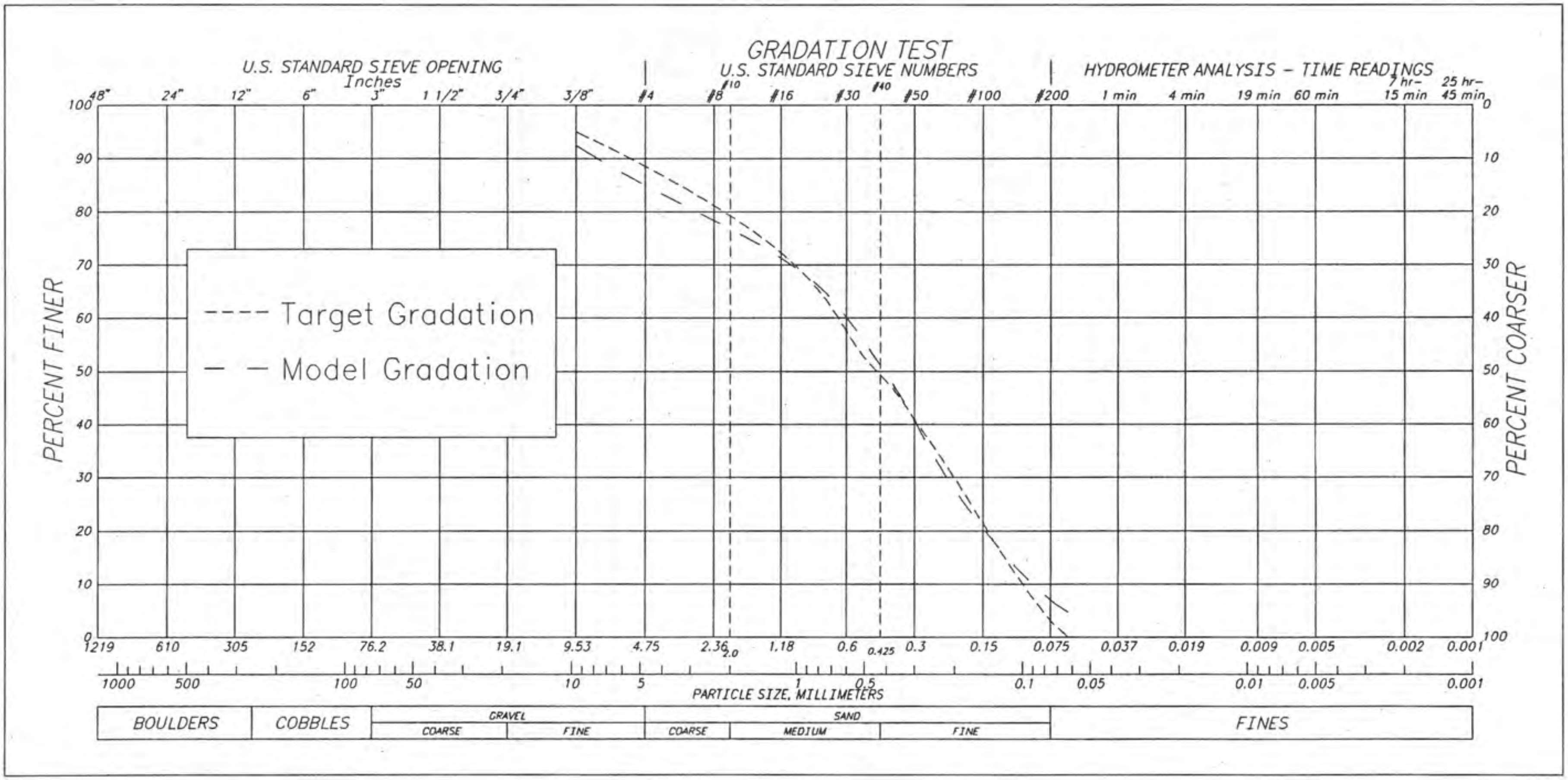
Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)

Project # : 531762
Sample : DFE Sample #4
Site taken from: sediment box
Performed by : E.M.S.
Date : 7/26/94

Weight of Dry Soil before sieving = 2124 g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of D.S. [g]	Accumulated Weight Ret. [g]	% Retained	% Finer	[mm]	Model Gradation	Target Gradation
3/8"	9.510	162.0	162.0	7.6	92.4	9.51	92.4%	95.0%
#4	4.760	172.0	334.0	8.1	84.3	4.76	84.3%	89.0%
#18	1.000	267.0	601.0	12.6	71.7	1	71.7%	73.0%
0.0232"	0.589	248.0	849.0	11.7	60.0	0.589	60.0%	57.0%
#35	0.500	101.0	950.0	4.8	55.3	0.5	55.3%	52.0%
#45	0.354	196.0	1146.0	9.2	46.0	0.354	46.0%	46.0%
0.0116"	0.295	118.0	1264.0	5.6	40.5	0.295	40.5%	40.0%
#70	0.210	281.0	1545.0	13.2	27.3	0.21	27.3%	32.0%
#170	0.088	403.0	1948.0	19.0	8.3	0.088	8.3%	5.0%
#230	0.063	76.0	2024.0	3.6	4.7	0.063	4.7%	0.0%
Pan	-------	98.0	2122.0	4.6	0.1			


GRADATION TEST
U.S. STANDARD SIEVE OPENING Inches
U.S. STANDARD SIEVE NUMBERS
HYDROMETER ANALYSIS - TIME READINGS
PERCENT FINER
PERCENT COARSER
---- Target Gradation
— — Model Gradation
PARTICLE SIZE, MILLIMETERS
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SAND
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FINES

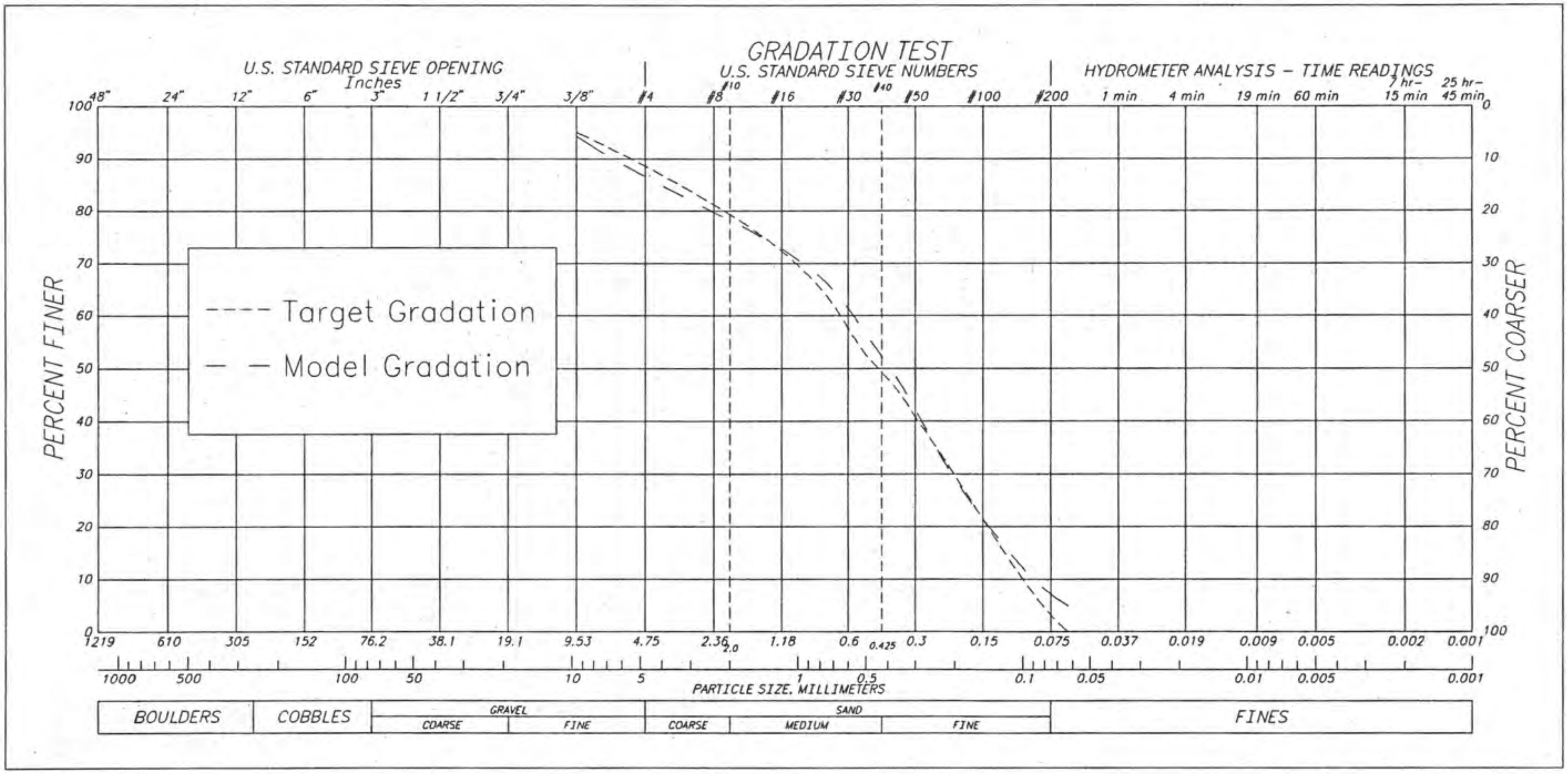
Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)

Project # : 531762
Sample : DFE Sample #5
Site taken from: sediment box
Performed by : T.L.
Date : 7/27/94

Weight of Dry Soil before sieving = 1367.4 g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of D.S. [g]	Accumulated Weight Ret. [g]	% Retained	% Finer	[mm]	Model Gradation	Target Gradation
3/8"	9.510	79.0	79.0	5.8	94.2	9.51	94.2%	95.0%
#4	4.760	117.0	196.0	8.6	85.7	4.76	85.7%	89.0%
#18	1.000	172.3	368.3	12.6	73.1	1	73.1%	73.0%
0.0232"	0.589	160.7	529.0	11.8	61.3	0.589	61.3%	57.0%
#35	0.500	71.2	600.2	5.2	56.1	0.5	56.1%	52.0%
#45	0.354	116.8	717.0	8.5	47.6	0.354	47.6%	46.0%
0.0116"	0.295	75.8	792.8	5.5	42.0	0.295	42.0%	40.0%
#70	0.210	173.4	966.2	12.7	29.3	0.21	29.3%	32.0%
#170	0.088	292.0	1258.2	21.4	8.0	0.088	8.0%	5.0%
#230	0.063	42.1	1300.3	3.1	4.9	0.063	4.9%	0.0%
Pan	-------	52.1	1352.4	3.8	1.1			


GRADATION TEST
U.S. STANDARD SIEVE OPENING
Inches
U.S. STANDARD SIEVE NUMBERS
HYDROMETER ANALYSIS – TIME READINGS
PERCENT FINER
PERCENT COARSER
Target Gradation
Model Gradation
PARTICLE SIZE, MILLIMETERS
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FINES

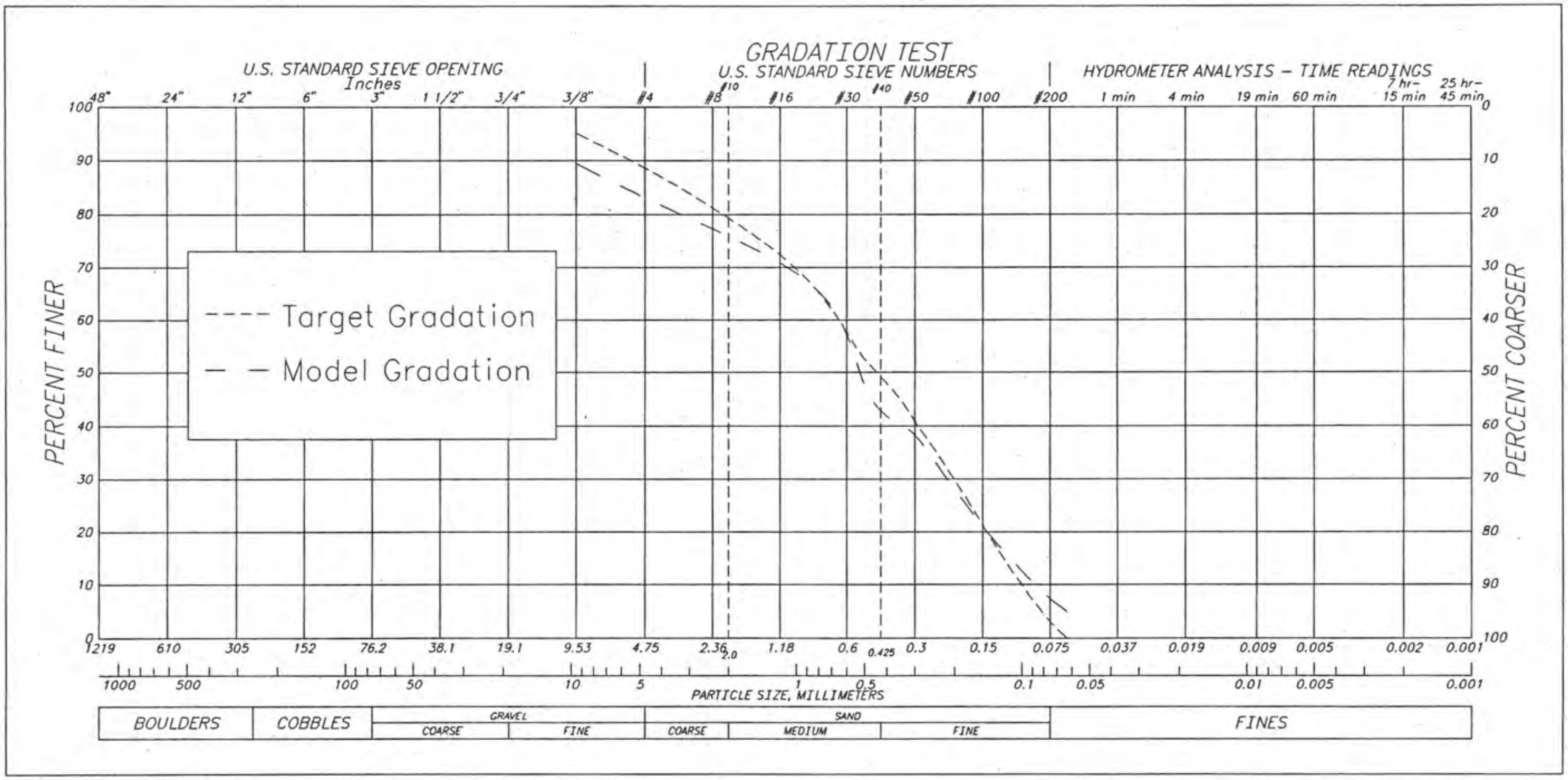
Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)

Project # : 531762
Sample DFE Sample #6
Site taken from: sediment box
Performed by : T.L.
Date : 7/27/94

Weight of Dry Soil before sieving 1465.6 g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of D.S. [g]	Accumulated Weight Ret. [g]	% Retained	% Finer	[mm]	Model Gradation	Target Gradation
3/8"	9.510	155.0	155.0	10.6	89.4	9.51	89.4%	95.0%
#4	4.760	100.1	255.1	6.8	82.6	4.76	82.6%	89.0%
#18	1.000	163.3	418.4	11.1	71.5	1	71.5%	73.0%
0.0232"	0.589	176.4	594.8	12.0	59.4	0.589	59.4%	57.0%
#35	0.500	218.9	813.7	14.9	44.5	0.5	44.5%	52.0%
#45	0.354	62.5	876.2	4.3	40.2	0.354	40.2%	46.0%
0.0116"	0.295	18.8	895.0	1.3	38.9	0.295	38.9%	40.0%
#70	0.210	154.0	1049.0	10.5	28.4	0.21	28.4%	32.0%
#170	0.088	285.4	1334.4	19.5	9.0	0.088	9.0%	5.0%
#230	0.063	58.1	1392.5	4.0	5.0	0.063	5.0%	0.0%
Pan	-------	71.5	1464.0	4.9	0.1			


GRADATION TEST
U.S. STANDARD SIEVE OPENING
Inches
U.S. STANDARD SIEVE NUMBERS
HYDROMETER ANALYSIS – TIME READINGS
PERCENT FINER
PERCENT COARSER
---- Target Gradation
— — Model Gradation
PARTICLE SIZE, MILLIMETERS
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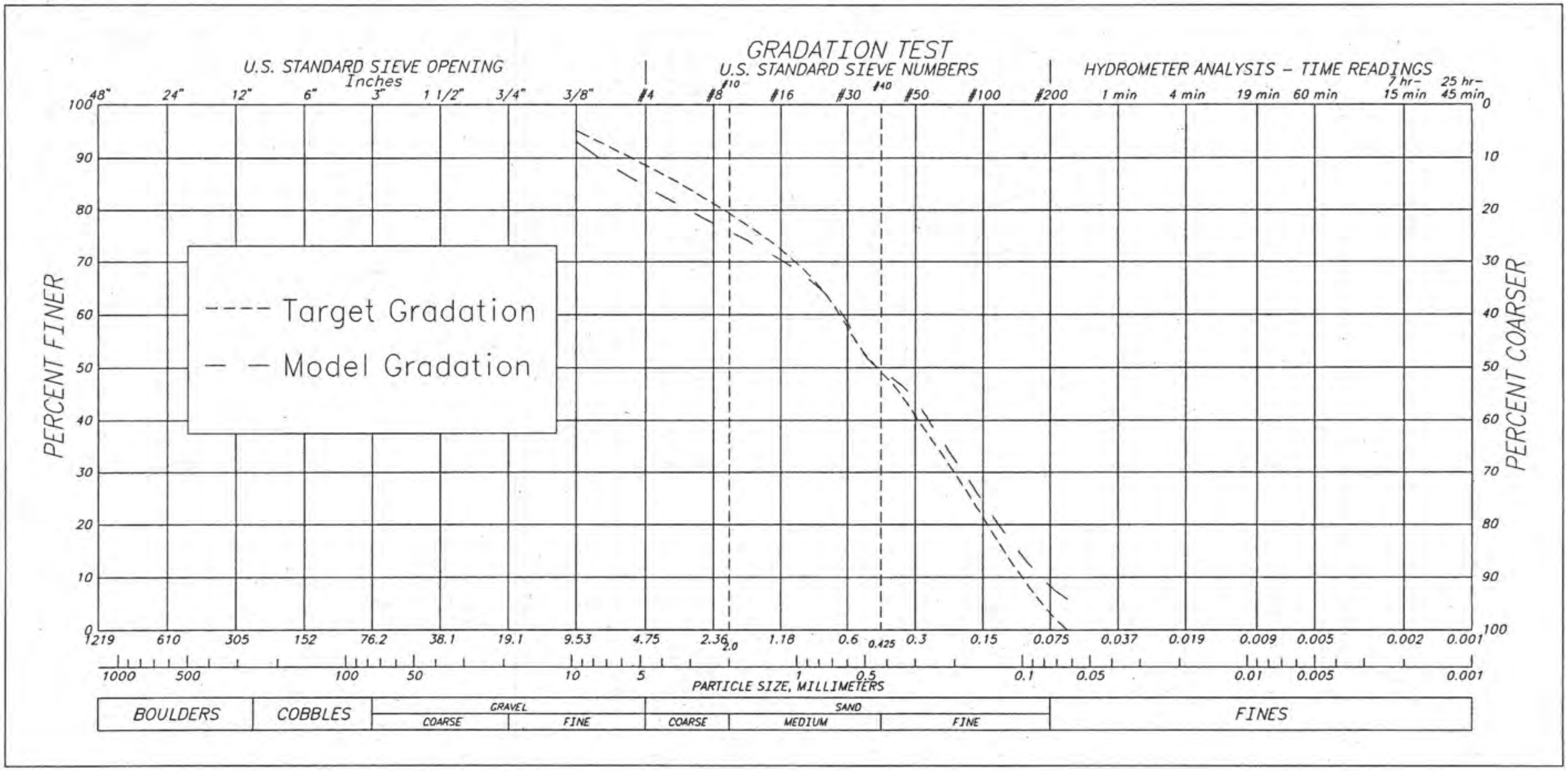
Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)

Project # :	531762
Sample :	DFE Sample #7
Site taken from:	sediment box
Performed by :	E.M.S.
Date :	8/7/94

Weight of Dry Soil before sieving = 1445 g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of D.S. [g]	Accumulated Weight Ret. [g]	% Retained	% Finer	[mm]	Model Gradation	Target Gradation
3/8"	9.510	102.0	102.0	7.1	92.9	9.51	92.9%	95.0%
#4	4.760	136.0	238.0	9.4	83.5	4.76	83.5%	89.0%
#18	1.000	188.0	426.0	13.0	70.5	1	70.5%	73.0%
0.0232"	0.589	163.0	589.0	11.3	59.2	0.589	59.2%	57.0%
#35	0.500	123.0	712.0	8.5	50.7	0.5	50.7%	52.0%
#45	0.354	46.0	758.0	3.2	47.5	0.354	47.5%	46.0%
0.0116"	0.295	57.0	815.0	3.9	43.6	0.295	43.6%	40.0%
#70	0.210	145.0	960.0	10.0	33.6	0.21	33.6%	32.0%
#170	0.088	349.0	1309.0	24.2	9.4	0.088	9.4%	5.0%
#230	0.063	51.0	1360.0	3.5	5.9	0.063	5.9%	0.0%
Pan	-------	85.0	1445.0	5.9	0.0			


GRADATION TEST
U.S. STANDARD SIEVE OPENING
Inches
U.S. STANDARD SIEVE NUMBERS
HYDROMETER ANALYSIS – TIME READINGS
PERCENT FINER
PERCENT COARSER
---- Target Gradation
— — Model Gradation
PARTICLE SIZE, MILLIMETERS
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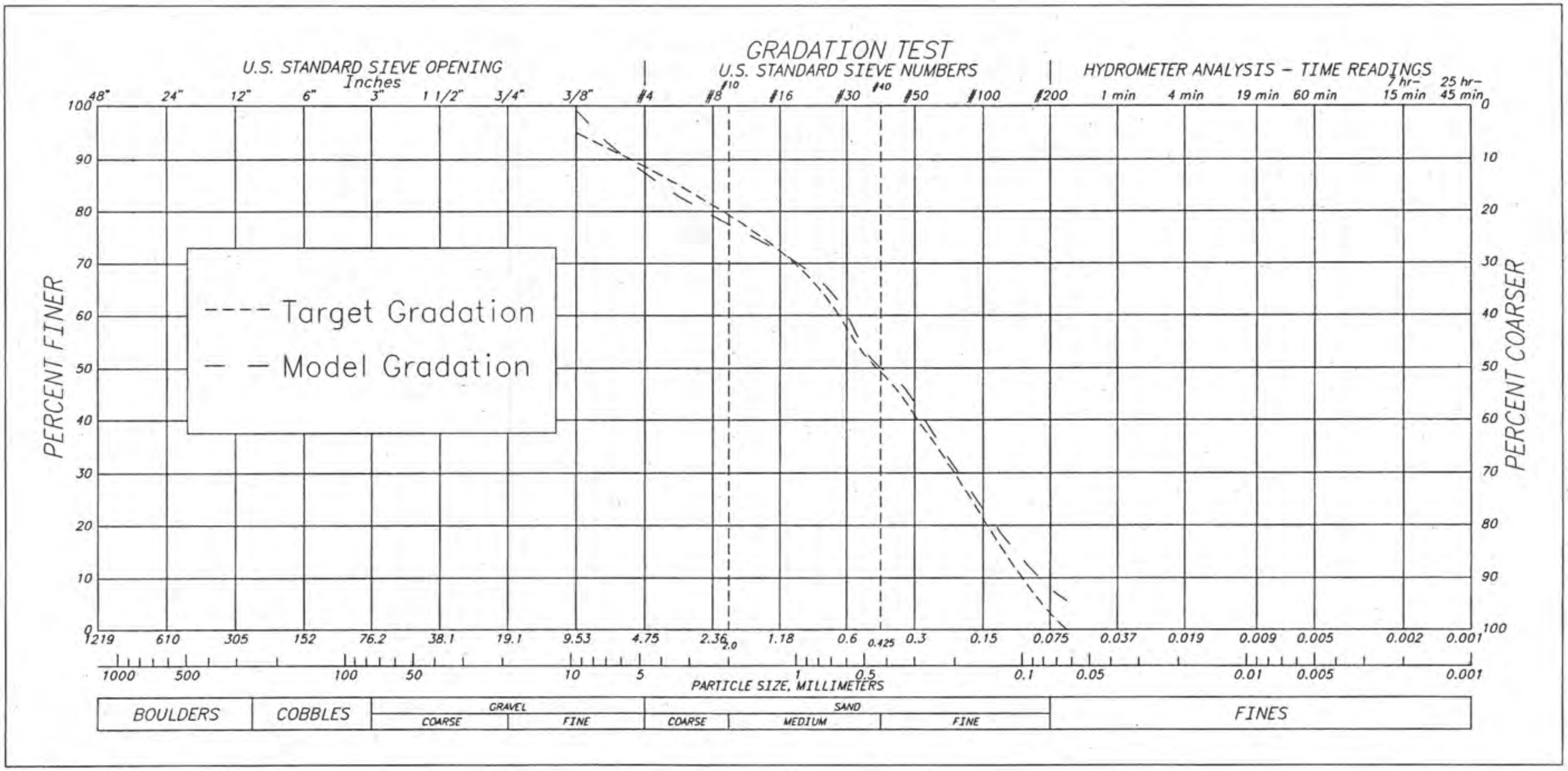
Dam Foundation Erosion

Soils Testing: Grain Size Determination (Mechanical Method)

Project # : 531762
Sample : DFE Sample #8
Site taken from: sediment box
Performed by : E.M.S.
Date : 8/7/94

Weight of Dry Soil before sieving = 1523 g

Sieve Number [U.S. Std.]	Mesh Size [mm]	Weight of D.S. [g]	Accumulated Weight Ret. [g]	% Retained	% Finer	[mm]	Model Gradation	Target Gradation
3/8"	9.510	13.0	13.0	0.9	99.1	9.51	99.1%	95.0%
#4	4.760	220.0	233.0	14.4	84.7	4.76	84.7%	89.0%
#18	1.000	187.0	420.0	12.3	72.4	1	72.4%	73.0%
0.0232"	0.589	171.0	591.0	11.2	61.2	0.589	61.2%	57.0%
#35	0.500	148.0	739.0	9.7	51.5	0.5	51.5%	52.0%
#45	0.354	52.0	791.0	3.4	48.1	0.354	48.1%	46.0%
0.0116"	0.295	77.0	868.0	5.1	43.0	0.295	43.0%	40.0%
#70	0.210	176.0	1044.0	11.6	31.5	0.21	31.5%	32.0%
#170	0.088	337.0	1381.0	22.1	9.3	0.088	9.3%	5.0%
#230	0.063	56.0	1437.0	3.7	5.6	0.063	5.6%	0.0%
Pan	-------	85.0	1522.0	5.6	0.1			


GRADATION TEST
U.S. STANDARD SIEVE OPENING
Inches
U.S. STANDARD SIEVE NUMBERS
HYDROMETER ANALYSIS - TIME READINGS
48" 24" 12" 6" 3" 1 1/2" 3/4" 3/8"
#4 #8 #10 #16 #30 #40 #50 #100 #200
1 min 4 min 19 min 60 min 7 hr- 15 min 25 hr- 45 min
PERCENT FINER
PERCENT COARSER
---- Target Gradation
— — Model Gradation
1219 610 305 152 76.2 38.1 19.1 9.53 4.75 2.36 2.0 1.18 0.6 0.425 0.3 0.15 0.075 0.037 0.019 0.009 0.005 0.002 0.001
1000 500 100 50 10 5 1 0.5 0.1 0.05 0.01 0.005 0.001
PARTICLE SIZE, MILLIMETERS
BOULDERS
COBBLES
GRAVEL
COARSE
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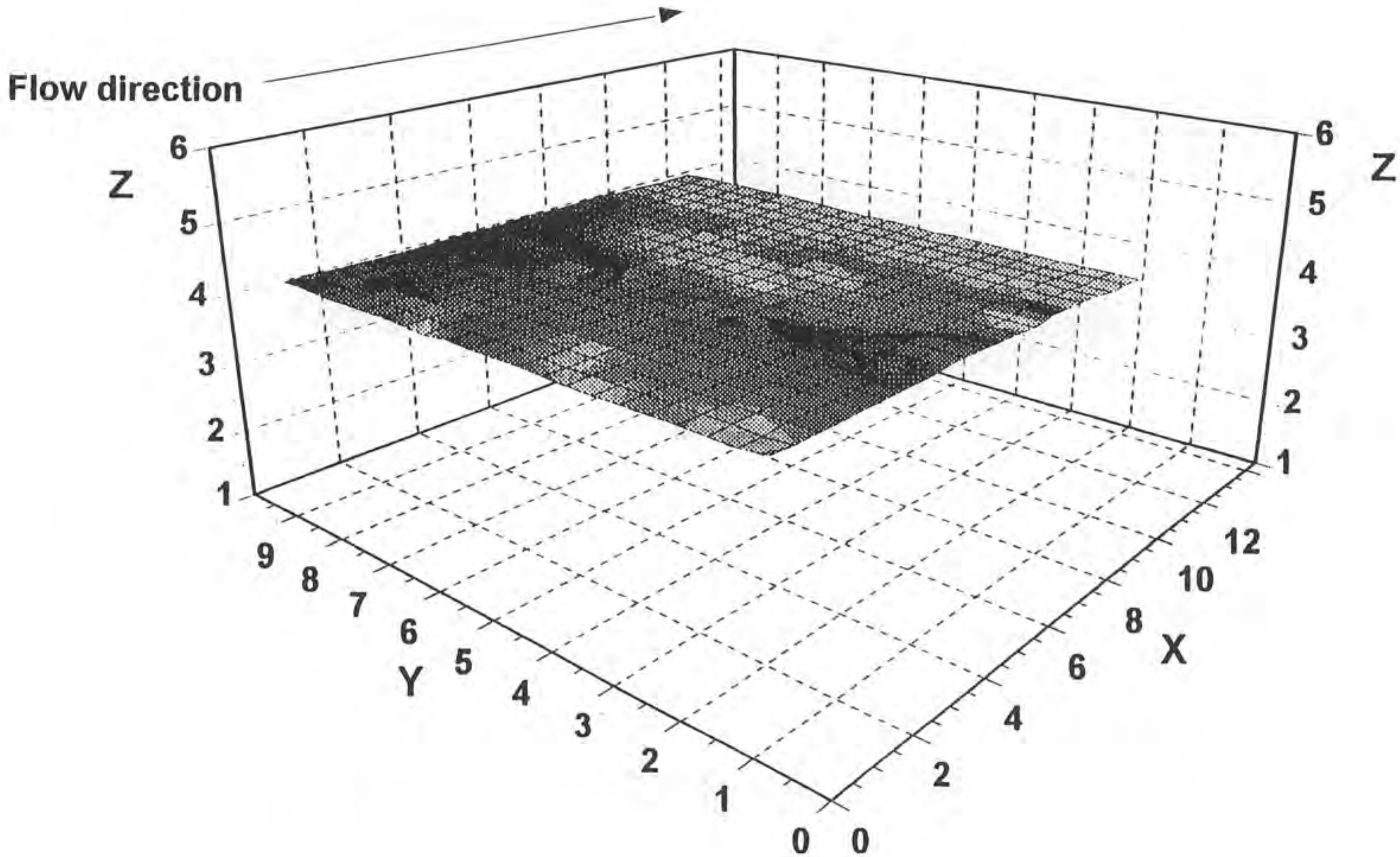
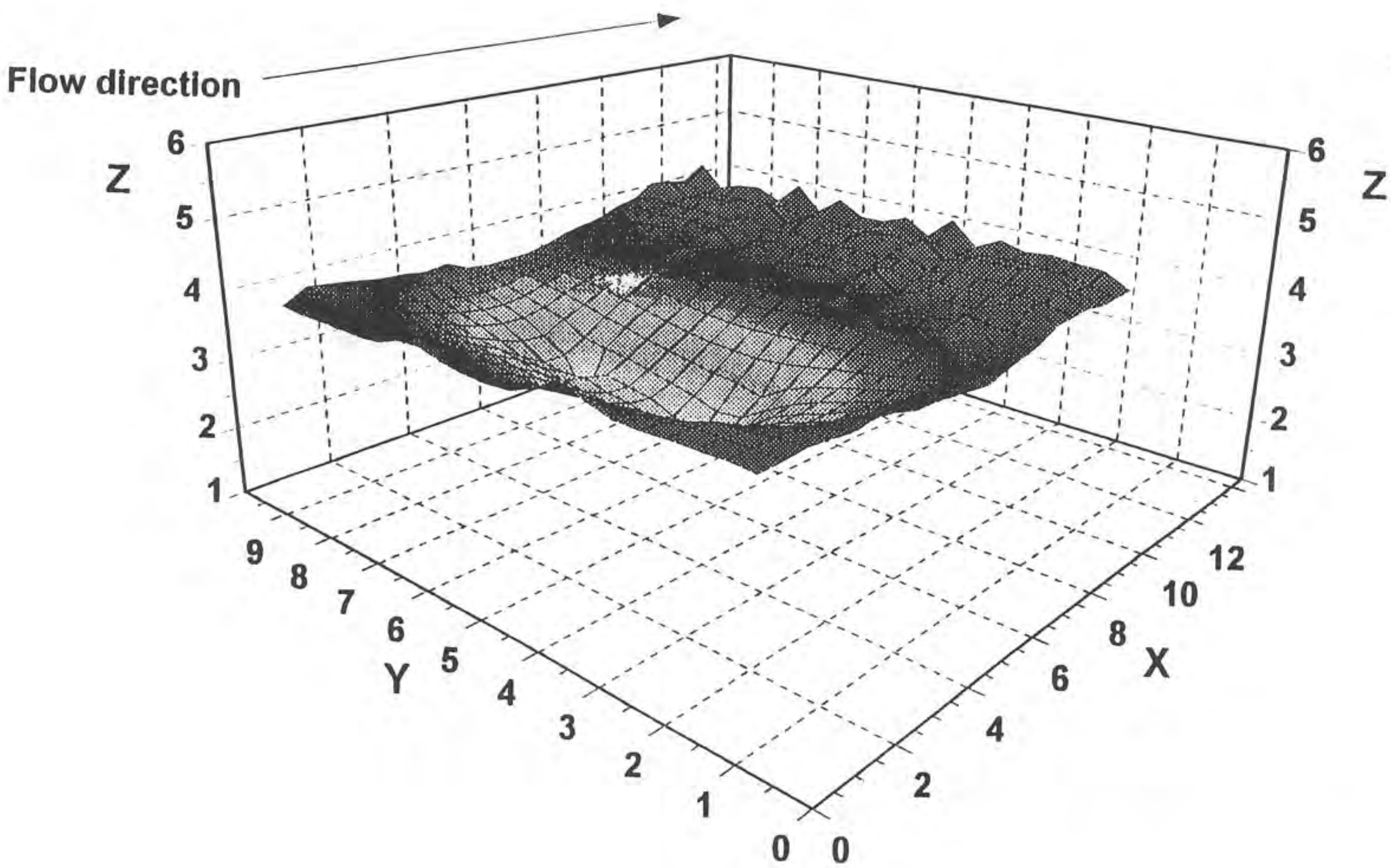
COARSE
MEDIUM
FINE
FINES

Appendix F - Three Dimensional Graphs of Erosion Hole

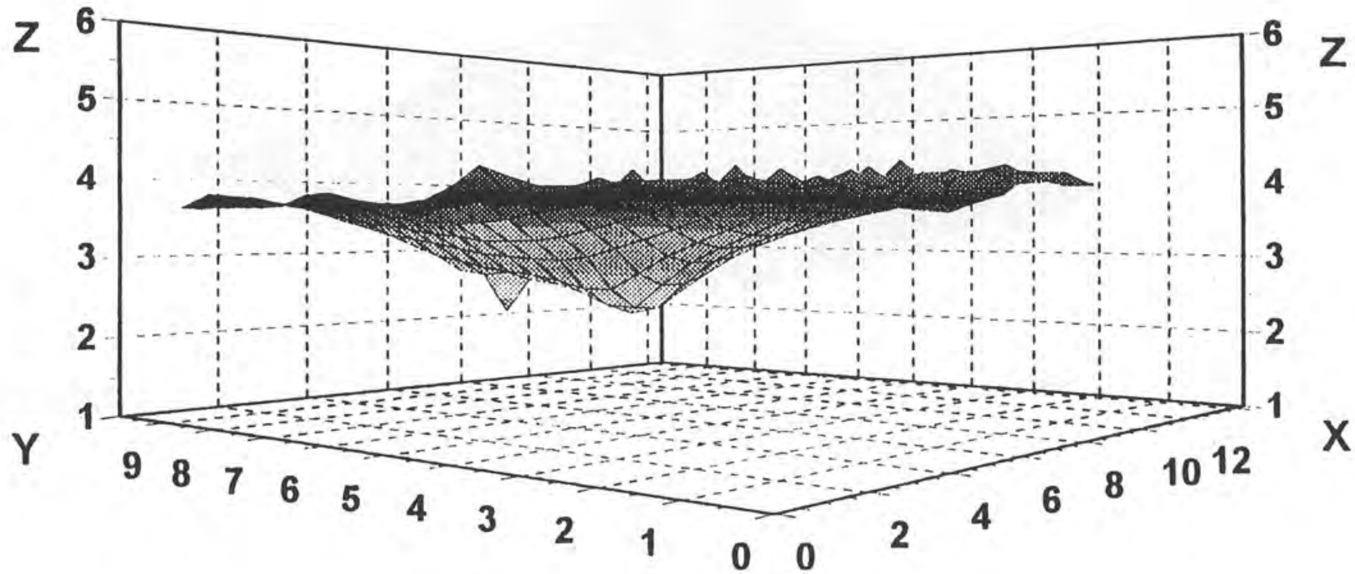
DFE Scale Model Run 2: Initial Surface



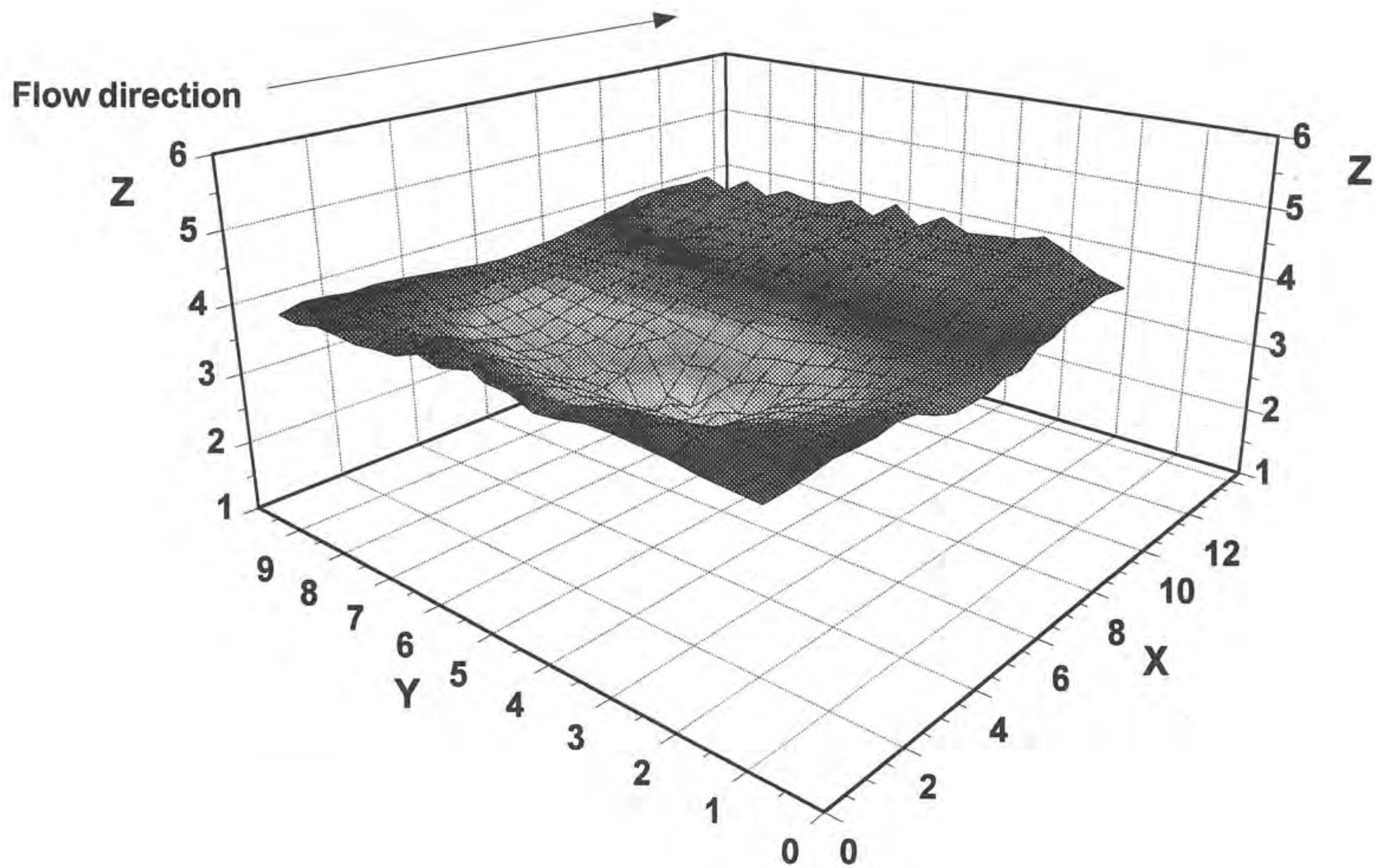
DFE Scale Model Run 2: 15 minutes



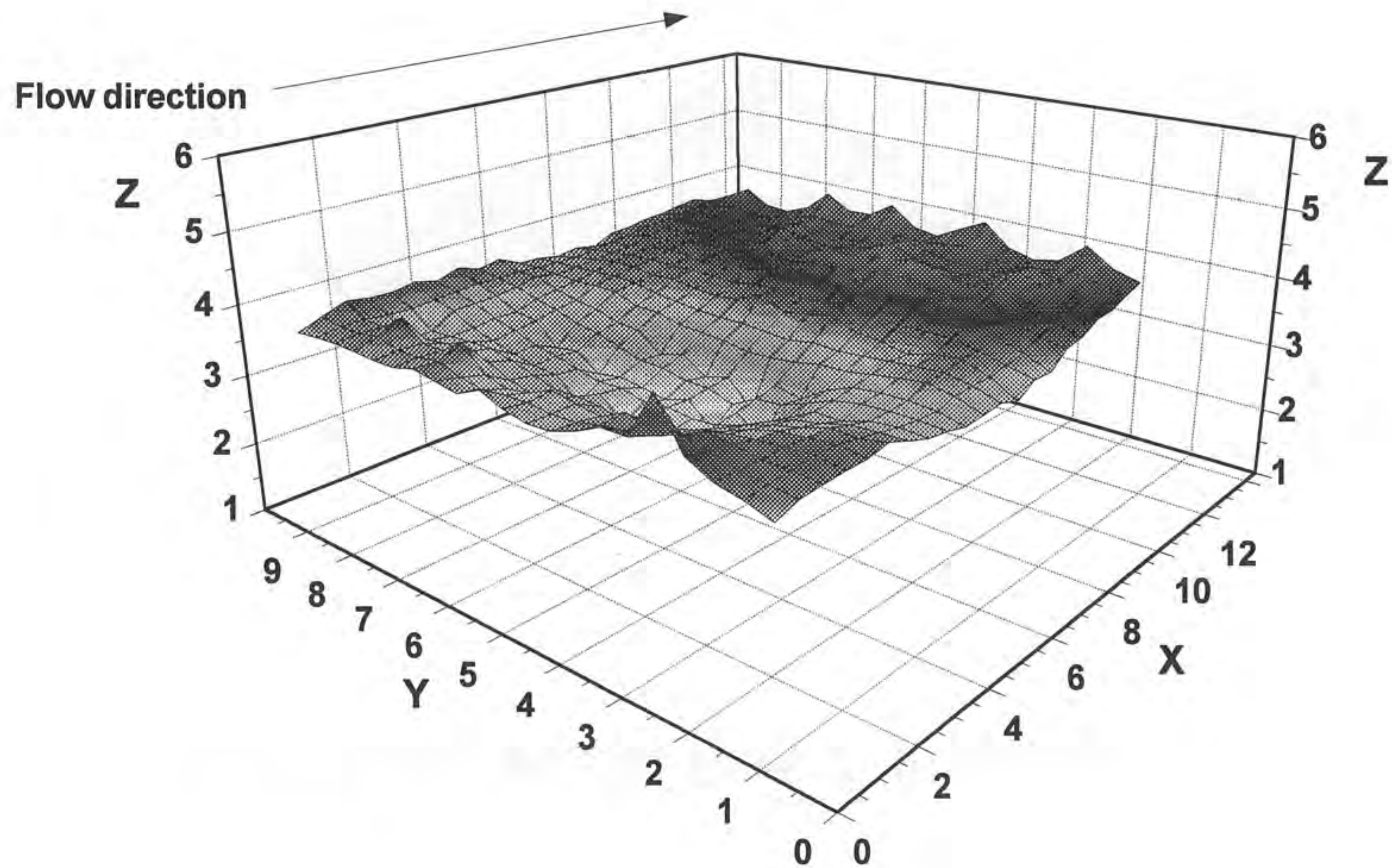
DFE Scale Model Run 2: 15 minutes



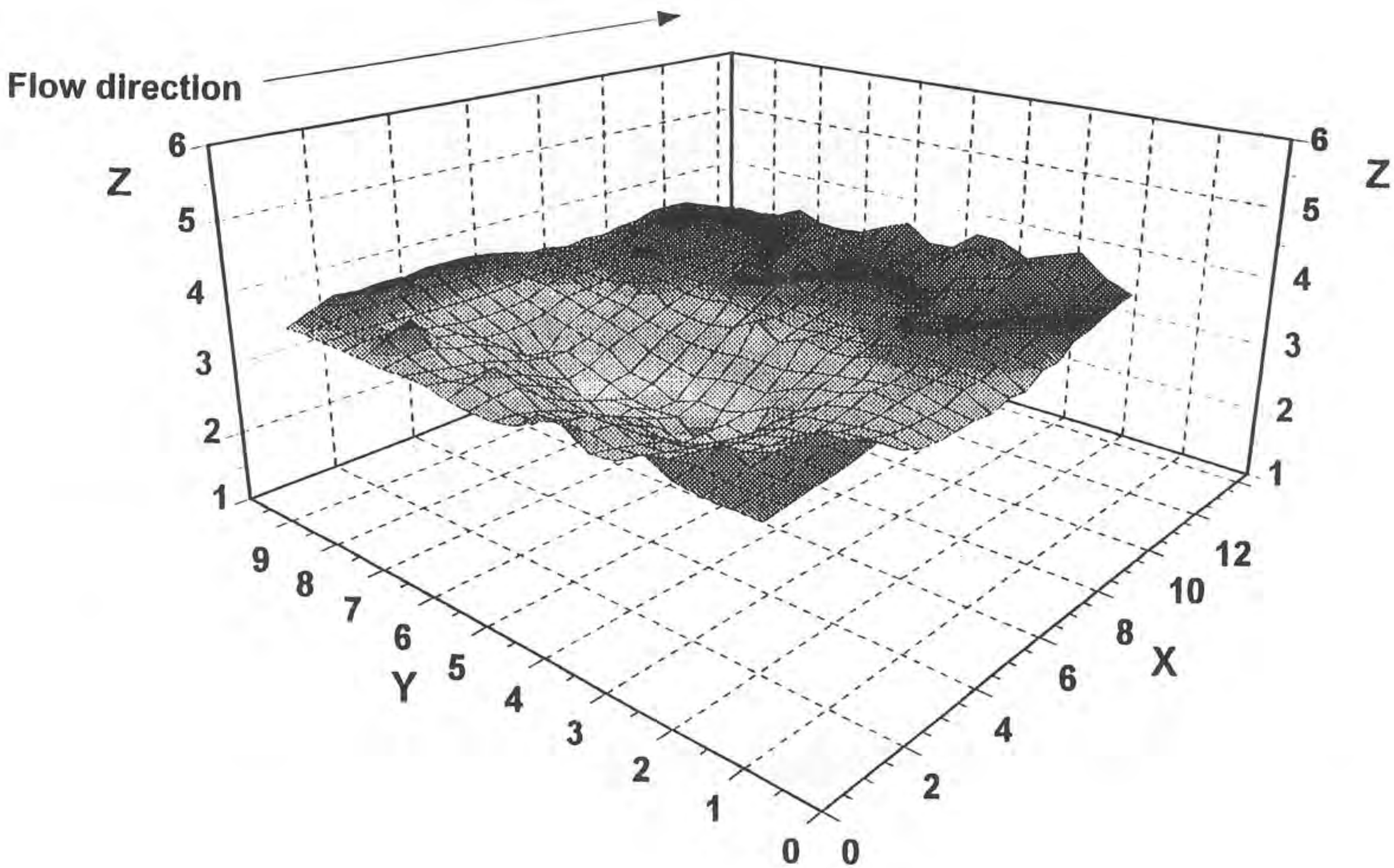
Revised: DFE Scale Model Run 2: 30 minutes



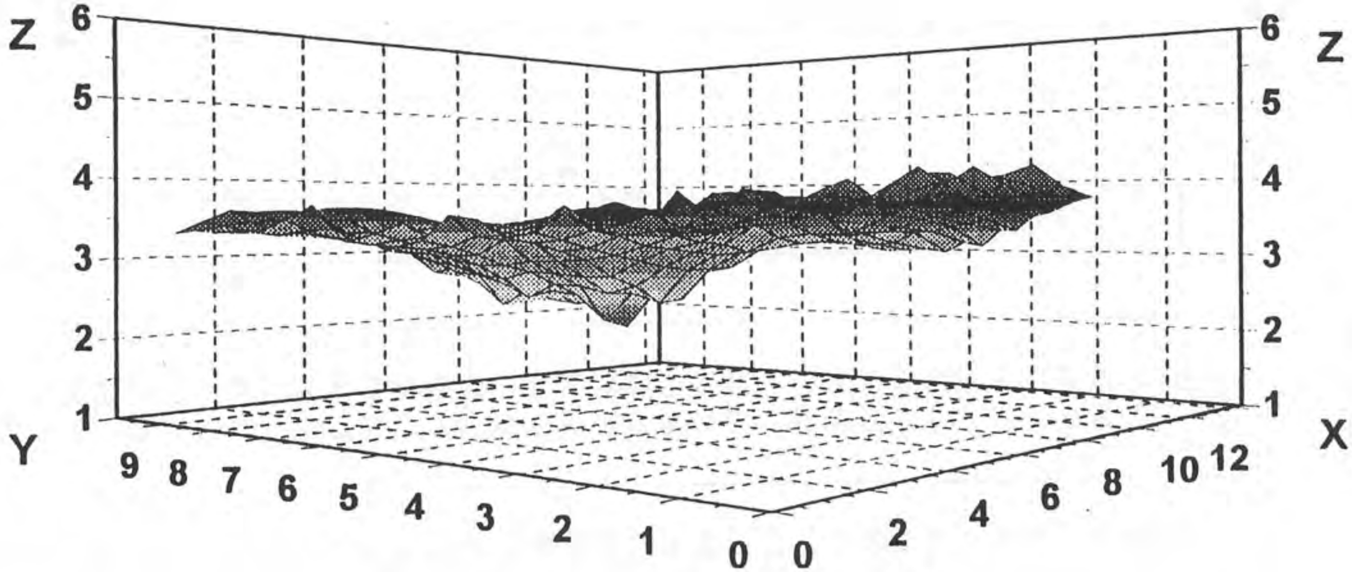
Revised: DFE Scale Model Run 2: 1 hour



DFE Scale Model Run 2: 2 hours



DFE Scale Model Run 2: 2 hours



DFE Contour Data

Run # : 2
Duration : 0 min
Rod Length : 1.33 ft

Observed Data			Adj. to DFE coordinate sys.		
X [ft]	Y [ft]	Z [ft]	X [ft]	Y [ft]	Z [ft]
2.00	20.55	81.83	1.11	1.43	3.99
2.00	21.00	81.88	1.11	1.88	3.94
2.00	21.50	81.88	1.11	2.38	3.94
2.00	21.99	81.84	1.11	2.87	3.98
2.00	22.49	81.85	1.11	3.37	3.97
2.00	23.00	81.87	1.11	3.88	3.95
2.00	23.52	81.85	1.11	4.40	3.97
2.00	24.03	81.84	1.11	4.91	3.98
2.00	24.51	81.83	1.11	5.39	3.99
2.00	25.04	81.84	1.11	5.92	3.98
2.00	25.52	81.81	1.11	6.40	4.01
2.00	26.01	81.86	1.11	6.89	3.96
2.00	26.50	81.84	1.11	7.38	3.98
2.00	27.04	81.80	1.11	7.92	4.02
2.00	27.48	81.85	1.11	8.36	3.97
2.00	27.99	81.84	1.11	8.87	3.98
2.00	28.51	81.82	1.11	9.39	4.00
2.00	29.03	81.82	1.11	9.91	4.00
2.50	20.55	81.85	1.61	1.43	3.97
2.50	21.00	81.88	1.61	1.88	3.94
2.50	21.47	81.85	1.61	2.35	3.97
2.50	22.00	81.86	1.61	2.88	3.96
2.50	22.47	81.85	1.61	3.35	3.97
2.50	23.00	81.86	1.61	3.88	3.96
2.50	23.50	81.84	1.61	4.38	3.98
2.50	23.99	81.86	1.61	4.87	3.96
2.50	24.50	81.85	1.61	5.38	3.97
2.50	25.00	81.82	1.61	5.88	4.00
2.50	25.48	81.83	1.61	6.36	3.99
2.50	26.00	81.83	1.61	6.88	3.99
2.50	26.48	81.85	1.61	7.36	3.97
2.50	26.99	81.85	1.61	7.87	3.97
2.50	27.50	81.84	1.61	8.38	3.98
2.50	28.00	81.85	1.61	8.88	3.97
2.50	28.49	81.82	1.61	9.37	4.00
2.50	29.03	81.80	1.61	9.91	4.02
3.00	20.55	81.84	2.11	1.43	3.98
3.00	21.00	81.83	2.11	1.88	3.99
3.00	21.57	81.86	2.11	2.45	3.96
3.00	22.02	81.84	2.11	2.90	3.98
3.00	22.53	81.84	2.11	3.41	3.98

Observed Data X [ft]	Observed Data Y [ft]	Observed Data Z [ft]	Adj. to DFE coordinate sys. X [ft]	Adj. to DFE coordinate sys. Y [ft]	Adj. to DFE coordinate sys. Z [ft]
3.00	23.02	81.84	2.11	3.90	3.98
3.00	23.49	81.84	2.11	4.37	3.98
3.00	23.98	81.86	2.11	4.86	3.96
3.00	24.54	81.86	2.11	5.42	3.96
3.00	25.03	81.84	2.11	5.91	3.98
3.00	25.48	81.83	2.11	6.36	3.99
3.00	26.03	81.82	2.11	6.91	4.00
3.00	26.51	81.85	2.11	7.39	3.97
3.00	26.98	81.83	2.11	7.86	3.99
3.00	27.50	81.81	2.11	8.38	4.01
3.00	27.97	81.80	2.11	8.85	4.02
3.00	28.48	81.84	2.11	9.36	3.98
3.00	29.02	81.82	2.11	9.90	4.00
6.00	20.55	82.77	5.11	1.43	3.99
6.00	21.05	82.74	5.11	1.93	4.02
6.00	21.50	82.77	5.11	2.38	3.99
6.00	22.00	82.77	5.11	2.88	3.99
6.00	22.50	82.76	5.11	3.38	4.00
6.00	22.99	82.78	5.11	3.87	3.98
6.00	23.49	82.75	5.11	4.37	4.01
6.00	24.00	82.78	5.11	4.88	3.98
6.00	24.99	82.75	5.11	5.87	4.01
6.00	25.00	82.79	5.11	5.88	3.97
6.00	25.50	82.76	5.11	6.38	4.00
6.00	26.00	82.74	5.11	6.88	4.02
6.00	26.49	82.78	5.11	7.37	3.98
6.00	26.99	82.77	5.11	7.87	3.99
6.00	27.49	82.76	5.11	8.37	4.00
6.00	28.00	82.78	5.11	8.88	3.98
6.00	28.49	82.77	5.11	9.37	3.99
6.00	28.99	82.76	5.11	9.87	4.00
6.50	20.55	82.73	5.61	1.43	4.03
6.50	21.00	82.76	5.61	1.88	4.00
6.50	21.50	82.76	5.61	2.38	4.00
6.50	22.00	82.73	5.61	2.88	4.03
6.50	22.50	82.75	5.61	3.38	4.01
6.50	22.99	82.74	5.61	3.87	4.02
6.50	23.50	82.79	5.61	4.38	3.97
6.50	24.00	82.77	5.61	4.88	3.99
6.50	24.49	82.76	5.61	5.37	4.00
6.50	25.00	82.76	5.61	5.88	4.00
6.50	25.50	82.80	5.61	6.38	3.96
6.50	26.00	82.74	5.61	6.88	4.02
6.50	26.51	82.77	5.61	7.39	3.99
6.50	27.00	82.74	5.61	7.88	4.02
6.50	27.50	82.73	5.61	8.38	4.03
6.50	28.00	82.73	5.61	8.88	4.03
6.50	28.50	82.77	5.61	9.38	3.99

Rod length: 0.39

Observed Data			Adj. to DFE coordinate sys.		
X [ft]	Y [ft]	Z [ft]	X [ft]	Y [ft]	Z [ft]
6.50	28.99	82.74	5.61	9.87	4.02
7.00	20.55	82.73	6.11	1.43	4.03
7.00	21.00	82.75	6.11	1.88	4.01
7.00	21.50	82.74	6.11	2.38	4.02
7.00	22.00	82.76	6.11	2.88	4.00
7.00	22.50	82.76	6.11	3.38	4.00
7.00	23.00	82.79	6.11	3.88	3.97
7.00	23.50	82.76	6.11	4.38	4.00
7.00	23.99	82.77	6.11	4.87	3.99
7.00	24.49	82.78	6.11	5.37	3.98
7.00	25.00	82.78	6.11	5.88	3.98
7.00	25.50	82.78	6.11	6.38	3.98
7.00	26.00	82.76	6.11	6.88	4.00
7.00	26.49	82.76	6.11	7.37	4.00
7.00	26.99	82.76	6.11	7.87	4.00
7.00	27.50	82.77	6.11	8.38	3.99
7.00	28.00	82.75	6.11	8.88	4.01
7.00	28.50	82.76	6.11	9.38	4.00
7.00	29.00	82.76	6.11	9.88	4.00
7.50	20.55	82.73	6.61	1.43	4.03
7.50	21.00	82.73	6.61	1.88	4.03
7.50	21.49	82.74	6.61	2.37	4.02
7.50	22.00	82.77	6.61	2.88	3.99
7.50	22.50	82.79	6.61	3.38	3.97
7.50	22.99	82.78	6.61	3.87	3.98
7.50	23.50	82.73	6.61	4.38	4.03
7.50	24.00	82.77	6.61	4.88	3.99
7.50	24.49	82.77	6.61	5.37	3.99
7.50	25.00	82.74	6.61	5.88	4.02
7.50	25.50	82.75	6.61	6.38	4.01
7.50	25.99	82.76	6.61	6.87	4.00
7.50	26.50	82.75	6.61	7.38	4.01
7.50	27.00	82.73	6.61	7.88	4.03
7.50	27.50	82.70	6.61	8.38	4.06
7.50	28.00	82.75	6.61	8.88	4.01
7.50	28.49	82.75	6.61	9.37	4.01
7.50	29.00	82.75	6.61	9.88	4.01
8.00	20.55	82.76	7.11	1.43	4.00
8.00	21.00	82.75	7.11	1.88	4.01
8.00	21.50	82.76	7.11	2.38	4.00
8.00	22.00	82.81	7.11	2.88	3.95
8.00	22.50	82.80	7.11	3.38	3.96
8.00	23.00	82.81	7.11	3.88	3.95
8.00	23.50	82.81	7.11	4.38	3.95
8.00	24.00	82.82	7.11	4.88	3.94
8.00	24.50	82.83	7.11	5.38	3.93
8.00	24.98	82.81	7.11	5.86	3.95
8.00	25.50	82.81	7.11	6.38	3.95

Observed Data X [ft]	Observed Data Y [ft]	Observed Data Z [ft]	Adj. to DFE coordinate sys. X [ft]	Adj. to DFE coordinate sys. Y [ft]	Adj. to DFE coordinate sys. Z [ft]
8.00	26.00	82.81	7.11	6.88	3.95
8.00	26.50	82.79	7.11	7.38	3.97
8.00	26.99	82.79	7.11	7.87	3.97
8.00	27.50	82.80	7.11	8.38	3.96
8.00	28.00	82.77	7.11	8.88	3.99
8.00	28.50	82.75	7.11	9.38	4.01
8.00	29.03	82.77	7.11	9.91	3.99
8.50	20.55	82.78	7.61	1.43	3.98
8.50	21.00	82.77	7.61	1.88	3.99
8.50	21.50	82.80	7.61	2.38	3.96
8.50	22.00	82.79	7.61	2.88	3.97
8.50	22.49	82.78	7.61	3.37	3.98
8.50	23.00	82.78	7.61	3.88	3.98
8.50	23.50	82.79	7.61	4.38	3.97
8.50	24.00	82.79	7.61	4.88	3.97
8.50	24.49	82.82	7.61	5.37	3.94
8.50	25.00	82.82	7.61	5.88	3.94
8.50	25.50	82.80	7.61	6.38	3.96
8.50	26.00	82.81	7.61	6.88	3.95
8.50	26.48	82.80	7.61	7.36	3.96
8.50	27.00	82.80	7.61	7.88	3.96
8.50	27.50	82.79	7.61	8.38	3.97
8.50	28.00	82.76	7.61	8.88	4.00
8.50	28.52	82.77	7.61	9.40	3.99
8.50	29.03	82.70	7.61	9.91	4.06
9.00	20.55	82.77	8.11	1.43	3.99
9.00	21.00	82.79	8.11	1.88	3.97
9.00	21.50	82.77	8.11	2.38	3.99
9.00	22.00	82.78	8.11	2.88	3.98
9.00	22.50	82.77	8.11	3.38	3.99
9.00	22.99	82.80	8.11	3.87	3.96
9.00	23.50	82.79	8.11	4.38	3.97
9.00	24.00	82.78	8.11	4.88	3.98
9.00	24.50	82.79	8.11	5.38	3.97
9.00	25.00	82.84	8.11	5.88	3.92
9.00	25.50	82.80	8.11	6.38	3.96
9.00	25.99	82.79	8.11	6.87	3.97
9.00	26.50	82.80	8.11	7.38	3.96
9.00	27.00	82.80	8.11	7.88	3.96
9.00	27.50	82.79	8.11	8.38	3.97
9.00	28.00	82.76	8.11	8.88	4.00
9.00	28.49	82.76	8.11	9.37	4.00
9.00	29.00	82.76	8.11	9.88	4.00
9.50	20.55	82.80	8.61	1.43	3.96
9.50	20.99	82.80	8.61	1.87	3.96
9.50	21.48	82.79	8.61	2.36	3.97
9.50	22.00	82.77	8.61	2.88	3.99
9.50	22.50	82.79	8.61	3.38	3.97

Observed Data			Adj. to DFE coordinate sys.		
X [ft]	Y [ft]	Z [ft]	X [ft]	Y [ft]	Z [ft]
9.50	23.00	82.76	8.61	3.88	4.00
9.50	23.50	82.80	8.61	4.38	3.96
9.50	24.00	82.81	8.61	4.88	3.95
9.50	24.50	82.76	8.61	5.38	4.00
9.50	25.00	82.77	8.61	5.88	3.99
9.50	25.50	82.80	8.61	6.38	3.96
9.50	26.00	82.80	8.61	6.88	3.96
9.50	26.49	82.79	8.61	7.37	3.97
9.50	27.00	82.79	8.61	7.88	3.97
9.50	27.50	82.78	8.61	8.38	3.98
9.50	28.00	82.77	8.61	8.88	3.99
9.50	28.50	82.75	8.61	9.38	4.01
9.50	29.00	82.76	8.61	9.88	4.00
10.00	20.55	82.76	9.11	1.43	4.00
10.00	21.00	82.76	9.11	1.88	4.00
10.00	21.50	82.75	9.11	2.38	4.01
10.00	21.99	82.76	9.11	2.87	4.00
10.00	22.50	82.78	9.11	3.38	3.98
10.00	23.00	82.77	9.11	3.88	3.99
10.00	23.50	82.76	9.11	4.38	4.00
10.00	24.00	82.78	9.11	4.88	3.98
10.00	24.50	82.77	9.11	5.38	3.99
10.00	25.00	82.78	9.11	5.88	3.98
10.00	25.49	82.77	9.11	6.37	3.99
10.00	26.00	82.79	9.11	6.88	3.97
10.00	26.50	82.76	9.11	7.38	4.00
10.00	27.01	82.78	9.11	7.89	3.98
10.00	27.50	82.77	9.11	8.38	3.99
10.00	27.99	82.76	9.11	8.87	4.00
10.00	28.50	82.75	9.11	9.38	4.01
10.00	28.99	82.75	9.11	9.87	4.01
10.50	20.55	82.77	9.61	1.43	3.99
10.50	20.99	82.76	9.61	1.87	4.00
10.50	21.49	82.78	9.61	2.37	3.98
10.50	22.00	82.77	9.61	2.88	3.99
10.50	22.50	82.78	9.61	3.38	3.98
10.50	23.00	82.76	9.61	3.88	4.00
10.50	23.50	82.78	9.61	4.38	3.98
10.50	24.00	82.78	9.61	4.88	3.98
10.50	24.50	82.77	9.61	5.38	3.99
10.50	25.00	82.78	9.61	5.88	3.98
10.50	25.50	82.81	9.61	6.38	3.95
10.50	26.00	82.80	9.61	6.88	3.96
10.50	26.50	82.78	9.61	7.38	3.98
10.50	27.00	82.79	9.61	7.88	3.97
10.50	27.50	82.77	9.61	8.38	3.99
10.50	28.00	82.79	9.61	8.88	3.97
10.50	28.49	82.75	9.61	9.37	4.01

Observed Data			Adj. to DFE coordinate sys.		
X [ft]	Y [ft]	Z [ft]	X [ft]	Y [ft]	Z [ft]
10.50	28.99	82.73	9.61	9.87	4.03
11.00	20.55	82.76	10.11	1.43	4.00
11.00	21.00	82.79	10.11	1.88	3.97
11.00	21.49	82.78	10.11	2.37	3.98
11.00	22.00	82.80	10.11	2.88	3.96
11.00	22.50	82.78	10.11	3.38	3.98
11.00	23.00	82.78	10.11	3.88	3.98
11.00	23.49	82.78	10.11	4.37	3.98
11.00	23.99	82.79	10.11	4.87	3.97
11.00	24.50	82.78	10.11	5.38	3.98
11.00	25.00	82.79	10.11	5.88	3.97
11.00	25.49	82.79	10.11	6.37	3.97
11.00	26.00	82.80	10.11	6.88	3.96
11.00	26.50	82.77	10.11	7.38	3.99
11.00	27.00	82.78	10.11	7.88	3.98
11.00	27.50	82.79	10.11	8.38	3.97
11.00	28.00	82.79	10.11	8.88	3.97
11.00	28.49	82.76	10.11	9.37	4.00
11.00	28.99	82.78	10.11	9.87	3.98
11.50	20.55	82.77	10.61	1.43	3.99
11.50	21.00	82.81	10.61	1.88	3.95
11.50	21.49	82.79	10.61	2.37	3.97
11.50	21.99	82.81	10.61	2.87	3.95
11.50	22.50	82.79	10.61	3.38	3.97
11.50	22.99	82.78	10.61	3.87	3.98
11.50	23.50	82.79	10.61	4.38	3.97
11.50	24.00	82.80	10.61	4.88	3.96
11.50	24.49	82.80	10.61	5.37	3.96
11.50	24.99	82.78	10.61	5.87	3.98
11.50	25.50	82.80	10.61	6.38	3.96
11.50	26.00	82.78	10.61	6.88	3.98
11.50	26.50	82.78	10.61	7.38	3.98
11.50	27.00	82.80	10.61	7.88	3.96
11.50	27.50	82.79	10.61	8.38	3.97
11.50	27.99	82.81	10.61	8.87	3.95
11.50	28.49	82.81	10.61	9.37	3.95
11.50	28.99	82.79	10.61	9.87	3.97
12.00	20.85	82.80	11.11	1.73	3.96
12.00	21.00	82.81	11.11	1.88	3.95
12.00	21.50	82.77	11.11	2.38	3.99
12.00	22.00	82.86	11.11	2.88	3.90
12.00	22.50	82.81	11.11	3.38	3.95
12.00	23.00	82.82	11.11	3.88	3.94
12.00	23.50	82.82	11.11	4.38	3.94
12.00	24.00	82.81	11.11	4.88	3.95
12.00	24.50	82.80	11.11	5.38	3.96
12.00	25.00	82.82	11.11	5.88	3.94
12.00	25.50	82.80	11.11	6.38	3.96

Observed Data			Adj. to DFE coordinate sys.		
X [ft]	Y [ft]	Z [ft]	X [ft]	Y [ft]	Z [ft]
12.00	26.00	82.81	11.11	6.88	3.95
12.00	26.48	82.80	11.11	7.36	3.96
12.00	27.00	82.81	11.11	7.88	3.95
12.00	27.49	82.80	11.11	8.37	3.96
12.00	28.00	82.83	11.11	8.88	3.93
12.00	28.49	82.80	11.11	9.37	3.96
12.00	29.00	82.78	11.11	9.88	3.98
12.50	20.55	82.87	11.61	1.43	3.89
12.50	21.00	82.87	11.61	1.88	3.89
12.50	21.50	82.84	11.61	2.38	3.92
12.50	21.99	82.85	11.61	2.87	3.91
12.50	22.48	82.84	11.61	3.36	3.92
12.50	23.00	82.83	11.61	3.88	3.93
12.50	23.50	82.80	11.61	4.38	3.96
12.50	24.00	82.81	11.61	4.88	3.95
12.50	25.00	82.83	11.61	5.88	3.93
12.50	25.49	82.82	11.61	6.37	3.94
12.50	25.50	82.79	11.61	6.38	3.97
12.50	26.00	82.82	11.61	6.88	3.94
12.50	26.50	82.79	11.61	7.38	3.97
12.50	27.00	82.80	11.61	7.88	3.96
12.50	27.50	82.81	11.61	8.38	3.95
12.50	28.00	82.80	11.61	8.88	3.96
12.50	28.50	82.80	11.61	9.38	3.96
12.50	29.00	82.81	11.61	9.88	3.95
13.00	20.55	82.84	12.11	1.43	3.92
13.00	21.00	82.83	12.11	1.88	3.93
13.00	21.50	82.87	12.11	2.38	3.89
13.00	21.98	82.90	12.11	2.86	3.86
13.00	22.50	82.87	12.11	3.38	3.89
13.00	23.00	82.85	12.11	3.88	3.91
13.00	23.50	82.85	12.11	4.38	3.91
13.00	24.00	82.85	12.11	4.88	3.91
13.00	24.50	82.84	12.11	5.38	3.92
13.00	25.00	82.83	12.11	5.88	3.93
13.00	25.50	82.83	12.11	6.38	3.93
13.00	26.00	82.81	12.11	6.88	3.95
13.00	26.50	82.81	12.11	7.38	3.95
13.00	27.00	82.78	12.11	7.88	3.98
13.00	27.50	82.80	12.11	8.38	3.96
13.00	28.00	82.81	12.11	8.88	3.95
13.00	28.49	82.78	12.11	9.37	3.98
13.00	29.00	82.80	12.11	9.88	3.96
13.50	20.55	82.86	12.61	1.43	3.90
13.50	21.00	82.85	12.61	1.88	3.91
13.50	21.50	82.87	12.61	2.38	3.89
13.50	22.00	82.86	12.61	2.88	3.90
13.50	22.50	82.82	12.61	3.38	3.94

DFE Contour Data

Run # : 2
Duration : 0 min
Rod Length : 1.33 ft

Observed Data			Adj. to DFE coordinate sys.		
X [ft]	Y [ft]	Z [ft]	X [ft]	Y [ft]	Z [ft]
13.50	23.00	82.81	12.61	3.88	3.95
13.50	23.50	82.81	12.61	4.38	3.95
13.50	24.00	82.83	12.61	4.88	3.93
13.50	24.50	82.82	12.61	5.38	3.94
13.50	25.00	82.82	12.61	5.88	3.94
13.50	25.50	82.84	12.61	6.38	3.92
13.50	25.99	82.79	12.61	6.87	3.97
13.50	26.50	82.79	12.61	7.38	3.97
13.50	27.00	82.77	12.61	7.88	3.99
13.50	27.49	82.78	12.61	8.37	3.98
13.50	28.00	82.76	12.61	8.88	4.00
13.50	28.50	82.78	12.61	9.38	3.98
13.50	29.00	82.81	12.61	9.88	3.95

DFE Contour Data

Run # : 2
Duration : 15 min
Rod Length : 0.39 ft
Note: all measurements in feet

Observed Data X	Observed Data Y	Observed Data Z	Adj. to DFE coordinate sys. X	Adj. Y	Adj. Z	Adj. dZ
2.00	20.55	82.90	1.11	1.43	3.86	0.136
2.00	20.99	82.88	1.11	1.87	3.88	0.116
2.00	21.50	82.85	1.11	2.38	3.91	0.086
2.00	22.00	82.74	1.11	2.88	4.02	-0.024
2.00	22.50	82.73	1.11	3.38	4.03	-0.034
2.00	23.00	82.69	1.11	3.88	4.07	-0.074
2.00	23.50	82.69	1.11	4.38	4.07	-0.074
2.00	23.99	82.87	1.11	4.87	3.89	0.106
2.00	24.50	82.89	1.11	5.38	3.87	0.126
2.00	25.00	82.88	1.11	5.88	3.88	0.116
2.00	25.50	82.92	1.11	6.38	3.84	0.156
2.00	25.99	82.91	1.11	6.87	3.85	0.146
2.00	26.49	82.99	1.11	7.37	3.77	0.226
2.00	27.00	83.08	1.11	7.88	3.68	0.316
2.00	27.50	83.15	1.11	8.38	3.61	0.386
2.00	27.99	83.17	1.11	8.87	3.59	0.406
2.00	28.50	83.18	1.11	9.38	3.58	0.416
2.00	29.00	83.14	1.11	9.88	3.62	0.376
2.50	20.55	82.87	1.61	1.43	3.89	0.106
2.50	21.00	82.85	1.61	1.88	3.91	0.086
2.50	21.50	82.79	1.61	2.38	3.97	0.026
2.50	21.99	82.65	1.61	2.87	4.11	-0.114
2.50	22.50	82.72	1.61	3.38	4.04	-0.044
2.50	22.99	82.91	1.61	3.87	3.85	0.146
2.50	23.50	82.95	1.61	4.38	3.81	0.186
2.50	24.00	83.01	1.61	4.88	3.75	0.246
2.50	24.49	83.00	1.61	5.37	3.76	0.236
2.50	25.00	82.99	1.61	5.88	3.77	0.226
2.50	25.50	82.97	1.61	6.38	3.79	0.206
2.50	26.00	82.98	1.61	6.88	3.78	0.216
2.50	26.50	83.02	1.61	7.38	3.74	0.256
2.50	27.00	83.03	1.61	7.88	3.73	0.266
2.50	27.50	83.00	1.61	8.38	3.76	0.236
2.50	27.99	82.94	1.61	8.87	3.82	0.176
2.50	28.50	82.91	1.61	9.38	3.85	0.146
2.50	29.00	82.92	1.61	9.88	3.84	0.156
3.00	20.55	82.79	2.11	1.43	3.97	0.026
3.00	21.00	82.80	2.11	1.88	3.96	0.036
3.00	21.64	82.70	2.11	2.52	4.06	-0.064
3.00	21.99	82.75	2.11	2.87	4.01	-0.014
3.00	22.50	82.90	2.11	3.38	3.86	0.136
3.00	23.00	82.99	2.11	3.88	3.77	0.226
3.00	23.50	83.10	2.11	4.38	3.66	0.336

Observed Data				Adj. to DFE coordinate sys.			
X	Y	Z		X	Y	Z	dZ
3.00	24.00	83.16		2.11	4.88	3.60	0.396
3.00	24.50	83.18		2.11	5.38	3.58	0.416
3.00	25.00	83.18		2.11	5.88	3.58	0.416
3.00	25.50	83.16		2.11	6.38	3.60	0.396
3.00	26.00	83.13		2.11	6.88	3.63	0.366
3.00	26.50	83.11		2.11	7.38	3.65	0.346
3.00	27.00	83.04		2.11	7.88	3.72	0.276
3.00	27.50	82.95		2.11	8.38	3.81	0.186
3.00	28.00	82.91		2.11	8.88	3.85	0.146
3.00	28.50	82.88		2.11	9.38	3.88	0.116
3.00	29.00	82.92		2.11	9.88	3.84	0.156
3.50	20.55	82.78		2.61	1.43	3.98	0.016
3.50	21.00	82.69		2.61	1.88	4.07	-0.074
3.50	21.49	82.77		2.61	2.37	3.99	0.006
3.50	21.99	82.97		2.61	2.87	3.79	0.206
3.50	22.50	83.13		2.61	3.38	3.63	0.366
3.50	23.00	83.28		2.61	3.88	3.48	0.516
3.50	23.50	83.37		2.61	4.38	3.39	0.606
3.50	24.00	83.43		2.61	4.88	3.33	0.666
3.50	24.49	83.41		2.61	5.37	3.35	0.646
3.50	25.00	83.39		2.61	5.88	3.37	0.626
3.50	25.50	83.34		2.61	6.38	3.42	0.576
3.50	26.00	83.29		2.61	6.88	3.47	0.526
3.50	26.50	83.23		2.61	7.38	3.53	0.466
3.50	27.00	83.16		2.61	7.88	3.60	0.396
3.50	27.49	83.09		2.61	8.37	3.67	0.326
3.50	28.00	83.00		2.61	8.88	3.76	0.236
3.50	28.50	82.93		2.61	9.38	3.83	0.166
3.50	29.00	82.94		2.61	9.88	3.82	0.176
4.00	20.55	82.81		3.11	1.43	3.95	0.046
4.00	21.07	82.75		3.11	1.95	4.01	-0.014
4.00	21.50	82.99		3.11	2.38	3.77	0.226
4.00	22.00	83.22		3.11	2.88	3.54	0.456
4.00	22.50	83.41		3.11	3.38	3.35	0.646
4.00	23.00	83.53		3.11	3.88	3.23	0.766
4.00	23.50	83.69		3.11	4.38	3.07	0.926
4.00	24.00	83.73		3.11	4.88	3.03	0.966
4.00	24.50	83.71		3.11	5.38	3.05	0.946
4.00	24.70	83.68		3.11	5.58	3.08	0.916
4.00	25.50	83.61		3.11	6.38	3.15	0.846
4.00	25.97	83.49		3.11	6.85	3.27	0.726
4.00	26.50	83.46		3.11	7.38	3.30	0.696
4.00	27.00	83.46		3.11	7.88	3.30	0.696
4.00	27.47	83.30		3.11	8.35	3.46	0.536
4.00	28.00	83.16		3.11	8.88	3.60	0.396
4.00	28.49	83.02		3.11	9.37	3.74	0.256
4.00	29.00	82.96		3.11	9.88	3.80	0.196
4.65	20.55	81.88		3.76	1.43	3.96	0.036
4.65	20.68	81.86		3.76	1.56	3.98	0.016

od length: 1 ft

Observed Data			Adj. to DFE coordinate sys.			
X	Y	Z	X	Y	Z	dZ
4.65	21.00	81.99	3.76	1.88	3.85	0.146
4.65	21.50	82.29	3.76	2.38	3.55	0.446
4.65	22.00	82.56	3.76	2.88	3.28	0.716
4.65	22.47	82.79	3.76	3.35	3.05	0.946
4.65	22.98	83.01	3.76	3.86	2.83	1.166
4.65	23.50	83.18	3.76	4.38	2.66	1.336
4.65	23.98	83.25	3.76	4.86	2.59	1.406
4.65	24.49	83.20	3.76	5.37	2.64	1.356
4.65	25.00	83.16	3.76	5.88	2.68	1.316
4.65	25.50	83.03	3.76	6.38	2.81	1.186
4.65	26.00	82.85	3.76	6.88	2.99	1.006
4.65	26.50	82.79	3.76	7.38	3.05	0.946
4.65	27.00	82.75	3.76	7.88	3.09	0.906
4.65	27.50	82.59	3.76	8.38	3.25	0.746
4.65	28.00	82.37	3.76	8.88	3.47	0.526
4.65	28.69	82.13	3.76	9.57	3.71	0.286
4.65	29.00	82.11	3.76	9.88	3.73	0.266
5.00	20.55	81.92	4.11	1.43	3.92	0.076
5.00	21.00	82.08	4.11	1.88	3.76	0.236
5.00	21.50	82.35	4.11	2.38	3.49	0.506
5.00	22.00	82.64	4.11	2.88	3.20	0.796
5.00	22.50	82.93	4.11	3.38	2.91	1.086
5.00	23.00	83.19	4.11	3.88	2.65	1.346
5.00	23.50	83.38	4.11	4.38	2.46	1.536
5.00	24.00	83.44	4.11	4.88	2.40	1.598
5.00	24.50	83.40	4.11	5.38	2.44	1.556
5.00	25.00	83.32	4.11	5.88	2.52	1.476
5.00	25.50	83.18	4.11	6.38	2.66	1.336
5.00	26.00	83.00	4.11	6.88	2.84	1.156
5.00	26.50	82.95	4.11	7.38	2.89	1.106
5.00	27.00	82.81	4.11	7.88	3.03	0.966
5.00	27.50	82.64	4.11	8.38	3.20	0.796
5.00	28.00	82.44	4.11	8.88	3.40	0.596
5.00	28.49	82.29	4.11	9.37	3.55	0.446
5.00	29.00	82.19	4.11	9.88	3.65	0.346
5.50	20.55	82.01	4.61	1.43	3.83	0.166
5.50	20.99	82.17	4.61	1.87	3.67	0.326
5.50	21.50	82.42	4.61	2.38	3.42	0.576
5.50	22.00	82.71	4.61	2.88	3.13	0.866
5.50	22.50	83.01	4.61	3.38	2.83	1.166
5.50	23.00	83.30	4.61	3.88	2.54	1.456
5.50	23.49	83.48	4.61	4.37	2.36	1.636
5.50	24.00	83.59	4.61	4.88	2.25	1.746
5.50	24.50	83.66	4.61	5.38	2.18	1.816
5.50	25.00	83.56	4.61	5.88	2.28	1.716
5.50	25.45	83.33	4.61	6.33	2.51	1.486
5.50	26.00	83.13	4.61	6.88	2.71	1.286
5.50	26.50	83.09	4.61	7.38	2.75	1.246
5.50	27.00	82.97	4.61	7.88	2.87	1.126

Observed Data			Adj. to DFE coordinate sys.			
X	Y	Z	X	Y	Z	dZ
5.50	27.50	82.74	4.61	8.38	3.10	0.896
5.50	28.00	82.53	4.61	8.88	3.31	0.686
5.50	28.50	82.33	4.61	9.38	3.51	0.486
5.50	29.00	82.27	4.61	9.88	3.57	0.426
6.00	20.55	82.13	5.11	1.43	3.71	0.286
6.00	21.00	82.19	5.11	1.88	3.65	0.346
6.00	21.50	82.39	5.11	2.38	3.45	0.546
6.00	21.99	82.67	5.11	2.87	3.17	0.826
6.00	22.50	82.98	5.11	3.38	2.86	1.136
6.00	23.00	83.26	5.11	3.88	2.58	1.416
6.00	23.50	83.44	5.11	4.38	2.40	1.596
6.00	23.99	83.62	5.11	4.87	2.22	1.776
6.00	24.49	83.75	5.11	5.37	2.09	1.906
6.00	25.00	83.70	5.11	5.88	2.14	1.856
6.00	25.49	83.40	5.11	6.37	2.44	1.556
6.00	26.00	83.69	5.11	6.88	2.15	1.846
6.00	26.50	83.07	5.11	7.38	2.77	1.226
6.00	27.00	83.01	5.11	7.88	2.83	1.166
6.00	27.49	82.78	5.11	8.37	3.06	0.936
6.00	27.99	82.52	5.11	8.87	3.32	0.676
6.00	28.50	82.39	5.11	9.38	3.45	0.546
6.00	29.00	82.24	5.11	9.88	3.60	0.396
6.50	20.55	82.12	5.61	1.43	3.72	0.276
6.50	21.00	82.21	5.61	1.88	3.63	0.366
6.50	21.50	82.40	5.61	2.38	3.44	0.556
6.50	22.00	82.62	5.61	2.88	3.22	0.776
6.50	22.50	82.94	5.61	3.38	2.90	1.096
6.50	23.00	83.19	5.61	3.88	2.65	1.346
6.50	23.50	83.38	5.61	4.38	2.46	1.536
6.50	24.00	83.57	5.61	4.88	2.27	1.726
6.50	24.50	83.58	5.61	5.38	2.26	1.736
6.50	24.99	83.48	5.61	5.87	2.36	1.636
6.50	25.49	83.22	5.61	6.37	2.62	1.376
6.50	25.99	83.05	5.61	6.87	2.79	1.206
6.50	26.50	82.98	5.61	7.38	2.86	1.136
6.50	27.00	82.79	5.61	7.88	3.05	0.946
6.50	27.50	82.73	5.61	8.38	3.11	0.886
6.50	28.00	82.54	5.61	8.88	3.30	0.696
6.50	28.49	82.38	5.61	9.37	3.46	0.536
6.50	29.00	82.38	5.61	9.88	3.46	0.536
7.00	20.55	82.13	6.11	1.43	3.71	0.286
7.00	21.00	82.19	6.11	1.88	3.65	0.346
7.00	21.50	82.36	6.11	2.38	3.48	0.516
7.00	22.00	82.53	6.11	2.88	3.31	0.686
7.00	22.50	82.77	6.11	3.38	3.07	0.926
7.00	23.00	83.00	6.11	3.88	2.84	1.156
7.00	23.50	83.50	6.11	4.38	2.34	1.656
7.00	24.00	83.22	6.11	4.88	2.62	1.376
7.00	24.50	83.27	6.11	5.38	2.57	1.426

* The maximum depth for this run

Observed Data			Adj. to DFE coordinate sys.			
X	Y	Z	X	Y	Z	dZ
7.00	25.00	83.13	6.11	5.88	2.71	1.286
7.00	25.50	82.98	6.11	6.38	2.86	1.136
7.00	26.00	82.81	6.11	6.88	3.03	0.966
7.00	26.50	82.77	6.11	7.38	3.07	0.926
7.00	27.00	82.62	6.11	7.88	3.22	0.776
7.00	27.50	82.53	6.11	8.38	3.31	0.686
7.00	28.00	82.36	6.11	8.88	3.48	0.516
7.00	28.49	82.38	6.11	9.37	3.46	0.536
7.00	29.00	82.47	6.11	9.88	3.37	0.626
7.50	20.55	82.18	6.61	1.43	3.66	0.336
7.50	20.82	82.11	6.61	1.70	3.73	0.266
7.50	21.50	82.33	6.61	2.38	3.51	0.486
7.50	22.00	82.46	6.61	2.88	3.38	0.616
7.50	22.50	82.60	6.61	3.38	3.24	0.756
7.50	23.00	82.76	6.61	3.88	3.08	0.916
7.50	23.50	82.85	6.61	4.38	2.99	1.006
7.50	24.00	82.95	6.61	4.88	2.89	1.106
7.50	24.50	82.95	6.61	5.38	2.89	1.106
7.50	25.00	82.93	6.61	5.88	2.91	1.086
7.50	25.50	82.77	6.61	6.38	3.07	0.926
7.50	26.00	82.61	6.61	6.88	3.23	0.766
7.50	26.50	82.52	6.61	7.38	3.32	0.676
7.50	27.00	82.44	6.61	7.88	3.40	0.596
7.50	27.49	82.32	6.61	8.37	3.52	0.476
7.50	28.00	82.30	6.61	8.88	3.54	0.456
7.50	28.50	82.40	6.61	9.38	3.44	0.556
7.50	28.99	82.47	6.61	9.87	3.37	0.626
8.00	20.55	82.25	7.11	1.43	3.59	0.406
8.00	21.03	82.17	7.11	1.91	3.67	0.326
8.00	21.50	82.28	7.11	2.38	3.56	0.436
8.00	21.98	82.39	7.11	2.86	3.45	0.546
8.00	22.50	82.46	7.11	3.38	3.38	0.616
8.00	23.00	82.53	7.11	3.88	3.31	0.686
8.00	23.50	82.64	7.11	4.38	3.20	0.796
8.00	24.00	82.71	7.11	4.88	3.13	0.866
8.00	24.50	82.67	7.11	5.38	3.17	0.826
8.00	25.00	82.66	7.11	5.88	3.18	0.816
8.00	25.50	82.57	7.11	6.38	3.27	0.726
8.00	25.98	82.47	7.11	6.86	3.37	0.626
8.00	26.50	82.37	7.11	7.38	3.47	0.526
8.00	27.00	82.30	7.11	7.88	3.54	0.456
8.00	27.50	82.27	7.11	8.38	3.57	0.426
8.00	28.00	82.31	7.11	8.88	3.53	0.466
8.00	28.49	82.42	7.11	9.37	3.42	0.576
8.00	29.00	82.49	7.11	9.88	3.35	0.646
8.50	20.55	82.34	7.61	1.43	3.50	0.496
8.50	21.00	82.11	7.61	1.88	3.73	0.266
8.50	21.50	82.22	7.61	2.38	3.62	0.376
8.50	22.00	82.26	7.61	2.88	3.58	0.416

Observed Data				Adj. to DFE coordinate sys.		
X	Y	Z	X	Y	Z	dZ
8.50	22.50	82.30	7.61	3.38	3.54	0.456
8.50	23.00	82.36	7.61	3.88	3.48	0.516
8.50	23.50	82.37	7.61	4.38	3.47	0.526
8.50	23.99	82.38	7.61	4.87	3.46	0.536
8.50	24.48	82.43	7.61	5.36	3.41	0.586
8.50	24.99	82.43	7.61	5.87	3.41	0.586
8.50	25.49	82.34	7.61	6.37	3.50	0.496
8.50	26.00	82.28	7.61	6.88	3.56	0.436
8.50	26.50	82.22	7.61	7.38	3.62	0.376
8.50	27.00	82.17	7.61	7.88	3.67	0.326
8.50	27.50	82.22	7.61	8.38	3.62	0.376
8.50	28.00	82.24	7.61	8.88	3.60	0.396
8.50	28.50	82.34	7.61	9.38	3.50	0.496
8.50	29.00	82.46	7.61	9.88	3.38	0.616
9.00	20.55	82.19	8.11	1.43	3.65	0.346
9.00	21.00	82.07	8.11	1.88	3.77	0.226
9.00	21.50	82.08	8.11	2.38	3.76	0.236
9.00	22.00	82.11	8.11	2.88	3.73	0.266
9.00	22.50	82.13	8.11	3.38	3.71	0.286
9.00	23.00	82.12	8.11	3.88	3.72	0.276
9.00	23.50	82.12	8.11	4.38	3.72	0.276
9.00	24.00	82.15	8.11	4.88	3.69	0.306
9.00	24.50	82.18	8.11	5.38	3.66	0.336
9.00	25.00	82.15	8.11	5.88	3.69	0.306
9.00	25.50	82.14	8.11	6.38	3.70	0.296
9.00	26.00	82.11	8.11	6.88	3.73	0.266
9.00	26.50	82.00	8.11	7.38	3.84	0.156
9.00	27.00	82.05	8.11	7.88	3.79	0.206
9.00	27.50	82.12	8.11	8.38	3.72	0.276
9.00	28.00	82.14	8.11	8.88	3.70	0.296
9.00	28.50	82.22	8.11	9.38	3.62	0.376
9.00	29.00	82.36	8.11	9.88	3.48	0.516
9.50	20.55	82.13	8.61	1.43	3.71	0.286
9.50	21.50	81.50	8.61	2.38	4.34	-0.344
9.50	22.50	81.97	8.61	3.38	3.87	0.126
9.50	23.50	81.98	8.61	4.38	3.86	0.136
9.50	24.50	82.00	8.61	5.38	3.84	0.156
9.50	25.50	81.96	8.61	6.38	3.88	0.116
9.50	26.50	81.91	8.61	7.38	3.93	0.066
9.50	27.50	81.97	8.61	8.38	3.87	0.126
9.50	28.00	82.07	8.61	8.88	3.77	0.226
9.50	28.50	82.10	8.61	9.38	3.74	0.256
9.50	29.00	82.26	8.61	9.88	3.58	0.416
10.50	20.55	81.89	9.61	1.43	3.95	0.046
10.50	21.02	81.63	9.61	1.90	4.21	-0.214
10.50	21.50	81.68	9.61	2.38	4.16	-0.164
10.50	22.50	81.70	9.61	3.38	4.14	-0.144
10.50	23.50	81.68	9.61	4.38	4.16	-0.164
10.50	24.50	81.67	9.61	5.38	4.17	-0.174

DFE Contour Data

Run # : 2
Duration : 15 min
Rod Length : 0.39 ft
Note: all measurements in feet

Observed Data			Adj. to DFE coordinate sys.			
X	Y	Z	X	Y	Z	dZ
10.50	25.50	81.68	9.61	6.38	4.16	-0.164
10.50	26.50	81.67	9.61	7.38	4.17	-0.174
10.50	27.50	81.81	9.61	8.38	4.03	-0.034
10.50	28.50	81.90	9.61	9.38	3.94	0.056
10.50	29.00	82.14	9.61	9.88	3.70	0.296
11.50	20.55	81.79	10.61	1.43	4.05	-0.054
11.50	21.06	81.48	10.61	1.94	4.36	-0.364
11.50	21.50	81.48	10.61	2.38	4.36	-0.364
11.50	22.50	81.50	10.61	3.38	4.34	-0.344
11.50	23.50	81.55	10.61	4.38	4.29	-0.294
11.50	24.50	81.57	10.61	5.38	4.27	-0.274
11.50	25.50	81.59	10.61	6.38	4.25	-0.254
11.50	26.50	81.52	10.61	7.38	4.32	-0.324
11.50	27.49	81.61	10.61	8.37	4.23	-0.234
11.50	28.44	81.68	10.61	9.32	4.16	-0.164
11.50	29.00	81.95	10.61	9.88	3.89	0.106
12.50	20.55	81.93	11.61	1.43	3.91	0.086
12.50	21.30	81.45	11.61	2.18	4.39	-0.394
12.50	22.00	81.46	11.61	2.88	4.38	-0.384
12.50	22.50	81.48	11.61	3.38	4.36	-0.364
12.50	23.50	81.48	11.61	4.38	4.36	-0.364
12.50	24.50	81.48	11.61	5.38	4.36	-0.364
12.50	25.50	81.48	11.61	6.38	4.36	-0.364
12.50	26.50	81.50	11.61	7.38	4.34	-0.344
12.50	27.50	81.51	11.61	8.38	4.33	-0.334
12.50	28.50	81.56	11.61	9.38	4.28	-0.284
12.50	28.72	81.60	11.61	9.60	4.24	-0.244
12.50	29.00	81.74	11.61	9.88	4.10	-0.104
13.50	20.55	81.90	12.61	1.43	3.94	0.056
13.50	20.81	81.75	12.61	1.69	4.09	-0.094
13.50	21.00	81.70	12.61	1.88	4.14	-0.144
13.50	21.62	81.46	12.61	2.50	4.38	-0.384
13.50	22.50	81.47	12.61	3.38	4.37	-0.374
13.50	23.50	81.48	12.61	4.38	4.36	-0.364
13.50	24.50	81.46	12.61	5.38	4.38	-0.384
13.50	25.50	81.46	12.61	6.38	4.38	-0.384
13.50	26.50	81.49	12.61	7.38	4.35	-0.354
13.50	27.50	81.50	12.61	8.38	4.34	-0.344
13.50	28.56	81.52	12.61	9.44	4.32	-0.324
13.50	29.00	81.64	12.61	9.88	4.20	-0.204

DFE Contour Data

Run # : 2
Duration : 30 min
Rod Length : 0.40 ft (revised: TL 2/23/95)
Mean Depth: 3.64
Max Scour: 1.91 ft

Observed Data X [ft]	Observed Data Y [ft]	Observed Data Z [ft]	Adj. to DFE coordinate sys. X [ft]	Adj. Y [ft]	Adj. Z [ft]	dZ [ft]	
2.00	20.55	83.18	1.11	1.43	3.57	0.426	1.836 dmax
2.00	22.91	82.96	1.11	3.79	3.79	0.206	
2.00	23.28	83.01	1.11	4.16	3.74	0.256	
2.00	24.45	83.00	1.11	5.33	3.75	0.246	
2.00	24.62	83.07	1.11	5.50	3.68	0.316	
2.00	25.20	82.50	1.11	6.08	4.25	-0.254	
2.00	26.27	82.95	1.11	7.15	3.80	0.196	
2.00	27.70	83.18	1.11	8.58	3.57	0.426	
2.00	29.03	83.24	1.11	9.91	3.51	0.486	
2.43	21.00	83.18	1.54	1.88	3.57	0.426	
2.43	22.23	82.89	1.54	3.11	3.86	0.136	
2.43	23.50	83.00	1.54	4.38	3.75	0.246	
2.43	24.63	83.05	1.54	5.51	3.70	0.296	
2.43	25.80	82.83	1.54	6.68	3.92	0.076	
2.43	26.89	82.98	1.54	7.77	3.77	0.226	
2.43	28.20	83.01	1.54	9.08	3.74	0.256	
2.43	29.30	83.05	1.54	10.18	3.70	0.296	
2.70	20.55	83.18	1.81	1.43	3.57	0.426	
2.70	21.21	83.15	1.81	2.09	3.60	0.396	
2.70	21.87	82.90	1.81	2.75	3.85	0.146	
2.70	22.25	82.86	1.81	3.13	3.89	0.106	
2.70	23.18	82.95	1.81	4.06	3.80	0.196	
2.70	23.87	83.07	1.81	4.75	3.68	0.316	
2.70	24.69	83.10	1.81	5.57	3.65	0.346	
2.70	25.94	82.92	1.81	6.82	3.83	0.166	
2.70	27.05	82.94	1.81	7.93	3.81	0.186	
2.70	28.06	82.87	1.81	8.94	3.88	0.116	
2.70	29.03	82.98	1.81	9.91	3.77	0.226	
3.00	20.55	83.12	2.11	1.43	3.63	0.366	
3.00	21.25	83.05	2.11	2.13	3.70	0.296	
3.00	21.96	82.85	2.11	2.84	3.90	0.096	
3.00	23.31	83.05	2.11	4.19	3.70	0.296	
3.00	24.33	83.58	2.11	5.21	3.17	0.826	
3.00	25.96	83.02	2.11	6.84	3.73	0.266	
3.00	26.68	83.01	2.11	7.56	3.74	0.256	
3.00	28.11	82.89	2.11	8.99	3.86	0.136	
3.00	29.03	82.97	2.11	9.91	3.78	0.216	
4.00	20.55	83.01	3.11	1.43	3.74	0.256	
4.00	21.24	82.88	3.11	2.12	3.87	0.126	
4.00	21.58	82.84	3.11	2.46	3.91	0.086	
4.00	22.84	83.24	3.11	3.72	3.51	0.486	

Observed Data			Adj. to DFE coordinate sys.				
X [ft]	Y [ft]	Z [ft]	X [ft]	Y [ft]	Z [ft]	dZ [ft]	
4.00	23.75	83.39	3.11	4.63	3.36	0.636	
4.00	24.74	83.40	3.11	5.62	3.35	0.646	
4.00	25.76	83.26	3.11	6.64	3.49	0.506	
4.00	26.67	83.16	3.11	7.55	3.59	0.406	
4.00	27.68	83.08	3.11	8.56	3.67	0.326	
4.00	28.75	82.94	3.11	9.63	3.81	0.186	
4.50	20.55	83.12	3.61	1.43	3.63	0.366	
4.50	21.07	83.02	3.61	1.95	3.73	0.266	
4.50	21.65	83.22	3.61	2.53	3.53	0.466	
4.50	22.89	83.82	3.61	3.77	2.93	1.066	
4.50	25.90	83.76	3.61	6.78	2.99	1.006	
4.50	27.19	83.52	3.61	8.07	3.23	0.766	
4.50	27.96	83.29	3.61	8.84	3.46	0.536	
4.50	28.89	83.04	3.61	9.77	3.71	0.286	
4.50	29.03	83.00	3.61	9.91	3.75	0.246	
5.00	20.55	82.19	4.11	1.43	3.65	0.346	New length 1.3 ft
5.00	20.89	82.13	4.11	1.77	3.71	0.286	vised: TL 2/23/95)
5.00	21.64	82.40	4.11	2.52	3.44	0.556	
5.00	23.35	83.32	4.11	4.23	2.52	1.476	
5.00	24.40	83.41	4.11	5.28	2.43	1.566	
5.00	25.05	83.29	4.11	5.93	2.55	1.446	
5.00	25.43	83.15	4.11	6.31	2.69	1.306	
5.00	25.95	83.00	4.11	6.83	2.84	1.156	
5.00	26.85	82.90	4.11	7.73	2.94	1.056	
5.00	27.54	82.60	4.11	8.42	3.24	0.756	
5.00	28.14	82.38	4.11	9.02	3.46	0.536	
5.00	28.89	82.15	4.11	9.77	3.69	0.306	
5.50	20.55	82.14	4.61	1.43	3.70	0.296	
5.50	20.98	82.19	4.61	1.86	3.65	0.346	
5.50	23.44	83.43	4.61	4.32	2.41	1.586	
5.50	24.27	83.59	4.61	5.15	2.25	1.746	
5.50	25.10	83.43	4.61	5.98	2.41	1.586	
5.50	25.90	83.12	4.61	6.78	2.72	1.276	
5.50	26.87	83.02	4.61	7.75	2.82	1.176	
5.50	27.50	82.63	4.61	8.38	3.21	0.786	
5.50	28.25	82.47	4.61	9.13	3.37	0.626	
5.50	28.84	82.16	4.61	9.72	3.68	0.316	
5.50	29.03	82.21	4.61	9.91	3.63	0.366	
6.00	20.55	82.18	5.11	1.43	3.66	0.336	
6.00	20.79	82.19	5.11	1.67	3.65	0.346	
6.00	23.28	83.35	5.11	4.16	2.49	1.506	
6.00	24.22	83.56	5.11	5.10	2.28	1.716	
6.00	24.89	83.68	5.11	5.77	2.16	1.836	* maximum depth
6.00	25.64	83.32	5.11	6.52	2.52	1.476	
6.00	26.87	83.05	5.11	7.75	2.79	1.206	
6.00	27.74	82.63	5.11	8.62	3.21	0.786	
6.00	28.30	82.49	5.11	9.18	3.35	0.646	
6.00	28.92	82.29	5.11	9.80	3.55	0.446	

Observed Data			Adj. to DFE coordinate sys.			
X [ft]	Y [ft]	Z [ft]	X [ft]	Y [ft]	Z [ft]	dZ [ft]
6.50	20.55	82.32	5.61	1.43	3.52	0.476
6.50	20.90	82.27	5.61	1.78	3.57	0.426
6.50	21.30	82.33	5.61	2.18	3.51	0.488
6.50	22.12	82.67	5.61	3.00	3.17	0.826
6.50	23.14	83.15	5.61	4.02	2.69	1.306
6.50	23.70	83.38	5.61	4.58	2.46	1.536
6.50	24.50	83.45	5.61	5.38	2.39	1.606
6.50	25.00	83.52	5.61	5.88	2.32	1.676
6.50	25.44	82.32	5.61	6.32	3.52	0.476
6.50	25.65	83.11	5.61	6.53	2.73	1.266
6.50	26.07	82.91	5.61	6.95	2.93	1.066
6.50	26.88	82.78	5.61	7.76	3.06	0.936
6.50	27.40	82.68	5.61	8.28	3.16	0.836
6.50	27.80	82.47	5.61	8.68	3.37	0.626
6.50	28.70	82.28	5.61	9.58	3.56	0.436
6.50	29.00	82.29	5.61	9.88	3.55	0.446
7.00	20.55	82.48	6.11	1.43	3.36	0.636
7.00	21.66	82.44	6.11	2.54	3.40	0.596
7.00	22.48	82.74	6.11	3.36	3.10	0.896
7.00	23.38	83.08	6.11	4.26	2.76	1.236
7.00	24.10	83.20	6.11	4.98	2.64	1.356
7.00	24.86	83.17	6.11	5.74	2.67	1.326
7.00	25.63	82.23	6.11	6.51	3.61	0.386
7.00	26.58	82.69	6.11	7.46	3.15	0.846
7.00	27.59	82.54	6.11	8.47	3.30	0.696
7.00	28.40	82.34	6.11	9.28	3.50	0.496
7.00	29.00	82.38	6.11	9.88	3.46	0.536
7.50	20.55	82.50	6.61	1.43	3.34	0.656
7.50	20.80	82.40	6.61	1.68	3.44	0.556
7.50	21.27	82.33	6.61	2.15	3.51	0.486
7.50	22.10	82.48	6.61	2.98	3.36	0.636
7.50	23.02	82.73	6.61	3.90	3.11	0.886
7.50	24.00	82.92	6.61	4.88	2.92	1.076
7.50	24.82	82.90	6.61	5.70	2.94	1.056
7.50	25.60	82.74	6.61	6.48	3.10	0.896
7.50	26.20	82.60	6.61	7.08	3.24	0.756
7.50	26.83	82.57	6.61	7.71	3.27	0.726
7.50	27.60	82.38	6.61	8.48	3.46	0.536
7.50	28.17	82.37	6.61	9.05	3.47	0.526
7.50	29.00	82.46	6.61	9.88	3.38	0.616
8.00	20.55	82.47	7.11	1.43	3.37	0.626
8.00	21.18	82.28	7.11	2.06	3.56	0.436
8.00	21.66	82.38	7.11	2.54	3.46	0.536
8.00	22.74	82.46	7.11	3.62	3.38	0.616
8.00	23.46	82.60	7.11	4.34	3.24	0.756
8.00	24.11	82.64	7.11	4.99	3.20	0.796
8.00	24.94	82.60	7.11	5.82	3.24	0.756
8.00	25.80	82.44	7.11	6.68	3.40	0.596

Observed Data			Adj. to DFE coordinate sys.			
X [ft]	Y [ft]	Z [ft]	X [ft]	Y [ft]	Z [ft]	dZ [ft]
8.00	26.41	82.39	7.11	7.29	3.45	0.546
8.00	26.86	82.29	7.11	7.74	3.55	0.446
8.00	27.68	82.34	7.11	8.56	3.50	0.496
8.00	29.00	82.50	7.11	9.88	3.34	0.656
8.50	20.55	82.47	7.61	1.43	3.37	0.626
8.50	20.77	82.33	7.61	1.65	3.51	0.486
8.50	21.53	82.32	7.61	2.41	3.52	0.476
8.50	21.80	82.23	7.61	2.68	3.61	0.386
8.50	22.99	82.32	7.61	3.87	3.52	0.476
8.50	23.30	82.33	7.61	4.18	3.51	0.486
8.50	24.50	82.40	7.61	5.38	3.44	0.556
8.50	24.99	82.30	7.61	5.87	3.54	0.456
8.50	25.50	82.29	7.61	6.38	3.55	0.446
8.50	26.00	82.22	7.61	6.88	3.62	0.376
8.50	26.50	82.21	7.61	7.38	3.63	0.366
8.50	27.00	82.50	7.61	7.88	3.34	0.656
8.50	27.50	82.28	7.61	8.38	3.56	0.436
8.50	28.00	82.34	7.61	8.88	3.50	0.496
8.50	28.50	82.40	7.61	9.38	3.44	0.556
8.50	29.00	82.44	7.61	9.88	3.40	0.596
9.50	20.55	82.36	8.61	1.43	3.48	0.516
9.50	21.00	82.20	8.61	1.88	3.64	0.356
9.50	21.50	82.11	8.61	2.38	3.73	0.266
9.50	22.50	81.98	8.61	3.38	3.86	0.136
9.50	23.50	81.90	8.61	4.38	3.94	0.056
9.50	24.49	81.88	8.61	5.37	3.96	0.036
9.50	25.50	81.93	8.61	6.38	3.91	0.086
9.50	26.50	82.05	8.61	7.38	3.79	0.206
9.50	27.50	82.18	8.61	8.38	3.66	0.336
9.50	28.30	82.34	8.61	9.18	3.50	0.496
9.50	29.00	82.41	8.61	9.88	3.43	0.566
10.50	20.55	82.16	9.61	1.43	3.68	0.316
10.50	21.00	81.93	9.61	1.88	3.91	0.086
10.50	21.49	81.77	9.61	2.37	4.07	-0.074
10.50	22.50	81.70	9.61	3.38	4.14	-0.144
10.50	23.50	81.67	9.61	4.38	4.17	-0.174
10.50	24.49	81.68	9.61	5.37	4.16	-0.164
10.50	25.50	81.71	9.61	6.38	4.13	-0.134
10.50	26.50	81.83	9.61	7.38	4.01	-0.014
10.50	27.50	81.95	9.61	8.38	3.89	0.106
10.50	28.49	82.11	9.61	9.37	3.73	0.266
10.50	29.00	82.28	9.61	9.88	3.56	0.436
11.50	20.55	81.98	10.61	1.43	3.86	0.136
11.50	21.29	81.56	10.61	2.17	4.28	-0.284
11.50	21.50	81.53	10.61	2.38	4.31	-0.314
11.50	22.50	81.50	10.61	3.38	4.34	-0.344
11.50	23.49	81.53	10.61	4.37	4.31	-0.314
11.50	24.50	81.57	10.61	5.38	4.27	-0.274

DFE Contour Data

Run # : 2
Duration : 30 min
Rod Length : 0.40 ft (revised: TL 2/23/95)

Observed Data			Adj. to DFE coordinate sys.			
X [ft]	Y [ft]	Z [ft]	X [ft]	Y [ft]	Z [ft]	dZ [ft]
11.50	25.50	81.58	10.61	6.38	4.26	-0.264
11.50	26.50	81.63	10.61	7.38	4.21	-0.214
11.50	27.50	81.80	10.61	8.38	4.04	-0.044
11.50	28.17	81.83	10.61	9.05	4.01	-0.014
11.50	28.50	81.97	10.61	9.38	3.87	0.126
11.50	29.00	82.16	10.61	9.88	3.68	0.316
12.50	20.55	81.89	11.61	1.43	3.95	0.046
12.50	21.25	81.79	11.61	2.13	4.05	-0.054
12.50	21.50	81.48	11.61	2.38	4.36	-0.364
12.50	22.50	81.48	11.61	3.38	4.36	-0.364
12.50	23.49	81.48	11.61	4.37	4.36	-0.364
12.50	24.50	81.50	11.61	5.38	4.34	-0.344
12.50	25.50	81.51	11.61	6.38	4.33	-0.334
12.50	26.49	81.65	11.61	7.37	4.19	-0.194
12.50	27.50	81.60	11.61	8.38	4.24	-0.244
12.50	28.30	81.68	11.61	9.18	4.16	-0.164
12.50	29.00	81.98	11.61	9.88	3.86	0.136
13.50	20.55	81.97	12.61	1.43	3.87	0.126
13.50	21.50	81.65	12.61	2.38	4.19	-0.194
13.50	21.84	81.49	12.61	2.72	4.35	-0.354
13.50	22.50	81.47	12.61	3.38	4.37	-0.374
13.50	23.50	81.46	12.61	4.38	4.38	-0.384
13.50	24.50	81.48	12.61	5.38	4.36	-0.364
13.50	25.50	81.49	12.61	6.38	4.35	-0.354
13.50	26.50	81.53	12.61	7.38	4.31	-0.314
13.50	27.49	81.61	12.61	8.37	4.23	-0.234
13.50	28.50	81.68	12.61	9.38	4.16	-0.164
13.50	29.00	81.91	12.61	9.88	3.93	0.066

DFE Contour Data

Run # : 2
Duration : 60 min
Rod Length : 0.60 ft (revised: TL 2/23/95)
Mean Depth: 3.58
Max Scour: 1.78 ft

Observed Data X [ft]	Y [ft]	Z [ft]	Adj. to DFE coordinate sys. X [ft]	Y [ft]	Z [ft]	dZ [ft]	
2.00	20.55	83.18	1.11	1.43	3.37	0.626	1.706 dmax
2.00	21.55	83.00	1.11	2.43	3.55	0.446	
2.00	22.18	82.14	1.11	3.06	4.41	-0.414	
2.00	23.15	82.84	1.11	4.03	3.71	0.286	
2.00	25.15	82.93	1.11	6.03	3.62	0.376	
2.00	26.35	82.98	1.11	7.23	3.57	0.426	
2.00	28.00	83.08	1.11	8.88	3.47	0.526	
2.00	29.03	83.13	1.11	9.91	3.42	0.576	
3.00	20.55	83.04	2.11	1.43	3.51	0.486	
3.00	21.00	83.00	2.11	1.88	3.55	0.446	
3.00	22.09	82.83	2.11	2.97	3.72	0.276	
3.00	23.40	82.95	2.11	4.28	3.60	0.396	
3.00	24.26	83.10	2.11	5.14	3.45	0.546	
3.00	24.86	83.04	2.11	5.74	3.51	0.486	
3.00	26.55	82.80	2.11	7.43	3.75	0.246	
3.00	27.80	82.76	2.11	8.68	3.79	0.206	
3.00	29.03	82.86	2.11	9.91	3.69	0.306	
4.00	20.55	83.02	3.11	1.43	3.53	0.466	
4.00	21.13	82.86	3.11	2.01	3.69	0.306	
4.00	21.90	83.01	3.11	2.78	3.54	0.456	
4.00	22.96	83.43	3.11	3.84	3.12	0.876	
4.00	24.32	83.76	3.11	5.20	2.79	1.206	
4.00	25.51	83.65	3.11	6.39	2.90	1.096	
4.00	26.05	83.48	3.11	6.93	3.07	0.926	
4.00	26.78	83.22	3.11	7.66	3.33	0.666	
4.00	28.05	83.60	3.11	8.93	2.95	1.046	
4.00	29.03	82.88	3.11	9.91	3.67	0.326	
5.00	20.55	82.39	4.11	1.43	3.60	0.396	Rod length 1 ft
5.00	21.26	82.44	4.11	2.14	3.55	0.446	
5.00	23.62	83.52	4.11	4.50	2.47	1.526	
5.00	23.86	83.30	4.11	4.74	2.69	1.306	
5.00	24.69	83.51	4.11	5.57	2.48	1.516	
5.00	25.72	83.40	4.11	6.60	2.59	1.406	
5.00	26.68	83.12	4.11	7.56	2.87	1.126	
5.00	27.47	82.89	4.11	8.35	3.10	0.896	
5.00	28.40	82.53	4.11	9.28	3.46	0.536	
5.00	29.03	82.32	4.11	9.91	3.67	0.326	
6.00	20.55	82.64	5.11	1.43	3.35	0.646	
6.00	21.84	82.78	5.11	2.72	3.21	0.786	
6.00	23.06	83.40	5.11	3.94	2.59	1.406	
6.00	23.99	83.55	5.11	4.87	2.44	1.556	
6.00	24.98	83.49	5.11	5.86	2.50	1.496	

Observed Data			Adj. to DFE coordinate sys.				
X [ft]	Y [ft]	Z [ft]	X [ft]	Y [ft]	Z [ft]	dZ [ft]	
6.00	25.90	83.46	5.11	6.78	2.53	1.466	
6.00	26.75	83.22	5.11	7.63	2.77	1.226	
6.00	27.69	82.74	5.11	8.57	3.25	0.746	
6.00	28.50	82.48	5.11	9.38	3.51	0.486	
6.00	29.03	82.33	5.11	9.91	3.66	0.336	
7.00	20.55	82.79	6.11	1.43	3.20	0.796	
7.00	21.14	82.69	6.11	2.02	3.30	0.696	
7.00	21.85	82.66	6.11	2.73	3.33	0.666	
7.00	23.06	83.18	6.11	3.94	2.81	1.186	
7.00	23.98	83.70	6.11	4.86	2.29	1.706	* maximum depth
7.00	24.73	83.35	6.11	5.61	2.64	1.356	
7.00	25.55	83.22	6.11	6.43	2.77	1.226	
7.00	26.50	82.82	6.11	7.38	3.17	0.826	
7.00	27.38	82.67	6.11	8.26	3.32	0.676	
7.00	28.13	82.46	6.11	9.01	3.53	0.466	
7.00	29.03	82.35	6.11	9.91	3.64	0.356	
8.00	20.55	82.79	7.11	1.43	3.20	0.796	
8.00	21.28	82.45	7.11	2.16	3.54	0.456	
8.00	21.60	82.53	7.11	2.48	3.46	0.536	
8.00	23.10	82.67	7.11	3.98	3.32	0.676	
8.00	24.00	82.79	7.11	4.88	3.20	0.796	
8.00	25.01	82.69	7.11	5.89	3.30	0.696	
8.00	26.00	82.62	7.11	6.88	3.37	0.626	
8.00	27.10	82.41	7.11	7.98	3.58	0.416	
8.00	29.03	82.56	7.11	9.91	3.43	0.566	
9.00	20.55	82.82	8.11	1.43	3.17	0.826	
9.00	21.50	82.42	8.11	2.38	3.57	0.426	
9.00	22.26	82.60	8.11	3.14	3.39	0.606	
9.00	23.68	82.26	8.11	4.56	3.73	0.266	
9.00	24.80	82.30	8.11	5.68	3.69	0.306	
9.00	26.40	82.45	8.11	7.28	3.54	0.456	
9.00	27.55	82.40	8.11	8.43	3.59	0.406	
9.00	29.03	82.63	8.11	9.91	3.36	0.636	
10.00	20.55	82.65	9.11	1.43	3.34	0.656	
10.00	22.15	82.00	9.11	3.03	3.99	0.006	
10.00	23.50	82.00	9.11	4.38	3.99	0.006	
10.00	25.00	82.12	9.11	5.88	3.87	0.126	
10.00	26.40	82.26	9.11	7.28	3.73	0.266	
10.00	27.50	82.34	9.11	8.38	3.65	0.346	
10.00	28.49	82.48	9.11	9.37	3.51	0.486	
10.00	29.03	82.65	9.11	9.91	3.34	0.656	
11.00	20.55	82.41	10.11	1.43	3.58	0.416	
11.00	21.90	81.82	10.11	2.78	4.17	-0.174	
11.00	23.00	81.78	10.11	3.88	4.21	-0.214	
11.00	23.70	81.78	10.11	4.58	4.21	-0.214	
11.00	24.65	81.90	10.11	5.53	4.09	-0.094	
11.00	25.70	82.00	10.11	6.58	3.99	0.006	
11.00	27.00	82.15	10.11	7.88	3.84	0.156	

DFE Contour Data

Run # : 2
Duration : 60 min
Rod Length : 0.60 ft (revised: TL 2/23/95)

Observed Data			Adj. to DFE coordinate sys.			
X [ft]	Y [ft]	Z [ft]	X [ft]	Y [ft]	Z [ft]	dZ [ft]
11.00	28.32	82.30	10.11	9.20	3.69	0.306
11.00	29.03	82.51	10.11	9.91	3.48	0.516
12.00	20.55	82.24	11.11	1.43	3.75	0.246
12.00	21.69	81.68	11.11	2.57	4.31	-0.314
12.00	24.00	81.78	11.11	4.88	4.21	-0.214
12.00	26.00	81.93	11.11	6.88	4.06	-0.064
12.00	28.00	82.17	11.11	8.88	3.82	0.176
12.00	29.03	82.44	11.11	9.91	3.55	0.446
13.50	20.55	82.04	12.61	1.43	3.95	0.046
13.50	21.33	81.66	12.61	2.21	4.33	-0.334
13.50	23.20	81.61	12.61	4.08	4.38	-0.384
13.50	24.84	81.68	12.61	5.72	4.31	-0.314
13.50	26.00	81.72	12.61	6.88	4.27	-0.274
13.50	27.81	81.94	12.61	8.69	4.05	-0.054
13.50	29.03	82.28	12.61	9.91	3.71	0.286

DFE Contour Data

Run # : 2
Duration : 120 min
Rod Length : 1.16 ft

Observed Data X [ft]	Y [ft]	Z [ft]	Adj. to DFE coordinate sys. X [ft]	Y [ft]	Z [ft]	dZ [ft]
2.00	20.55	82.67	1.11	1.43	3.32	0.676
2.00	22.26	82.44	1.11	3.14	3.55	0.446
2.00	23.75	82.33	1.11	4.63	3.66	0.336
2.00	26.30	82.64	1.11	7.18	3.35	0.646
2.00	29.03	82.68	1.11	9.91	3.31	0.686
3.00	20.55	82.57	2.11	1.43	3.42	0.576
3.00	21.83	82.40	2.11	2.71	3.59	0.406
3.00	23.74	82.58	2.11	4.62	3.41	0.586
3.00	25.50	82.40	2.11	6.38	3.59	0.406
3.00	27.26	82.22	2.11	8.14	3.77	0.226
3.00	29.03	82.35	2.11	9.91	3.64	0.356
4.00	20.55	82.53	3.11	1.43	3.46	0.536
4.00	21.21	82.40	3.11	2.09	3.59	0.406
4.00	22.92	82.92	3.11	3.80	3.07	0.926
4.00	24.56	83.04	3.11	5.44	2.95	1.046
4.00	26.80	82.76	3.11	7.68	3.23	0.766
4.00	27.14	82.67	3.11	8.02	3.32	0.676
4.00	29.03	82.33	3.11	9.91	3.66	0.336
4.50	20.55	82.46	3.61	1.43	3.53	0.466
4.50	21.01	82.42	3.61	1.89	3.57	0.426
4.50	22.08	82.81	3.61	2.96	3.18	0.816
4.50	23.22	83.30	3.61	4.10	2.69	1.306
4.50	24.88	83.29	3.61	5.76	2.70	1.296
4.50	26.20	83.00	3.61	7.08	2.99	1.006
4.50	27.58	82.73	3.61	8.46	3.26	0.736
4.50	29.03	82.35	3.61	9.91	3.64	0.356
5.00	20.55	82.40	4.11	1.43	3.59	0.406
5.00	21.26	82.48	4.11	2.14	3.51	0.486
5.00	23.35	83.53	4.11	4.23	2.46	1.536
5.00	24.87	83.56	4.11	5.75	2.43	1.566
5.00	26.10	83.20	4.11	6.98	2.79	1.206
5.00	27.42	82.97	4.11	8.30	3.02	0.976
5.00	29.03	82.38	4.11	9.91	3.61	0.386
5.50	20.55	82.68	4.61	1.43	3.31	0.686
5.50	21.85	82.88	4.61	2.73	3.11	0.886
5.50	23.18	83.55	4.61	4.06	2.44	1.556
5.50	24.00	83.78	4.61	4.88	2.21	1.786
5.50	25.56	83.70	4.61	6.44	2.29	1.706
5.50	26.06	83.34	4.61	6.94	2.65	1.346
5.50	26.94	83.22	4.61	7.82	2.77	1.226
5.50	29.03	82.34	4.61	9.91	3.65	0.346
6.00	20.55	82.81	5.11	1.43	3.18	0.816
6.00	21.92	82.86	5.11	2.80	3.13	0.866

Observed Data			Adj. to DFE coordinate sys.			
X [ft]	Y [ft]	Z [ft]	X [ft]	Y [ft]	Z [ft]	dZ [ft]
6.00	23.16	83.50	5.11	4.04	2.49	1.506
6.00	23.91	83.84	5.11	4.79	2.15	1.846
6.00	24.60	83.80	5.11	5.48	2.19	1.806
6.00	25.37	83.68	5.11	6.25	2.31	1.686
6.00	26.12	83.28	5.11	7.00	2.71	1.286
6.00	26.83	83.33	5.11	7.71	2.66	1.336
6.00	29.03	82.35	5.11	9.91	3.64	0.356
6.50	20.55	82.87	5.61	1.43	3.12	0.876
6.50	21.95	82.78	5.61	2.83	3.21	0.786
6.50	22.80	83.18	5.61	3.68	2.81	1.186
6.50	23.75	83.68	5.61	4.63	2.31	1.686
6.50	24.66	83.77	5.61	5.54	2.22	1.776
6.50	25.44	83.64	5.61	6.32	2.35	1.646
6.50	26.22	83.12	5.61	7.10	2.87	1.126
6.50	27.42	82.89	5.61	8.30	3.10	0.896
6.50	29.03	82.35	5.61	9.91	3.64	0.356
7.00	20.55	82.87	6.11	1.43	3.12	0.876
7.00	21.75	82.64	6.11	2.63	3.35	0.646
7.00	22.51	82.87	6.11	3.39	3.12	0.876
7.00	23.53	83.28	6.11	4.41	2.71	1.286
7.00	24.73	83.36	6.11	5.61	2.63	1.366
7.00	25.46	83.35	6.11	6.34	2.64	1.356
7.00	26.16	82.96	6.11	7.04	3.03	0.966
7.00	27.45	82.69	6.11	8.33	3.30	0.696
7.00	29.03	82.37	6.11	9.91	3.62	0.376
7.50	20.55	82.92	6.61	1.43	3.07	0.926
7.50	20.86	82.83	6.61	1.74	3.16	0.836
7.50	21.57	82.58	6.61	2.45	3.41	0.586
7.50	22.75	82.82	6.61	3.63	3.17	0.826
7.50	23.56	83.02	6.61	4.44	2.97	1.026
7.50	25.82	82.90	6.61	6.70	3.09	0.906
7.50	26.67	82.69	6.61	7.55	3.30	0.696
7.50	27.79	82.49	6.61	8.67	3.50	0.496
7.50	29.03	82.44	6.61	9.91	3.55	0.446
8.50	20.55	82.95	7.61	1.43	3.04	0.956
8.50	21.13	82.58	7.61	2.01	3.41	0.586
8.50	22.36	82.47	7.61	3.24	3.52	0.476
8.50	23.40	82.50	7.61	4.28	3.49	0.506
8.50	24.42	82.49	7.61	5.30	3.50	0.496
8.50	26.62	82.34	7.61	7.50	3.65	0.346
8.50	28.58	82.48	7.61	9.46	3.51	0.486
8.50	29.03	82.58	7.61	9.91	3.41	0.586
9.50	20.55	82.84	8.61	1.43	3.15	0.846
9.50	21.24	82.48	8.61	2.12	3.51	0.486
9.50	22.18	82.21	8.61	3.06	3.78	0.216
9.50	25.20	82.13	8.61	6.08	3.86	0.136
9.50	27.26	82.29	8.61	8.14	3.70	0.296
9.50	29.03	82.65	8.61	9.91	3.34	0.656

DFE Contour Data

Run # : 2
Duration : 120 min
Rod Length : 1.16 ft

Observed Data			Adj. to DFE coordinate sys.			
X [ft]	Y [ft]	Z [ft]	X [ft]	Y [ft]	Z [ft]	dZ [ft]
10.50	20.55	82.68	9.61	1.43	3.31	0.686
10.50	22.14	81.94	9.61	3.02	4.05	-0.054
10.50	25.00	81.96	9.61	5.88	4.03	-0.034
10.50	28.32	82.38	9.61	9.20	3.61	0.386
10.50	29.03	82.65	9.61	9.91	3.34	0.656
11.50	20.55	82.51	10.61	1.43	3.48	0.516
11.50	21.00	82.27	10.61	1.88	3.72	0.276
11.50	21.91	81.80	10.61	2.79	4.19	-0.194
11.50	25.00	81.91	10.61	5.88	4.08	-0.084
11.50	28.16	82.26	10.61	9.04	3.73	0.266
11.50	29.03	82.59	10.61	9.91	3.40	0.596
12.50	20.55	82.36	11.61	1.43	3.63	0.366
12.50	21.72	81.70	11.61	2.60	4.29	-0.294
12.50	22.75	81.72	11.61	3.63	4.27	-0.274
12.50	25.49	81.97	11.61	6.37	4.02	-0.024
12.50	28.12	82.20	11.61	9.00	3.79	0.206
12.50	29.03	82.46	11.61	9.91	3.53	0.466
13.50	20.55	82.23	12.61	1.43	3.76	0.236
13.50	20.87	82.06	12.61	1.75	3.93	0.066
13.50	21.53	81.69	12.61	2.41	4.30	-0.304
13.50	22.89	81.74	12.61	3.77	4.25	-0.254
13.50	24.48	81.90	12.61	5.36	4.09	-0.094
13.50	26.50	82.13	12.61	7.38	3.86	0.136
13.50	27.59	82.32	12.61	8.47	3.67	0.326
13.50	29.03	82.52	12.61	9.91	3.47	0.526

Appendix G - PG&E Pit 4 Figures

1st Page: (11x17 Fold out)

Figure 22. General plan of Diversion Dam, Pit River Development No. 4, from Pit 4 Dam, Stability Under Flood Loading and Dam Break Analysis, Figure 1

2nd Page:

Figure 23. Pit 4 Dam - Abutment Erosion Study: Geologic Map of Abutment Areas, from Pit 4 Dam, Stability Under Flood Loading and Dam Break Analysis, Figure 2-1

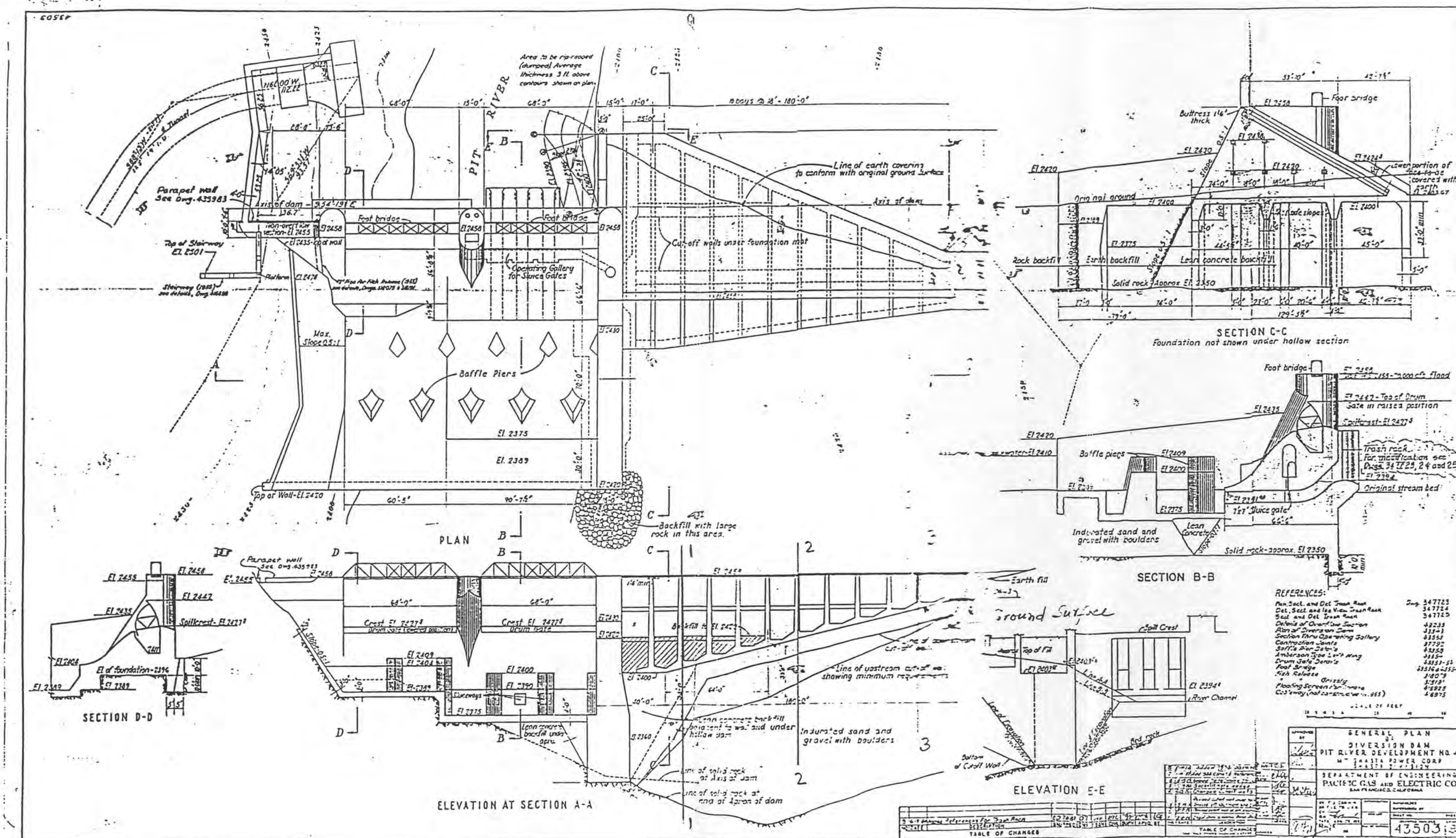
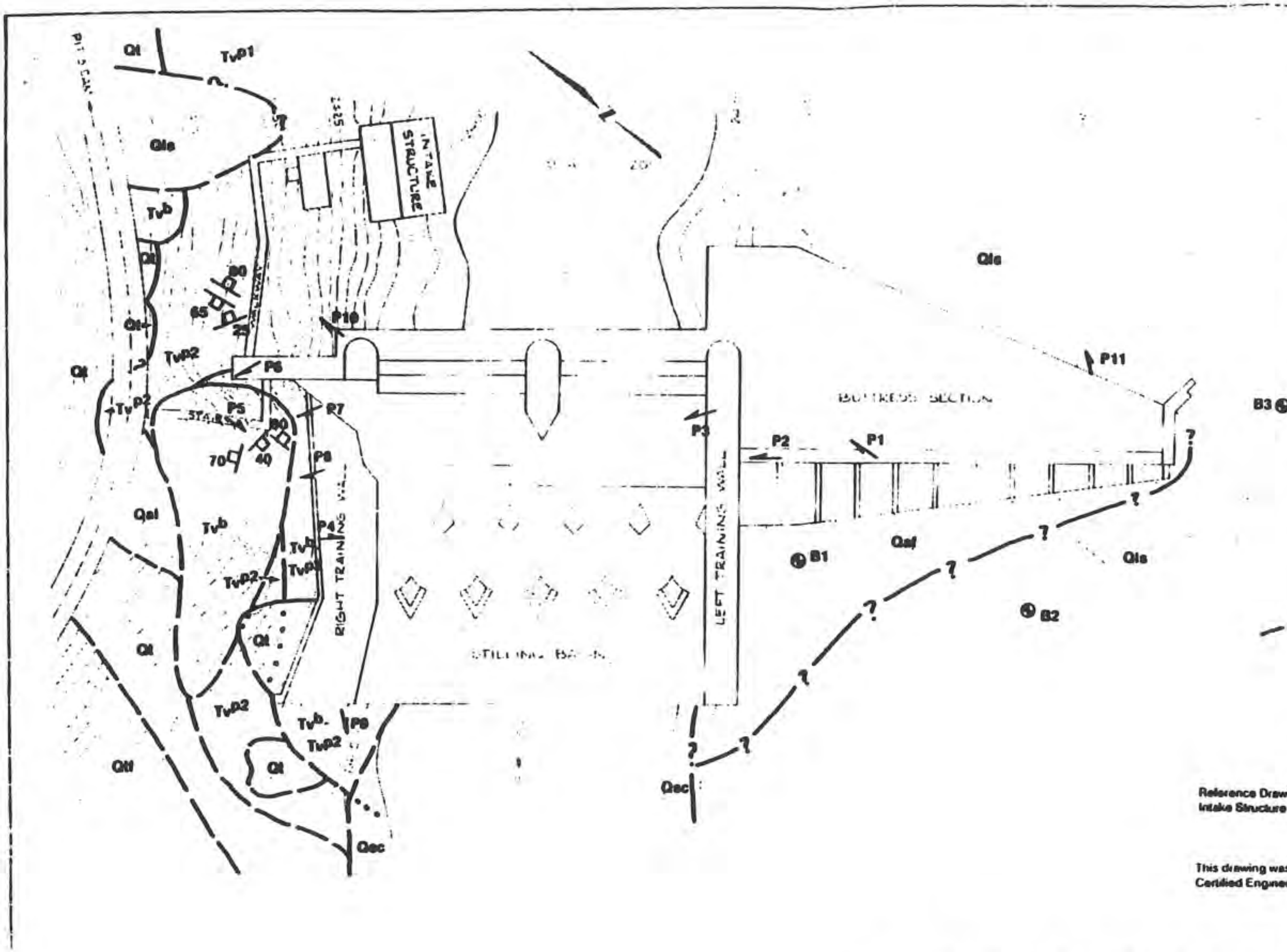

PLAN
SECTION C-C
Foundation not shown under hollow section
SECTION B-B
SECTION D-D
ELEVATION AT SECTION A-A
ELEVATION E-E
PIT RIVER
Baffle Piers
Foot bridge
Operating Gallery for Sluice Gates
Cut-off walls under foundation mat
Line of earth covering to conform with original ground surface
Axis of dam
Parapet wall See Dwg. 435983
Top of Stairway El. 2501
Top of Wall-El. 2420
Backfill with large rock in this area.
Area to be rip-rapped (dumped) Average thickness 3 ft. above contours shown on plan.
Original ground
Rock backfill
Earth backfill
Lean concrete backfill
Solid rock-Approx. El. 2350
Foot bridge
Buttress 1'6" thick
Top of Drum Gate in raised position
Spillcrest-El. 2427.5
Trash rack
Original stream bed
Sluice gate
Indurated sand and gravel with boulders
Lean Concrete
Solid rock-approx. El. 2350
Earth fill
Ground Surface
Crest El. 2427.5
Drum Gate
Line of upstream cut-off wall showing minimum requirements
Indurated sand and gravel with boulders
Line of solid rock at Axis of dam
Line of solid rock at end of Apron of dam
River Channel
Bottom of Cutoff Wall
REFERENCES:
TABLE OF CHANGES
GENERAL PLAN
OF
DIVERSION DAM
PIT RIVER DEVELOPMENT NO. 4
MT. SHASTA POWER CORP.
DEPARTMENT OF ENGINEERING
PACIFIC GAS AND ELECTRIC CO.
435033

FIGURE 4



EXPLANATION

Qal	Recent Artificial Fill - heterogeneous fill deposited as sidecast from road construction and buttress section foundation backfill.
Qsc	Recent Stream Deposits - sand, gravel, and boulders in active Pit River channel.
Qtl	Recent Talus Deposits - moderately coarse, loose, crudely bedded talus deposit comprised of slabby rock fragments to boulder size.
Qt	Recent Talus Deposits - moderately coarse, heterogeneous talus deposits with boulders up to 4 feet diameter. Parts colluvial in nature.
Qls	Quaternary Landslide Deposits - ancient landslide deposit on left abutment comprised of basaltic boulders and cobble-sized fragments set in reddish brown clayey matrix. Small heterogeneous deposit on right abutment area
Tv^b	Tertiary Basalt - dark grey, fine-grained, hard, blocky, flow rock. Moderately jointed with columnar jointing
Tv^b- Tv^{p2}	Tertiary Basalt, Basal Unit - basalt (Tvb) and joint filling gray tuff (Tvp2). Forms basal portion of basalt flow.
Tv^{p2}	Tertiary Tuff - gray to tan devitrified tuff comprised of medium grained volcanic rock fragments in fine-grained matrix. Contains zones of flow rock boulders and cobble sized material. Unit is intensely fractured.
Tv^{p1}	Tertiary Tuff - pink, gray, tan, mauve, and brown medium grained tuff. Unit contains thin beds of dark brown sandy tuff. Unit is well-fractured and contains numerous minor faults. The unit contains various volcanic clasts.

SYMBOLS

Geologic contact, dashed where approximate, dotted where concealed, queried where uncertain

Strike and dip of jointing, degrees

P1 Photograph location and number

B1 1987 Exploratory Boring

Reference Drawing: Exhibit L, Sheet 2A "Plan of Dam and Intake Structure Pit 4 Unit of Project 233"

This drawing was prepared by [signature]
Certified Engineering Geologist, California Number EG995

PROJECT NO.	PIT 4 DAM – ABUTMENT EROSION STUDY	FIGURE NO
97-100	GEOLOGIC MAP OF ABUTMENT AREAS	4

FIGURE 2-1

Appendix H - Trajectory Analysis

This appendix contains the derivation of the trajectory equation for the centerline of a free trajectory jet. The nappe must have full atmospheric pressure beneath the free-trajectory jet. Treating the lower nappe as a projectile, the kinematic equations are:

$$x = v_o t \cos\theta \tag{8}$$

$$y = -v_o t \sin\theta + \tfrac{1}{2} g t^2 + C' \tag{9}$$

Substituting equation 8 into equation 9 gives the vertical coordinate of the lower nappe surface.

$$y = -x \tan\theta + \frac{g x^2}{2 v_o^2 (\cos\theta)^2} + C' \tag{10}$$

Dividing equation 10 by the total energy head on the weir, H, and rearranging

$$\frac{y}{H} = \left(\frac{gH}{2 v_o^2 (\cos\theta)^2}\right)\left(\frac{x}{H}\right)^2 + (-\tan\theta)\left(\frac{x}{H}\right) + \left(\frac{C'}{H}\right) \tag{11}$$

then simplifying, the general equation for the lower nappe is:

$$\frac{y}{H} = A\left(\frac{x}{H}\right)^2 + B\left(\frac{x}{H}\right) + C \tag{12}$$

Since the horizontal velocity component is constant, the vertical thickness of the nappe, T, is constant. By inserting $D = T/H$ into equation 12, the equation for the centerline of the nappe is:

$$\frac{y_c}{H} = A\left(\frac{x_c}{H}\right)^2 + B\left(\frac{x_c}{H}\right) + C + \tfrac{1}{2} D \tag{13}$$

Equations 14 through 18 are experimental values for the coefficients. The values are from Chow [3]. Table 25 summarizes the values of the coefficients for the 22% of PMF flow. These values and equation 13 result in an expression for the trajectory of the jet over Pit 4 dam.

$$A = -0.425 + 0.25\left(\frac{h_v}{H}\right) \tag{14}$$

$$B = 0.411 - 1.603\left(\frac{h_v}{H}\right) - \sqrt{1.568\left(\frac{h_v}{H}\right)^2 - 0.892\left(\frac{h_v}{H}\right) + 0.127} \tag{15}$$

$$C = 0.150 - 0.45\left(\frac{h_v}{H}\right) \tag{16}$$

$$D = 0.57 - 0.02(10m)^2 e^{10m} \tag{17}$$

$$m = \left(\frac{h_v}{H}\right) - 0.208 \tag{18}$$

Table 25. Trajectory coefficients.

%PMF	h	q	h_v	A	B	C	m	D
22%	2.19	10.00	0.37	-0.38	0.00	0.07	-0.04	0.57

The next step in the analysis is to match the trajectory in the model. The following table, Table 26, tabulates the coordinates of the trajectory, and the tangent angle, θ. This angle will be matched in the model as one aspect of achieving similitude.

Table 26. Scale Model Trajectory

x_c	y_c	θ
0.00	2439.28	84.73
0.50	2439.24	79.81
1.00	2439.10	70.48
1.50	2438.88	62.11
2.00	2438.57	54.85
2.50	2438.18	48.69
3.00	2437.70	43.51
3.50	2437.13	39.15
4.00	2436.47	35.48
4.50	2435.72	32.36
5.00	2434.89	29.71
5.50	2433.97	27.42
6.00	2432.96	25.44
6.50	2431.87	23.71
7.00	2430.69	22.19
7.50	2429.42	20.84
8.00	2428.06	19.64
8.50	2426.61	18.57
9.00	2425.08	17.61
9.50	2423.46	16.74
10.00	2421.76	15.94
10.50	2419.96	15.22
11.00	2418.08	14.56
11.50	2416.11	13.95
12.00	2414.06	13.39
12.50	2411.91	12.88
13.00	2409.68	12.40
13.50	2407.36	11.95
14.00	2404.96	11.54
14.50	2402.47	11.15
15.00	2399.89	10.79
15.50	2397.22	10.45
16.00	2394.46	10.13
16.50	2391.62	9.83
17.00	2388.69	9.54
17.50	2385.67	9.28
18.00	2382.57	9.09
18.25	2380.98	8.90