UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	Docket Nos. 50-329 OM
	50-330 OM
CONSUMERS POWER COMPANY	
	Docket Nos. 50-329 OL
(Midland Plant Units 1 and 2)	50-330 OL

TESTIMONY

OF

DONALD F. LEWIS

ON BEHALF OF THE APPLICANT

REGARDING UNDERGROUND PIPING
AT THE MIDLAND PLANT

. . .

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AFFIDAVIT OF DONALD F. LEWIS

My name is Donald F. Lewis. I am employed by Bechtel Associates Professional Corporation as the acting assistant project engineer and the engineering group supervisor for the Midland Nuclear Project. In this position, I am responsible for licensing activities, including evaluation of specific design issues with respect to licensing and technical requirements.

I have a total of 15 years of experience in the nuclear power industry. Nine of these years have been in the design and construction of commercial nuclear power plants. The balance of my experience has been in the United States Navy as an officer in the Naval Nuclear Propulsion Program. I have a Bachelor of Science degree in Physics from Rensselaer Polytechnic Institute. In addition, during my service as a naval officer, I attended the United States Navy Nuclear Power School in Bainbridge, Maryland and the United States Navy Nuclear Power Training Prototype Unit in West Milton, New York.

In 1973, after leaving the Navy, I went to work for Bechtel Power Corporation as the nuclear steam supply system coordinator on Portland General Electric Company's Pebble Springs Nuclear Project and held the same position on Iowa Power Company's Central Iowa Nuclear Project. In these positions, I was responsible for incorporation of the reactor and reactor auxiliary systems into the plant design, schedule and licensing effort.

Beginning in 1976, I served as the nuclear discipline specialist in Bechtel's Ann Arbor area office. In this position, I was responsible for providing technical assistance to projects on nuclear, environmental, and licensing matters. I have also held the position of mechanical nuclear design group supervisor for the American Electric Power Nuclear Plant studies. I am also the former Vice Chairman of the Michigan Section of the American Nuclear Society, and was a past member of the ANS 51 Standard Committee to develop PWR design criteria.

In connection with my current positions as assistant project engineer and engineering supervisor for the Midland nuclear project, I am responsible for licensing activities with respect to the underground safety related piping at the Midland Nuclear Plant, as well as evaluation of specific design issues with respect to licensing and technical requirements.

I am primarily responsible for this testimony on the underground piping, with significant input provided by Consumers Power Company in Section 3.0 through 3.6. I affirm that the statements in this affidavit and in the underground piping testimony are true and correct, to the best of my knowledge and belief.

Donald F. Lewis

Donald F. Lewis

Sworn and subscribed to before me this 7 day of October, 1982.

Notary Public, Washtenaw County

[illegible] A. [illegible]
NOTARY PUBLIC, WASHTENAW CO., MICH
MY COMMISSION EXPIRES NOV.[illegible], [illegible]

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REFERENCES

1. CPCo letter Serial 16881, 5/3/82 (attached)
2. CPCo letter Serial 16269, 3/16/82 (attached)
3. ASME Subsection ND, 1971 Edition w/ Addenda through Summer, 1973
4. ASME Subsection ND, 1977 Edition

TABLES

FIGURES

UNDERGROUND PIPING

1.0 BACKGROUND

1.1 SCOPE OF TESTIMONY

This testimony provides updated information regarding underground piping at the Midland Plant. It addresses open items identified during hearings held in February, 1982 on the subject of underground piping and tanks. The open items for which the applicant was responsible are the following:

- Provide to the NRC staff soil profiles along the service water system piping and information establishing 3 inches of overall future predicted settlement.
- Resolve with the NRC staff the curve to be used to define the relationship of piping strain to piping ovality.
- Submit to the NRC staff the replacement program for the 36-inch diameter service water system piping.
- Submit to the NRC staff the program for monitoring settlement and strain in the service water system and other seismic Category I piping.

One open item to be resolved by the NRC staff was to address corrosion of piping at the Midland plant. This testimony addresses the results of actions taken to address concerns for the corrosion of underground stainless steel safety related piping.

1.2 GENERAL

At the time of the submittal of the previous testimony on underground piping and tanks, concerns for the adequacy of the

underground piping and tanks had been identified and addressed. Commitments had been made to undertake specific remedial fixes and institute monitoring programs. Since that time, the design for the remedial fixes and the program for monitoring of the underground piping have been substantially defined. In addition, open items with the NRC staff have been resolved. In the process of fulfilling previous commitments and finalizing the design, some modifications to the design have been made. These modifications have been reviewed and approved by the NRC staff. The following sections of this testimony will identify modifications to the design and monitoring program.

2.0 SOIL PROFILES ALONG SERVICE WATER SYSTEM PIPING & SETTLEMENT INFORMATION

Prior to the previous hearings on underground piping in February, 1982, the applicant had provided to the NRC staff sketches that showed the results of soils borings and related the locations of these borings to two of the underground service water system pipes. These sketches have been referred to as soil profiles. During the previous hearings on underground piping in February, 1982, the NRC staff requested that similar sketches be provided for the remaining underground service water system pipes. These sketches were provided to the NRC staff in March, 1982. Our understanding from the NRC staff is that these profiles provided the information required.

Information establishing the basis for the applicant's estimate of 3 inches of overall settlement for the next 40 years for buried piping located on fill material which is not replaced was provided to the NRC staff by the applicant's letter, Serial 16881, dated May 3, 1982(1). Our understanding from the NRC staff is that no open or unresolved items exist with respect to this estimate of future settlement at this time.

3.0 MONITORING PROGRAM FOR UNDERGROUND PIPING

At the time of the previous hearings on underground piping, the NRC staff and the applicant had reached agreement on the concept of relating piping ovality to piping strain and to utilize this relationship in a monitoring program for the piping during plant operation. A specific strain to ovality relationship had been developed by the applicant and submitted to the NRC staff(2). Resolution of this relationship was identified as an open item in the previous hearings. This item has now been resolved and the agreed upon relationship is presented in Figure 1 to this testimony.

The general concept of long term monitoring for the underground safety grade piping subjected to soil settlement has not changed since the previous hearing testimony presented in February 1982. Various details have been modified as a result of comments received from the NRC staff. In addition, we have agreed to monitor the building penetration clearance (rattlespace) of certain pipes and to limit the laydown loads over buried safety grade utilities. This section summarizes the results of the monitoring program changes from the previous testimony presented by the applicant.

3.1 STRAIN GAGE MONITORING

Because of the differences the staff and applicant had in methodology for determining the strain versus ovality relationship, the curve for the 26 inch diameter piping was redefined based on experimental data. The curve shown in Figure 1 is the result of a conservative plot through the experimental data available on strain versus ovality. This curve is used to determine the equivalent strains for the allowable ovality and the measured ovality data taken on the Midland service water piping.

The ovality allowable is 4% (equivalent to 0.0048 inch/inch strain), which includes the appropriate safety factor agreed upon previously. Using the curve of Figure 1, the ovalization data measured in the 26 inch diameter pipe can be transformed to an equivalent strain. This equivalent strain value is subtracted from the allowable (.0048 inch/inch) to determine the future allowable for the strain monitoring stations selected on the piping. Table 1 shows the measured ovality, corresponding meridional strain, and future allowable strain for all strain monitoring stations on the buried Midland safety grade piping. The method used to calculate the future allowable strain allows the pipe strain resulting from soil settlement before the 1981 data to be accounted for at each station. Table 1 also specifies the number of strain gages for each monitoring station. The number of gages were determined by reviewing the pipe elevation profiles for abrupt inflection points and critical buckling zones. The strain gages are to be mounted one pipe diameter apart along the top line of the pipe and centered at the given monitoring station.

3.2 VERTICAL SETTLEMENT MARKERS

Vertical settlement markers were added at various monitoring stations to supplement the pipe strain gage measurements. Their locations have been chosen in accordance with the following guidelines:

1. Locations where loosely compacted soil may exist, based on borings taken throughout the plant site fill material.
2. Locations where high future differential settlement could potentially occur due to underlying utilities.

Figure 2 is a monitoring station location diagram for both strain gage monitors and settlement markers. Stations which have settlement markers are indicated by a star notation as referenced by the sketch legend. Figure 3 is a drawing of a typical pipe settlement marker which will be attached directly to the pipe.

The vertical settlement measurements shall be based upon the initial installation survey of the markers. This survey shall establish an elevation datum. The subsequent surveys shall be compared against the datum to calculate the pipe movements. The differential vertical displacement from the initial datum to the current survey measurement shall be used for comparison to the acceptance criteria. The acceptance criteria is tied to the conservative upper limit of predicted maximum future settlement (3 inches).

3.3 TECHNICAL SPECIFICATION ACCEPTANCE CRITERIA AND ACTIONS

If either the future allowable strain specified in Table A or 75% of the vertical settlement criteria 3 inches is reached, a reportable

occurrence will be enforced. Increased monitoring frequency will be required. NRC notification and an engineering evaluation of the situation shall be initiated. Supplemental reports to the NRC will follow the initial notification to describe the final resolution and actions. Such actions may include excavation of piping in the affected zone for visual examination and possible replacement or sleeving. Strain gages which are determined to be providing faulty data will be recalibrated or replaced within ninety days during the first five years of monitoring.

3.4 MONITORING FREQUENCY

The monitoring frequency has changed slightly since the applicant's previously submitted testimony. The measuring frequency for the monitoring stations is the same for both strain gages and vertical settlement markers. The monitoring schedule submitted in the FSAR technical specification is as follows:

1. At least once per 30 days during the first 6 months of unit operation and until the observed settlement has stabilized at less than or equal to 0.10 inches from the previous reading.

2. At least once per 90 days during the first 5 years of plant operation for all stations. After the fifth year, a report to the NRC on the need to continue monitoring the field stations based on the evaluation of time history plots of the collected data.

3. After the fifth year of plant operation, anchor stations shall be monitored on a yearly basis for plant operating life.

4. In case of an unusual event (seismic, system upset conditions) monitor all stations immediately.

5. Upon a reportable occurrence, increase monitoring frequency on a basis as determined necessary by the licensee and the NRC.

3.5 RATTLESPACE MONITORING

The penetration clearances (rattlespace) of certain pipes will also be monitored for adequate clearance. The piping penetrations into buildings where the safety grade pipes have not been reanalyzed and rebedded will be monitored. Penetrations to be monitored at the auxiliary building are associated with the following piping: 18-1HCB-1, 18-1HCB-2, 18-2HCB-1, 18-2HCB-2, 26-0HBC-15, 26-0HBC-16, 26-0HBC-19, 26-0HBC-20. At the diesel generator building, the following penetrations will be monitored: 8-1HBC-311, 8-1HBC-310, 8-2HBC-81, 8-2HBC-82.

The soil settlement, seismic, and thermal displacements will be combined and compared to the available annular space to ensure at least a 0.5 inch safety margin. The monitoring frequency will be yearly for the first five years of plant operation.

3.6 LAYDOWN LOADS AND SAFETY GRADE UTILITIES

Load limits have been specified to prevent a surcharging effect from laydown loads for long term storage over buried safety grade piping

and conduits. Exclusion zones will be used to designate the affected safety grade utility and the maximum allowable loads and time limits. Table 2 is the proposed technical specification limits to be submitted in the FSAR. The basis for the specified limits is an allowable surcharge settlement of 0.5 inches at a depth 7 feet below the ground surface, which is the average utility depth. The control procedure to administer this program will be handled in conjunction with the plant operating procedures for controlling heavy loads inside the plant.

4.0 REINSTALLATION PROGRAM FOR 36" AND 26" SERVICE WATER SYSTEM PIPING

During the previous evidentiary hearing on underground piping, the applicant committed to replace the 36-inch diameter service water system piping as a result of the inability to reach resolution with the NRC staff as to the adequacy of the existing piping. Following those hearings in April, 1982, it was determined that it was also necessary to rebed a portion of the buried 26-inch diameter servce water piping as part of a fill replacement program to resolve potential liquefaction concerns. The following subsections of this testimony will discuss the basis for and extent of the rebedding of the 26-inch diameter piping and the program for the replacement of the 36-inch diameter buried service water pipes. The reinstallation program was first submitted to the NRC in March, 1982 by applicant's Serial 16269 dated March 16, 1982[2]. The NRC staff reviewed the design associated with the reinstallation program in detail in the course of an audit held in August, 1982. It is our understanding that at this time, no open items exist between the NRC staff and the applicant regarding this reinstallation program.

4.1 DEFINITIONS

The following definitions are for terms as they are used in this testimony:

Replace - The removal of existing buried pipe and the installation of new pipe.

Rebed - The exposure of the existing buried pipe, removal of underlying soil, placement of new underlying fly ash concrete fill, and realigment of existing pipe,repair coating, and backfill around and over pipe.

Reinstall - Encompasses both the replacing and rebedding of piping discussed in this testimony.

4.2 BASIS FOR REINSTALLATION PROGRAM

The ability of the safety related buried pipe at the Midland nuclear plant to perform its intended safety functions over the life of the plant has been discussed extensively with the NRC staff. Agreement has been reached between Consumers Power Company and the NRC staff on the acceptability of a portion of the safety related piping. However, because no agreement has been reached on appropriate acceptance criteria for the 36-inch buried service water system piping, the applicant will replace it.

Some 26-inch diameter buried service water system piping, the ability of which to perform its intended safety function over the life of the plant was deemed acceptable, will nevertheless be rebedded as part of the fill replacement program to resolve liquefaction concerns(2). The necessity of rebedding this pipe was brought into focus in early 1982.

The results of the dewatering recharge tests confirmed that the ground water level in the area adjacent to the intake structures (SWPS and CWIS) would rise above el. 610' (the technical specification action limit) within a restrictively short time after loss of dewatering capability. Therefore, action was initiated to obtain NRC concurrence to rebed the affected pipe using a fill material that was not subject to liquefaction.

4.3 SCOPE OF REINSTALLATION PROGRAM

The reinstallation program discussed herein includes the replacement of the buried 36-inch diameter service water system piping in the vicinity of the service water pump structure and the rebedding of the two buried 26-inch diameter service water lines immediately adjacent to the circulating water intake structure. Figure 4 of this testimony identifies the boundary of the reinstallation program.

The lines to be replaced are identified as:

36"-OHBC-15

36"-OHBC-16

36"-OHBC-19

36"-OHBC-20

These are the service water supply and return lines at the point of entry to and from the service water pump structure. The replacement will be made from a point inside the service water pump structure near the penetration up to, but not including, the T-fitting.

The pipes to be rebedded are portions of lines 26"-OHBC-53 and 26"-OHBC-54. These are service water supply and return lines to and from the diesel generator and turbine buildings. The lines to be rebedded extend from the 36" lines to a point even with the southwest edge of the circulating water intake structure.

4.4 SOILS AND FILL CONDITIONS

Logs of exploratory borings along the sections of 26-inch and 36-inch diameter pipe to be reinstalled indicate that the subsurface soil consists of heterogeneous compacted fill from the ground surface (el. 634') to approximately el. 600'. The fill material rests on very dense, natural sands or hard, silty clays. Blowcounts observed in exploration borings adjacent to the service water pump structure and the circulating water intake structure indicate that sands are loose to medium dense above el. 610' and have the potential of liquifying if not dewatered and a safe shutdown earthquake occurs at the site.

Fill material within the limits indicated on Figure 4 will be excavated down to el. 610' and replaced with a suitable material to minimize settlement and prevent liquifaction. Predicted future settlement, considering replacement of loose or soft fill material, is not expected to exceed 1 1/2 inches. Loads from these settlements are included in the pipe design.

The replacement fill material will be a type of low-strength fly ash concrete similar to the material known by the brand name K-KRETE. The properties of the new fill material will be similar to those provided in Table 3 to this testimony. These properties will be verified by testing.

4.5 MATERIALS

The existing 36-inch diameter buried pipe will be replaced with pipe of 36-inch diameter, 0.625" nominal wall thickness, welded ASME SA-672, Grade B-70, Class 20, hydrostatically tested in accordance with ASTM A-530, Sec. 5.

The pipe is locally isolated from the differential settlement caused by the transition from the old fill to the new fill by encasing it in a compressible material. The compressibility of this material is such that the pipe is effectively suspended from where it is actually in contact with the old fill to where it is actually in contact with the new fill (see Figure 4).

The material to be used to replace the excavated fill is described in Section 4.4.

4.6 ANALYSES

The reinstalled buried pipe has been analyzed for appropriate ASME load combinations and settlement stresses. The ASME Code Equations 8, 9, and 10(3) and Code Case 1606-1 include stresses due to:

a) Design and peak pressure

b) Weight and sustained loads (including overburden)

c) Seismic inertial loads (both OBE and SSE)

d) Thermal expansion

e) Seismic anchor movements

Table 4 shows a summary of computed stresses compared to allowable stresses for the ASME code equations and Code Case 1606-1. The allowable stresses are taken from the ASME Code(3), Appendix I, for the materials and operating temperature relevant to the piping under discussion. Pipe support and component loads are combined in accordance with FSAR Table 3.9-3A.

The new 36-inch diameter service water piping is analyzed utilizing Bechtel computer program ME101, which is described in FSAR Section 3.9.1.2. Response spectrum analysis is performed using the SWPS

response spectra. Piping is modeled from equipment anchors in the SWPS to fictitious two-way restraints located 30 feet from the new fill/old fill interface. Soil stiffnesses for both the old and the new fill are considered in this analysis. The seismic stresses within the piping system are evaluated for both the upset and faulted conditions per ASME Section III, Division I, Paragraph ND 3652.2 and Code Case 1606-1. Seismic effects of buried piping are considered for design of supports and restraints located inside the SWPS.

Thermal analysis utilizes Bechtel computer program ME101. A mathematical model is prepared for all of the buried piping, piping inside the SWPS and some portions of piping inside the auxiliary building. Soil effects are considered in the analysis by modeling soil springs and the frictional effect is accounted for by modifying the thermal expansion. Thermal stresses are evaluated per ASME Section III, Division I, Paragraph ND-3652.3, Equation 10 or Equation 11.

The mathematical model for the seismic anchor movement (SAM) analysis considers all piping inside the SWPS and includes buried piping to locations 30 feet from SWPS wall. The model considers all pipe supports, equipment nozzle connections, and expansion joints. Seismic anchor movements are applied to all restraints and anchors inside the SWPS. Buried piping is considered in the analysis to be out of phase with piping inside the SWPS. SAM stresses are combined with thermal stresses and evaluated per ASME Section III, Division I, Paragraph ND 3652.3, Equation 10 or Equation 11.

The settlement analysis considers the effect of future soil settlement. The settlement is considered for both the new fill and also the existing fill. The piping mathematical model encompasses all piping in the SWPS and terminates 30 feet beyond the new fill/old fill interface. The worst combinations of settlement are considered. The first case considers that the old soil will settle 3 inches while the new fill does not settle. The second case assumes that future settlement of the new fill will be 1 1/2 inches and no settlement will occur in the old soil and the SWPS. The settlement stresses for both cases are evaluated individually per ASME Section III, Division I, Paragraph NC 3652.3, Equation 10a[4]. Settlement effects of buried piping are considered for the design of expansion joints, supports, and restraints located inside the SWPS.

4.7 REINSTALLATION PROCEDURE

The reinstallation of these lines will be coordinated with the SWPS underpinning. The excavation required to expose these lines and replace unsuitable fill and the excavation for underpinning of the SWPS will be contiguous.

The underground utilities that will be exposed during the excavation work will be supported and protected as necessary to preclude damage. A list of structures, facilities, and utilities that may be encountered or affected by this excavation is included in Table 5. Precautions to preclude damage may include measures such as:

a) Shoring and bracing supporting fill

b) Complete temporary support

c) Staking utility locations prior to excavation

d) Hand excavation near utilities

Because of the need for the 36-inch pipe to meet the startup testing schedule, the 36-inch pipe will be replaced, and then temporarily backfilled for frost protection, by early February, 1983. Subsequently, during the 1983 construction season, the temporary backfill will be removed and the soil replacement and 26-inch pipe rebedding program will be completed.

The existing 36-inch pipe to be replaced will be cut at the tee fitting and at a point inside the SWPS near the penetration

During the soil replacement and pipe rebedding stage of the reinstallation program, the lines will be left in place and temporarily supported. The 26-inch pipe to be rebedded will be exposed to at least the tee where it connects to the 36-inch line and to a point approximately even with the southwest edge of the CWIS. The 36-inch pipe which was replaced will again be exposed. The soil beneath the pipes, within the limits shown in Figure 4, will be removed and replaced with fly ash concrete (as discussed in Section 4.4). Before being rebedded, the pipe will be inspected to verify the integrity of the pipe and the external corrosion coating and then encased in compressible material where applicable.

The pipe will be fabricated and installed, and the material used to replace unsuitable fill and to backfill the excavation will be placed, in accordance with existing design drawings and specifications. Relevant documents include:

a) Drawing 7220-M-169(Q), Yard Piping Plan Area E

b) Specification 7220-M-204(Q), Field Fabrication and Installation of Piping for Nuclear Service

c) Specification 7220-M-214(Q), Piping System Erection Fit-Up Control

d) Specification 7220-G-8, Protective Coating for Buried Carbon Steel Pipe

e) Drawing 7220-C-2031(Q), Excavation Area Plan and Section

f) Specification 7220-C-211(Q), Backfill

g) Specification 7220-C-230(Q), Operating Onsite and Offsite Batch Plant and Furnish Concrete

5.0 CORROSION OF UNDERGROUND STAINLESS STEEL PIPING

Excavation under the Unit 1 condensate storage tank in June of 1979 revealed pitting corrosion on the buried 6-inch stainless steel fill line, 6"-1HCD-513. In October of 1980, two further instances of corroded buried stainless steel pipe were noted, on line 1 1/2"-OECD-62, and on abandoned line 4"-2HCB-18. All three of these instances were ultimately attributed to stray welding current corrosion. None of these instances was in a safety related line.

Because of the observed corrosion of buried stainless steel, some concern existed that corrosion of buried safety related stainless steel lines might lead to failure of those lines. A survey showed that the only buried safety related lines were 18"-1&2HCB-1 and -2. These are the borated water storage tank (BWST) discharge lines leading south from the BWSTs into the auxiliary building. It was decided to excavate and inspect these lines in the vicinity of a plant grounding grid cable, which passes near the pipes at the point where the pipes pass under the

tank farm retaining wall. The plant grounding grid is a network of buried bare copper cables attached to normally noncurrent-carrying metal equipment, structures, and components to electrically ground them. Near the grounding grid is the likeliest location for stray welding current corrosion to occur. The excavation has been completed, and the inspection of the pipes revealed no corrosion or pitting.

Examination of the only buried safety related stainless steel lines in the location most likely to experience stray welding current corrosion has shown no evidence of such corrosion. Therefore, it is concluded that the pipe would not fail in service, and the subject concern poses no risk to the safe operation of the Midland plant.

069372

Consumers Power Company

Reference 1
in OF Lewis' Oct. '82
Testimony

James W Cook
Vice President - Projects, Engineering and Construction

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May 3, 1982

Harold R Denton, Director
Office of Nuclear Reactor Regulation
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US Nuclear Regulatory Commission
Washington, DC 20555

MIDLAND PROJECT
MIDLAND DOCKET NO 50-329, 50-330
UNDERGROUND PIPING INFORMATION REQUESTED DURING APRIL 16, 1982 MEETING
FILE: 0485.16 SERIAL: 16881
REFERENCES: (1) J W COOK LETTER TO H R DENTON,
SERIAL 16269, DATED MARCH 16, 1982
(2) J W COOK LETTER TO H R DENTON,
SERIAL 16638, DATED APRIL 15, 1982
ENCLOSURES: (1) TABLE 1.0 MONITORING STATION OVALITY
AND CORRESPONDING STATION
(2) BURIED CATEGORY 1 LINES AND TANKS
(3) ADDITIONAL GEOTECHNICAL INFORMATION

The purpose of this letter is to provide confirmatory information regarding several issues discussed during a meeting between the NRC Staff and Consumers Power Company. The meeting was held in Bethesda on April 16, 1982.

Enclosure 1 is an expansion of the table previously submitted by our letter, Serial 16638, dated April 15, 1982. Additional information is provided specifying the future allowable strain based on an acceptance criteria and technical specification limit of 0.48% strain. The number of strain gages has also been specified in the table. The number of gages were determined by reviewing the pipe elevation profiles for abrupt inflection points and critical buckling zones. The strain gages are to be mounted one pipe diameter apart at a given monitoring station.

At the April 16 meeting a concern arose about the accuracy of the vibrating wire strain gages. In a telephone conference with the Irad Gage Company, they indicated the instrument is accurate to 10 (μinch/inch) as a worst case condition for any type of vibrating wire gage. This includes accounting for inaccuracies in installation and calibrations. This accuracy is an order of magnitude greater than the accuracy required for the strain measurements to be taken (.0001 in/in vs .00001 in/in).

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A clarification on the technical specification limits and requirements proposed in the pipe monitoring program submitted March 16, 1982 is necessary. Our intention is to use the 4% ovality (equivalent .0048 inch/inch strain) which includes appropriate safety factors as the technical specification unless we can justify a higher value at a later date. If the specified limit is reached we would immediately notify the NRC Staff and increase the monitoring frequency to one month intervals. In parallel with the Staff notification an engineering evaluation of the situation would be performed. This evaluation would consider the remedial action necessary to restore the safety function and reliability of the service water system to overall plant operations. The actions necessary may very well include excavation of the piping in the affected zone for visual examination and possible replacement or sleeving.

The NRC Staff asked Consumers Power Company to verify that no other buried Category 1 pipes remain unidentified. Enclosure 2 is a current table of all the buried seismic Category 1 lines and tanks. The pressurization lines and tanks have been added to the list of buried Category 1 piping. The control room pressurization lines and tanks were installed during the summer 1981, and therefore not subjected to the soils settlement problems. The penetration pressurization lines and tanks have not been installed; however appropriate procedures for soil settlement will be followed. The list does not include the 48-inch diameter (48-OHBC-2) discussed in Enclosure 3 of our letter, Serial 16638, dated April 15, 1982.

The NRC Staff expressed a concern regarding the margins for future settlement at the wall penetration of pipeline 26-OHBC-15. Our investigations indicate that there is a 90° elbow fitting in this line immediately upon exiting the building. Any bending moment developed due to soils settlement will be transformed to an equal torque value. This load transformation causes the vertical deflection due to settlement to change to an angle of twist on the pipe at the penetration. This angle of twist has no effect on the annulus clearance of the wall penetration and therefore the only real clearance we need to assure is the seismic rattlespace (0.3693 inch). The margin we presently have is 0.6307 inches which is a factor of 1.7 times the conservative estimate of seismic rattlespace.

The NRC Geotechinical Branch requested information concerning soils and its relation to buried utilities. Enclosure 3 addresses the concerns expressed about the prediction of maximum future settlement for plant life (3.0 inches) and the isolated sand pocket near the diesel fuel tanks. A concern was also expressed about the soil properties used in estimating the soil forces required to deform condensate line (20-1HCD-169) into its present configuration. We have responded by seperately providing the Structural Mechanics Assoiciates calculations estimating the soil capacity at Midland.

We believe the information supplied satisfies the concerns the NRC Staff expressed during the recent April meeting.

J A Mooney
Executive Manager
Midland Project Office

For J W Cook

JWC/WJC/mkh

CC Atomic Safety and Licensing Appeal Board, w/o
CBechhoefer, ASLB, w/o
PChen, ETEC, w/a
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069372

BCC RCBauman, P-14-312B, w/o
JEBrunner, M-1079, w/a
WGCorley, PCA, w/a
PJGriffin, P-24-513, w/a
RWHuston, Washington, w/a
DFLewis, Bechtel, w/a
JAMooney, P-14-115A, w/a
DBMiller, Midland, w/a
MIMiller, IL&B, w/a
JARutgers, Bechtel, w/a
JRSchaub, P-13-309A, w/a
PPSteptoe, IL&B, w/a
TRThiruvengadam, P-14-400, w/a
JTsacoyeanes, Teledyne Engineering, w/a
FCWilliams, IL&B, w/a
NRC Correspondence File

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Reference 2
in D.F. Lewis' Oct. '82
Testimony

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March 16, 1982
WJC 7-82

Harold R Denton, Director
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MIDLAND PROJECT
MIDLAND DOCKET NO 50-329, 50-330
ADDITIONAL INFORMATION CONCERNING SAFETY GRADE BURIED PIPING
FILE: 0485.16 SERIAL: 16269
REFERENCE: J W COOK LETTER TO H R DENTON,
SERIAL 15093, DATED DECEMBER 15, 1981
ENCLOSURES: (1) FUTURE MONITORING PROGRAM OF BURIED SERVICE WATER PIPING FOR MIDLAND PLANT UNITS 1 AND 2
(2) REINSTALLATION PROGRAM FOR 26-INCH AND 36-INCH DIAMETER BURIED SERVICE WATER PIPES AT THE MIDLAND NUCLEAR PLANT

By means of the subject enclosures we are providing additional documentation of the remedial measures to assure the performance of buried service water piping. The enclosures describe the agreement in principle with the NRC Staff on the remedial action necessary to resolve the Staff concerns. The agreements were reached during the recent soils hearings on underground piping held on February 18 and 19, 1982.

The enclosure on the future monitoring program for the existing 26-inch service water piping covers 2 types of monitoring; vertical settlement monitoring and pipe strain monitoring. It describes the monitoring station locations and the details of selection criteria, monitoring frequency, acceptance criteria and instrumentation for both types of monitoring.

The enclosure on reinstallation of service water piping describes the engineering and construction aspects necessary to accomplish the remedial actions. It describes the replacement of the 36-inch diameter piping agreed upon during the soils hearing and rebedding of a portion of Pipelines 26-OHBC-53 and 26-OHBC-54 in front to the circulating water intake structure.

The rebedding of 26-inch diameter piping is an additional commitment since the soils hearings, based on the recently evaluated results of the dewatering recharge test. The results indicate that the soils north of the service water pump structure and the circulating water intake structure would have only a three-day limit to prevent the potential for soil liquefaction during a seismic event and a dewatering pump failure. As a consequence, the fill in

the affected area will be replaced. The area covers a zone where the 36-inch diameter piping is being replaced and also a zone where Pipelines 26-OHBC-53 and 26-OHBC-54 are buried. The fill replacement with suitably compacted fill will eliminate the need to rely on the dewatering system in this area to prevent liquefaction.

We believe the enclosures adequately describe the remedial measures to be taken to assure the performance of the service water piping throughout the lifetime of the plant.

James W. Cook

JWC/WJC/dsb

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BCC RCBauman, P-14-312B, w/o
AJBoos, Bechtel, w/a
JEBrunner, M-1079, w/a
WGCorley, w/a
RWHuston, Washington, w/a
JAMooney, P-14-115A
DBMiller, Midland, w/a
MIMiller, IL&B, w/a
JARutgers, Bechtel, w/a
JRSchaub, P-13-309A
PPSteptoe, IL&B, w/a
TRThiruvengadam, P-14-400, w/a
JTsacoyeanes, Teledyne Engineering, w/a
FCWilliams, IL&B, w/a
Licensing Clerk
NRC Correspondence File

oc0382-0044a100

TABLE 1

Monitoring Station Ovality and Corresponding Strain

Station	Measured Ovality (%)	Meridional Strain (%)	Future Allowable Strain (%)	No of Strain Gages
Line: 26-OHBC 15			Allowable Strain = .48%	
1	1.25	0.25	0.23	2
2	2.34	0.35	0.13	2
3	1.87	0.31	0.17	2
4	1.88	0.32	0.16	3
5	2.34	0.35	0.13	2
6	1.56	0.28	0.20	2
7	2.34	0.35	0.13	2
8	1.24	0.25	0.23	2
Line: 26-OHBC 16				
1	2.18	0.34	0.14	3
2	2.18	0.34	0.14	2
3	2.34	0.35	0.13	3
4	2.18	0.34	0.14	2
5	1.40	0.27	0.21	2
6	1.72	0.29	0.19	2
7	1.12	0.23	0.25	2
Line: 26-OHBC 53				
A1	NA	NA	0.48	2
1	1.40	0.27	0.21	2
2	2.96	0.40	0.08	2
3	2.18	0.34	0.14	3
4	2.18	0.34	0.14	2
5	1.40	[illegible]	0.21	2
6	1.56	[illegible]	0.20	2
Line: 26-OHBC 54				
A1	NA	NA	0.48	2
1	2.50	0.36	0.12	2
2	2.50	0.36	0.12	3
3	2.18	0.34	0.14	2
4	2.03	0.32	0.16	2
5	2.50	0.36	0.12	3
6	2.03	0.32	0.16	2

Station	Measured Ovality (%)	Meridional Strain (%)	Future Allowable Strain (%)	No of Strain Gages
Line: 26-OHBC 55				
A1	NA	NA	0.48	2
1	2.03	0.32	0.16	2
2	1.47	0.27	0.21	2
3	1.56	0.28	0.20	2
4	1.56	0.28	0.20	2
Line: 26-OHBC 56				
A1	NA	NA	0.48	2
1	1.09	0.22	0.26	2
2	1.87	0.31	0.17	2
3	0.90	0.21	0.27	2
4	2.49	0.36	0.12	2
Line: 26-OHBC 19				
A1	0.78	0.19	0.29	2
1	1.87	0.31	0.17	2
2	1.87	0.31	0.17	3
3	1.87	0.31	0.17	2
4	0.90	0.22	0.26	2
5	0.89	0.21	0.27	2
Line: 26-OHBC 20				
A1	1.09	0.24	0.24	2
1	1.87	0.31	0.17	2
2	1.09	0.24	0.24	2
3	1.87	0.31	0.17	2
4	1.87	0.31	0.17	3
5	1.79	0.30	0.18	2
Miscellaneous Lines				
18-1HCB-1				
A1(Vlv pit)	NA	NA	0.48	2
A2	NA	0.04	0.44	2
18-1HCB-2				
A1 (Vlv pit)	NA	NA	0.48	2
A2	NA	0.04	0.44	2

Station	Measured Ovality (%)	Meridional Strain (%)	Future Allowable Strain (%)	No of Strain Gages
Miscellaneous Lines - Reference: SK-C-745				
18-2HCB-1				
A1 (Vlv pit)	NA	NA	0.48	2
A2	NA	0.015	0.47	2
18-2HCB-2				
A1 (Vlv pit)	NA	NA	0.48	2
A2	NA	0.015	0.47	2
8-1HBC-311				
A1	NA	NA	0.48	2
8-1HBC-310				
A1	NA	NA	0.48	2
8-2HBC-82				
A1	NA	NA	0.48	2
8-2HBC-81				
A1	NA	NA	0.48	2
8-2HBC-311				
A1	NA	NA	0.48	2
8-2HBC-310				
A1	NA	NA	0.48	2
8-1HBC-81				
A1	NA	NA	0.48	2
8-1HBC-82				
A1	NA	NA	0.48	2

TABLE 2

LAYDOWN LOAD ALLOWABLES

Loaded Area	Allowable Load (psf) (< 2 months)	Allowable Load (psf) (> 2 months)
10' x 10'	1,500	500[1]
20' x 20'	750	500[1]
40' x 40'	500	225
100' x 100'	325	150

(1) Any long-term load in excess of 500 psf will be evaluated on a case-by-case basis.

TABLE 3

SUMMARY OF SOIL CONSTANTS FOR FLY ASH CONCRETE

		OBE 0.06g	SSE 0.18g[2]	References
Bedrock	Compression wave velocity	10,000 fps	10,000 fps	1,2
	Shear wave velocity	5,000 fps	5,000 fps	1,2
	Surface wave velocity	4,675 fps	4,675 fps	1,3
	Maximum particle velocity (all wave types)	2.88 in/sec	8.64 in/sec	4
	Maximum particle acceleration (all wave types)	23.16 in/sec^2	69.48 in/sec^2	3,5
Fill	Soil unit weight	130 pcf	130 pcf	
	Poisson's ratio	0.25	0.25	
	Angle of internal friction	25°	25°	
	Coefficient of lateral pressure	0.33	0.33	
	Coefficient of friction	0.466	0.466	
	Shear wave velocity[3]			
	E max	3,322 fps	3,322 fps	
	E min	1,500 fps	1,500 fps	
	Ultimate compressive strength	250 psi	250 psi	
	Maximum soil strain in/in	$(6.17)\ 10^{-5}$ in/in	$(1.85)\ 10^{-4}$	1

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(1) (deleted)

(2) SSE acceleration has been increased by 50% to provide a margin for the site-specific response spectra.

(3) The shear modulus and Young's modulus are assumed to remain constant with shear strain.

SUMMARY OF SOIL CONSTANTS FOR FLY ASH CONCRETE (Continued)

REFERENCES:

1) TPO Design Guide C-2.44, Seismic Analyses of Structures and Equipment for Nuclear Power Plants, Rev 0

2) Subsurface Investigation and Foundation Soil Report, Vol 2 of 2, Dec 1975, Appendix 2C

3) Iqbal, M.A., and Goodling, E.C. Jr., Seismic Design of Buried Piping, 2nd ASCE Specialty Conference on Structural Design of Nuclear Power Plant Facilities, New Orleans, Louisiana, Dec 1975

4) Newmark, N.M., Blume, J A., and Kapur, K.K., Seismic Design Spectra for Nuclear Powe Plants, ASCE, Journal of the Power Division, Nov 1973

5) Midland Civil Design Criteria, Standard C-501, Rev 11

TABLE 4

ENCLOSURE 1

ASME CODE CHECK - STRESS SUMMARY FOR

BURIED SERVICE WATER PIPING[1]

(Stresses in psi)

Line Number	Description	Normal Eq 8[2] Actual Stress	Normal Eq 8[2] Allowable Stress	Upset Eq 9[2] Actual Stress	Upset Eq 9[2] Allowable Stress	Faulted Code Case 1606-1[2] Actual Stress	Faulted Code Case 1606-1[2] Allowable Stress	Thermal Eq 10[2] Actual Stress	Thermal Eq 10[2] Allowable Stress
36/26"-OHBC-15	SW Supply	6,642	17,500	8,094	21,000	10,876	42,000	14,092	26,250
36/26"-OHBC-16	SW Return	6,642	17,500	8,084	21,000	9,525	42,000	19,895	26,250
36/26"-OHBC-19	SW Supply	6,642	17,500	8,153	21,000	10,866	42,000	4,580	26,250
36/26"-OHBC-20	SW Return	6,642	17,500	7,848	21,000	9,053	42,000	9,409	26,250
26"-OHBC-53	SW Supply	5,842	17,500	17,972	21,000	30,101	42,000	10,128	26,250
26"-OHBC-54	SW Return	5,842	17,500	10,847	21,000	15,852	42,000	13,742	26,250
26"-OHBC-55	SW Supply	5,842	17,500	11,488	21,000	17,134	42,000	10,875	26,250
26"-OHBC-56	SW Supply	5,842	17,500	10,301	21,000	14,760	42,000	21,764	26,250

NOTES:

1. This table shows maximum stresses in the above lines. The extent of the pipe summarized here matches that included in Enclosure 2.

2. Piping stress summaries:

   a. Equation 8

      Stresses included = design pressure, weight and sustained loads (includes overburden)
      Allowable stress = $1.0S_h$ - in accordance with ASME NC-3652.1 and Section III, Division 1, Appendix I

   b. Equation 9

      Stresses included = peak pressure, weight and sustained loads (includes overburden), occasional load (OBE)
      Allowable stress = $1.2S_h$ - in accordance with ASME NC-3652.2 and Section III, Division 1, Appendix I

   c. Code Case 1606

      Stresses included = peak pressure, weight and sustained loads (includes overburden), occasional load (SSE)
      Allowable stress = $2.4S_h$ - in accordance with Code Case 1606 and Section III, Division 1, Appendix I

   d. Equation 10

      Stresses included = thermal expansion, anchor movement (OBE)
      Allowable stress = S_A - in accordance with ASME NC-3652.3 and Section III, Division 1, Appendix I

MIDLAND PLANT UNITS 1 AND 2

REINSTALLED BURIED PIPE STRESS SUMMARY

LINE 36"-0HBC-15

(Stresses in psi)

Data Point	Pressure	Weight	Overburden	Thermal	Settlement[1]	Seismic[2] (SSE)	Seismic Anchor Movement (OBE)	Total
86 (Tee in Line 36"-0HBC-15)	2,442	2,958	0	9,110	10	1,219	1,286	17,025
215 (90° Elbow)	2,442	648	0	4,673	12	926	9,419	18,120
350	2,442	46	0	25	2	116	4	2,635
351 (Outside Face of SWPS)	1,434	0	4,200	16	1	102	3	5,756
35A	1,434	0	4,200	16	1	70	3	5,724
352	1,434	0	4,200	16	1	70	3	5,724
353	1,434	0	4,200	16	5	74	3	5,732
354	1,434	0	4,200	39	28	107	3	5,811
355	2,442	0	4,200	351	91	350	20	7,454
356 (Tee for Line 26"-0HBC-53)	2,442	0	4,200	2,752	534	2,063	135	12,126
358 (36" x 26" Reducer)	2,442	0	4,100	654	1,468	553	30	9,247
360	1,742	0	4,100	-	6,079	1,172	0	13,093
361 (Start of Compressible Material)	1,742	3,569	0	5	23,747	5,565	0	34,628
361A	1,742	1,080	0	3	6,990	2,214	0	12,026
361B	1,742	2,091	0	1	9,766	4,566	0	18,166
382 (End of Compressible Material)	1,742	537	0	1	26,522	940	0	29,742

TABLE 4

Enclosure 2
Sheet 1
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Line 36"-OBHC-15 (Continued)

Data Point	Pressure	Weight	Overburden	Thermal	Settlement[1]	Seismic[2] (SSE)	Seismic Anchor Movement (OBE)	Total
38A	1,742	0	4,100	1	-	2,198	0	8,041
38B	1,742	0	4,100	1	-	2,041	0	7,884
38C	1,742	0	4,100	0	-	1,413	0	7,255
38D	1,742	0	4,100	0	-	787	0	6,629
38E	1,742	0	4,100	0	-	306	0	6,148
38F	1,742	0	4,100	0	-	0	0	5,842

NOTES:

[1] Settlement stresses shown are the maximum values determined by either a 3-inch differential settlement between new fill and the old fill, or a 1-1/2-inch differential settlement between the new fill and the SWPS.

[2] Values shown are based on dynamic seismic analysis. A check by an analysis based on BC-TOP-4 techniques for the buried portion of the lines will be completed to consider the new fill condition. If the check reveals higher stresses due to the BC-TOP-4 analysis, the tabulated values will be revised.

TABLE 4

MIDLAND PLANT UNITS 1 AND 2

REINSTALLED BURIED PIPE STRESS SUMMARY

LINE 36"-0HBC-16

(Stresses in psi)

TABLE 4

Data Point	Pressure	Weight	Overburden	Thermal	Settlement[1]	Seismic[2] (SSE)	Seismic Anchor Movement (OBE)	Total
847 (36" x 30" Reducer to Line 30"-0HBC-34)	2,442	189	0	1,196	4,218	649	2,735	11,429
845	2,442	515	0	1,380	6,713	865	3,188	15,103
830 (Tee for Line 36"-0HBC-1)	2,442	2,588	0	5,874	20,835	2,797	14,021	48,557
835A	2,442	404	0	1,255	5,540	382	860	10,883
835	2,442	380	0	-	9,631	-	-	12,453
834	1,434	150	0	1,305	11,373	117	2,524	16,903
-----	-----	-----	-----	------	------	-----	-----	------
836 (Outside Face of SWPS)	1,434	0	4,200	853	8,754	168	2,579	17,988
90A	1,434	0	4,200	786	1,926	72	571	8,989
90B	1,434	0	4,200	784	798	93	157	7,466
90R	1,434	0	4,200	1,262	1,152	523	150	8,721
230 (Tee for Line 26"-0HBC-54)	2,442	0	4,200	6,179	4,869	2,883	846	21,419
90Q (36" x 26" Reducer to Line 26"-0HBC-16)	2,442	0	4,200	267	695	748	164	8,516
90P	1,742	0	4,100	403	5,477	165	36	11,923
90N (Start of Compressible Material)	1,742	-	0	121	23,726	0	0	25,589
90LC	1,742	-	0	121	11,166	-	-	13,029
90LB	1,742	-	0	121	1,394	-	-	3,257
90LA	1,742	-	0	121	13,953	-	-	15,816
90L (End of Compressible Material)	1,742	-	0	121	26,513	-	-	28,376

NOTES:

[1] See Note 1 for Line 36"-0HBC-15.
[2] See Note 2 for Line 36"-0HBC-15.

Enclosure 2
Sheet 3
8/25/82

MIDLAND PLANT UNITS 1 AND 2

REINSTALLED BURIED PIPE STRESS SUMMARY

LINE 36"-0HBC-19

(Stresses in psi)

Data Point	Pressure	Weight	Overburden	Thermal	Settlement[1]	Seismic[2] (SSE)	Seismic Anchor Movement (OBE)	Total
32 (Tee in Line 36"-0HBC-19)	2,442	1,731	0	2,761	16	2,445	1,277	10,672
200 (90° Elbow)	2,442	1,717	0	3,243	32	2,139	1,337	10,910
204	2,442	456	0	437	14	666	122	4,137
20A	2,442	1,306	0	2,141	80	2,352	396	8,717
20B (90° Elbow)	2,442	1,114	0	2,010	80	1,877	196	7,719
208	2,442	109	0	349	14	176	4	3,094
209	2,442	109	0	349	14	176	4	3,094
210	2,442	110	0	349	14	176	4	3,095
700	2,442	113	0	349	14	176	4	3,098
-----	-----	-----	-----	-----	------	------	----	------
701 (Outside Face of SWPS)	1,434	0	4,200	212	9	107	3	5,965
702	1,434	0	4,200	212	9	107	3	5,965
703	1,434	0	4,200	212	9	107	3	5,965
704	1,434	0	4,200	212	9	107	3	5,965
705	1,434	0	4,200	212	9	107	3	5,965
706	1,434	0	4,200	212	9	107	3	5,965
707	1,434	0	4,200	212	9	107	3	5,965
735	1,434	0	4,200	212	9	107	3	5,965
740	1,434	0	4,200	212	9	107	3	5,965
742	1,434	0	4,200	215	11	108	3	5,971
743	1,434	0	4,200	290	46	112	3	6,085
745	2,442	0	4,200	402	87	642	4	7,777
750 (Tee for Line 26"-0HBC-55)	2,442	0	4,200	3,379	544	3,023	18	13,606
755	2,442	0	4,200	704	1,489	750	0	9,585
762	1,742	0	4,100	217	6,039	1,189	0	13,287
765 (Start of Compressible Material)	1,742	3,568	0	40	23,746	5,556	0	34,652

TABLE 4

Data Point	Pressure	Weight	Overburden	Thermal	Settlement[1]	Seismic[2] (SSE)	Seismic Anchor Movement (OBE)	Total
765A	1,742	1,080	0	24	6,990	2,215	0	12,051
765B	1,742	2,091	0	8	9,766	4,558	0	18,165
780 (End of Compressible Material)	1,742	537	0	8	26,522	944	0	29,753
78A	1,742	0	4,100	10	-	2,195	0	8,047
78B	1,742	0	4,100	7	-	2,038	0	7,887
78C	1,742	0	4,100	4	-	1,410	0	7,256
78D	1,742	0	4,100	2	-	785	0	6,629
78E	1,742	0	4,100	1	-	305	0	6,148
78F	1,742	0	4,100	0	-	0	0	5,842

NOTES:

[1]See Note 1 for Line 36"-0HBC-15.
[2]See Note 2 for Line 36"-0HBC-15.

TABLE 4

MIDLAND PLANT UNITS 1 AND 2

REINSTALLED BURIED PIPE STRESS SUMMARY

LINE 36"-0HBC-20

(Stresses in psi)

Data Point	Pressure	Weight	Overburden	Thermal	Settlement[1]	Seismic[2] (SSE)	Seismic Anchor Movement (OBE)	Total
886 (Tee at Line 36"-0HBC-1 Inside SWPS)	2,442	391	0	3,251	5,301	741	1,550	13,676
887 (90° Elbow)	2,442	1,741	0	1,686	15,307	1,464	1,882	24,522
890	2,442	464	0	580	3,450	332	282	7,550
892 (90° Elbow)	2,442	795	0	4,239	15,125	2,046	2,570	27,217
894 (90° Elbow)	2,442	916	0	2,642	13,112	1,678	2,280	23,070
896	2,442	462	0	496	2,342	234	394	6,370
897 (90° Elbow)	2,442	915	0	4,231	15,877	1,484	2,937	27,886
898	2,442	490	0	597	2,707	1,751	1,156	9,143
-----	-----	-----	-----	-----	------	------	-----	------
899 (Outside Face of SWPS)	1,434	0	4,200	486	2,170	1,965	1,013	11,268
A99	1,434	0	4,200	357	1,538	373	233	8,135
B99	1,434	0	4,200	351	1,508	38	148	7,679
C99	1,434	0	4,200	351	1,508	40	148	7,681
D99	1,434	0	4,200	351	1,508	38	148	7,679
E99	1,434	0	4,200	351	1,508	38	148	7,679
F99	1,434	0	4,200	351	1,508	38	148	7,679
G99	1,434	0	4,200	351	1,508	38	148	7,679
H99	1,434	0	4,200	351	1,508	38	148	7,679
J99	1,434	0	4,200	351	1,508	38	148	7,679
K99	1,434	0	4,200	368	1,508	40	148	7,698
L99	1,434	0	4,200	368	1,508	-	148	7,658
M99	1,434	0	4,200	546	1,508	38	148	7,874
N99	2,442	0	4,200	805	2,479	485	246	10,657
700 (Tee for Line 26"-0HBC-56)	2,442	0	4,200	8,309	4,611	2,411	1,100	23,073
P99	2,442	0	4,200	336	635	423	43	8,079
O99 (36" x 26" Reducer)	1,742	0	4,100	1,185	6,534	189	22	13,772

TABLE 4

Enclosure 2
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TABLE 4

Data Point	Pressure	Weight	Overburden	Thermal	Settlement[1]	Seismic[2] (SSE)	Seismic Anchor Movement (OBE)	Total
R99 (Start of Compressible Material)	1,742	-	0	310	23,749	0	0	25,801
S99 (End of Compressible Material)	1,742	-	0	300	26,525	-	-	32,667

NOTES:

[1]See Note 1 for Line 36"-0HBC-15.
[2]See Note 2 for Line 36"-0HBC-15.

MIDLAND PLANT UNITS 1 AND 2

REINSTALLED BURIED PIPE STRESS SUMMARY

LINE 26"-0HBC-53

(Stresses in psi)

Data Point	Pressure	Weight	Overburden	Thermal	Settlement[1]	Seismic[2] (SSE)	Seismic Anchor Movement (OBE)	Total
356 (Tee at 36"-0HBC-15)	1,742	0	4,100	9,633	58	6,623	495	22,651
365	1,742	0	4,100	9,633	59	1,239	495	17,268
366	1,742	0	4,100	336	12	4,624	11	10,825
367 (90° Elbow)	1,742	0	4,100	4,931	53	12,826	48	23.700
368	1,742	0	4,100	2,293	5	4,048	4	12,192
380	1,742	0	4,100	326	4	1,275	1	7,448
384	1,742	0	4,100	654	5	8,491	3	14,995
385 (90° Elbow)	1,742	0	4,100	3,168	22	24,259	12	33,303
390 (45° Elbow)	1,742	0	4,100	4,138	9	11,680	15	21,684
391	1,742	0	4,100	2,316	1	2,294	7	10,460
392	1,742	0	4,100	39	0	65	0	5,946
393	1,742	0	4,100	22	0	22	0	5,946
394	1,742	0	4,100	1	0	18	0	5,861
395	1,742	0	4,100	0	0	18	0	5,860
396	1,742	0	4,100	0	0	18	0	5,860
398	1,742	0	4,100	0	0	18	0	5,860
399	1,742	0	4,100	0	0	18	0	5,860
500	1,742	0	4,100	0	0	18	0	5,860
501	1,742	0	4,100	0	0	18	0	5,860
502	1,742	0	4,100	0	0	18	0	5,860
503	1,742	0	4,100	0	0	18	0	5,860
504	1,742	0	4,100	0	0	18	0	5,860
505	1,742	0	4,100	0	0	18	0	5,860
506	1,742	0	4,100	0	0	18	0	5,860
507	1,742	0	4,100	0	0	18	0	5,860
508	1,742	0	4,100	0	0	18	0	5,860
509	1,742	0	4,100	0	0	18	0	5,860
510	1,742	0	4,100	0	0	18	0	5,860
511	1,742	0	4,100	0	0	18	0	5,860
512	1,742	0	4,100	0	0	18	0	5,860
513	1,742	0	4,100	0	0	18	0	5,860
514	1,742	0	4,100	0	0	18	0	5,860
515	1,742	0	4,100	0	0	18	0	5,860
516	1,742	0	4,100	0	0	18	0	5,860

TABLE 4

Enclosure 2

Sheet 8

TABLE 4

Data Point	Pressure	Weight	Overburden	Thermal	Settlement[1]	Seismic[2] (SSE)	Seismic Anchor Movement (OBE)	Total
517	1,742	0	4,100	0	0	18	0	5,860
518	1,742	0	4,100	0	0	18	0	5,860
519	1,742	0	4,100	0	1	18	0	5,861
520	1,742	0	4,100	0	20	19	0	5,881
521	1,742	0	4,100	0	139	30	0	6,011
522	1,742	0	4,100	0	1,887	388	0	8,117
523 (Start of Compressible Material)	1,742	3,526	0	0	23,310	5,003	0	33,581
523A	1,742	1,106	0	0	6,765	2,072	0	11,685
523B	1,742	2,100	0	0	9,780	4,174	0	17,796
550 (End of Compressible Material)	1,742	545	0	0	26,325	876	0	29,488
50A	1,742	0	4,100	0	0	2,020	0	7,862
50B	1,742	0	4,100	0	0	1,872	0	7,714
50C	1,742	0	4,100	0	0	1,294	0	7,136
50D	1,742	0	4,100	0	0	720	0	6,562
50E	1,742	0	4,100	0	0	279	0	6,121
50F	1,742	0	4,100	0	0	0	0	5,842

NOTES:

[1]See Note 1 for Line 36"-0HBC-15.
[2]See Note 2 for Line 36"-0HBC-15.

TABLE 4

MIDLAND PLANT UNITS 1 AND 2

REINSTALLED BURIED PIPE STRESS SUMMARY

LINE 26"-0HBC-54

(Stresses in psi)

Data Point	Pressure	Weight	Overburden	Thermal	Settlement[1]	Seismic[2] (SSE)	Seismic Anchor Movement (OBE)	Total
290 (Tee at 36"-0HBC-16)	1,742	0	4,100	11,158	8,279	10,010	2,584	37,873
291	1,742	0	4,100	-	-	281	38	6,161
A40 (45° Elbow)	1,742	0	4,100	8,897	3,705	703	148	19,295
B40	1,742	0	4,100	7,615	1,201	196	39	14,893
C40	1,742	0	4,100	578	24	20	1	6,465
D40	1,742	0	4,100	5	11	20	0	5,878
E40	1,742	0	4,100	3	1	18	0	5,864
F40	1,742	0	4,100	1	1	18	0	5,862
G40	1,742	0	4,100	1	1	0	0	5,844
H40	1,742	0	4,100	1	1	-	0	5,844
J40	1,742	0	4,100	1	1	-	0	5,844
K40	1,742	0	4,100	1	1	-	0	5,844
L40	1,742	0	4,100	1	1	-	0	5,844
M40	1,742	0	4,100	1	1	-	0	5,844
N40	1,742	0	4,100	1	1	-	0	5,844
P40	1,742	0	4,100	1	1	-	0	5,844
Q40	1,742	0	4,100	1	1	-	0	5,844
R40	1,742	0	4,100	1	1	-	0	5,844
S40	1,742	0	4,100	1	1	-	0	5,844
T40	1,742	0	4,100	1	1	-	0	5,844
U40	1,742	0	4,100	1	1	-	0	5,844
V40	1,742	0	4,100	1	1	-	0	5,844
W40	1,742	0	4,100	1	1	-	0	5,844
X40	1,742	0	4,100	1	1	-	0	5,844
Y40	1,742	0	4,100	1	1	-	0	5,844
Z40	1,742	0	4,100	1	1	-	0	5,844
A45	1,742	0	4,100	1	1	-	0	5,844
B45	1,742	0	4,100	1	1	-	0	5,844
C45	1,742	0	4,100	1	1	-	0	5,844
D45	1,742	0	4,100	1	1	-	0	5,844
E45	1,742	0	4,100	1	1	-	0	5,844
F45	1,742	0	4,100	2	1	-	0	5,845
G45	1,742	0	4,100	4	3	-	0	5,849
H45	1,742	0	4,100	3	2	-	0	5,847

Data Point	Pressure	Weight	Overburden	Thermal	Settlement[1]	Seismic[2] (SSE)	Seismic Anchor Movement (OBE)	Total
J45	1,742	0	4,100	3	261	-	0	6,106
K45	1,742	0	4,100	3	535	-	0	6,380
L45 (Start of Compressible Material)	1,742	-	0	3	23,664	-	0	25,409
M45 (End of Compressible Material)	1,742	-	0	15	26,489	-	0	28,246

NOTES:

[1]See Note 1 for Line 36"-0HBC-15.
[2]See Note 2 for Line 36"-0HBC-15.

TABLE 4

TABLE 4

MIDLAND PLANT UNITS 1 AND 2

REINSTALLED BURIED PIPE STRESS SUMMARY

LINE 26"-0HBC-55

(Stresses in psi)

Data Point	Pressure	Weight	Overburden	Thermal	Settlement[1]	Seismic[2] (SSE)	Seismic Anchor Movement (OBE)	Total
750 (Tee at 36"-0HBC-19)	1,742	0	4,100	4,180	285	11,292	36	21,635
782	1,742	0	4,100	4,180	1,098	527	36	11,683
785 (45° Elbow)	1,742	0	4,100	10,862	8,227	1,376	13	26,320
786	1,742	0	4,100	6,909	3,20[illegible]	708	3	16,664
787 (Start of Compressible Material)	1,742	3,520	0	655	23,4[illegible]	5,075	0	34,436
787A	1,742	1,109	0	388	6,845	2,106	0	12,190
787B	1,742	2,099	0	120	9,753	4,223	0	17,937
800 (End of Compressible Material)	1,742	550	0	147	26,352	894	0	29,685
80A	1,742	0	4,100	165	-	2,049	0	8,056
80B	1,742	0	4,100	99	-	1,898	0	7,839
80C	1,742	0	4,100	52	-	1,312	0	7,206
80D	1,742	0	4,100	21	-	731	0	6,594
80E	1,742	0	4,100	4	-	284	0	6,130
80F	1,742	0	4,100	0	-	0	0	5,842

NOTE:

(1) See Note 1 for Line 36"-0HBC-15.
(2) See Note 2 for Line 36"-0HBC-15.

MIDLAND PLANT UNITS 1 AND 2

REINSTALLED BURIED PIPE STRESS SUMMARY

LINE 26"-0HBC-56

(Stresses in psi)

Data Point	Pressure	Weight	Overburden	Thermal	Settlement[1]	Seismic[2] (SSE)	Seismic Anchor Movement (OBE)	Total
700 (Tee at 36"-0HBC-20)	1,742	0	4,100	8,572	19,211	8,918	2,251	44,794
701	1,742	0	4,100	-	-	270	48	6,160
A65 (45° Elbow)	1,742	-	4,100	21,588	7,127	728	176	35,461
B65	1,742	-	4,100	12,755	2,270	164	37	21,068
C65 (Start of Compressible Material)	1,742	-	0	808	23,452	0	0	26,002
D65 (End of Compressible Material)	1,742	-	0	197	26,354	-	0	28,293

NOTES:

[1]See Note 1 for Line 36"-0HBC-15.
[2]See Note 2 for Line 36"-0HBC-15.

TABLE 4

TABLE 5

STRUCTURES, FACILITIES, AND UTILITIES ENCOUNTERED OR AFFECTED BY EXCAVATION

1. Service water pump structure*
2. Circulating water intake structure
3. Railroad spur to diesel generator building and transformer area (Line D)
4. Permanent dewatering wells*
5. Oily waste lines
6. Fire water lines
7. Circulating water lines
8. Security duct bank
9. Electrical duct banks*
10. 48-inch diameter service water line to cooling tower*
11. 66-inch diameter pond blowdown line
12. Service water metering pit

*Safety-related, or otherwise required to be covered by the quality assurance program.

MIDLAND STRAIN vs OVALITY CURVE

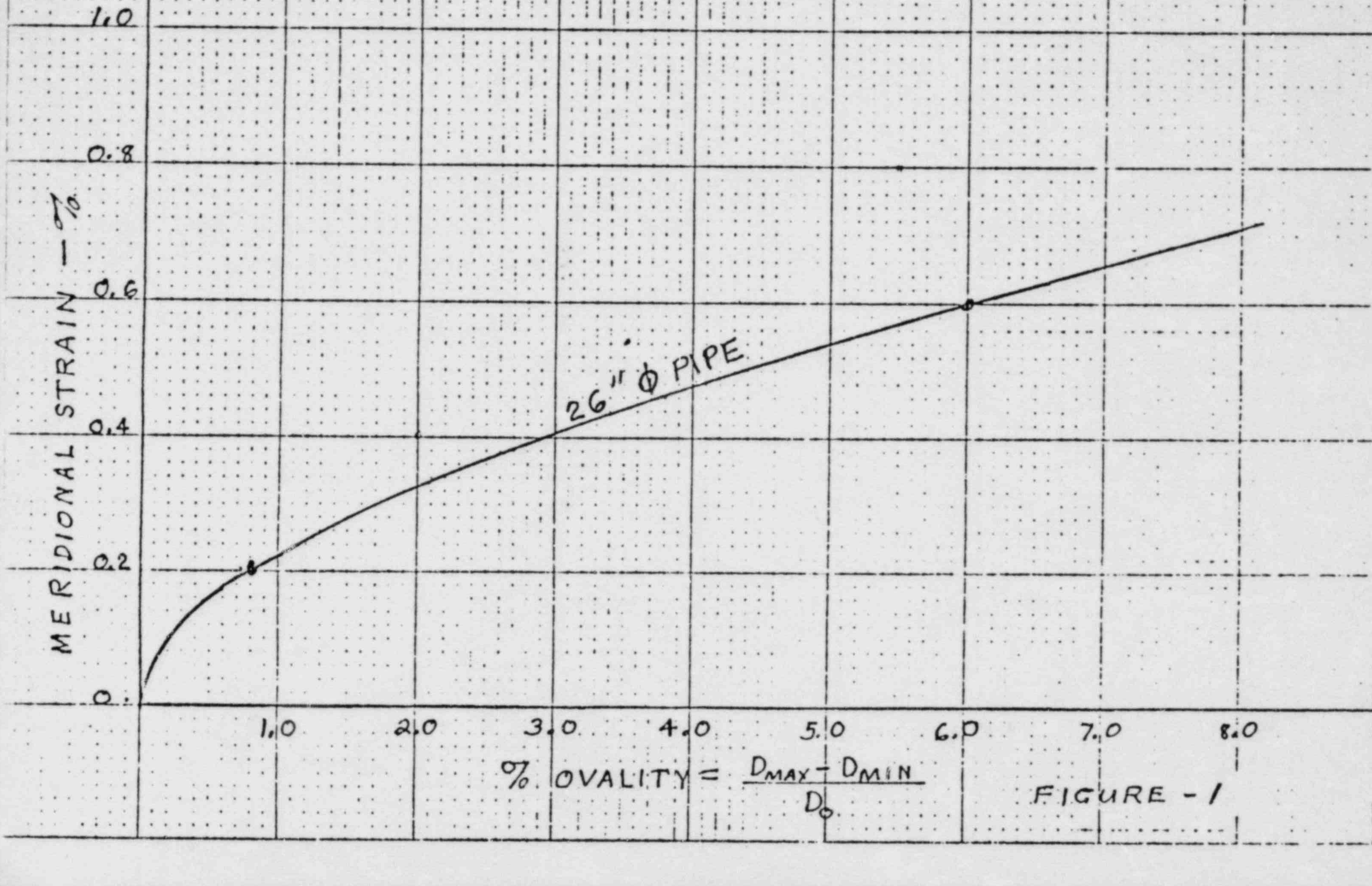
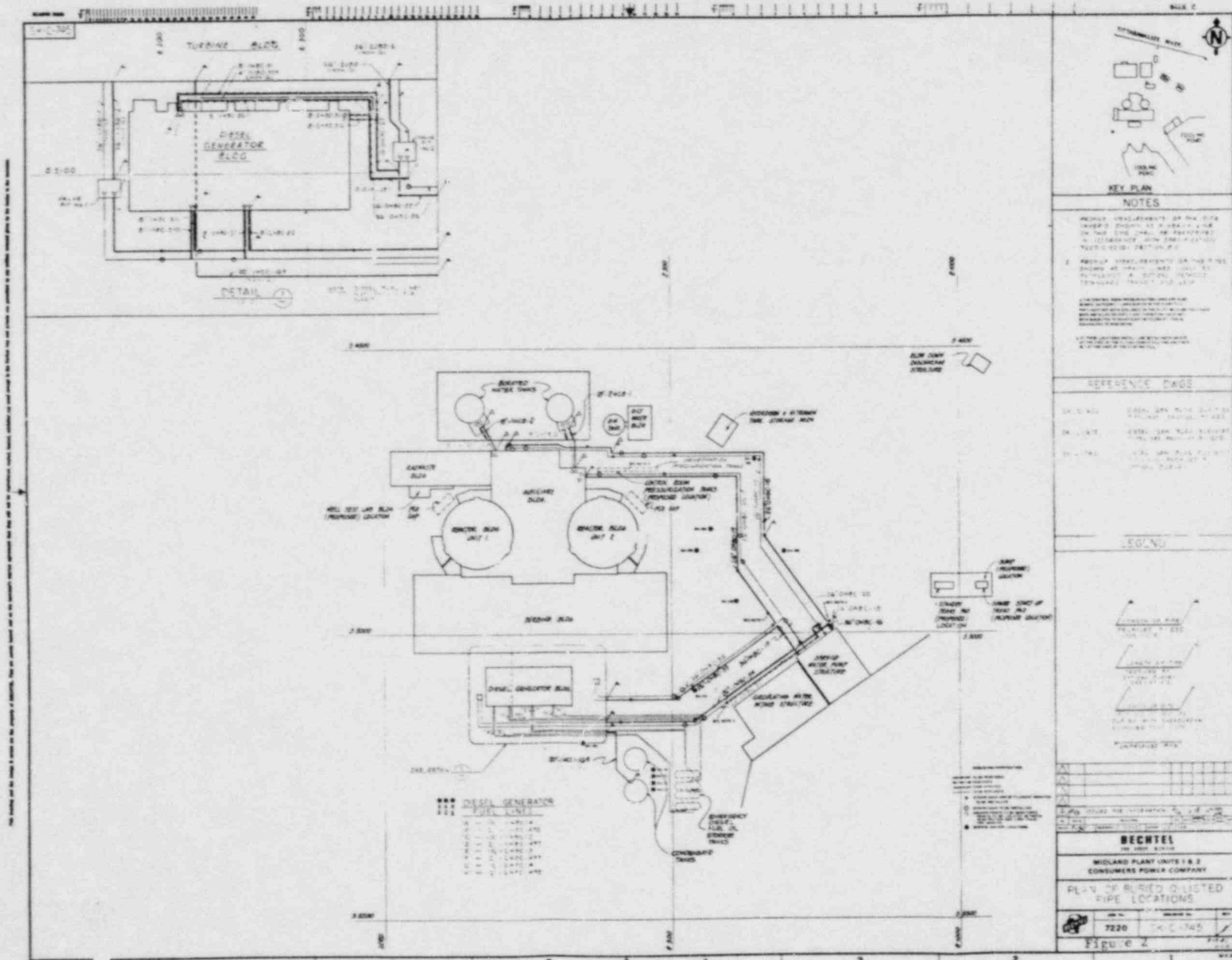
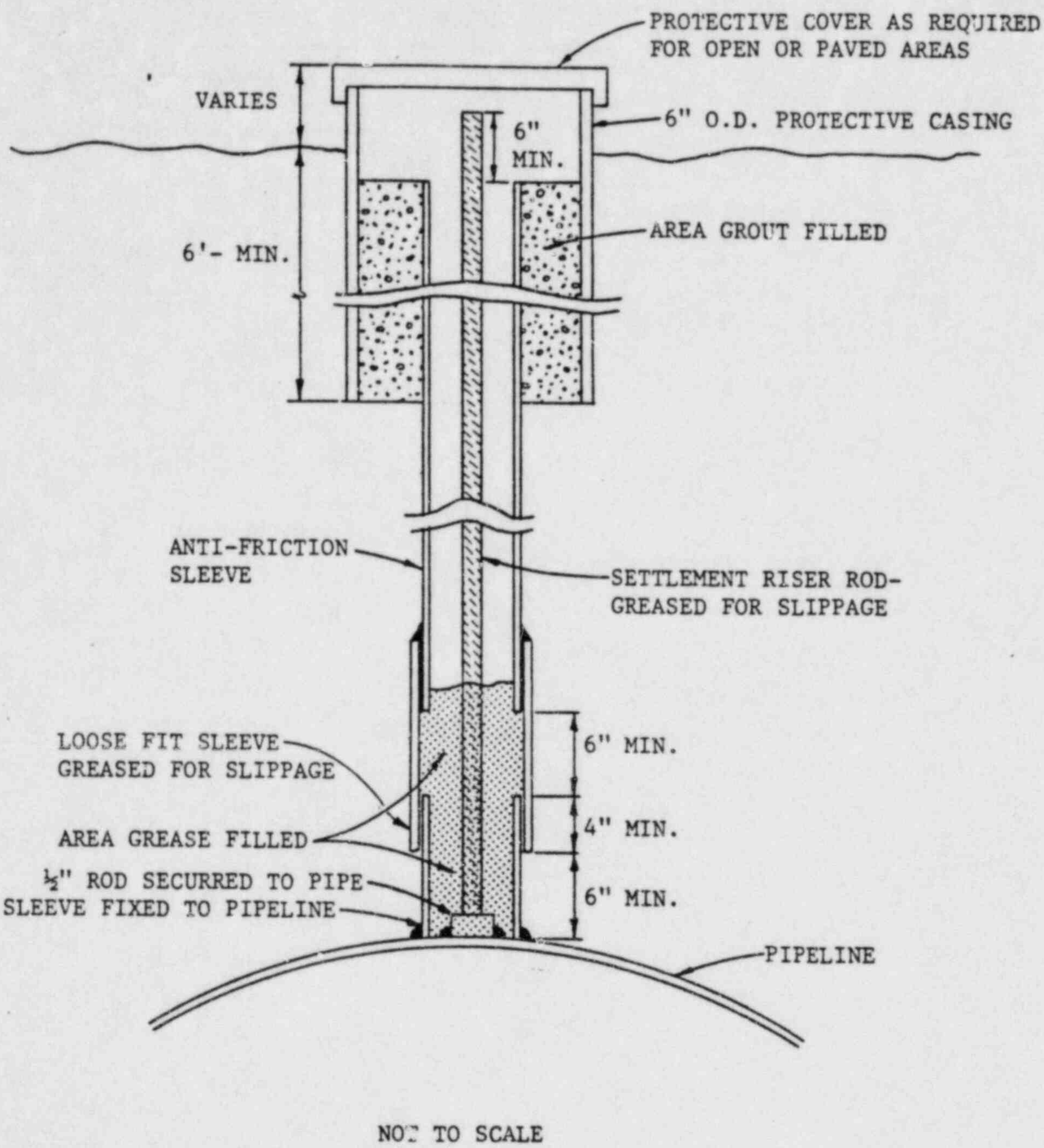


FIGURE - 1

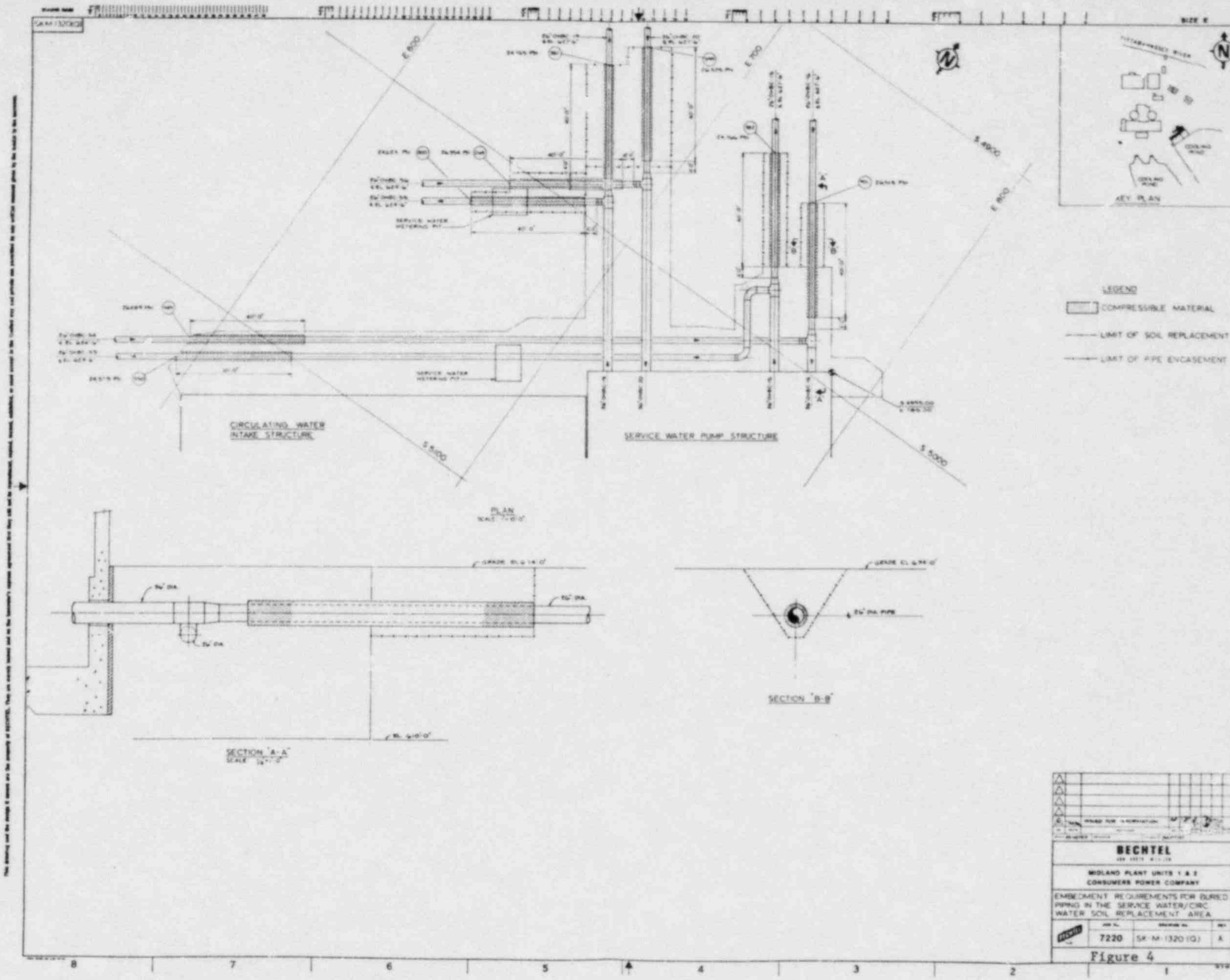


TURBINE BLDG
DIESEL GENERATOR BLDG
DETAIL
KEY PLAN
NOTES
REFERENCE DWGS
LEGEND
BORATED WATER TANKS
AUXILIARY BLDG
REACTOR BLDG UNIT 1
REACTOR BLDG UNIT 2
TURBINE BLDG
DIESEL GENERATOR BLDG
DIESEL GENERATOR FUEL LINES
EMERGENCY DIESEL FUEL OIL STORAGE TANKS
CONDENSATE TANKS
CIRCULATING WATER INTAKE STRUCTURE
SERVICE WATER PUMP STRUCTURE
BLOW DOWN DISCHARGE STRUCTURE
BECHTEL
MIDLAND PLANT UNITS 1 & 2
CONSUMERS POWER COMPANY
PLAN OF BURIED Q-LISTED PIPE LOCATIONS
7220
SK-C-745

Figure 2



PIPE SETTLEMENT MARKER
FIGURE 3



CIRCULATING WATER INTAKE STRUCTURE
SERVICE WATER PUMP STRUCTURE
SERVICE WATER METERING PIT
PLAN
SECTION "A-A"
SECTION "B-B"
LEGEND
COMPRESSIBLE MATERIAL
LIMIT OF SOIL REPLACEMENT
LIMIT OF PIPE ENCASEMENT
KEY PLAN
COOLING POND
S 4900
S 5000
S 5100
E 600
E 700
E 800
BECHTEL
MIDLAND PLANT UNITS 1 & 2
CONSUMERS POWER COMPANY
EMBEDMENT REQUIREMENTS FOR BURIED PIPING IN THE SERVICE WATER/CIRC WATER SOIL REPLACEMENT AREA
7220
SK-M-1320 (Q)
A

Figure 4

Table C-1

Magnitude and Direction of Forces Acting on Each Slice -- Deep Failure Surface

Slice No.	Total Volume ft^3	Volume Above Water Level ft^3	Volume Below Water Level ft^3	Effec. Weight of Slice* kips	Structural Loads Including Surcharge kips	Total Vertical Force kips	Average Angle of Inclination α	Angle of Inclination Between Slices
1	30.3	4.9	25.4	2.50	3.96	6.46	60.5°	
								14°
2	22.91	2.5	20.41	1.82	2.02	3.84	22°	
								5°
3	24.42	2.5	21.92	1.93	2.02	3.95	8°	
								0°
4	24.42	2.5	21.92	1.93	12.14	14.07	- 8°	
								5°
5	22.91	2.5	20.41	1.82	12.14	13.96	-22°	
								14°
6	30.3	4.9	25.4	2.5	24.27	26.77	-60.5°	

* Slice weights were calculated using a unit weight of 135 pcf for the portion of the slice above water level, and a submerged unit weight of 72.5 pcf for the portions below water level.

Table C-2

Long Term Effective Stress on Deep Sliding Surface
Mobilized Friction Angle 16°

Slice No.	L_o Length of Arc ft	L_i Length of Chord ft	Reaction Force kips	$\frac{R \cos 16°}{L_i}$ $\bar{\sigma}_n$ psf	$\frac{R \sin 16°}{L_i}$ τ_n psf	ψ degrees	$\bar{\sigma}_1$ psf	$\bar{\sigma}_3$ psf	$K_c=\sigma_1/\sigma_3$
1	10.47	9.6	13.4	1342	385	60	2009	1120	1.79
2	2.62	2.6	6.9	2551	732	60	3819	2128	1.79
3	2.62	2.5	5.88	1900	648	60	3383	1887	1.79
4	2.62	2.5	16.50	6344	1820	60	9496	5293	1.79
5	2.62	2.6	20.0	7394	2120	60	11066	6170	1.79
6	10.47	9.6	27.1	2713	778	60	4060	2264	1.79

Table C-3

RESISTING MOMENTS AGAINST SLIDING UNDRAINED SHEAR STRENGTH FROM FIGURE 14
DEEP CIRCULAR SLIDING SURFACE

Slice no.	P_i Soil surcharge above slice kips	d_i Arm of surcharge around 0 ft	Surcharge induced moment $P_i \cdot d_i$ lbs/ft	$\bar{\sigma}_n$ Effective normal stress at bottom of slice psf	τ_{ff} Undrained shear strength psf	ℓ Length of arch along bottom of slice, ft	$\tau_{ff} \cdot \ell$ Resistance Along base Of Slice	Radius of sliding surface r, ft	Strength-induced moment around 0 lbs/ft
1	3.96	7.5	29,700	1342	1830	10.47	19,160	10	191,600
2	2.02	3.75	7,575	2551	2520	2.62	6,602	10	66,020
3	2.02	1.25	2,525	2261	2350	2.62	6,157	10	61,570
4	-	-	-	6344	4700	2.62	12,314	10	123,140
5	-	-	-	7394	5300	2.62	13,886	10	138,860
6	-	-	-	2713	2610	10.47	27,326	10	273,260
			39,800						854,457

Table C-4

FACTOR OF SAFETY UNDER COMBINED STATIC AND DYNAMIC LOADING
DEEP CIRCULAR SLIDING SURFACE
UNDRAINED SHEAR STRENGTH FROM FIGURE 14

1 - Contribution of Shear Strength - weightless mass

$M_{R1} = \Sigma M_o = 854,457$ lbs/ft

2 - Contribution of Surcharge

$M_{R2} = \Sigma M_o = 39,800$

3 - Contribution of Weight

$M_{R3} = \Sigma M_o = 0$

Equilibrium of Moments Around Center of Sliding Mass

$$P_u \times \frac{B}{2} = M_{R1} + M_{R2} + M_{R3}$$

$$P_u \times \frac{10}{2} = 854,457 + 39,800 = 894,257 \text{ lbs/ft}$$

$$P_u = \frac{894,257}{5} = 178,851 \text{ lbs}$$

$$FS = \frac{P_u/B - \gamma D_f}{q_t - \gamma D_f} = \frac{17,885 - 810}{6,054 - 810} = 3.25$$

Table C-5

RESISTING MOMENTS AGAINST SLIDING UNDRAINED SHEAR STRENGTH FROM FIGURE 13
DEEP, CIRCULAR SLIDING SURFACE

Slice No.	P_i Soil Surcharge Above Slice kips	d_i Arm of Surcharge Around 0 ft	Surcharge Induced Moment $P_i \cdot d_i$ lbs/ft	$\bar{\sigma}_n$ Effective Normal Stress at Bottom Of slice psf	τ_{ff} Undrained Shear Strength psf	ℓ Length Of arch Along Bottom of Slice, ft	* $\tau_{ff} \cdot \ell$ Resistance Along base Of slice	Radius Of Sliding Surface r, ft	Strength-Induced Moment Around 0 lbs/ft
1	3.96	7.5	29,700	1,342	1,500	10.47	15,705	10	157,050
2	2.02	3.75	7,575	2,551	2,180	2.62	5,711	10	57,110
3	2.02	1.25	2,525	2,261	2,020	2.62	5,292	10	52,920
4	-	-	-	6,344	4,360	2.62	11,423	10	114,230
5	-	-	-	7,394	4,940	2.62	12,943	10	129,430
6	-	-	-	2,713	2,300	10.47	24,081	10	240,810
			39,800						751,550

* Undrained shear strength obtained from results carried out with anisotropic as well as isotropically consolidated samples.

Table C-6

FACTOR OF SAFETY UNDER COMBINED STATIC AND DYNAMIC LOADING
DEEP, CIRCULAR SLIDING SURFACE
UNDRAINED SHEAR STRENGTH FROM FIGURE 13

1 - Contribution of Shear Strength - weightless mass

$M_{R1} = 751,550$ lbs/ft

2 - Contribution of Surcharge

$M_{R2} = 39,800$ lbs/ft

3 - Contribution of Weight

$M_{R3} = 0$ weights balance out

Equilibrium of Moments Around Center of Sliding Mass

$$P_u \times \frac{B}{2} = M_{R1} + M_{R2}$$

$$P_u \times \frac{10}{2} = 751,550 + 39,800 = 791,350 \text{ lbs/ft}$$

$$P_u = \frac{791,350}{5} = 158,270 \text{ lbs}$$

$$FS = \frac{P_u/B - \gamma D_f}{q_t - \gamma D_f} = \frac{15,827 - 810}{6,054 - 810} = 2.86$$

TABLE C-7

MAGNITUDE AND DIRECTION OF FORCES ACTING ON EACH SLICE
INTERMEDIATE FAILURE SURFACE

Slice No.	Volume Above Water Level ft^3	Volume Below Water Level ft^3	Weight of Slice Above Water Level kips	Weight of Slice Below Water Table kips	Bouyant Weight of Slice kips	Structural Loads Including Surcharge kips	Total Vertical Force kips	Average Angle of Inclination α, at Bottom of slice	β Average Angle of Inclination Of Force Between slices
1	2.90	9.53	.392	.691	1.08	2.36	3.44	64°	
									18°
2	2.7	16.6	.364	1.20	1.56	2.19	3.75	30°	
									9°
3	2.7	19.01	.364	1.38	1.74	2.19	3.93	7°	
									0°
4	2.3	16.23	.310	1.176	1.49	11.16	12.65	- 9°	
									- 8.5°
5	2.7	16.42	.364	1.19	1.55	13.1	14.65	-27°	
									-26°
6	4.58	11.28	.618	.818	1.43	24.25	25.68	-52°	

Table C-8

LONG TERM EFFECTIVE STRESS ON INTERMEDIATE SLIDING SURFACE
MOBILIZED FRICTION ANGLE OF 18.5°

Slice No.	L_o Length of Arch ft	L_i Length of Chord ft	Reaction Force R kips	$\frac{R_{cos}\ 18.5°}{L_i}$ $\bar{\sigma}_n$ psf	τ_n $\frac{R_{sin}\ 18.5°}{L_i}$ psf	ψ degrees	σ_1 psf	σ_3 psf	σ_1/σ_3
1	7.08	6.95	7.31	997	334	60	1,576	804	1.96
2	3.08	3.02	6.5	2041	683	60	3,224	1647	1.96
3	2.70	2.66	6.56	2338	783	60	3,694	1886	1.96
4	2.37	2.33	15.25	6207	2076	60	9,803	5008	1.96
5	2.91	2.89	19.31	6336	2120	60	10,008	5112	1.96
6	8.25	8.25	23.75	2730	913	60	4,311	2203	1.96

Table C-9

RESISTING MOMENTS AGAINST SLIDING
INTERMEDIATE SLIDING SURFACE
UNDRAINED SHEAR STRENGTH FROM FIGURE 14

Slice No.	W_i* Effective Weight Of Slice kips	n_i Arm of Weight W_i Around Center 0 ft	Weight-Induced Moment $w_i \cdot n_i$ lbs-ft/ft	P_i Soil Surcharge kips	d_i Arm of Surcharge P_i around Center 0 ft	Surcharge Induced Moment $P_i\ d_i$ lbs-ft/ft	$\bar{\sigma}_n$ psf	τ_{ff} Undrained Shear Strength psf	ℓ Length Of arch Along base Of Slice ft	Resistance At the Base of The slice $\tau_{ff}\ \ell$ psf	Radius of Circle r ft	Shear Strength Induced Moment lbs-ft/ft
1	1.08	6.37	6,880	2.36	6.86	16,190	997	1,640	7.08	11,611	8.25	95,790
2	1.56	4.05	6,318	2.19	4.05	8,870	2,041	2,230	3.08	6,868	8.25	56,661
3	1.74	1.35	2,349	2.19	1.35	2,956	2,338	2,400	2.70	6,480	8.25	53,460
4	1.14	-1.15	- 1,311	-	-	-	6,207	4,600	2.37	10,902	8.25	89,941
5	0.468	-3.2	- 1,498	-	-	-	6,336	4,680	2.91	13,619	8.25	112,357
6	-	-	-	-	-	-	2,730	2,620	8.25	21,615	-	-
			12,738			28,016						408,210

*Weight of portion of slice on the circular sliding mass

Table C-10

FACTOR OF SAFETY UNDER COMBINED STATIC AND DYNAMIC LOADING
INTERMEDIATE FAILURE SURFACE ACTIVE - CIRCULAR
UNDRAINED SHEAR STRENGTH FROM FIGURE 14

1 - Contribution of Shear Strength - weightless mass

$P'_o \times \frac{r}{2} = \sum_{i=1}^{5} S_{ui} \ell_i r$

$P'_o \times 4.13 = 408,210$

$P'_o = 98.96$ kips

2 - Contribution of Surcharge

$P''_o \times \frac{r}{2} = \sum_{i=1}^{3} P_i d_i$

$P''_o \times 4.13 = 28,016$

$P''_o = 6.78$ kips

3 - Contribution of Weight

$P'''_o \times \frac{2}{3} r = \sum_{i=1}^{3} W_i n_i$

$P'''_o \times 5.5 = 12,738$

$P'''_o = 2.32$ kips

$P'_o + P''_o + P'''_o = 108.06$ kips

Equilibrium of Forces Acting on Wedge of Sliding Mass Underneath Footing

$2(P'_o + P''_o + P'''_o + S_{u6} \ell_6) \cos 52° = P_u + W_w$

$2(98.96 + 6.78 + 2.32 + 21.62)\ .615 = P_u + 2.89$ kips

$159.5 \text{ kips} = P_u + 2.89$

$P_u = 156.6$ kips

$$FS = \frac{P_u/B - \gamma D_f}{q_t - \gamma D_f} = \frac{15,660 - 810}{6,054 - 810} = 2.83$$

Table C-11

RESISTING MOMENTS AGAINST SLIDING
UNDRAINED SHEAR STRENGTH FROM FIGURE 13

Slice No.	W_i Effective Weight Of Slice kips	n_i Arm of Weight W_i Around Center 0 ft	Weight-Induced Moment $w_i \cdot n_i$ lbs-ft/ft	P_i Soil Surcharge kips	d_i Arm of Surcharge P_i around Center 0 ft	Surcharge Induced Moment P_i d_i lbs-ft/ft	$\bar{\sigma}_n$ psf	τ_{ff} Undrained Shear Strength psf	ℓ Length Of arch Along base Of Slice ft	Resistance At the Base of The slice τ_{ff} ℓ psf	Radius of Circle r ft	Shear Strength Induced Moment lbs-ft/ft
1	1.08	6.37	6,880	2.36	6.86	16,910	997	1300	7.08	9,204	8.25	75,933
2	1.56	4.05	6,318	2.19	4.05	8,870	2041	1900	3.08	5,852	8.25	48,279
3	1.74	1.35	2,349	2.19	1.35	2,956	2338	2060	2.70	5,562	8.25	45,886
4	1.14	-1.15	- 1,311	-	-	-	6207	4290	2.37	10,167	8.25	83,880
5	0.468	-3.2	- 1,498	-	-	-	6336	4350	2.91	12,658	8.25	104,432
6	-	-	-	-	-	-	2730	2300	8.25	18,975	-	-
			12,738			28,016						358,410

Table C-12

FACTOR OF SAFETY UNDER COMBINED STATIC AND EARTHQUAKE LOADING
INTERMEDIATE SURFACE
UNDRAINED SHEAR STRENGTH FROM FIGURE 13

1 - Contribution of Shear Strength

$P'_o \times 4.13 = 358,410$

$P'_o = 86.78$ kips

2 - Contribution of Surcharge

$P''_o \times \frac{r}{2} \times \sum_{i=1}^{3} P_i \; d_i$

$P''_o \times 4.13 = 28,016$

$P''_o = 6.78$ kips

3 - Contribution of Weight

$P'''_o \times \frac{2}{3} r = \sum_{i=1}^{3} W_i \; n_i$

$P'''_o \times 5.5 = 12,738$

$P'''_o = 2.32$ kips

$P'_o + P''_o + P'''_o = 108.06$ kips

Equilibrium of Forces Acting on Wedge of Sliding Mass Underneath Footing

$2(P'_o + P''_o + P'''_o + S_{u6} \ell_6) \cos 52° = P_u + W_w$

$2(86.78 + 6.78 + 2.32 + 18.86)$ .615 kips $= P_u + 2.89$ kips

141.13 kips $= P_u + 2.89$

$P_u = 138.24$ kips

$$FS = \frac{P_u/B - \gamma D_f}{q_t - \gamma D_f} = \frac{13,824 - 810}{6,054 - 810} = 2.48$$

Table C-13

RESISTING MOMENTS AGAINST SLIDING
INTERMEDIATE FAILURE SURFACE
ACTIVE - CIRCULAR - PASSIVE WEDGE

Slice No.	W_i Effective Weight Of Slice kips	n_i Arm of Weight W_i Around Center 0 ft	Weight-Induced Moment $W_i \cdot n_i$ lbs-ft/ft	P_i Soil Surcharge kips	d_i Arm of Surcharge P_i around Center 0 ft	Surcharge Induced Moment $P_i\ d_i$ lbs-ft/ft	$\bar{\sigma}_n$ psf	τ_{ff} Undrained Shear Strength psf	ℓ Length Of arch Along base Of Slice ft	Resistance At the Base of The slice $\tau_{ff}\ \ell$ psf	Radius of Circle r ft	Shear Strength Induced Moment lbs-ft/ft
1	-	-	-	-	-	-	-	-	-	-	-	-
2	1.56	4.05	6,318	2.19	4.05	8,870	2,041	2,230	3.02	6,868	8.25	56,661
3	1.74	1.35	2,349	2.19	1.35	2,956	2,338	2,400	2.54	6,480	8.25	53,460
4	1.14	-1.15	- 1,311	-	-	-	6,207	4,600	2.54	10,902	8.25	89,941
5	0.468	-3.2	- 1,498	-	-	-	6,336	4,680	3.02	13,619	8.25	112,357
6	-	-	-	-	-	-	2,730	2,620	7.02	21,615	8.25	-
			5,858			11,826						312,419

$\sigma_a = 2(S_{ua}) + q$; $S_{ua} = 1,520$ psf

$\sigma_b = 2(S_{ub}) + \sigma_{vb}$; $\sigma_{vb} = 1,325$ psf; $S_{ub} = 1,820$ psf

$\sigma_a = 2(1,520) + 810 = 3,850$ psf

$\sigma_b = 2(1,820) + 1325 = 4,965$ psf

$F_1 = 3,850 \times 6.25 = 24.06$ kips

$F_2 = 1/2\ (4,965 - 3,850) \times 6.25 = 3.48$ kips

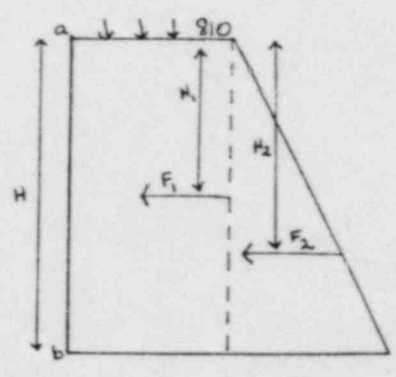


Table C-14

FACTOR OF SAFETY UNDER COMBINED STATIC AND DYNAMIC LOADING
INTERMEDIATE SURFACE WITH PASSIVE WEDGE
UNDRAINED SHEAR STRENGTH FROM FIGURE 14

1 - Contribution of Shear Strength - weightless mass

$$P_o' \times \frac{r}{2} = \sum_{i=2}^{5} S_{ui}\, \ell_i\, r + F_1H_1 + F_2H_2$$

$P_o' \times 4.13 = (312,419 + 75,067 + 14,512)$ lbs/ft

$P_o' = 97.33$ kips

2 - Contribution of Surcharge

$$P_o'' \times \frac{r}{2} = \sum_{i=2}^{3} P_i\, d_i$$

$P_o'' \times 4.13 = 11,825$ lbs/ft

$P_o'' = 2.86$ kips

3 - Contribution of Weight

$$P_o''' \times \frac{2}{3} r = \sum_{i=2}^{5} W_i\, n_i$$

$P_o''' \times 5.5 = 5,858$ lbs/ft

$P_o''' = 1.06$ kips

$P_o' + P_o'' + P_o''' = 101.2$ kips

Equilibrium of Forces Acting on Footing and Wedge of Sliding Mass Underneath

$$2(P_o' + P_o'' + P_o''' + S_{u6}\ell_6) \cos 52° = P_u + W_w$$

$2(101.2 + 21.61) \times .615 = P_u + 2.89$ kips

$151.11 \text{ kips} = P_u + 2.89$ kips

$P_u = 148.22$ kips

$$FS = \frac{P_u/B - \gamma D_f}{q_t - \gamma D_f} = \frac{14,822 - 810}{6,054 - 810} = 2.67$$

Table C-15

RESISTING MOMENTS AGAINST SLIDING
INTERMEDIATE FAILURE SURFACE
ACTIVE - CIRCULAR - PASSIVE
UNDRAINED SHEAR STRENGTH FROM FIGURE 13

Slice No.	W_i Effective Weight Of Slice kips	n_i Arm of Weight W_i Around Center 0 ft	Weight-Induced Moment $w_i \cdot n_i$ lbs-ft/ft	P_i Soil Surcharge kips	d_i Arm of Surcharge P_i around Center 0 ft	Surcharge Induced Moment P_i d_i lbs-ft/ft	$\bar{\sigma}_n$ psf	τ_{ff} Undrained Shear Strength psf	ℓ Length Of arch Along base Of Slice ft	Resistance At the Base of The slice τ_{ff} ℓ psf	Radius of Circle r ft	Shear Strength Induced Moment lbs-ft/ft
1	-	-	-	-	-	-	-	-	-	-	-	-
2	1.56	4.05	6,318	2.19	4.05	8,870	2,041	1,900	3.08	5,852	8.25	48,279
3	1.74	1.35	2,349	2.19	1.35	2,956	2,338	2,060	2.70	5,562	8.25	45,886
4	1.14	-1.15	- 1,311	-	-	-	6,207	4,290	2.37	10,167	8.25	83,880
5	0.468	-3.2	- 1,498	-	-	-	6,336	4,350	2.91	12,658	8.25	104,432
6	-	-	-	-	-	-	2,730	2,300	8.25	18,975	-	-
			5,858			11,826						282,477

$\sigma_a = 2(S_{ua}) + q$; $S_{ua} = 1200$

$\sigma_b = 2(S_{ub}) + \sigma_{vb}$; $\sigma_{vb} = 1325$; $S_{ub} = 1500$

$\sigma_a = 2(1200) + 810 = 3210$ psf

$\sigma_b = 2(1500) + 1325 = 4325$ psf

$F_1 = 3210 \times 6.25 = 20.06$ kips

$F_2 = 1/2\ (4325 - 3210) \times 6.25 = 3.48$ kips

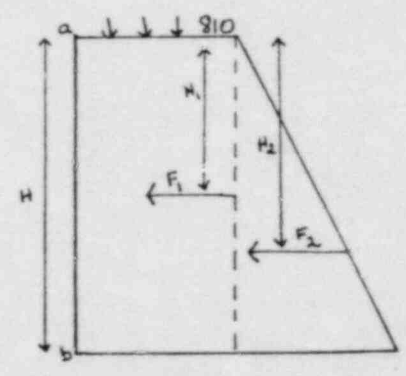


Table C-16

FACTOR OF SAFETY UNDER COMBINED STATIC AND DYNAMIC LOADING
INTERMEDIATE SURFACE WITH PASSIVE WEDGE
UNDRAINED SHEAR STRENGTH FROM FIGURE 13

1 - Contribution of Shear Strength

$$P_o' \times \frac{r}{2} = \sum_{i=2}^{5} S_{ui} \ell_i r + F_1H_1 + F_2H_2$$

$$P_o' \times 4.13 = (282,477 + 62,597 + 14,512)$$

$$P_o' = 87.06 \text{ kips}$$

2 - Contribution of Surcharge

$$P_o'' \times \frac{r}{2} = \sum_{i=2}^{3} P_i d_i$$

$$P_o'' \times 4.13 = 11,825 \text{ lbs/ft}$$

$$P_o'' = 2.86 \text{ kips}$$

3 - Contribution of Weight

$$P_o''' \times \frac{2}{3} r = \sum_{i=2}^{5} W_i n_i$$

$$P_o''' \times 5.5 - 5,858 \text{ lbs/ft}$$

$$P_o''' = 1.06 \text{ kips}$$

Equilibrium of Forces Acting on Footing and Wedge of Sliding Mass Underneath

$$2(P_o' + P_o'' + P_o''' + S_{u6}\ell_6) \cos 52° = P_u + W_w$$

$$2(87.06 \div 2.86 + 1.06 + 18.98) \times 0.615 = P_u + W_w$$

$$135.2 \text{ kips} = P_u + 2.89$$

$$132.4 = P_u$$

$$FS = \frac{P_u/B - \gamma D_f}{q_t - \gamma D_f} = \frac{13,240 - 810}{6,054 - 810} = 2.37$$

Table C-17

Magnitude and Direction of Forces Acting on Each Slice Shallow Surface

Slice No.	Total Volume ft^3	Volume Above Water Level ft^3	Volume Below Water Level ft^3	Effec. Weight of Slice kips	Structural Loads Including Surcharge kips	Total Vertical Force kips	Average Angle of Inclination α at bottom of Slice	Angle of Inclination β of forces Between Slices
1	7.0	2.0	5.0	0.63	1.62	2.25	67.5°	
								22.5°
2	14.58	2.5	12.08	1.21	2.02	3.23	32.8°	
								10.3°
3	17.28	2.5	14.78	1.40	2.02	3.42	10.3°	
								0°
4	17.28	2.5	14.78	1.40	12.14	13.54	-10.3°	
								-10.3°
5	14.58	2.5	12.08	1.21	12.14	13.35	-32.8°	
								-22.5°
6	12.51	4.5	8.01	1.19	24.27	25.46	-45°	

*Slice weights were calculated using a unit weight of 135 pcf for the portion of the slice above water level, and a submerged unit weight of 72.5 pcf for the portions below water level.

Table C-18

Long Term Effective Stresses on Shallow Sliding Surface
- Mobilized Friction Angle Equal to 19° -

Slice No.	L_o Length Arc ft	L_i Length Chord ft	Reaction Force kips	$\frac{R \cos 19°}{L_i}$ σ_n psf	τ_n psf	ψ degrees	σ_1 psf	σ_3 psf	$K_c=\sigma_1/\sigma_3$
1	[illegible].5	5.42	5.0	872	300	60	1392	699	1.99
2	3.02	2.92	5.63	1823	628	60	2911	1460	1.99
3	2.54	2.50	5.94	2246	774	60	3587	1799	1.99
4	2.54	2.50	16.25	4800	2116	60	9898	4924	1.99
5	3.02	2.92	15.75	5100	1756	60	8141	4086	1.99
6	7.08	7.08	23.62	3154	1086	60	5035	2527	1.99

Table C-19
RESISTING MOMENTS AGAINST SLIDING SURFACE
DIESEL GENERATOR BUILDING
SHALLOW FAILURE SURFACE
UNDRAINED SHEAR STRENGTH FROM FIGURE 14

Slice no.	w_i Bouyant weight of slice kips	n_i Arm of slice weight around 0, ft	Weight induced moment $w_i \cdot n_i$ lbs/ft	P_i Soil surcharge above slice kips	d_i Arm of surcharge around 0	Surcharge induced moment $P_i \cdot d_i$ lbs/ft	$\bar{\sigma}_n$ Effective normal stress at bottom of slice psf	τ_{ff} Undrained shear strength at bottom of slice psf	ℓ Length of arch along bottom of slice slice, ft	$\tau_{ff}\ \ell$ Resistance at bottom of slice	Radius of sliding surface r, ft	Shear strength induced moment lbs/ft
1	0.63	5.66	3565	1.62	6.0	9,720	872	1560	5.55	8,658	7	60,606
2	1.21	3.75	4537	2.02	3.75	7,575	1823	2100	3.02	6,342	7	44,394
3	1.40	1.25	1750	2.02	1.25	2,525	2246	2350	2.54	5,969	7	41,783
4	1.05	-1.25	-1310	-	-	-	6146	4580	2.54	11,633	7	81,431
5	0.37	-3.33	-1245	-	-	-	5100	3990	3.02	12,050	7	84,350
6	-	-	-	-	-	-	3154	2860	7.08	20,249	-	-
			7297			19,820						312,564

TABLE C-20

FACTOR OF SAFETY UNDER COMBINED STATIC AND DYNAMIC LOADING
DIESEL GENERATOR BUILDING
SHALLOW FAILURE SURFACE
ACTIVE - CIRCULAR

1 - Contribution of Shear Strength

$$P'_o \times m_o = \sum_{i=1}^{5} S_u \ell_i \; r$$

$$P'_o \times 3.5 = 312{,}564$$

$$P'_o = \frac{312{,}564}{3.5} = 89.3 \text{ kips/ft of wall}$$

2 - Contribution of Surcharge

$$P''_o \times m_o = \sum_{i=1}^{3} P_i d_i$$

$$P''_o \times 3.5 = 19{,}820$$

$$P''_o = \frac{19{,}820}{3.5} = 5.66 \text{ kips}$$

3 - Contribution of Weight

$$P'''_o \times m_1 = \sum_{i=1}^{5} W_i \; n_i$$

$$P'''_o \times 4.66 = 7{,}297$$

$$P'''_o = \frac{7{,}297}{4.66} = 1.56 \text{ kips}$$

Equilibrium of Forces Acting on the Footing and Active Wedge of Soil Underneath

$$P'_o + P''_o + P'''_o = 89.3 + 5.66 + 1.56 = 96.52 \text{ kips}$$

$$2(P'_o + P''_o + P'''_o + S_{u6}\ell_6) \cos 45° = P_u + W_w$$

$$2(96.52 + 20.25) \times 0.707 = P_u + W_w$$

$$2(116.77) \times 0.707 = P_u + 2.38 \text{ kips}$$

$$165.11 \text{ kips} = P_u + 2.38 \text{ kips}$$

$$P_u = 162.73 \text{ kips}$$

$$FS = \frac{\frac{162{,}730}{10} - 810}{6{,}054 - 810} = 2.95$$

Table C-21
RESISTING MOMENTS AGAINST SLIDING
SHALLOW FAILURE SURFACE
UNDRAINED SHEAR STRENGTH FROM FIGURE 13

Slice no.	w_i Bouyant weight of slice kips	n_i Arm of slice weight around center of sliding surface ft	Weight induced moment $w_i \cdot n_i$ lbs/ft	Soil surcharge above slice P_i kips	d_i arm of surcharge P_i around center of sliding surface ft	Surcharge induced moment $P_i d_i$ lbs/ft	σ_n Effective normal stress at bottom of slice psf	τ_{ff} Undrained shear strength at bottom of slice psf	ℓ length of arch along bottom of slice ft	$\tau_{ff} \ell$ resistance at the bottom of slice	Radius of sliding surface r, ft	Shear strength-induced moment lbs/ft
1	0.63	5.66	3565	1.62	6.0	9,720	872	1240	5.55	6,882	7	48,174
2	1.21	3.75	4537	2.02	3.75	7,575	1823	1780	3.02	5,376	7	37,632
3	1.40	1.25	1750	2.02	1.25	2,525	2246	2010	2.54	5,105	7	35,735
4	1.05	-1.25	-1310	-	-	-	6146	4230	2.54	10,744	7	75,208
5	0.37	-3.33	-1245	-	-	-	5100	3660	3.02	11,053	7	77,371
6	-	-	-	-	-	-	3154	2540	7.08	17,983	-	-
			7297			19,820						274,210

Table C-22

FACTOR OF SAFETY UNDER COMBINED STATIC AND DYNAMIC LOADING
DIESEL GENERATOR BUILDING
SHALLOW FAILURE SURFACE
UNDRAINED SHEAR STRENGTH FROM FIGURE 13

1 - Contribution of Shear Strength

$$P_o' \times m_o = \sum_{i=1}^{5} S_u \ell_i r$$

$$P_o' \times 3.5 = 274,210$$

$$P_o' = \frac{274,210}{3.5} = 78.34 \text{ kips}$$

2 - Contribution of Surcharge

$$P_o'' \times m_o = \sum_{i=1}^{3} P_i d_i$$

$$P_o'' \times 3.5 = 19,820$$

$$P_o'' = \frac{19,820}{3.5} = 5.66 \text{ kips}$$

3 - Contribution of Weight

$$P_o''' \times m_1 = \sum_{i=1}^{5} W_i n_i$$

$$P_o''' \times 4.66 = 7,297$$

$$P_o''' = 1.56 \text{ kips}$$

Equilibrium of Forces Acting on the Footing and the Active Wedge of Soil Underneath

$$P_o' + P_o'' + P_o''' = 78.34 + 5.66 + 1.56 = 85.56 \text{ kips}$$

$$2(P_o' + P_o'' + P_o''' + S_{u6}\ell_6) \cos 45° = P_u + W_w$$

$$S_{u6}\ell_6 = 17.98 \text{ kips (see Table 3)}$$

$$2(85.56 + 17.98) \times 0.707 = P_u + 2.38 \text{ kips}$$

$$2(103.54) \times 0.707 - P_u + 2.38 \text{ kips}$$

$$146.4 \text{ kips} = P_u + 2.38 \text{ kips}$$

$$144 \text{ kips} = P_u$$

$$FS = \frac{P_u/B - \gamma D_f}{q_t - \gamma D_f} = \frac{14,400 - 810}{6,054 - 810} = 2.59$$

Table C-23

RESISTING MOMENTS AGAINST SLIDING
DIESEL GENERATOR BUILDING
SHALLOW SURFACE WITH ACTIVE - CIRCULAR - PASSIVE WEDGE
UNDRAINED SHEAR STRENGTH FROM FIGURE 14

Slice No.	W_i Effective Weight Of Slice kips	n_i Arm of Weight W_i Around Center 0 ft	Weight-Induced Moment $W_i \cdot n_i$ lbs-ft/ft	P_i Soil Surcharge kips	d_i Arm of Surcharge P_i around Center 0 ft	Surcharge Induced Moment $P_i\ d_i$ lbs-ft/ft	$\bar{c}_n$ psf	τ_{ff} Undrained Shear Strength psf	ℓ Length Of arch Along base Of Slice ft	$\tau_{ff}\ell$ Resistance At the Base of The slice psf	Radius of Circle r ft	Shear Strength Induced Moment lbs-ft/ft
2	1.21	3.75	4,537	2.02	3.75	7,575	1,823	2,100	3.02	6,342	7	44,394
3	1.40	1.25	1,750	2.02	1.25	2,525	2,246	2,350	2.54	5,969	7	41,783
4	1.05	-1.25	-1,312	-	-	-	6,146	4,580	2.54	11,633	7	81,431
5	0.37	-3.33	-1,232	-	-	-	5,100	3,990	3.02	12,050	7	84,350
6	-	-	-	-	-	-	3,154	2,860	7.02	20,077	-	-
			3,743			10,100						251,958

$\sigma_a = 2(S_{ua}) + q$; $S_{ua} = 1,520$ psf; $q = 810$ psf

$\sigma_b = 2(S_{ub}) + \sigma_{vb}$; $S_{ub} = 1,770$ psf; $\sigma_{vb} = 1,235$ psf

$\sigma_a = 2(1,520) + 810 = 3,850$ psf

$\sigma_b = 2(1,770) + 1,235 = 4,775$ psf

$F_1 = 3,850 \times 5' = 19.25$ kips

$F_2 = 1/2 \cdot 5(4775-3850) = 2.31$ kips

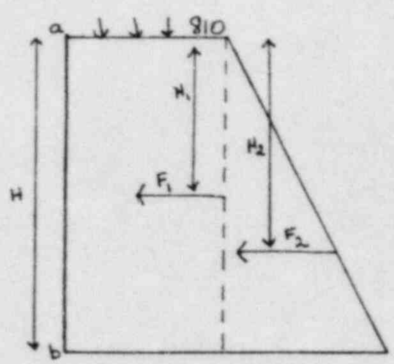


Table C-24
UNDRAINED SHEAR STRENGTH FROM FIGURE 14
CALCULATION OF FACTOR OF SAFETY UNDER COMBINED STATIC AND DYNAMIC LOADING
SHALLOW SLIDING SURFACE WITH ACTIVE - CIRCULAR - PASSIVE WEDGE
UNDRAINED SHEAR STRENGTH FROM FIGURE 14

1 - Contribution of Shear Strength - weightless mass

$\Sigma m_o = 0$

$F_1H_1 + F_2H_2 + \sum_{i=1}^{5} S_{ui}\ \ell_i\ r = P'_o \times m_o$

$19{,}250 \times 2.5\ 2{,}310 \times 3.33 + 251{,}958 = P'_o \times 3.5$

$307{,}775 = P'_o \times 3.5$

$P'_o = 87.94$ kips

2 - Contribution of Surcharge

$\Sigma m_o = 0$

$P''_o\ m_o = \sum_{i=1}^{2} P_i\ d_i$

$P''_o \times 3.5 = 10{,}100$

$P''_o = 2.88$ kips

3 - Contribution of Weight

$\Sigma m_o = 0$

$P'''_o \times m'_o = \sum_{i=1}^{5} W_i\ n_i$

$P'''_o \times 4.66 = 3{,}743$

$P'''_o = 0.8$ kips

Equilibrium of Forces Acting on Footing and Active Wedge Underneath

$2(P'_o + P''_o + P'''_o + S_{u6}\ell_6) \cos 45° = P_u\ W_w$

$2(87.94 + 2.88 + 0.8 + 20.1) \times 0.707 = P_u + 2.38$ kips

158 kips $= P_u + 2.38$

155.6 kips $= P_u$

$$FS = \frac{P_u/B - \gamma D_f}{q_t - \gamma D_f} = \frac{15{,}560 - 810}{6{,}054 - 810} = 2.81$$

Table C-25

RESISTING MOMENTS AGAINST SLIDING
SHALLOW SURFACE WITH ACTIVE, CIRCULAR and PASSIVE WEDGES
UNDRAINED SHEAR STRENGTH FROM FIGURE 13

Slice no.	w_i Bouyant weight of slice kips	n_i Arm of slice weight around center of sliding surface ft	Weight induced moment $w_i \cdot n_i$ lbs/ft	Soil surcharge above slice P_i kips	d_i Arm of surcharge P_i around center of sliding surface ft	Surcharge induced moment $P_i\ d_i$ lbs/ft	σ_n Effective normal stress at bottom of slice psf	τ_{ff} Undrained shear strength at bottom of slice psf	ℓ Length of arch along bottom of slice ft	$\tau_{ff}\ell$ Resistance at the bottom of slice	Radius of sliding surface r, ft	Shear strength-induced moment lbs/ft
2	1.21	3.75	4537	2.02	3.75	7,575	1823	1780	3.02	5,376	7	37,632
3	1.40	1.25	1750	2.02	1.25	2,525	2246	2010	2.54	5,105	7	35,735
4	1.05	-1.25	-1312	-	-	-	6146	4230	2.54	10,744	7	75,208
5	0.37	-3.33	-1232	-	-	-	5100	3660	3.02	11,053	7	77,371
6	-	-	-	-	-	-	3154	2540	7.08	17,983	-	-
			3743			10,100						225,946

- CALCULATION OF PASSIVE WEDGE RESISTANCE -

$\sigma_a = 2(S_{ua}) + q;\ S_{ua} = 1200;\ q = 810$ psf

$\sigma_b = 2(S_{ub}) + \sigma_{vb};\ S_{ub} = 1450;\ \sigma_{vb} = 1235$ psf

$\sigma_a = 2(1200) + 810 = 3210$ psf

$\sigma_b = 2(1450) + 1235 = 4135$ psf

$F_1 = 3210 \times 5' = 16.05$ kips

$F_2 = 1/2\ (5)(4135-3210) = 2.31$ kips

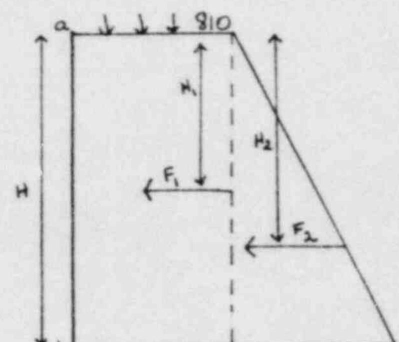


Table C-26

CALCULATION OF FACTOR OF SAFETY UNDER COMBINED STATIC AND DYNAMIC LOADING
SHALLOW SLIDING SURFACE WITH ACTIVE - CIRCULAR - PASSIVE WEDGE
UNDRAINED SHEAR STRENGTH FROM FIGURE 13

1 - Contribution of Shear Strength - weightless mass

$\Sigma m_o = 0$

$F_1H_1 + F_2H_2 + \sum_{i=1}^{5} S_{ui}\ell_i\ r = P'_o \times m_o$

$16.05 \times 2.5 \times 2.31 \times 3.33 + 225{,}946 = P'_o \times 3.5$

$273{,}763 - P'_o \times 3.5$

$P'_o = 78.22$ kips

2 - Contribution of Surcharge

$\Sigma m_o = 0$

$P''_o\ m_o = \sum_{i=1}^{2} P_i\ d_i$

$P''_o \times 3.5 = 10{,}100$

$P''_o = 2.88$ kips

3 - Contribution of Weight

$\Sigma m_o = 0$

$P'''_o \times m'_o = \sum_{i=1}^{5} W_i\ n_i$

$P'''_o \times 4.66 = 3{,}743$

Equilibrium of Forces Acting on Footing and Active Wedge Underneath

$2(P'_o + P''_o + P'''_o + S_{u6}\ell_6) \cos 45° = P_u + W_w$

$2(78.22 + 2.88 + 0.8 + 17.98) \times 0.707 = P_u + 2.38$ kips

$141.23 \text{ kips} = P_u + 2.38$

$P_u = 138.9$ kips

$$FS = \frac{P_u/B - \gamma D_f}{q_t - \gamma D_f} = \frac{13{,}890 - 810}{6{,}054 - 810} = 2.49$$

Table C-27

BEARING CAPACITY CALCULATIONS
INTERMEDIATE CIRCLE (CIRCULAR FAILURE SURFACE)
LOWERED WATER TABLE
γ = 135 pcf

Slice No.	Volume (ft^3)	Weight (kips)	Structural Load and Surcharge (kips)	Total Vertical Force (kips)	Average Inclination α At Bottom Of Slice	Average Inclination β Of Force Between Slices
1	12.4	1.67	2.36	4.03	64°	
						18°
2	19.3	2.61	2.19	4.80	30°	
						9°
3	21.7	2.93	2.19	5.12	7°	
						0°
4	18.5	2.50	11.16	13.66	- 9°	
						- 8.5°
5	19.1	2.58	13.10	15.68	-27°	
						-26°
6	15.9	2.15	24.25	26.40	-52°	

Table C-28

LONG TERM EFFECTIVE STRESS ON INTERMEDIATE SLIDING SURFACE (CIRCULAR)
(LOW WATER TABLE, MOBILIZED FRICTION ANGLE = 15.5°)

Slice No.	L_o Length Of Arc (ft)	L_i Length of Chord (ft)	R Reaction Force (kips)	$\frac{R_{cos} 15.5°}{L_i} = \sigma_N$ (psf)	$\frac{R_{sin} 15.5°}{L_i} = \tau$ (psf)	ψ degrees	σ_1 (psf)	σ_3 (psf)	σ_1/σ_3
1	7.08	6.95	8.2	1140	315	60	1,685	958	1.76
2	3.08	3.02	7.3	2330	645	60	3,447	1958	1.76
3	2.70	2.66	7.8	2825	780	60	4,176	2375	1.76
4	2.37	2.33	16.5	6825	1890	60	10,099	5734	1.76
5	2.91	2.89	20.2	6735	1870	60	9,974	5655	1.76
6	8.25	8.25	24.1	2815	780	60	4,166	2365	1.76

Table C-29

RESISTING MOMENTS AGAINST SLIDING
INTERMEDIATE FAILURE SURFACE WITH PASSIVE WEDGE
UNDRAINED SHEAR STRENGTH FROM FIGURE 14
LOW WATER LEVEL

Slice No.	W_i Effective Weight Of Slice kips	n_i Arm of Weight W_i Around Center 0 ft	Weight-Induced Moment $W_i \cdot n_i$ lbs-ft/ft	P_i Soil Surcharge kips	d_i Arm of Surcharge P_i around Center 0 ft	Surcharge Induced Moment $P_i\ d_i$ lbs-ft/ft	$\bar{\sigma}_n$ psf	τ_{ff} Undrained Shear Strength psf	ℓ Length Of arch Along base Of Slice ft	Resistance At the Base of The slice $\tau_{ff}\ \ell$ psf	Radius of Circle r ft	Shear Strength Induced Moment lbs-ft/ft
2	2.61	4.05	10,570	2.19	4.05	8,870	2330	2400	3.08	7,392	8.25	60,984
3	2.93	1.35	3,955	2.19	1.35	2,956	2825	2680	2.7	7,236	8.25	59,697
4	2.12	-1.15	- 2,441	-	-	-	6825	4950	2.37	11,731	8.25	96,780
5	.871	-3.2	- 2,788	-	-	-	6735	4900	2.91	14,259	8.25	117,637
6	-	-	-	-	-	-	2815	2680	8.25	22,110	-	-
			9,296			11,826						335,098

$\sigma_a = 2(\tau_{ffa}) + q;\ \tau_{ffa} = 1520$

$\sigma_b = 2(\tau_{ffb}) + \sigma_{vb};\ \sigma_{vb} = 1654$ psf; $\tau_{ffb} = 2010$

$\sigma_a = 2(1520) + 810 = 3850$ psf

$\sigma_b = 2(2010) + 1654 = 5674$ psf

$F_1 = 3850 \times 6.25 = 24.06$ kips

$F_2 = \frac{1}{2}\ (5674 - 3850) \times 6.25 = 5.7$ kips

$H_1 = 3.12$

$H_2 = 4.17$

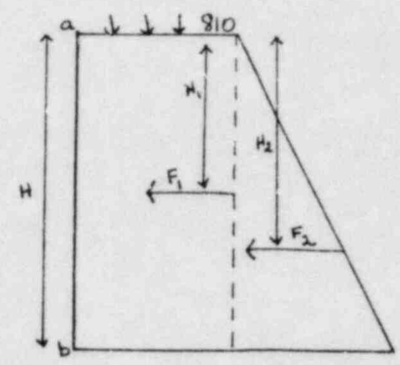


Table C-30

FACTOR OF SAFETY UNDER COMBINED STATIC AND EARTHQUAKE LOADING
INTERMEDIATE SURFACE
ACTIVE-CIRCULAR-PASSIVE
UNDRAINED SHEAR STRENGTH FROM FIGURE 14
LOW WATER LEVEL

1 - Contribution of Strength

$P_o' \times 4.13 = 24.06 \text{ kips} \times 3.12 + 5.7 \text{ kips}$

$\times 4.17 + 335{,}098 \text{ lbs}$

$P_o' \times 4.13 = 433{,}934 \text{ lbs}$

$P_o' = 105.07 \text{ kips}$

2 - Contribution of Surcharge

$P_o'' \times 4.13 = 11{,}826$

$P_o'' = 2.86 \text{ kips}$

3 - Contribution of Weight

$P_o''' \times \frac{2}{3} r = 9{,}296$

$P_o''' = 1.69 \text{ kips}$

$P_o' + P_o'' + P_o''' = 109.62 \text{ kips}$

Equilibrium of Forces on Active Wedge Below Footing

$2(P_o' + P_o'' + P_o''' + \tau_{ff6}\ell_6) \cos 52° = P_u + W_w$

$2(109.62 + 22.11) \times 0.615 = P_u + 4.39 \text{ kips}$

$162.02 = P_u + 4.39 \text{ kips}$

$P_u = 157.64 \text{ kips}$

$$FS = \frac{\frac{157{,}640}{10} - 810}{6{,}054 - 810} = 2.85$$

Table C-31

RESISTING MOMENTS AGAINST SLIDING
INTERMEDIATE FAILURE SURFACE WITH PASSIVE WEDGE
UNDRAINED SHEAR STRENGTH FROM FIGURE 13
LOW WATER TABLE

Slice No.	W_i Effective Weight Of Slice kips	n_i Arm of Weight W_i Around Center 0 ft	Weight-Induced Moment $w_i \cdot n_i$ lbs-ft/ft	P_i Soil Surcharge kips	d_i Arm of Surcharge P_i around Center 0 ft	Surcharge Induced Moment $P_i\ d_i$ lbs-ft/ft	$\bar{\sigma}_n$ psf	τ_{ff} Undrained Shear Strength psf	ℓ Length Of arch Along base Of Slice ft	Resistance At the Base of The slice $\tau_{ff}\ \ell$ psf	Radius of Circle r ft	Shear Strength Induced Moment lbs-ft/ft
2	2.61	4.05	10,570	2.19	4.05	8,870	2330	2070	3.08	6,376	8.25	52,602
3	2.93	1.35	3,955	2.19	1.35	2,956	2825	2350	2.70	6,345	8.25	52,346
4	2.12	-1.15	- 2,441	-	-	-	6825	4630	2.37	10,973	8.25	90,527
5	.871	-3.2	- 2,788	-	-	-	6735	4580	2.91	13,328	8.25	109,956
6	-	-	-	-	-	-	2815	2330	8.25	19,222	8.25	-
			9,296			11,826						305,431

$\sigma_a = 2(\tau_{ffa}) + q;\ \tau_{ffa} = 1200$

$\sigma_b = 2(\tau_{ffb}) + \sigma_{ov};\ \sigma_{vb} = 1654$ psf; $\tau_{ffb} = 1670$

$\sigma_a = 2(1200) + 810 = 3210$ psf

$\sigma_b = 2(1670) + 1654 = 4994$ psf

$F_1 = 3210 \times 6.25 = 20.06$ kips

$F_2 = \frac{1}{2}\ (4994 - 3210) \times 6.25 = 5.57$ kips

$H_1 = 3.12$

$H_2 = 4.17$

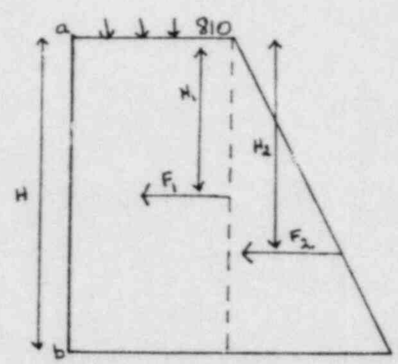


Table C-32

FACTOR OF SAFETY UNDER COMBINED STATIC AND EARTHQUAKE LOADING
INTERMEDIATE SURFACE WITH PASSIVE WEDGE
LOW WATER LEVEL
ACTIVE-CIRCULAR-PASSIVE
UNDRAINED SHEAR STRENGTH FROM FIGURE 13

1 - Contribution of Strength

$P_o' \times 4.13 = 20.06 \text{ kips} \times 3.12 + 5.57 \text{ kips} \times 4.17 + 305{,}431$

$P_o' \times 4.13 = 391{,}245$

$P_o' = 94.73$ kips

2 - Contribution of Surcharge

$P_o'' \times 4.13 = 11{,}826$

$P_o'' = 2.86$

3 - Contribution of Weight

$P_o''' \times 5.5 = 9296$

$P_o''' = \frac{9296}{5.5} = 1.69$

$P_o' + P_o'' + P_o''' = 99.28$ kips

Equilibrium of Forces on Wedge Below Footing

$2(P_o' + P_o'' + P_o''' + \tau_{ff6}\ell_6) \cos 52° = P_u + W_w$

$2(99.28 + 19.22) \times 0.615 = P_u + 4.39$ kips

$145.75 = P_u + 4.39$

$P_u = 141.36$ kips

$$FS = \frac{\frac{141{,}360}{10} - 810}{6{,}054 - 810} = 2.54$$

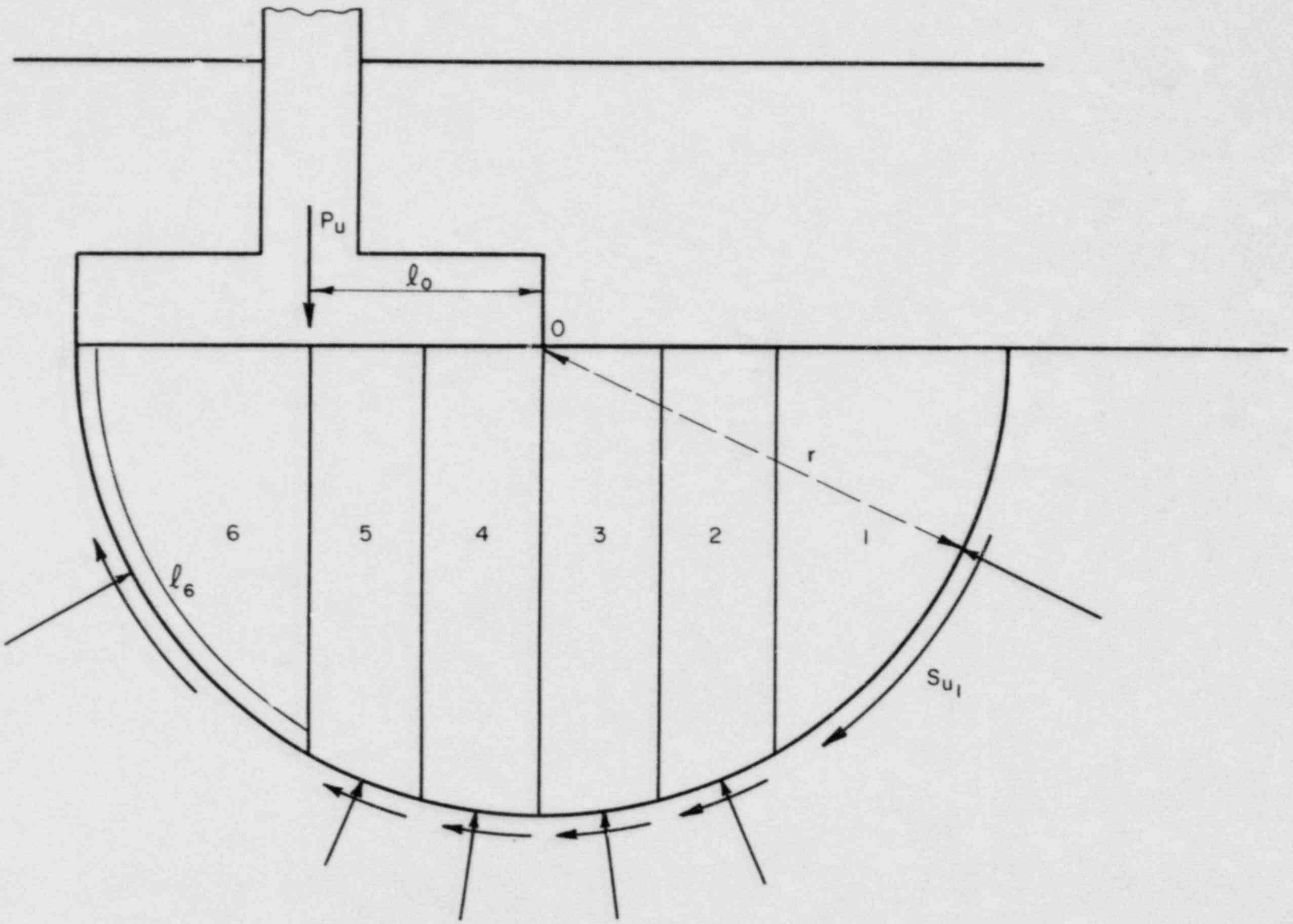


Figure C-1. Deep Circular Sliding Surface

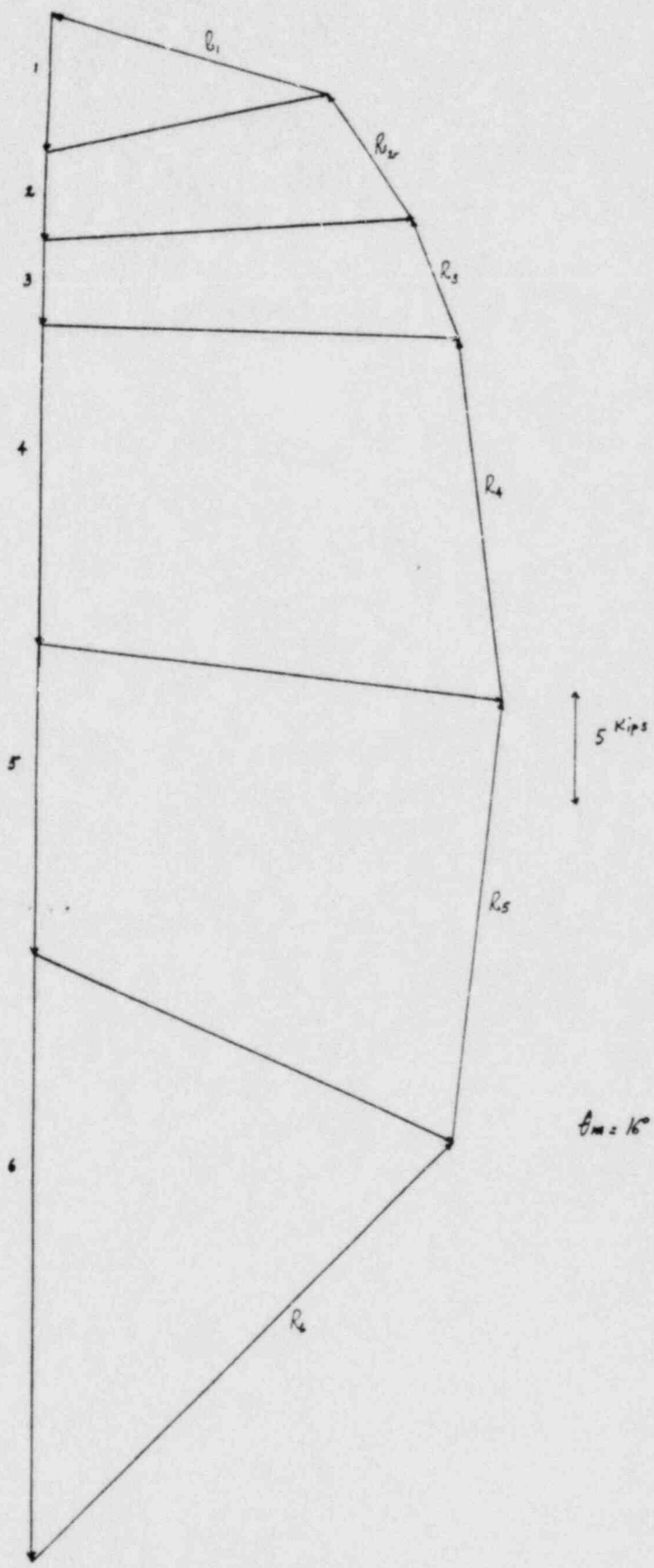


Figure C-2 Equilibrium Force Polygon - Deep Sliding Surface

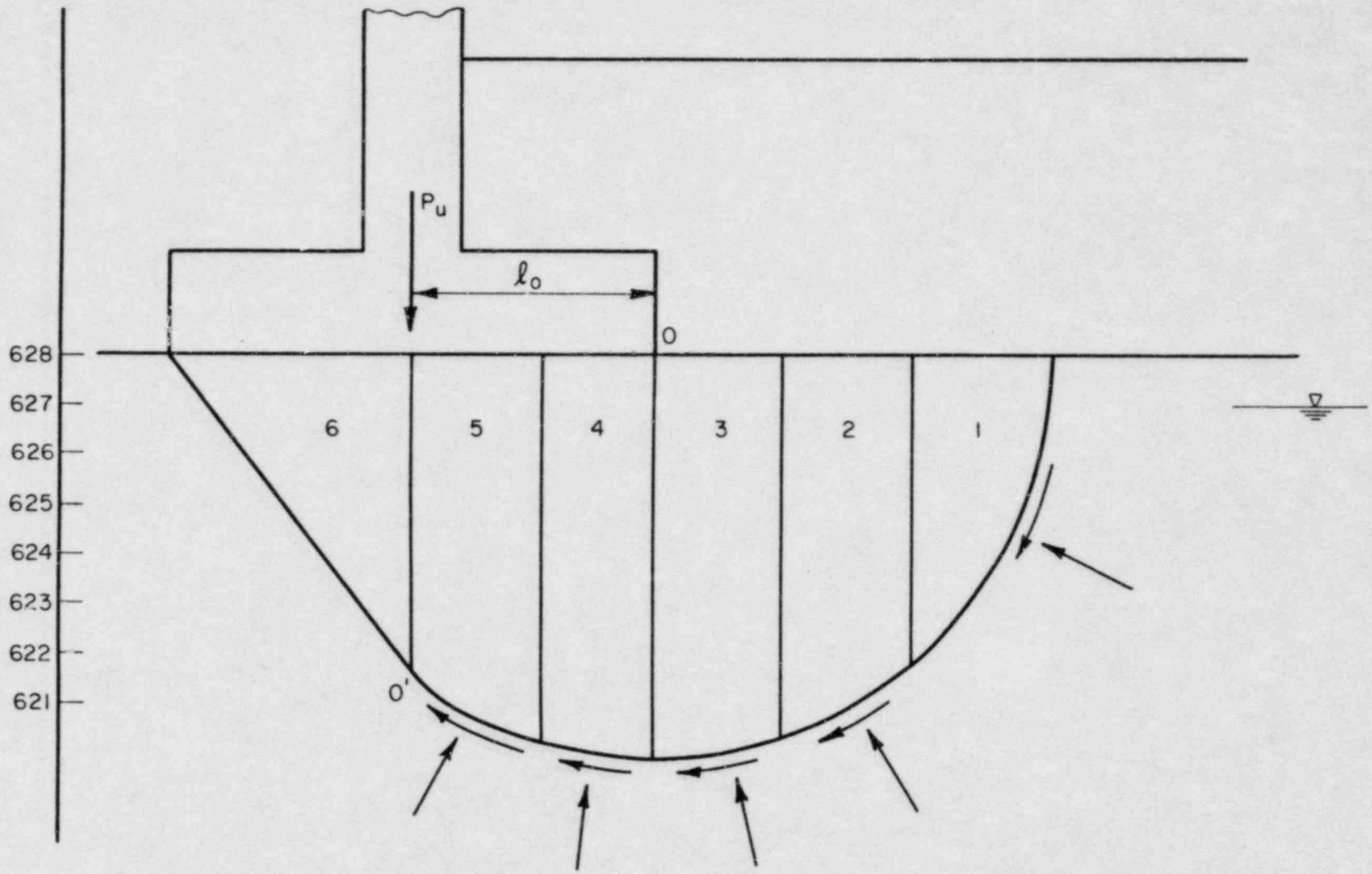


Figure C-3. Intermediate Sliding Surface

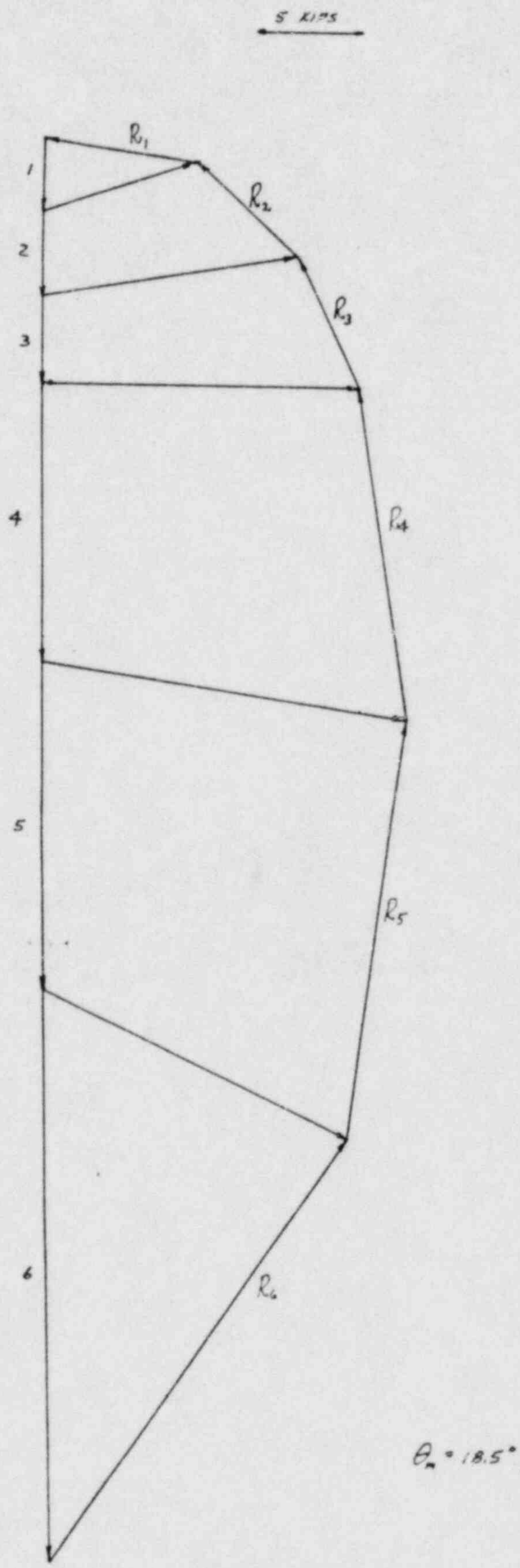


FIGURE C-4 Equilibrium Force Polygon - Intermediate Sliding Surface

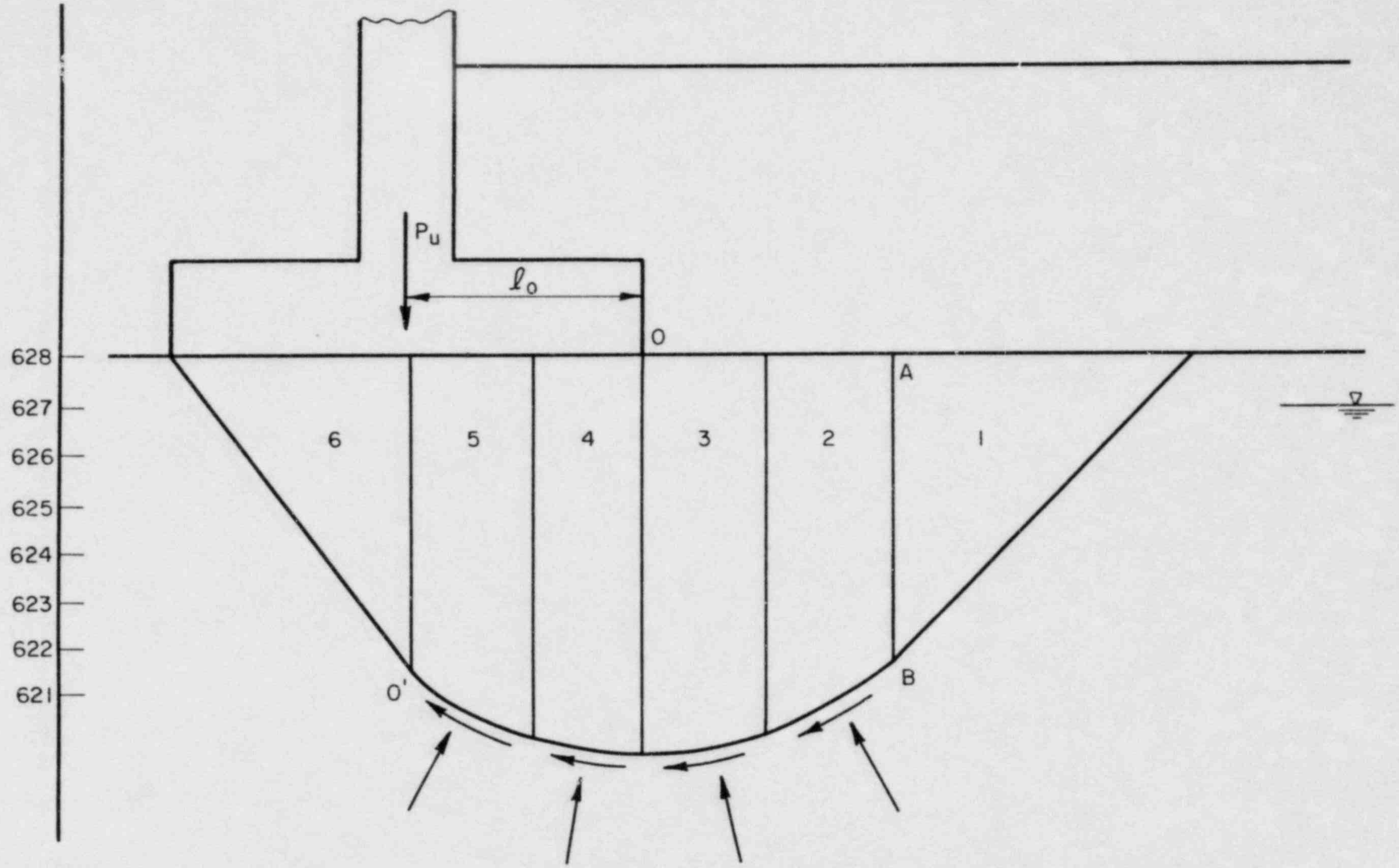


Figure C-5. Intermediate Sliding Surface with Passive Wedge

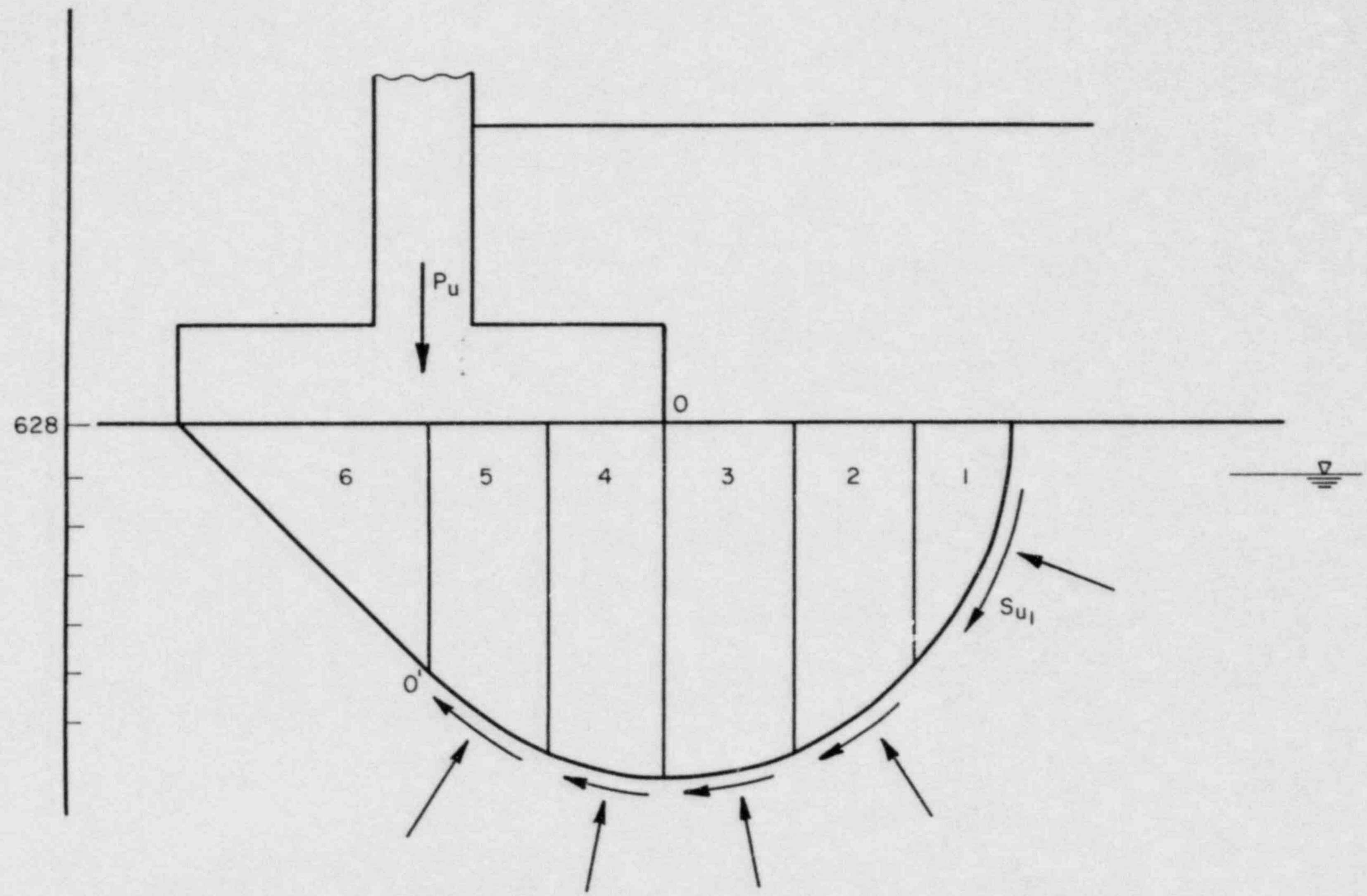


Figure C-6. Shallow Sliding Surface

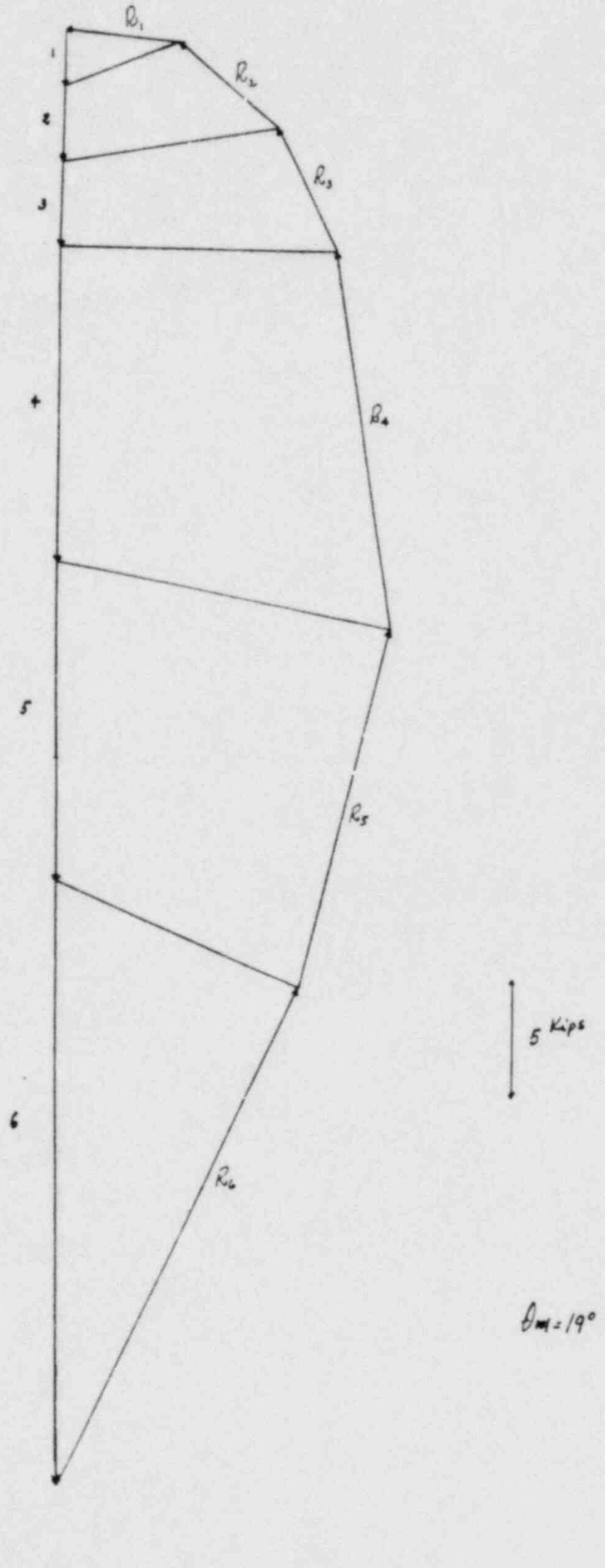


FIGURE C-7 Equilibrium Force Polygon - Shallow sliding surface

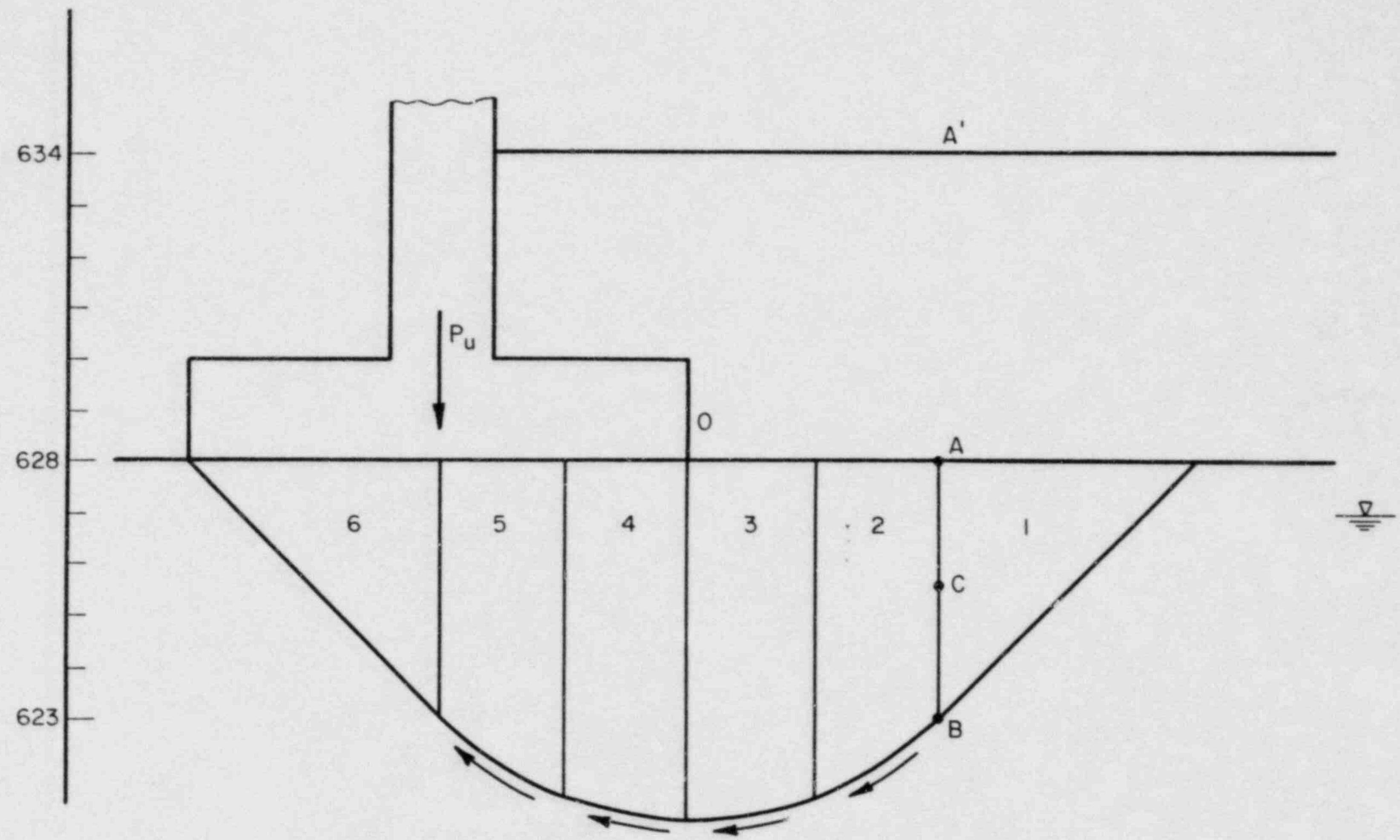


Figure C-8. Shallow Sliding Surface with Passive Wedge

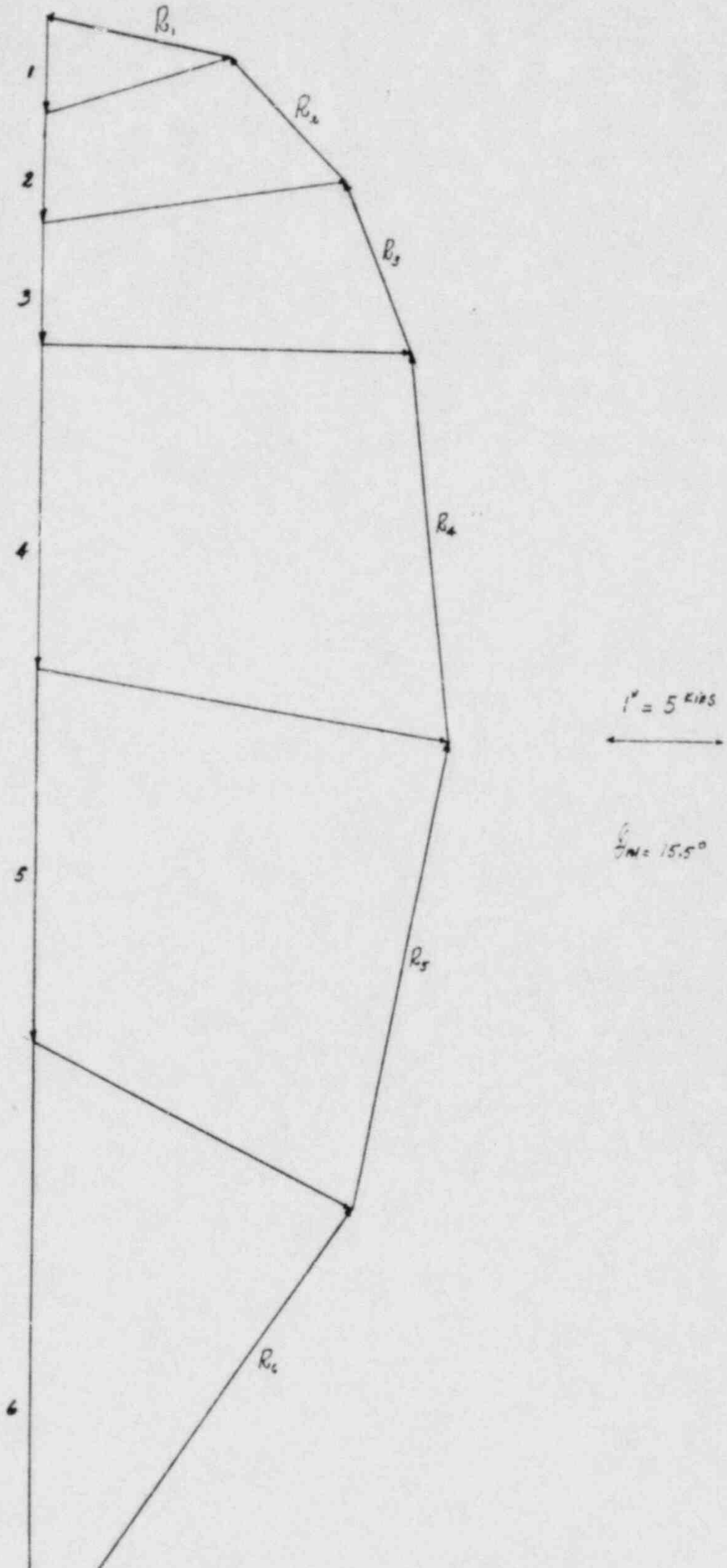


Figure C-9. Equilibrium Force Polygon -
Intermediate Sliding Surface
Low Water Table