MILE POST 7 WEST RIDGE RAILROAD RELOCATION, DAM EXTENSIONS, AND STREAM MITIGATION PROJECT ENVIRONMENTAL ASSESSMENT WORKSHEET (EAW)

RECORD OF DECISION – FINDING OF FACT 28.i
1975 WAHLER REPORT

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Evaluation of

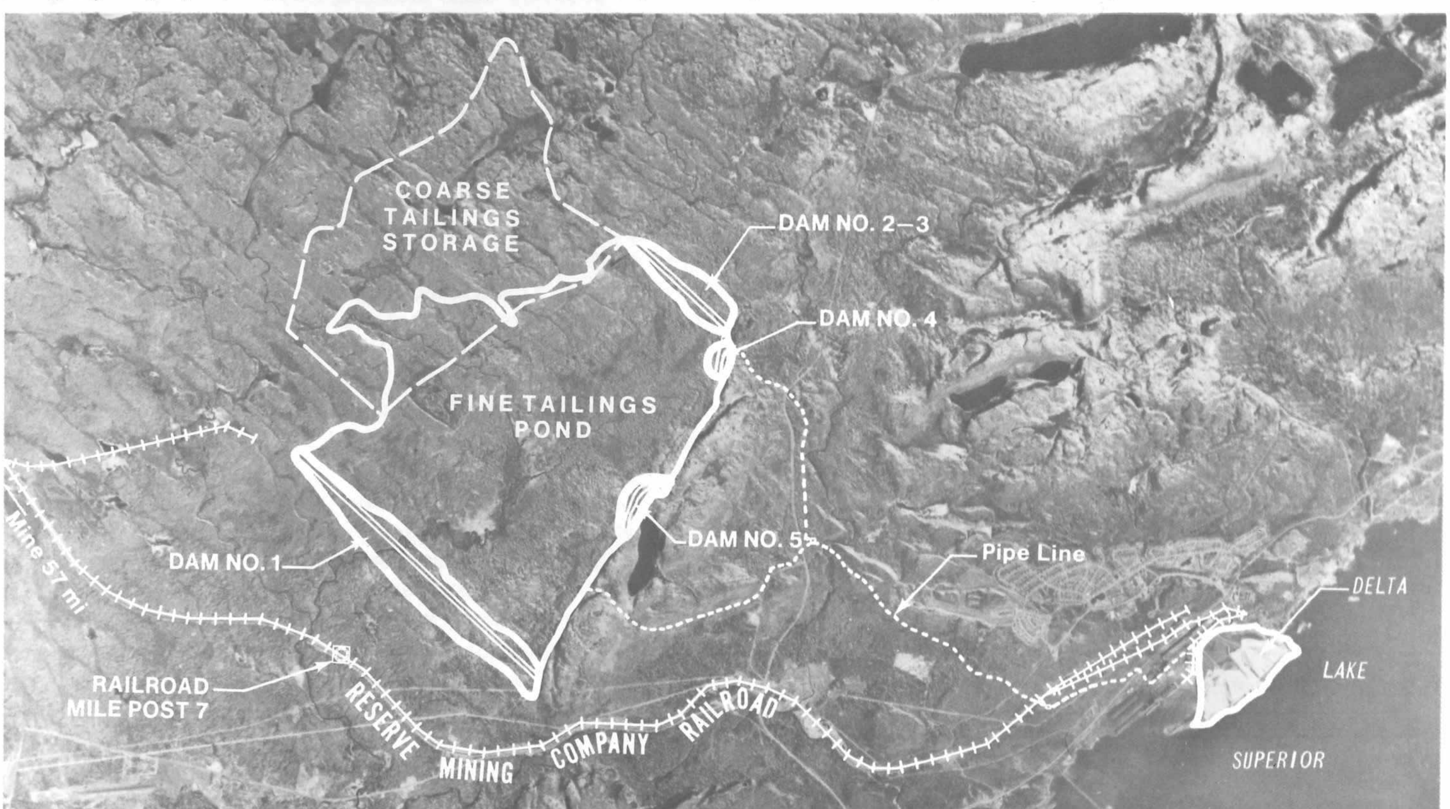
MILE POST 7 ON-LAND TAILINGS DISPOSAL PLAN

Proposed by Reserve Mining Company

Performed by W.A. Wahler and Associates
For the State of Minnesota

Long fought in the courts by the Justice Department and various environmental groups, Reserve Mining Company's disposal of tailings from its iron ore concentration plant into Lake Superior has been prohibited by the U.S. District Court and the Eighth U.S. District Court of Appeals. The Court found that the 67,000 tpd tailings discharge posed a potential threat to public health and violates Federal and State pollution control requirements. Reserve Mining Company is proposing an alternate on-land disposal system for coarse and filtered tailings and fine tailings slurry in a basin which would be formed by the construction of a dam and 3 dikes at Mile Post 7. The disposal system is being designed to handle 40 years disposal of about 900,000,000 tons of refuse at a cost estimated at more than $250 million.

W. A. Wahler and Associates was retained by the State of Minnesota to independently review Reserve Mining Company's proposed preliminary tailings disposal plans and to provide the Minnesota Pollution Control Agency and the Department of Natural Resources with technical support and recommendations regarding the acceptability of Reserve's proposed plans which these agencies must approve before the plans can be implemented. Casagrande Consultants from Cambridge, Massachusetts, and Michael Baker, Jr., Inc., Engineers, of Beaver, Pennsylvania were similarly retained and cooperated in the accumulation of data and also have made independent assessments of Reserve Mining Company's proposed preliminary plans for these agencies. WAWA reviewed available court testimony and Reserve's preliminary plans and studies, and carried out limited independent site and laboratory investigations as the basis for forming the conclusions and recommendations reported herein. Conclusions and comments regarding the matters are made in the report and additional studies and specific design considerations are recommended. Final plans were not part of this stage review.



Proposed On-land Tailings Disposal Plan

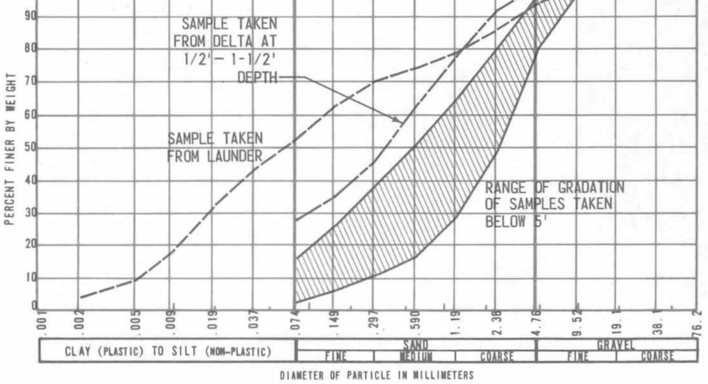
DNR- PCA EXH. #25 A

Lake Disposal System

For 20 years, the Silver Bay Concentration Plant Tailings have been disposed of in Lake Superior. Until environmental concern brought this operation into national controversy, Reserve Mining Company considered this an effective and economical way of disposing of the tailings. Cummingtonite asbestiform fibers, which are a constituent of the Silver Bay tailings, were found not only in the air around the plant, but also in the water supply for several municipalities which get their raw water from Lake Superior. The court found that the tailings, along with airborne emissions, posed a potential threat to the public health; and that the discharges violated Federal and State pollution control regulations. Current operations have been allowed to continue pending development of a suitable alternative disposal scheme. Any remaining threat, then, would come from the tailings that have already been discharged into the lake or which remain entrapped in the delta. The delta must be stabilized for plant site or other future beneficial use, and control of wind, wave, and current erosion.

The disposal system now consists of two launders transporting a slurry consisting of finely ground, low value and barren minerals, including Cummingtonite asbestiform fibers to the lake. The coarser particles settle out adjacent to the shore line forming a delta about a mile long and a half mile wide. The finer fraction does not settle out immediately but continues to flow as a heavy density current along the lake bottom with additional material settling out on the way to the lower levels of the lake. Some very fine, almost colloidal-sized Cummingtonite asbestiform fiberous particles go into suspension and have apparently dispersed over a wide area of the lake.

The suspended fibers constitute a current health concern. It is not now known how long the fibers will remain in suspension in the lake after cessation of disposal, but their concentration should reduce significantly in a reasonably short time. Fibers from the heavy density current that have come to rest on the lake bottom will not readily be stirred up and go into suspension after a few years of normal lake sedimentation has had a chance to bury them. In any event, these fibers are beyond the reach of today's technology and economy, and nature will have to



Gradation of Tailings in Delta

be relied on for their removal. In the meantime, municipal water supplies can be filtered to remove fibers. In the future the largest remaining potentially free source of fibers from past operations will be in the delta and in any on-land fills built of tailings. Absolute preclusion of additional fibers from the delta is not possible so until medical science can determine a standard, reasonable and achievable control must be maintained and the results closely monitored.

The program proposed to stabilize the delta is to construct a rockfill breakwater so as to protect about 50 acres of the delta for plant expansion. This breakwater would be over-built and maintained so that wave action along with judicious dumping of rock will eventually erode and riprap the delta slope outside of the breakwater to a depth of 40 feet below the water surface. About 2,000,000 cubic yards of tailings will erode away to reach a stabilized level. The area not covered by rock would be fertilized and seeded to inhibit wind erosion.

We believe that four objectives must be considered in evaluating the proposed delta stabilization measures: (1) integrity of supported structures; (2) containment of incorporated fibers; (3) control of erosion; and (4) drift control. The delta must support critical plant facilities and space must be protected during the life of the plant. We believe that this can be successfully done as long as the proposed rockfill breakwater is maintained. It is too much to expect the riprap blanket to protect the delta for many years after maintenance is stopped because the normal solid rock shoreline in the area is being continuously wave-cut by nature.

The proposed flattening of the seaward side of the initial dike by wave attack in order to develop a stabilized beach on which to place riprap will probably occur about as expected provided that close observation and control is maintained during the prolonged construction period. Rockfill and possibly some dredging may be necessary to direct the erosion to the desired shape. This can probably be better and more economically done by control during the erosion period than by planning based on model studies. We believe that additional model studies are not necessarily needed for this aspect of the plan. The existing delta can serve as the model and by carefully monitoring its changing shape, final stabilization can be developed. The aspect of this part of the plan which has not, in our opinion, been adequately studied and shown to be acceptable is the potential for a continued supply of fibers to the lake water from the tailings in the delta as the beach erodes to its stable slope. We believe that the occurrence of entrapped particles and any colloids suspended in the entrapped pore water may pose problems when liberated by this erosional process and that this problem must be given further consideration.

The plan to control erosion (wind and water) by vegetation, will work only as long as maintenance is continued. A more long lasting measure would be to cover the top of the delta on the shore side of the breakwater with a few feet of soil and/or rock chips.

With regard to concern for erosion of the delta by currents or littoral drift, we believe that the "controlled erosion" part of the stabilization scheme could cause a drift problem at the harbor and westward from the delta. After the stabilization plan has been carried to completion and the beach is covered by rock, this problem would probably be minimal with most, if not all, of the drift being lost to the lake depths. Some maintenance, specifically dredging, may be required, but fibers liberated by such dredging may again contaminate the lake. Reasonable requirements and control will be needed to stabilize the delta.

Land Disposal System

The iron ore from the mine at Babbitt is hauled to Silver Bay for processing by company-owned railway. It is proposed to build the new tailings disposal facility adjacent to Mile Post 7 along the existing railway. The coarse cobbs and filtered tailings from the plant will be transported to this site by rail for disposal in a dump. These materials will also be combined to build one dam and three dikes forming an impoundment into which the fine tailings slurry will be pumped. Slurry will be thickened at the plant and pumped through a five-mile pipeline to the impoundment. An earthfill starter dam, about 50 feet high and about 4,000 feet long, will be constructed across Big Thirtynine Creek, a tributary of the Beaver River. The main dam, approximately 150 feet high and over 12,000 feet long, will then be constructed contiguous with this starter dam. Dikes, varying in height from 100 to 140 feet, will be constructed across three low areas along the periphery of the impoundment limiting the area covered by tailings to about 4.6 square miles. The dry cobbs dump, which will cover about 3 square miles, will be placed just upstream of the impoundment. Diversion dams will be constructed across two streams that would otherwise discharge across the dry cobbs dump area, to minimize the amount of water flowing into the impoundment. Seepage emanating from the dam, dikes, and the foundation soils will be collected and returned to the impoundment. During the operating period, all storm water will be retained in the impoundment. If there is a need to discharge water it will have to be filtered to prevent emission of fibrous water to the lake. The water remaining in the reservoir when operations are suspended will have to be filtered.

Surface and subsurface investigations of the dam and dike sites have not yet been completed. The areas which have been explored indicate that the foundations will consist of lacustrine soils and glacial till overlying bedrock. The lacustrine clays and silts are saturated and the dams will have to be constructed in easy stages to minimize the probability of construction delays due to embankment instability.

Sand drains have been proposed to permit faster construction of the starter dam. We believe that an earlier start on the starter dam and sufficiently flat upstream and downstream slopes is an alternative solution which may perform better and more economically than the proposed sand drains, and that further consideration of this alternative has merit.

There are several pervious zones in the impoundment foundation and rim. These consist of fractured bedrock, talus, and sands and gravels. Care will have to be exercised to assure that all of these zones that may be exposed are adequately filtered and covered by constructed membranes and/or controlled slurry disposal techniques.

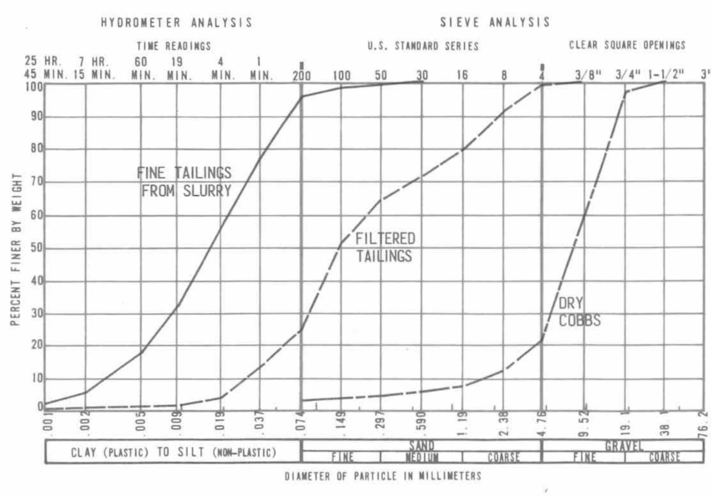
Except for a concern shared by the designers, that the rate of construction be monitored and carefully controlled to minimize the probability of a construction foundation failure and the concern that all pervious areas in the foundation and impoundment periphery be blanketed and filtered, the proposed dam and dike layout and preliminary designs appear to be acceptable, providing of course, that the exploratory investigations are carried to completion and the embankments are fully designed in accordance with contemporary final design practice.

During operation, the water level in the impoundment will be operated so as to minimize wind erosion and asbestiform particle dust formation. Perhaps some spraying or other measures beyond those presently proposed will be required, but such can be added as necessary if monitoring indicates that the proposed procedures are not effective. Consideration should be given to placing mine waste on the cobb slopes to minimize erosion in the future.

The abandonment plan envisions creation of a few small lakes or ponds on the tailings surface and discharge of the stream runoff over a riprapped spillway. This plan has some questionable aspects requiring more consideration. We believe that the surface area can be protected from excessive wind erosion by vegetation, but are concerned about future rainfall on the cobb dump picking up fibers as it seeps through the fill and concentrates on top of the natural ground level to emerge and flow into the impoundment as spring water. After abandonment, this water will feed the surface streams on top of the impoundment that will eventually be discharged into the Beaver River. We believe that the proposed provisions for this eventuality are inadequate and that the basic design will have to provide filtration zones (possibly constructed on filtered tailings and cobbs) to eliminate the fibers emerging from these springs, and that adequate mineral ground cover will have to be placed over the tailings area to preclude future erosion from excavating fibers from the tailings and their inclusion in the outflow to the Beaver River.

We believe that the disposal system design and abandonment plan can be modified to minimize the maintenance needed to keep the asbestiform fibers contained, but that some maintenance will be perpetually required to preclude eventual breaching of the facility by relentless erosion over a long period of time.

With the above considerations adequately taken care of, it is our opinion that a safe dump and impoundment structure can be built at Mile Post 7.



Gradation of Tailings for Land Disposal

Monitoring Programs

The on-land disposal plan contemplates a 40-year life, after which abandonment is planned. During this time it is possible that some factors will change from those presently foreseen and incorporated in the plan. Additionally, there will undoubtedly be improvements in refuse disposal technology as well as in the ore concentration technology and processing. In order to provide a basis for assessing the effectiveness of the proposed plan and for any needed future modifications, adequate operational records and assessments must be made. A comprehensive instrumentation and inspection program must, therefore, be initiated and carried on throughout the operational life of the project as part of the company's plan as well as a condition of approval. An adequate monitoring program is the only sound basis for judging the program's performance or on which changes can be made. Both wind and water erosion will be at work on the delta; therefore, these forces must be assessed and their effects monitored. Continued monitoring of Lake Superior for Cummingtonite fiber levels should also be carried out to provide a basis for assessing the effect of cessation of disposal into the lake and the performance of the delta stabilization plan. The tailings dump and impoundments have the additional aspects of stability and seepage to monitor. The seepage must be monitored for both quality and quantity to assure that all needs, as well as regulations regarding health and safety, are met. It will be necessary to review all data regularly to assess its meaning. It is the results of these reviews that will be the objective of the monitoring programs—not the accumulation of data per se.

Regulatory Review and Approval

The regulatory review and approval authority and responsibility of the State of Minnesota Pollution and Control Agency and the Department of Natural Resources require that the health, safety, and environmental aspects of the proposed project be reviewed and approved prior to implementation. All proposed modifications to the approved plan will also have to be reviewed and approved in the future as will the final cessation of activities and operations plans at the end of the life of the mine operation. The responsibility of the agencies requires that they monitor the operations to assure that the plan is carried out as approved and that the plan operates as expected regardless of approval. The plan will, therefore, have to be approved subject to various defined provisions in order to provide for reasonable economy as well as to assure effectiveness. This requires that the State as well as the Mining Company maintain adequate technical and review capability, and proper relationships and programs to assure that the program is carried out as intended. This is a matter of legal requirement for both the mining company and the agencies. It is also in the interests of both the company and the agencies as well as the public that this charge be carried out adequately to lessen the probability and consequences of liability for any accident or failure that might occur as well as to minimize the probability that environmental concern will obstruct mining and processing operations in the future. It is natural that company—agency experiences with this review and approval program will influence other mining industry—agency relationships in the future. This is the first major interrelationship of its kind in the State. As a result of this experience, the agencies will obviously be more oriented to mining health and safety problems in the future than they have been in the past. The public's and company's interests lie in having each party to this involvement carry out their respective responsibilities and duties with this in mind.

Limitations

WAWA was retained to make this independent interim review of available preliminary data and plans and to render comments and recommendations relative to the probability that the plan proposed will perform as claimed, as required by the courts, and as expected of properly designed works. This report covers only the preliminary data and plans available at the time of the study and as such does not deal with a proposed final plan. The final plan will be based not only on the available data reviewed, but also on data obtained on the basis of recommendations made at this time and on subsequently discovered site and material factors. The final design and its basis will have to be reviewed on its own merit at such time as it is submitted for approval. All subsequent modifications will have to be reviewed for suitability by the agencies if and when proposed by the mining company. This report, therefore, constitutes only a preliminary or interim review with comments and recommendations regarding the approval and permits being reserved until the final plan is reviewed.

Acknowledgments

Acknowledgment must be made of the professional and cooperative assistance the "Reserve Project Team", especially Dr. Ronald Hays, Attorney Morris Sherman, and Mr. Memos Katsoulis, as well as the staffs of the Pollution Control Agency and the Department of Natural Resources, rendered to us in our locating and gathering of the voluminous data accumulated over years of court involvement for this review. Acknowledgment must also be given to Leo and Dirk Casagrande, Casagrande Consultants, and C. Y. Chen and John Rapp of Michael Baker, Jr., Inc., for their cooperation in joint data gathering and development operations. Reserve Mining Company also cooperatively and effectively implemented our site and plant review visits, and made data and plans available upon request. Without this cooperative and effective help, the assignment could not have been carried to completion within the short time available.

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REVIEW OF RESERVE MINING COMPANY'S PRELIMINARY MILE POST 7 TAILINGS DISPOSAL PLAN

SILVER BAY, MINNESOTA

FOR

STATE OF MINNESOTA

POLLUTION CONTROL AGENCY
DEPARTMENT OF NATURAL RESOURCES

AUGUST 1975

W. A. WAHLER & ASSOCIATES

ENGINEERS & CONSULTANTS

DAM AND RESERVOIR ENGINEERING AND GEOLOGY

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REVIEW OF RESERVE MINING COMPANY'S PRELIMINARY MILE POST 7 TAILINGS DISPOSAL PLAN

SILVER BAY, MINNESOTA

FOR

STATE OF MINNESOTA
POLLUTION CONTROL AGENCY
DEPARTMENT OF NATURAL RESOURCES

This report was prepared by W. A. Wahler and Associates at the request of the "Reserve Project Team" for the State of Minnesota Pollution Control Agency and Department of Natural Resources. The study reported on was an independent review of the preliminary plan for on-land disposal of taconite ore process tailings at Mile Post 7 and for the abandonment of the present disposal in Lake Superior. This plan has been submitted by the Reserve Mining Company for approval by the above agencies. The report contains our opinions regarding the plan as proposed and the needed investigations and considerations for the final design.

W. A. Wahler and Associates has addressed those aspects of the Mile Post 7 Tailings Disposal Plan with which it has experience. We do not have legal, medical, process plant or air emissions expertise; therefore, any and all information or comments made herein on these subjects are presented only as part of the discussion to provide perspective, and are not professional opinions. W. A. Wahler and Associates is qualified in all aspects of geotechnical engineering applied to water and mining projects. We have specialized in tailings disposal systems and earth dams since 1960.

I hereby certify that this report was prepared in part by me and in total under my direct supervision and that I am a duly Registered Professional Engineer under the laws of the State of Minnesota, Registration No. PE 11475.

W. A. WAHLER AND ASSOCIATES

ORIGINAL SIGNED BY

W. A. Wahler, President
August 27, 1975

REVIEW OF

RESERVE MINING COMPANY'S

PRELIMINARY MILE POST 7 TAILINGS DISPOSAL PLAN

SILVER BAY, MINNESOTA

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CHAPTER I

GENERAL

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GENERAL

A. INTRODUCTION

The Reserve Mining Company initiated taconite mining and primary and secondary crushing operations in 1955 at a site near Babbitt with fine crushing, concentration, pelletizing, shipping, and power plant facilities at Silver Bay, Minnesota. The taconite is transported to Silver Bay by Company-owned 47-mile long railway where it is processed, with the resulting iron ore pellets being shipped from the company's harbor and the tailings being disposed of in the lake. Present production is about 10.4 million tons of iron ore pellets and 20 million tons of tailings per year. Reportedly this is about 12 percent of the iron ore produced and about 8 percent of the iron ore used in the United States.

The lake side tailings disposal system was considered by the Company to be both effective and economical until it became embroiled in environmental controversy. In 1973, Cummingtonite asbestiform fibers were discovered in the air around Silver Bay and in several municipal water supplies which obtained their raw water from Lake Superior. Apparently, as a result, the court, in 1974, found that the tailings discharge, posed a potential threat to the public health, and that the discharges violated Federal and State pollution control regulations. The Company is being allowed a reasonable opportunity to convert its operations to on-land disposal of tailings and to restrict its air emissions. Our studies, however, are not involved with the plant air emissions and are limited to the plan submitted to the Minnesota State Pollution Control Agency and Department of Natural Resources for the approval of a new tailings disposal system and the abandonment of the present lakeshore delta system. Our only interest in air quality at this site has to do with wind erosion of tailings from the delta, the new disposal area, and a concern for a number of fills in the plant area which have been built over the years using tailings sand. The plant emissions problem is beyond our field of competence and is being handled by others.

According to the Arthur D. Little, Inc., report concerning On-Land Tailings Disposal and Air Quality Plan (dated April 3, 1975), the mine at Babbitt presently contains about 1.2 billion tons of taconite in a deposit 9.9 miles long by about 2,800 feet in width. The depth of stripping varies from about 2 to 20 feet and the maximum thickness of ore is about 175 feet. The taconite contains about 24 to 25 percent iron. The lean and barren constitutents are mainly quartz and iron silicates. We also understand that an iron silicate, Cummingtonite--the mineral contaminant which is at the bottom of the pollution problem resulting in the tailings disposal system change--is found in the taconite ore processed at Silver Bay in both asbestiform and euhedral particle forms. When the ore is ground up for processing, a small amount of Cummingtonite by weight produces a very large number of very fine asbestiform fibers which have, historically, been wasted into the air and into the tailings slurry. These fibers, which are less than 5 μm in size (about colloidal size), are hard to filter out of the water and can be carried in suspension by both air and water for great distances. This makes their control very difficult.

We understand that the health hazard associated with the Cummingtonite asbestiform fibers is complex. Industrial health studies have linked airborne Cummingtonite asbestiform fibers to human cancer. These studies have shown that the cancer seems to show up only after long periods of exposure and/or long after exposure. Although a fairly clear link appears to have been found between the airborne fibers and cancer, only a relatively few cases have been reported. Industrial correlation between waterborne fibers and cancer appears to be less well established. The cancer link, however, appears to have been strong enough to convince the court that a potential, if not imminent, threat exists. In situations like this where the resulting cancer may develop a long time after initial exposure, it is very hard to establish criteria or standards relating to the health threat on a scientific basis. Judgment must, therefore, be used in the meanwhile.

Mile Post 7 is presently proposed by the Reserve Mining Company for the on-land disposal facilities. The present lake disposal system is to be abandoned after being used as the site for plant expansion needed to permit the tailings slurry to be pumped to the Mile Post 7 site. Slurry thickeners, water clarifiers, and pumps will be located on the delta. A dry cobbing plant and other facilities will be located adjacent to present plant buildings.

Other sites are being proposed by various interested parties, but the Mile Post 7 site is the only one submitted to the State of Minnesota Pollution Control Agency and the Department of Natural Resources by the Reserve Mining Company for approval. Alternate sites have not been submitted for approval and are not being reviewed by W. A. Wahler and Associates. It is the abandonment of the lake disposal system and the Mile Post 7 plan for on-land disposal that is being reviewed herein for acceptability. The submittals to date have included only preliminary information and plans. Final plans and backup information will be subsequently submitted and reviewed at a later date.

As a result of our studies of available information, we conclude that although the basic data needed to evaluate the final plans are deficient in several final design aspects, the system layout, site conditions, and construction materials for the Mile Post 7 scheme are basically amenable to evaluation and the design of a safe and effective disposal system if the needed additional investigation and design studies are carried out for final design. The plan for stabilizing the tailings impoundment and the stabilization and abandonment of the existing Lake Superior delta both require more study and the consideration of additional factors in order to make the plans more suitable, but the studies needed are amenable to completion and suitable solutions appear to be available providing that the tailings impoundment and the rockfill breakwater can be maintained after abandonment.

The most serious present deficiency in the delta plan is backup for the acceptability of allowing 2,000,000 cubic yards of the tailings to be disturbed before stabilization is initiated. Because the danger from the fibers in the delta has not been found to be imminent, some disturbance may be justifiable. After the situation has been quantified, decisions as to what must be done can rationally be made. Depending on the nature of the problem, it may be better to dredge the beach to its stable shape at an early date rather than let it erode naturally. Conversely, conditions may be found to warrant stabilization of only the space needed for the plant operations and the rest of the delta allowed to erode away. These additional studies and detailed designs are needed before the plan can be approved because the construction approval must be based on definitive plans and specifications and not on generalized programs. This is necessary because the performance of these facilities will be expected to be specific, not approximate.

B. AUTHORIZATION

The review program covered by this report has been carried out under the terms of an agreement, dated June 26, 1975, between the State of Minnesota and W. A. Wahler and Associates, and a supplemental agreement thereto, dated August 1975.

C. PURPOSE OF REPORT

The purpose of this report is to document our present interim conclusions regarding the preliminary plans for the development of an on-land tailings disposal site at Mile Post 7 and abandonment of the lake disposal system on Lake Superior, as proposed by the Reserve Mining Company for approval. Reserve is presently conducting further studies and has yet to present definitive plans and specifications for review. Therefore, the comments and conclusions reported at this time are presented for evaluation by the State agencies involved and, if approved, can be accounted for in Reserve's final design, thereby simplifying the final review and minimizing the probability that, at that late date, more data will be required or that the plans will have to be modified to gain approval.

D. SCOPE OF REPORT

The scope of this report is limited to reviewing the on-land Mile Post 7 tailings disposal plans and those for the stabilization of the existing tailings delta on the basis of presently existing data, and data obtained by W. A. Wahler and Associates, Casagrande Consultants, and Michaël Baker, Jr., Inc., for supplemental and verification purposes. Studies have been limited to the Mile Post 7 site and alternative sites have not been evaluated. Plant air emissions have not been considered in these studies. Conclusions and recommendations relating to approval or permit restrictions cannot be made at this time because the final project, with detailed plans and specifications, has not yet been submitted for review by the State.

E. LIMITATIONS

This report presents the results of W. A. Wahler and Associates' review of presently available data on Reserve Mining Company's proposed on-land tailings disposal project at Mile Post 7. As discussed above, the report presents our conclusions on those aspects of the project for which sufficient data is available and for which sufficient studies have been made to permit conclusions to be drawn. Because the data necessary for final design is not available, there are a number of important areas and details on which full conclusions cannot be made at this time. Where this is the case, we have drawn those conclusions we can, and have commented on potential problem areas and needs for additional information and/or controls where needed.

It is important to recognize that what has been presented to date by and for Reserve Mining Company does not represent either a final design-level plan or documentation. This is true, not only because plans and specifications have yet to be presented, but also because a number of critical elements and features still need to be addressed. It is apparent that the project designers recognize many of the areas where information and data still need to be acquired and where supplementary details need to be worked out but, for various reasons such as availability of access to certain portions of the site, this work has not been completed and reports on these activities are still pending. Thus, it is possible, at this time, to make only assessments as to the gross adequacy of the plan and the probable effectiveness of some of the proposed details and treatments. After the needed data and final plans and specifications have been submitted, they can be reviewed and recommendations made as to the provisions to be made in the construction permit.

F. DATA, PLANS, AND REPORTS REVIEWED

W. A. Wahler and Associates obtained a number of documents through the State of Minnesota Pollution Control Agency, the Department of Natural Resources, and the Reserve Project Team for review. In addition, W. A. Wahler and Associates made a literature search in these cogent areas of concern, making that data available to those performing the project review. Finally, W. A. Wahler and Associates, Casagrande Consultants, and Michael Baker, Jr., Inc., made some independent studies for supplemental and verification purposes. The results of these latter studies are published in Appendix A and B of this report for the data developed by W. A. Wahler and Associates, and in the individual company reports for the Casagrande Consultants and Michael Baker, Jr., Inc., data. A list of the data made available by the State agencies is presented in Appendix D, and a list of selected references from our literature search is presented in Appendix E.

G. ORGANIZATION OF REPORT

Our report has been organized so that the entire study is summarized in the project summary appearing at the front of the report. This summary covers the whole review in summary form--it is not a summary of conclusions and recommendations. This section has been prepared so that it can be used in the report and separately as an independent document where only limited detail of the W. A. Wahler and Associates study is needed. The conclusions and recommendations have not all been summarized in the project summary. We have taken this approach because we believe that a clear understanding of all conclusions and recommendations, in the proper context, can only be had by reading the entire report.

The General Chapter appears next. This chapter presents the introduction and general data concerning the project study and report. The next chapter presents our discussions, conclusions, and recommendations regarding the stabilization and abandonment of the delta in Lake Superior. Following is the chapter on the Mile Post 7 tailings disposal site. Finally, there is a discussion regarding regulatory control, intended to transmit a general idea of the process for those in the State agencies and the Reserve Mining Company, as well as the concerned public, with an interest in how this review and the subsequent reviews will probably be carried out to meet the intent of the law in this matter.

H. ACKNOWLEDGMENTS

Acknowledgment is given to the professional and cooperative assistance which the Reserve Project Team rendered; especially Dr. Ronald Hays, Attorney Morris Sherman, and Mr. Memos Katsoulis, as well as the staffs of the Pollution Control Agency and the Department of Natural Resources, who helped us locate and gather, for this review, the voluminous data accumulated over years of court involvement. Acknowledgment is also given Leo and Dirk Casagrande, Casagrande Consultants, and C. Y. Chen and John Rapp of Michael Baker, Jr., Inc., for their cooperation in joint data gathering and development operations. Reserve Mining Company also cooperatively and effectively implemented our site and plant review visits, and made data and plans available upon request. Without this cooperative and effective help, the assignment could not have been carried to completion within the short time available.

The principal documents which formed the basis for our review were the Design Report, prepared by Klohn Leonoff Consultants, Ltd., of Vancouver, British Columbia, Canada, and the Environmental Report, prepared by Arthur D. Little, Inc., of Cambridge, Massachusetts. Although the investigations and designs have not been completed, these reports were well prepared and contained a great deal of detailed information. The fact that these reports were well organized and professionally prepared made our review of the voluminous available data possible within so short a time schedule.

Our report contains numerous suggestions and recommendations in regard to future investigations and studies, design and specification details, and construction inspection and monitoring. This should in no way be considered a reflection on the adequacy of the work done to date by Reserve Mining Company's consultants. The work accomplished thus far represents preliminary design-level investigations and studies, which are being augmented and brought to the final design level for submittal at a later date. From our review of the Klohn Leonoff report, it is obvious to us that the designers recognize the need to further examine and consider, at the appropriate time, many of the areas of concern we have identified.

I. COMMENTS

The principal considerations guiding the Reserve Mining Company's design of the Mile Post 7 tailings disposal program are summarized in Volume I of the Arthur D. Little, Inc., Environmental Report Concerning On-Land Tailings Disposal and Air Quality Plan. We believe that some comments on these basic design considerations, based on the presently available interim period data, plans, and reports would be useful to the company, as well as to the State agencies involved in reviewing the plan. The basic considerations as enumerated in the above report are stated below in italics with our comments following each "consideration."

"...All tailings deposited on land with no discharge to surface waters or Lake Superior."

The proposed plan should accomplish this objective with reasonable assurance. Some additional consideration will still have to be given to assuring that seepage from the tailings impoundment will either be reasonably free from contaminants or that it will be returned to the impoundment for all time(?).

"...No visible emissions from the various stacks other than water vapor or steam. Bag filters employed in areas with any significant particulate emissions including pelletizing. In addition, applicable particulate emissions standards be met."

We have not reviewed these aspects of the plan and therefore are not qualified to comment on them.

"...Existing tailings beach along Lake Superior to be established as a permanent shoreline."

Available information does not provide a basis for determining whether a compelling need exists to stabilize the present delta shoreline other than as it provides building space for plant expansion and as it would otherwise adversely affect the harbor operations. We believe that the nature of the delta with regard to future lake contamination must be studied in order to determine a need, if any, to stabilize the delta from the public's standpoint and, if such need exists, to provide a basis for evaluating the consequences and effectiveness of such stabilization. This could preclude, or at least minimize, the probability of problems in this area in the future. There is also the possibility that the delta area could serve some public purpose after its use to Reserve has lapsed.

"...Entire tailings disposal area planned so that maintenance will essentially be built in as an integral part of the total plan."

This objective is essential to the public's acceptance of the abandonment plan. While it is probable that the proposed vegetation plan will minimize dust pollution, there is still question as to the need for more positive measures to preclude postabandonment surface water pollution at both the delta and tailings dump and impoundments.

"...Adequate safety precautions included in the design and construction of all dams and dikes."

Although additional information and final plans and specifications must be reviewed before final comments can be made on this matter, we are convinced that this objective can be accomplished and that investigations and design work under way at present, and as recommended in this report and the reports prepared by Casagrande Consultants and Michael Baker, Jr., Inc., will lead to safe impounding structures.

"...Downstream slopes of dams to be terraced to aid revegetation and to blend with the natural topography of the area."

These measures should provide environmentally acceptable and reasonably stable slopes. Consideration should be given to riprapping groin and toe areas where necessary to assure low maintenance slopes.

"...Prevention of windborne dust from the on-land deposit."

We believe that the vegetative provisions now planned will be adequate to minimize the dust problem but are still concerned about the surface waters problem--suspended Cummingtonite asbestiform fibrous particles in the water flowing over and from the tailings impoundment after abandonment.

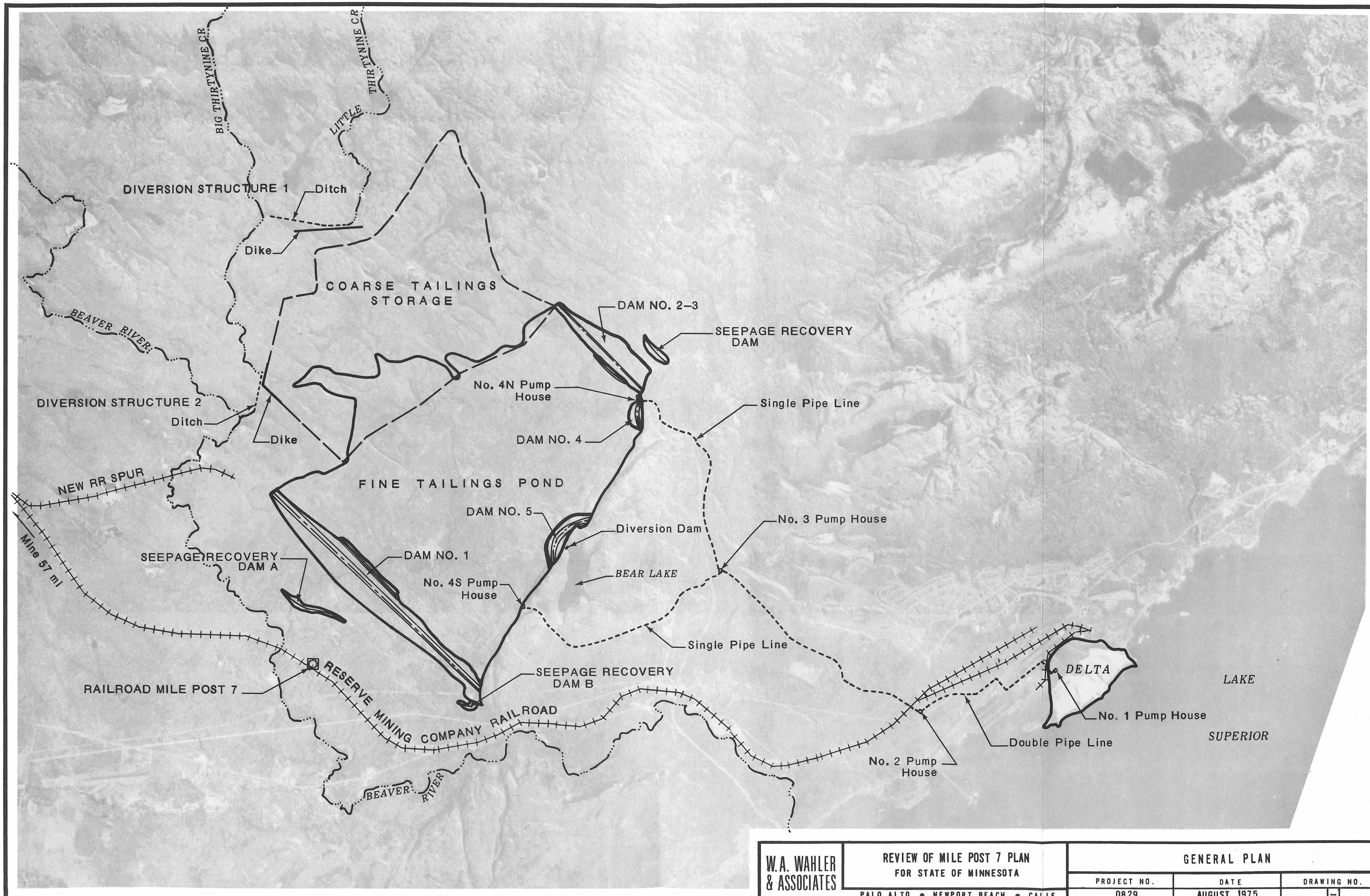
"...Perpetual maintenance of tailings disposal site with a guarantee on maintenance by Armco and Republic, the shareholders of Reserve."

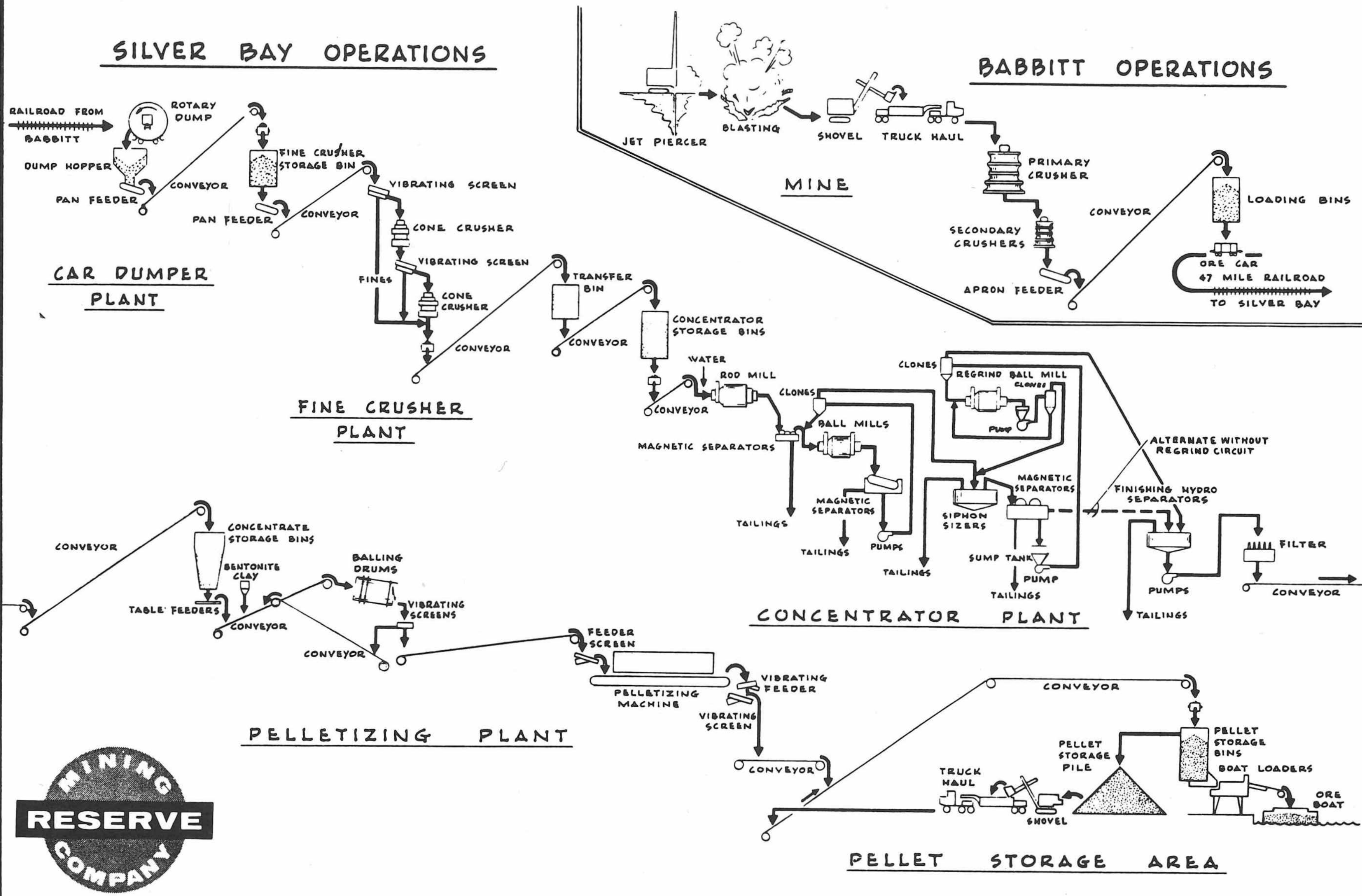
We are not qualified to express a meaningful opinion on this matter.

"...Forty (40) years production limitation."

We are not qualified to express a meaningful opinion on this matter.

In summary, we believe that the plan being prepared is basically sound and can be made to meet the objectives outlined above in a reasonable manner with only a few additional studies and provisions. We are not convinced that all of the objectives must be met on a 100 or zero percent basis and believe that reasonable objectives that can be met are better than absolute objectives that might be violated, however inconsequentially.


BIG THIRTYNINE CR.
LITTLE THIRTYNINE CR.
DIVERSION STRUCTURE 1
Ditch
Dike
COARSE TAILINGS STORAGE
DAM NO. 2–3
SEEPAGE RECOVERY DAM
BEAVER RIVER
No. 4N Pump House
DIVERSION STRUCTURE 2
Ditch
Dike
Single Pipe Line
DAM NO. 4
NEW RR SPUR
FINE TAILINGS POND
DAM NO. 5
Diversion Dam
No. 3 Pump House
Mine 57 mi
SEEPAGE RECOVERY DAM A
DAM NO. 1
No. 4S Pump House
BEAR LAKE
Single Pipe Line
DELTA
LAKE
RAILROAD MILE POST 7
RESERVE MINING COMPANY RAILROAD
SEEPAGE RECOVERY DAM B
No. 1 Pump House
SUPERIOR
Double Pipe Line
No. 2 Pump House
BEAVER RIVER
W.A. WAHLER & ASSOCIATES
REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA
PALO ALTO • NEWPORT BEACH • CALIF.
GENERAL PLAN
PROJECT NO. 0829
DATE AUGUST 1975
DRAWING NO. –



RESERVE MINING COMPANY

Source: Reserve Mining Company

W.A. WAHLER & ASSOCIATES

PALO ALTO • NEWPORT BEACH • CALIF.

REVIEW OF MILE POST 7 PLAN
FOR STATE OF MINNESOTA

SCHEMATIC FLOW DIAGRAM
CURRENT RESERVE MINING COMPANY OPERATION

PROJECT NO.	DATE	DRAWING NO.
0829	AUGUST 1975	I-2

CHAPTER II

LAKE DISPOSAL SYSTEM

CHAPTER II

LAKE DISPOSAL SYSTEM

A. INTRODUCTION

For 20 years, the Silver Bay Concentration Plant tailings have been disposed of in Lake Superior. Until environmental concern brought this operation into national controversy, this practice was followed by the Company as an effective and economical way of disposing of the tailings. After long controversy over the acceptability of this type of disposal, Cummingtonite asbestiform fibers, which are a constituent of the Silver Bay tailings, were found not only in the air around the plant, but also in the water supply for several municipalities which get their raw water from Lake Superior. Although we are not legal or medical experts, we understand that the court found that the tailings posed a potential threat to the public health and that the discharges violated Federal and State pollution control regulations. This method of disposal is, therefore, to be abandoned.

Current operations have been allowed to continue pending development of a suitable alternative to continued disposal in the lake. In the future, all tailings will be disposed of on land. Any remaining threat then, would come from the tailings that have already been discharged into the lake. Our concern with the delta is primarily with the abandoned tailings and their stabilization for plant site or other future beneficial use, and control of wind, wave, and current erosion.

The lake disposal system presently consists of two launders transporting slurry from 22 concentrators by gravity to the lake shore, northeast of the Silver Bay Harbor. The tailings in the slurry consist of finely-ground, low value and barren minerals, including Cummingtonite asbestiform fibers. The coarser tailings particles settle out adjacent to the shoreline to form a delta about a mile long and a half-mile wide. The finer fraction of the tailings does not settle out immediately and continues flowing as a heavy density current along the lake bottom, gradually settling out as it flows to the lower levels of the lake. Some very fine, almost colloidal sized Cummingtonite asbestiform fibrous particles have also gone into suspension in the lake and have apparently dispersed over a wide area.

Suspended fibers in the air and lake constitute the health concern. Measures to minimize future emissions to the air by wind erosion and to water by slurry emissions are the essence of the Mile Post 7 on-land disposal system. Only nature can remove those fibers presently in the air and water. It is not presently known how long the fibers will remain in suspension in the lake after disposal has ceased, but it is probable that the concentration will reduce significantly, although probably not to zero, over a reasonable number of years. Time only will tell. It is also probable that the fibers from the heavy density current that have come to rest on the lake bottom will constitute only a minor continuing source of new fibers available to go into suspension after a few years of normal lake sedimentation has had a chance to bury them. In any event, these fibers are beyond the reach of today's technology and economy, and nature will have to be relied upon for their removal from the lake water. In the meantime, the only practical protection from these fibers, if they pose a continuing threat, lies in filtering municipal water supplies.

The largest remaining source of fibers from present and past operations will then be in the delta and in the various on-land fills, roads, etc., that have been built over the years. Some of the existing fibers will probably remain in the water indefinitely. Absolute preclusion of additional fibers from getting into the water from the existing delta is not possible. It will be necessary, therefore, to visualize the delta stabilization problem in a practical manner and to manage the problem so as to minimize their liberation to the degree practical. Because we do not yet know enough about the Cummingtonite asbestiform fiber threat to set standards, we must do the best we can to minimize the problem, on the basis of judgment, until medical science provides a scientific basis for setting more absolute standards. In the meantime, reasonable and achievable control must be maintained and the results closely monitored.

The program proposed by the Reserve Mining Company to stabilize the delta is to construct a rockfill breakwater so as to protect about 50 acres of the delta for plant expansion purposes. This breakwater would be overbuilt and maintained so as to develop a well-graded riprap slope on the lake side. Erosion and wave action would be used to readjust the rock on the slope, with judicious additional dumping of rock from time to time, so as to eventually cover the delta slope with rock outside of the breakwater to a depth in the lake of 40 feet (below most of the wave and current action) after the beach slope has stabilized. It is estimated that about 2 million cubic yards of tailings will have been eroded away in this beach stabilization period. The area not covered by rock would be fertilized and seeded to inhibit wind erosion.

We believe that four objectives must be considered in evaluating the proposed delta stabilization measures:

1. Integrity of supported structures
2. Containment of incorporated fibers
3. Control of erosion
4. Drift control

First, because the delta is to support critical plant facilities and structures, the required space must be protected during the operational life of the plant or any other beneficial use to which the area is put. We believe that this can be successfully done as long as the proposed well-graded rockfill breakwater is maintained. It is too much to expect the riprap blanket to protect the delta for many years after maintenance is stopped, because the normal solid rock shoreline in the area is being continuously wave-cut by nature. In addition to protecting the site from waves and erosion, proper foundation support will have to be provided to minimize differential settlement if any erosion can occur in the vicinity of the building or facility foundations.

Although conclusive data have not been developed to prove it beyond any doubt, the proposed flattening of the seaward side of the initial dike by wave attack, in order to develop a stabilized beach on which to place riprap, will probably occur about as expected. Close observation will have to be maintained during the prolonged construction period. Rockfill and possibly some dredging will have to be used as necessary to direct the erosion to the desired shape. This can probably be better and more economically done by control during the erosion period than by planning based on model studies. Because the final shape need not be precise, and because judicious dredging or riprap placement can be used to control the erosion within reasonable limits, the exact behavior of the erosion need not be known in advance. It is only important to stabilize it when it is at the proper level. We believe that additional model studies may not be needed for this aspect of the plan if proper monitoring and concurrent dredging or riprapping is practiced, because the data derived therefrom will not be of too much actual help in achieving the stabilization desired.

We also believe that the breakwater and riprap scheme will work. Although we cannot now assess the post-abandonment maintenance requirement, we believe that good records covering the period that Reserve occupies the site should provide an adequate basis for final abandonment provisions and/or continued maintenance. An assessment can be made about 40 years hence, relieving the necessity to guess now, when more adequate data will be available in time to permit proper abandonment. Reserve would do well to develop a reserve account to provide for funding work required at that time. Our assessment that the plan will work assumes, however, that the gradation of the rock will consist of a proper mixture of rock fines and coarse particles. The particles must be fine enough to preclude wave washing of sand from beside and underneath the larger particles, and large enough to prevent displacement by wave action. Perhaps dry cobbs (if shown to be benign) should be added to mine strippings to achieve the necessary gradation.

The aspect of this part of the delta stabilization plan which has not, in our opinion, been adequately studied and shown to be acceptable is the potential for continued supply of Cummingtonite asbestiform fibers to the lake water from the tailings in the delta as the beach erodes to its "stable" slope. We believe that the occurrence of entrapped particles and any colloids suspended in the entrapped pore water may pose problems when liberated by this erosional process. It is also possible that, if this is not a problem, stabilization of the delta beyond that required for stability of the structures built thereon may be unnecessary. We believe, therefore, that this problem must be given further consideration.

The plan to control erosion (wind and water) using vegetative cover will, we feel, work only as long as maintenance is continued. A more long-lasting measure would be to cover the top of the delta, on the shore side of the breakwater, with a few feet of soil and/or well-graded rock chips. Vegetative cover might not then be needed, and lasting, low maintenance protection would have been provided. This need not have been finally decided until a number of years of experience indicates what will ultimately be needed.

With regard to concern for erosion of the delta by currents or littoral drift, we believe that the "controlled erosion" part of the stabilization scheme will initiate most of the drift problem at the harbor and westward from the delta. After the stabilization plan has been carried to completion and the beach is covered by filtered rock, this problem will probably be minimal with most, if not all, of the drift being lost to the lake depths. Some maintenance dredging will possibly be required to keep the harbor operational. Any dredging carried out to protect the harbor, combined with flood flows from the Beaver River, should work to prevent littoral drift from becoming a major problem to the southwest, which is the probable direction in which this type of problem will develop, if any. Any dredging operations that are required will probably liberate some Cummingtonite fibers into the lake water.

We believe that the delta can be adequately stabilized as long as reasonable expectations prevail and the stabilization program is carried out with proper controls.

B. SITE CONDITIONS

1. General Description of Site Area

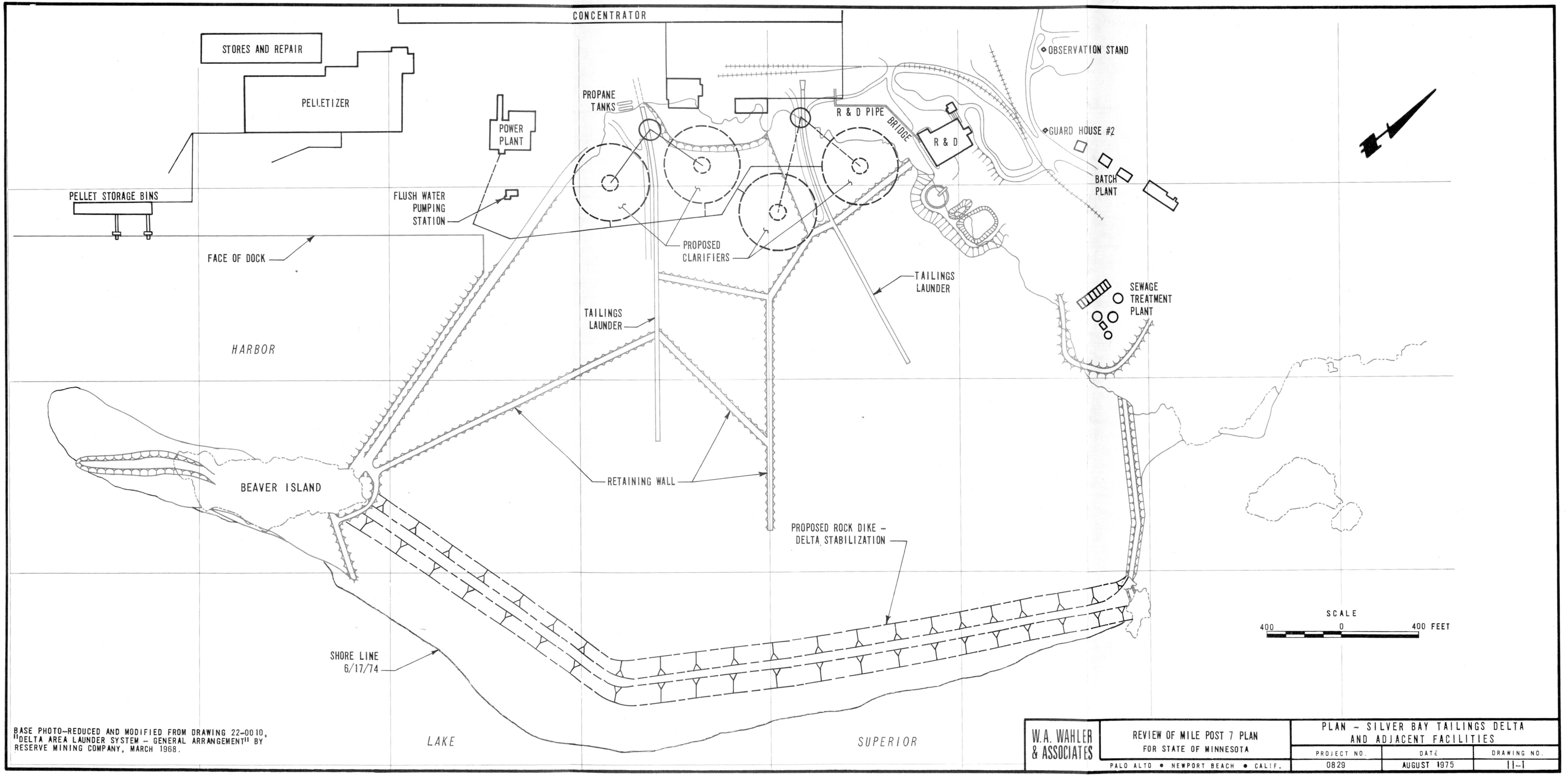
The taconite tailings delta described in this report is located on the northeast shore of Lake Superior near the city of Silver Bay, Minnesota, and is about 50 miles northeast of Duluth. Reserve Mining Company operates a taconite processing plant and a deep-draft harbor next to the delta. The community of Silver Bay lies just to the northwest, generally within a mile of the plant. Most of the inhabitants of Silver Bay are involved with the Reserve Company processing and mining operations.

The tailings delta presently encompasses an area of approximately 230 acres. The delta is confined on the northeast end by a small breakwater structure extending from the shore to a small rock island. The Silver Bay deep-draft harbor is located on the southwest side of the delta and is separated by a large retaining wall which ties into Beaver Island.

2. Climatology

Lake Superior lies entirely within the north temperate zone and, thus, is subject to frequent outbreaks of continental polar air throughout the year. The climate at Silver Bay is influenced significantly by the immediate presence of Lake Superior; as a result, the mean temperature for January is 10^{o}F. warmer than temperatures for the northern and northwestern portions of Minnesota, and 5^{o} to 10^{o} cooler in July.

Normal monthly temperatures for Two Harbors, Minnesota, 25 miles southwest of Silver Bay, are 14.8^{o}F for January, the coldest month, and 65.3^{o}F for August, the warmest month. Precipitation averages about 28.5 inches annually, and in general, storm fronts track in a west to east direction. Prevailing wind directions at Silver Bay vary frequently throughout the year, but for the largest percentage of time, the direction is typically with a northwest trend. The average wind speed is roughly 12mph, and generally varies between 10 and 14mph.



CONCENTRATOR
STORES AND REPAIR
PELLETIZER
POWER PLANT
PROPANE TANKS
R & D PIPE BRIDGE
R & D
OBSERVATION STAND
GUARD HOUSE #2
BATCH PLANT
PELLET STORAGE BINS
FLUSH WATER PUMPING STATION
FACE OF DOCK
PROPOSED CLARIFIERS
TAILINGS LAUNDER
SEWAGE TREATMENT PLANT
HARBOR
TAILINGS LAUNDER
RETAINING WALL
BEAVER ISLAND
PROPOSED ROCK DIKE - DELTA STABILIZATION
SCALE
400 0 400 FEET
SHORE LINE 6/17/74
LAKE
SUPERIOR
BASE PHOTO-REDUCED AND MODIFIED FROM DRAWING 22-0010, "DELTA AREA LAUNDER SYSTEM - GENERAL ARRANGEMENT" BY RESERVE MINING COMPANY, MARCH 1968.
W.A. WAHLER & ASSOCIATES
REVIEW OF MILE POST 7 PLAN
FOR STATE OF MINNESOTA
PALO ALTO • NEWPORT BEACH • CALIF.
PLAN - SILVER BAY TAILINGS DELTA AND ADJACENT FACILITIES
PROJECT NO. 0829
DATE AUGUST 1975
DRAWING NO. II-1

3. Basic Coastal Conditions

a. Lake Levels - Lake Superior has a surface area of 31,800 square miles and an average depth of 487 feet. The maximum depth is approximately 1330 feet. Records published by the U.S. Lake Survey show that the lake levels have fluctuated slightly over 4 feet since 1860. The usual pattern of seasonal variation consists of high levels in summer and early fall, and low levels in winter, with an average seasonal variation of 1.2 feet. The average level of the lake is Elevation 602.2 feet above New York datum. The highest one-month average level occurred in August 1876 at 604.1 feet, and the lowest one-month average level occurred in April 1926 at 600.0 feet.

b. Principal Wave Directions - The principal waves on Lake Superior are generated by the force of the wind on the water surface. For a given storm, maximum wave heights are determined by wind speed and direction. The Silver Bay delta, because of its location on Lake Superior and the general trend of the shoreline, is exposed to wind waves generated from storms from approximately N40°E to S40°W in a clockwise direction. General wind-wave data concerning the frequency of occurrence of waves that can be expected at Silver Bay for wave heights ranging from 2 to 17 feet, are available from a report published by the U.S. Corps of Engineers titled, "Wave Action and Breakwater Location, Taconite Harbor (Two Islands), Lake Superior, Minnesota, Technical Memorandum No. 2-405." These data were initially prepared in 1948 in connection with a model study of Silver Bay Harbor conducted by the Waterways Experiment Station at Vicksburg, Mississippi, and were later used (about 1955) for the Taconite Harbor study. These data indicate that the most frequent storm direction to which the delta is exposed is from the northeast and that these storms also produce the highest waves.

c. Near-Shore Lake Circulation Patterns

No available data was found regarding near-shore currents and/or general circulation patterns for Lake Superior near Silver Bay. This would be valuable data to obtain because the mechanisms of sediment transport and the subsequent disposition of material could be more accurately evaluated or monitored. Near-shore currents are normally generated by winds, and move according to the prevailing wind direction. Predictably, these currents are more intense during periods of strong winds, and gradually decay as the wind speed declines. Coastal modification, however, can have a substantial influence on these near-shore circulation trends. Often, eddy currents are created which are peculiar to certain wind directions, and which often have a very erosive effect on the adjacent coastline; therefore, these currents may have both stability (delta) and drift connotations justifying research in this area. In the meantime, we speculate that the currents are predominantly southwesterly along the shore.

C. DELTA

1. General

Mill tailings have been disposed of for the past 20 years by deposition into Lake Superior. About 67,000 tons of tailings and about a million tons of slurry water per day are currently being disposed of in the lake. Some of the tailings settle out when they enter the lake, some remain suspended in the slurry water, and some become suspended in the lake water. The coarser materials settle out close to shore to form a delta. The finer materials flow into the lake remaining in suspension or finally settling out on the lake bottom.

The material on the lake bottom or suspended in the lake water is beyond the reach of present technology and economy. It will remain where it is until the suspended material finally settles out and the natural processes of sedimentation cover up the bottom deposits. The delta, however, will remain on the shoreline while normal and storm waves and littoral currents erode it away at a rate unknown at this time. It is only with the delta, therefore, that we can still deal.

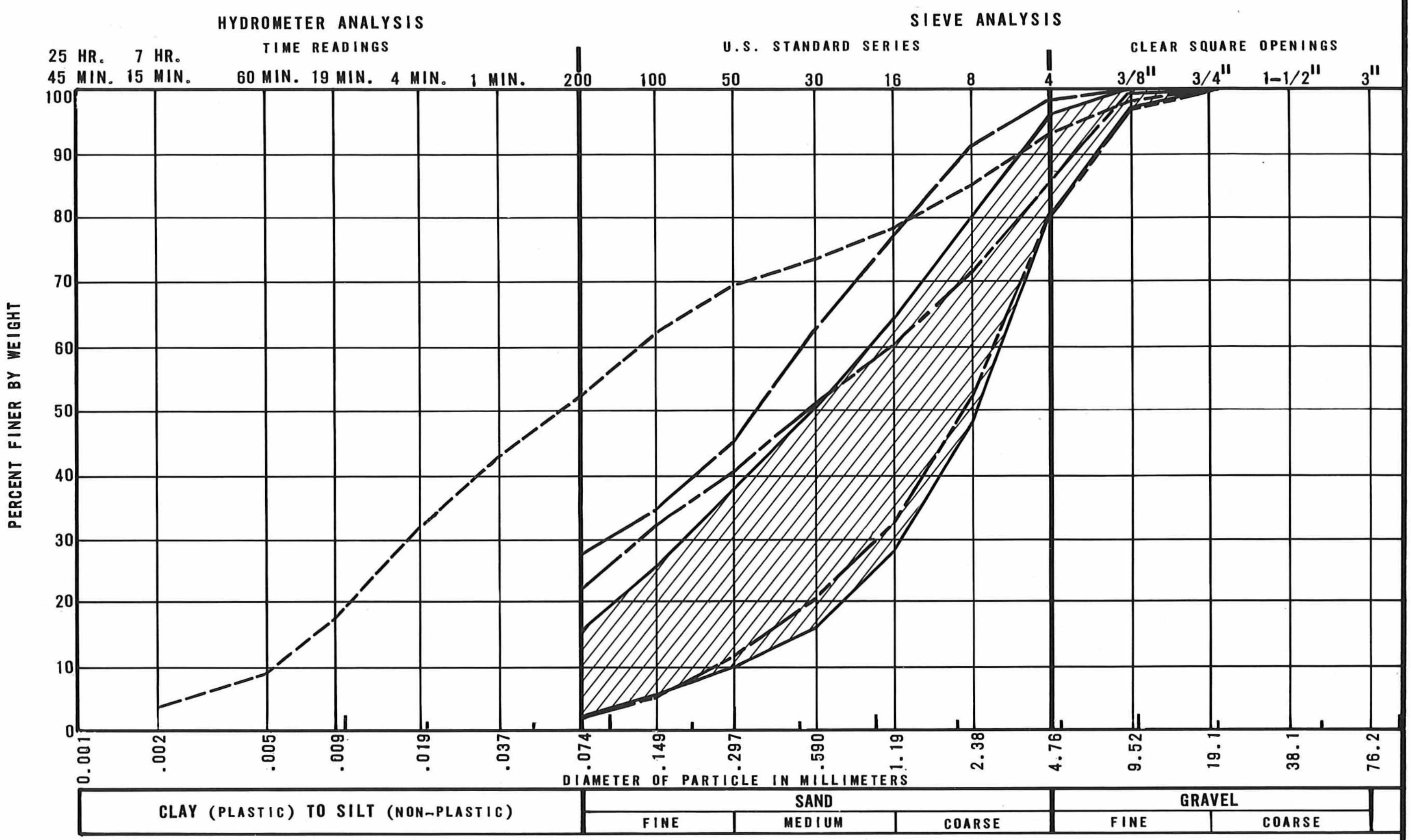
The delta presently consists of a sand-like material deposit having an above-water extension of about one-half mile from shore and a shoreline length of one mile. The delta shoreline is confined by Silver Bay Harbor breakwater and Beaver Island on the southwest, and a rocky outcrop on the northeast. The lakeward slope of the delta surface is about 50 horizontal to 1 vertical, or approximately 1 degree (or a 2% slope). The edge, where the slope drops off steeply, is about 200 feet vertically above the lake bottom at its edge, and 600 feet above the toe of the slope. The outside slope is inclined 3 horizontal to 1 vertical, or about 18 degrees, lakeward.

The delta presently (summer 1975) contains about 80 million cubic yards, or 122 million tons, of coarse tailings, assuming the density to average 113 pcf. It is estimated that about 225 million tons of tailings have been deposited in the lake since 1955. This leaves about 112 million tons of fine-grained material deposited on the lake bottom or in suspension in the water.

2. Tailings

Most ores contain varying quantities of high grade, lean, and barren materials. In the concentration process, the higher grade minerals are separated from the lower grade and useless minerals. The barren and other uneconomical minerals are the leftover or waste materials--the tailings. The tailings are finely-ground mineral particles having a gradation range dictated by the fracturing pattern of the ore and the grinding processes. The economic value of the tailings is generally on a par with sand on the local market; therefore, most tailings are disposed of as economically as possible as a waste or refuse product. The gradation characteristics of the present delta and tailings materials are presented on Drawing II-2.

Tailings are generally transported as a slurry from the concentration plant and subsequently discharged at a disposal site. Following discharge, the slurry temporarily carries most of the tailings as a suspension,



KEY

RANGE OF GRADATION OF SAMPLES TAKEN FROM BELOW 5'.

SAMPLE TAKEN FROM DELTA AT ½'–1½' DEPTH (HOLE 1001).

SAMPLE TAKEN FROM DELTA AT ½'–1½' DEPTH (HOLE 1005).

SAMPLE TAKEN FROM DELTA AT 17'–18' DEPTH.

SAMPLE TAKEN FROM LAUNDER

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REVIEW OF MILE POST 7 PLAN
FOR STATE OF MINNESOTA

GRADATION OF TAILINGS IN DELTA

PROJECT NO. 0829

DATE AUGUST 1975

DRAWING NO. II-2

depending on flow velocity to maintain the carrying power. When the velocity falls below certain limits, various constituents fall out of suspension and are deposited on the "stream" bed. Coarser and heavier materials leave suspension first, and the lighter and finer-grained materials remain in suspension for a longer time. The finest materials sometimes remain suspended in the slurry water, because these materials are near colloidal size and have the ability to remain suspended for long times after the velocity of flow is zero. These suspended particles, along with dissolved minerals, represent a potential source of pollution. Where the concentration of suspended, colloidal and/or dissolved minerals is great enough, the slurry may pollute streams or bodies of water into which it flows.

The tailings from the Reserve Mining Company operations are partly of the normal mineral-aggregate composition, but this ore contains Cummingtonite in asbestiform which, after the grinding process, appears in the $<5\mu m$ particle-size range. These particles have been judged to be potentially hazardous by the courts, and are fine enough to remain in suspension a long time. Lake disposal of the tailings has been prohibited by the courts in order to keep these particles out of the air and domestic water supplies in the future. The containment of these particles is the objective of the alternative on-land disposal system.

3. Formation

The delta is formed by sedimentation of the coarser fractions of the tailings from the relatively high water content slurry disposed of from the concentration plant. The slurry, reportedly consisting of 2.7% solids by volume, or about 8 to 10% by weight, has an extraordinarily high volume of water in relation to the solids content. This slurry, when it leaves the launder, flows over a reach of the existing delta surface to the lake. The slope of the top of the delta is about 2%. The slurry stream courses back and forth across the delta top in typical braided stream fashion. The relatively steep slope, and the high water content of the slurry, tends to make this process as much an erosion process as a deposition process. The result is that the delta surface does not tend to build up. Because the slurry is thin, and the gradient across the delta is relatively steep, it has a high suspension-carrying capacity. It should be able to carry most of the finer materials as suspended material rather than as a bedload material. This is particularly true of very fine colloidal-sized materials. It is, therefore, probable that most of the bedload deposition takes place at the edge of the delta. At that point the velocity of the slurry is stopped rather suddenly by the lake water level, causing a quick energy loss with a resulting bedload rejection at about the shoreline. The suspended and colloidal solids probably flow out into the lake as a density current as discussed elsewhere. Thus, the delta is built outward rather than upward.

There is evidence that there is some deposition of bedload on the surface of the delta, but this material is likely reworked several times as the stream braids sweep back and forth across the delta with a resulting washing action. Thus, there is reason to expect that most of the very fine material in the slurry that is deposited in the delta is washed and rewashed crossing the delta on its way to the lake. However, the sweep of the braided streams across the delta face may not be a continuous sweep; therefore, there are probably finer deposits in some areas where the currents are slower or where the initially deposited material is not reworked.

This is quite evident in the gradations of the tailings materials shown on Drawing II-2. The tailings sample represented in this drawing was obtained in July 1975 by the Reserve Project Team, and the gradation was obtained in the WAWA laboratory. The other samples shown were tested by Soil Exploration Company of St. Paul, Minnesota, and transmitted to Reserve Mining Company by Klohn Leonoff, Consultants, Ltd., June 19, 1975. The tailings leaving the concentrator plant have about 50% by weight passing the #200 sieve. One near-surface sample had about 25%, and a second about 2%, passing the #200 sieve. The slurry bedload is dumped at the edge of the tailings delta, with most of the material falling or being washed over the slope to filter down through the still lake water to come to rest on the slope at the angle of repose. During this process, the finer particles again have the opportunity to go into suspension in the lake, minimizing the amount to be deposited in the lake. The samples taken from deeper in the delta were more consistently coarser, with 26 of the 29 samples having 2 to 16% passing the #200 sieve. One of the deeper samples had a minus

200 fraction of 22%. Thus, even the finest-grained samples have only about half of the fines that were originally in the slurry when it was in the launder. The rest of the samples had less than one-fourth the original fines (minus #200 sieve) content. Thus, an argument can be made that the delta probably does not contain a large percentage of Cummingtonite asbestiform fibers, and that those that do remain after the thorough washing experienced in the delta formation process will not be easily liberated. What this means in quantitative and allowable terms is not yet known, and needs yet to be determined by a precise investigation of the occurrence of Cummingtonite fibers in the delta. Standard soil mechanics gradation tests by themselves are not adequate for this determination.

4. Comments

The delta exists! We do not know exactly how much Cummingtonite in the form of asbestiform fibers exists entrapped in the body and pore water of the delta, nor do we know how easily these fibers can be liberated. In addition, we do not have any standards by which the remaining potential threat can be measured. We know that cessation of disposal into the lake will eliminate the major source of "feed" of fibers. Although we do not have adequate quantitative data on which to base a firm estimate of the amounts involved, what we do know indicates that the entrapped fibers would be only a very small portion of the original content--perhaps on the order of one hundredth to one thousandth as much. We also know, however, that the fibers in any tailings that are eroded by wave or current action can probably be liberated into the lake, although we do not know how readily. It is also evident that it is physically impossible to preclude the possibility of any erosion of the delta for all time. Thus, there is probably no way to reduce future emissions to zero. The problem then resolves itself to determining exactly how much fibrous material exists in the delta in order to determine the type and degree of preventive measures that are needed to minimize liberation of fibers, and to provide a basis for assessing the adequacy of the solution. The proposed scheme may well be the best one to pursue, but it may also be inadequate in some respects. Conversely, further study may indicate that the proposed solution is more than is required. If no stabilization is required, the best future use may be as a recreational beach. If such were the case, the public interest might be best served by not ruining it by rock stabilization.

Because it is physically impossible to eliminate all possible erosion of the delta for all time, the stabilization, if needed, must be based on keeping the emission of fibers to an acceptable level. When this is determined, the solution will be evident.

D. ABANDONMENT CONSIDERATIONS

Present plans for the future of the delta consist essentially of the use of a portion of the area for construction of additional plant facilities, the construction of a breakwater-armor or riprap system to stabilize the majority of the delta, and surface stabilization of the area behind the breakwater against wind erosion by planting vegetative cover. After the plant operational life has expired, the delta would be abandoned permanently, and maintained as necessary in perpetuity.

The aspects of the delta that must be assessed with regard to abandonment are:

1. The integrity of the on-land disposal system elements to be founded on the delta.
    a. Stability of structures founded on delta
    b. Suitability of proposed rock dike system
    c. Maintenance or other requirements necessary as part of the approval of the abandonment scheme

2. The suitability of the abandonment plan for the delta from a health and safety standpoint.
    a. An assessment of the occurrence of contaminants in the delta mass and the allowable delta erosion from the standpoint of lake and water supply pollution

b. An assessment of future dust problems from the delta after abandonment and/or measures to control dust

c. An assessment of the contribution of pollutants into the lake by the final proposed abandonment scheme

3. The final operating and abandonment plan which must be suitable in all regards before final approval (not possible at this time).

Available data and details of the tentatively proposed plan are insufficient at present to make a definitive evaluation (for approval) of final operating and abandonment plans; therefore, only comments regarding the overall concept can be made at this time. Available data regarding the occurrence of Cummingtonite asbestiform fibers in the delta are insufficient to determine the degree of problem that might exist, as well as to assess how the stabilization of the delta would have to be carried out from the standpoint of public health and safety. Lacking firm data, we have had to use personal observation, experience, and theoretical approaches to try to determine the approximate nature and degree of concern that we should have with regard to the delta. Our efforts in this regard have been separated into two categories:

1. Makeup of delta
   a. Determine physical size and shape
   b. Determine constituents of delta
   c. Evaluate mechanism of buildup
   d. Project delta makeup to time of abandonment

2. Delta degradation and dispersal of asbestiform fibers into Lake Superior for each alternative scheme.
   a. Determine effects of coastal processes on delta
      (1) Littoral currents
      (2) Storm waves
   b. Evaluate mechanism of material transport and dispersion within the lake.

In order to assess the relative merits of the proposed plan for suitability, we believe that it is useful to consider the ramifications of possible alternatives. We, therefore, considered the alternatives listed below. These alternatives were considered for comparative, perspective and analytical purposes only, and should not be considered as necessarily viable alternatives for the final selection.

I. Continued Lake Disposal - Continued lake disposal for the life of the mine with unprotected abandonment at the end of mine operation. Since this represents the present operating situation, it can be considered the "base" against which to compare the effects and costs of the other alternatives. This alternative provides baseline data, even though the scheme is not viable due to court rulings now in effect.

II. Complete Delta Removal and On-Land Disposal - Removal of the delta and on-land disposal of such material as can be salvaged from the lake. This can be considered a limiting ("maximum") case against which to compare the effects and costs of the other alternatives.

III. Armored Shore Protection - Complete armored protection of the delta to minimize its continuance as a source of undesirable particles to pollute Lake Superior for "all time."

IV. Removal of Top of Delta - Remove for land disposal, or for disposal at depth in the lake, that portion of the delta that is affected by storm-waves and currents.

V. Immediate Abandonment Without Permanent Protection - Protection would only be provided for buildings constructed thereon during the period of operation--no stabilization of delta mass.

The scheme proposed by Reserve is a combination of the basic concepts in Alternatives III and IV, in that it provides partial breakwater protection combined with natural wave cut beach front shaping with the subsurface slope unprotected.

Basic to a study of these alternatives is the determination of the physical shape and characteristics of the delta at a specific point in time, and the definition and systemization of the pollutant availability and dispersal or liberation mechanism, including dissemination of contaminating particle matter after it enters the lake. We have estimated these factors in Section C, where we also indicated the data which we believe are needed for definitive evaluation. The probable effect of the delta on the lake can then only be crudely estimated over the life of its existence for each case. Comparisons of the expected consequences, and rough relative cost of each alternative with Reserve's proposed solution, serves as our basis for evaluating the proposed solution and defining the data needed for final design and evaluation.

A discussion of the above five alternatives and comparison with the proposed Mile Post 7 plan solution is presented below:

I. <u>Continued Lake Disposal</u> - Although this would be less expensive than the proposed scheme, the disposal of tailings would continue to feed fibrous contaminants into Lake Superior and, therefore, has been prohibited. Cessation of this continued supply would reduce feeding new contaminants into the lake by a very great ratio to that small amount that will emanate from the delta or be eroded from various on-land tailings fills. This may or may not be an acceptable level of protection in itself. There is not enough data available to assess this aspect of this alternative (see V below).

II. <u>On-Land Disposal of Delta</u> - The on-land disposal of the delta to rid the lake of this future source of fibers has not only <u>not</u> been proven to be necessary by virtue of its continuing ability to provide an unacceptable and unprotectable supply of fibers to the lake, but is also <u>not</u> a viable alternative because if the fiber problem is not critical, its cost cannot be justified. If the delta were found to be undesirable, this approach would require constructing a supplemental disposal facility for more than 110 million cubic yards of coarse tailings on-land, with its attendant environmentally undesirable land use and cost. Also, dredging disturbances would probably liberate more of the entrapped fibers into the lake, possibly causing a greater concentration than now exists, at least immediately following the dredging activities. This is a self-defeating alternative, in all respects.

III. Armored Shore Protection - Complete armoring of the entire delta would be very hard and expensive to accomplish (the submarine slope is steep, approximately at the angle of repose). Additional fibers would be liberated during construction, and the added protection is not justified because erosional processes at depth are believed to be minimal. Additionally, the life of such protection is short in terms of perpetuity; therefore, a major maintenance program would be involved. Data on near-slope currents are needed for more reliable evaluation of this alternative, but the known difficulties of armoring this slope make it an undesirable alternative unless proven to be essential.

IV. Removal of Top of Delta - Removal by on-land or deep submarine disposal of the top of the delta would be relatively economical and easy to do. Such a plan would consist of dredging off the top 40 to 50 feet of material to clear the area of tailings within the zone of maximum current and wave activity. This plan, however, would have the same environmentally undesirable effects of scheme II, although not to quite the same extent.

V. Immediate Abandonment Without Permanent Protection - If the delta were found to contain a noncritical amount of contaminating asbestiform fibers, and could be expected to last a long enough time to prevent an unacceptable concentration of liberated fibers, this could be the most viable alternative, except as it affects the buildings built thereon.

The Reserve Plan - On the whole, after considering possible alternatives, the Reserve plan appears to be the most viable approach. It will, however, be necessary to accurately assess the fiber content of the delta to decide if anything actually needs to be done about it, or if alternative V is preferable because of the cost involved and because riprapping of the delta will destroy it for a possible recreational use. Finally, the data are needed to make it possible to assess whatever scheme should be pursued.

E. STRUCTURAL STABILITY

If it is found necessary to retain the integrity of the delta after its abandonment in order to either minimize future liberation of entrapped Cummingtonite fibers, or to maintain the delta as real estate for future beneficial use, the delta stabilization plan will have to be more conservatively designed than would be required if it is only necessary to stabilize the delta for the period of time that the structures built thereon must remain operational, and during which period continuing maintenance is practical. As discussed elsewhere, we believe that the nature of any future problem from fibers in the delta has not yet been established on a sound basis; therefore, we recommend that the studies described in Section I be carried out to provide a basis for determination if, and to what degree, stabilization is required, as well as a basis for design and evaluation of needed stabilization.

Assuming that the stability of the delta is not essential after the abandonment of the mine and concentration operations, then there would be no justification for any permanent solution to the problem. Then only a simple breakwater structure with provisions for maintenance would be needed to protect structures built thereon during the operational life of the project. If stability is needed, it must be recognized that protection to the degree that no fibers could be liberated is impractical; therefore, the approach to stabilization has to be to minimize the problem which it can't prevent. Our evaluation, therefore, has proceeded on that basis.

The structural stability of the delta as a land mass appears to be relatively good as it now exists. This statement must be qualified, however, because we know nothing about the foundation (lake bottom sediments) on which the delta rests; therefore, there may be a long-term stability problem if this material is not stable. The probability of major slope instability, other than that caused by foundation failure, earthquake or erosion, is very low unless an attempt is made to riprap the entire slope. In the event of an earthquake of the maximum probable magnitude, some minor instability of the outer slope can definitely be expected. We do not have the data necessary to assess the possibility of liquefaction of the delta mass due to a major earthquake, but there may be such a potential. It is probable that the structures presently planned for construction on the delta are near enough to the shore to be outside the portion of the mass that would be affected. But since the probability of such an earthquake is very low, it is probably justifiable to ignore this possibility, unless structures of major importance are planned for the outer limits of the delta. This, however, is an operational investment, and not a public safety concern, whereas the earthquake concern with the on-land impoundment is a public, as well as an operational, concern. The other consequence of such liquefaction would be the liberation of fibers into the lake, but this probability is also very low, and the measures necessary to prevent such an occurrence are not without their own adverse ecological impact.

Left alone, therefore, we believe the slope will probably be relatively stable with regard to sliding. If an attempt is made to riprap the slope, there is a high probability that unless this is done very carefully and extensively, it could result in mass as well as local surficial instability. The probability is that an attempt to riprap the slope would necessitate the construction of a very large buttress-type fill, rather than a thin riprap protection layer. The cost and disturbance that this will incur make it undesirable unless proven to really be essential.

With regard to the stability of a breakwater constructed on the tailings mass, we believe that the Reserve plan is very well founded and represents an innovative approach to this very difficult problem. The construction of a heavy rock mass at the edge of the slope would probably result in failure during construction, without much chance of it being ever completed without being set back. The setback as proposed by Reserve also has the additional merit of the provision of a beach to help dissipate the force of wave action before the waves hit the breakwater itself. Stabilization of the beach by well-graded (filtered) rock to preserve this wave dissipation feature is necessary to stabilization of the delta. Our biggest question with the design of this aspect of the plan has to do with the construction of the needed filters underlying the breakwater rock fill and the riprap fill, and overlying the tailings material on the delta surface. A proper design can be made. It can also be constructed. It is not probable that the rock can be spread over the delta in either a uniform manner or uniform gradation as needed to keep the delta sand from eroding from beneath and between unprotected large rock particles, using the construction procedure proposed to date. Positive control will have to be exercised to assure a well-constructed armor plating job.

Stabilization from erosion should be considered from two standpoints:

1) Undercutting of the slope at depth, and
2) Erosional liberation of fibers from the tailings mass.

With regard to undercutting instability, the currents--littoral and storm--should be studied at the face of the slope, as soon as tailings disposal has been discontinued, and needed measurements made. This problem can be evaluated at that time. With regard to erosional liberation of fibers from the armored surface and unarmored slope, this will probably be quite minimal, but can be proven only after needed data on fiber occurrence in the tailings has been accrued. The fiber liberation, if any, should probably gradually decrease as the surface and near-surface fibers are liberated and the near-surface tailings material remaining in place becomes a sterile zone covering deeper tailings with greater fiber concentrations.

Relative to the stability of structures founded on the tailings in the delta, data sufficient for their design are probably available from the holes drilled in the delta by Klohn. It may be necessary to support some structures on piles if there is any possibility that the foundation area could be subject to erosion. We do not consider review of this aspect of the project to be critical to the plan because, if this feature develops problems, maintenance can and will be used to keep them operational as needed.

F. SURFACE STABILITY

The erosional stability of the surface of the delta slope has been dealt with in Section E, above. The stability of the delta top with regard to wind, rain, and waste water spill erosion should be amenable to protection by vegetative covering as long as maintenance is performed. Only experience will tell if adequately permanent cover can be achieved over the whole surface so that it will persist after abandonment, or whether a more positive well-graded rock or soil cover will be required to do the job. In the event that Reserve feels that it is economically interesting to them to try relying on vegetative cover alone, we believe that they should be allowed to propose and try such a program, meanwhile keeping records adequate for the assessment of maintenance problems to be expected after abandonment. A 40-year history should be adequate for such a determination. The basic consideration would then be first cost vs. maintenance cost. Final abandonment requirements can then be set on a rational basis.

G. HARBOR MAINTENANCE

Because the prevailing winds tend to be from the northeast, and the delta is northeast of the harbor, the probability is that the principal currents and drift from the delta will be toward the harbor. Therefore, probably the greatest problem from drift will be experienced at the harbor, possibly requiring some dredging following unusually severe storm periods. This is an operational problem, and probably will not be a public safety problem. If maintenance costs so dictate, supplemental works may be required by Reserve.

If not, adequate records should be kept and final abandonment consideration of this matter left up to indications derived therefrom on the basis of experience. Final approval need not be given to the delta stabilization scheme until near the end of the operational period. Both Reserve and the public benefit from taking a reasonably long-term view of this matter.

H. MONITORING PROGRAM

Small-scale model tests have provided some insight into how the delta will fare after the continuing supply of tailings is cut off. These tests, however, have not provided the answers to all of the design questions. Alternative to making more detailed, larger scale tests would be the use of the delta itself as a full-scale model for a few years to develop the needed design data. This alternative is viable only if the amount of Cummingtonite fibers liberated during the erosional period were proven to be at an acceptable level. However, the presently proposed stabilization plan has the same limitation, even if based on extensive model testing data. Such an approach would involve basing tentative approval on a preliminary plan with adequate monitoring to permit not only evaluation and projection of the erosion pattern, but also permit the control of the erosional pattern if it develops to the point where stabilization is desired or where its control is required to protect other works. This may appear to be a less positive concept than to design the operation on the basis of large-scale, expensive, but not necessarily accurate, tests before approval is granted, but it need not be a risky approach if proper control is maintained, and a more suitable solution to the problem is probable.

We believe that an adequate monitoring program can be fairly easily developed. This monitoring program should primarily concern itself with shore processes, rather than overall stability in the traditional soil mechanics sense. The major construction problem to be resolved is how the movement of small particles subjected to wave forces and currents will shape the beach and/or liberate Cummingtonite fibers. The simplest form of monitoring the beach slope would be to run careful and consistent surface and below-water surface topographic or sounding surveys at regular intervals, based on the experience developed in the first year following cessation of tailings disposal, with supplemental surveys following major storms.

A more expensive program to set up, but cheaper to operate, would be one utilizing monuments that would also be surveyed, but from land, at regular intervals. This approach would develop more precise data at fixed points, but would not produce the detailed information needed over the delta as a whole. It would not be practical to use this approach to obtain data deeper on the delta slope.

The monitoring program should not only include periodic surveys of the delta surface, and subaqueous sounding of the lake area surrounding the tailings, but should also include investigations of wave heights for various climatic conditions, lake currents, and wind velocities and direction. Estimates of suspended matter (extent and volume) should be made routinely during the operational period of time as an aid in determining how much of, and how far, the material has been or continues to be dispersed throughout the lake.

I. NEEDED INVESTIGATIONS

Currently available data needed for design and for evaluating the effectiveness of the design is deficient in several respects, the most important of which pertains to the actual make-up of the tailings mass and the possible ways entrapped fibrous particles can be liberated or, conversely, kept entrapped during the foreseeable future. Desirable data concerning wave- and various types of current processes, and data on the medical nature of the asbestiform threat, would also be helpful. But, because the probability of obtaining scientifically valid data in these fields in time to be useful in the design is probably negligible, it will most likely be necessary to proceed using best professional judgment in these areas, and monitor the results as a basis for permitting continuing reappraisal of solutions to the delta problems. This may appear to some to be begging the issue, but current technology does not permit absolute solutions to these problems at this time. However, it is within the capability of current technology to better assess, on a statistically valid basis, the make-up of the delta as it pertains to amount, state, and condition of Cummingtonite asbestiform fibers.

This analysis should be made on the basis of a statistically valid number of holes located so as to be representative of the conditions expected in the delta. A sufficient number of samples of the material in the delta should be taken at a number of depths from the top to the bottom. Care must be taken to obtain whole samples including their entrapped pore water. Carefully run gradation tests must be conducted, with special care given to the minus #200 sieve fraction, and especially the colloidal-sized material. Chemical and/or mineral analyses should also be made to provide a basis for evaluating quantitatively the Cummingtonite asbestiform fiber fraction. Physical tests should also be made to ascertain the density of the material, and the degree of liberty these fibers have when acted on by various forces expected to pertain during the future.

We believe that at least two holes should be drilled deep enough to explore the lake sediments on which the tailings rest to permit an evaluation to be made of the long-range stability of the slope.

If there were a need for a foolproof design on which to base approval, a great amount of large-scale model testing would be called for. However, such tests are very time-consuming, as well as costly, and their design use would still be speculative. Therefore, we feel that the best approach would be to save the cost of such studies and apply the funds towards adequately monitoring conditions after stopping tailings disposal in the lake, as well as the stabilization program construction and operation phases. This data could be used better to assure that the adopted final design plan is made to work during the time while Reserve will be on the scene. Tentatively approved approaches can then be tried and amended as necessary to minimize post-abandonment maintenance.

CHAPTER III

LAND DISPOSAL SYSTEM

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LAND DISPOSAL SYSTEM

A. INTRODUCTION

As a result of the order to cease disposing of tailings in the lake, several on-land locations have been proposed by various entities for development. However, the Reserve Mining Company is presently proposing to develop a site referred to as Mile Post 7. The other sites being discussed have not been considered in our studies because our review is limited to the plan presently being proposed by the Reserve Mining Company in their application for approval.

The taconite from the mine at Babbitt is hauled to Silver Bay for processing by company-owned railway. It is proposed to build the new tailings disposal facility at a site adjacent to Mile Post 7 along the existing railway, about 7 miles from the plant site. The coarse cobbs and filtered tailings from the plant will be transported to this site by rail, using the taconite cars on their return trip to the mine, for disposal in a coarse tailings dump. The coarse cobbs and filtered tailings will be combined and used as construction material with which to build one dam and three dikes to form an impoundment into which the fine tailings will be pumped in slurry form. The slurry will be thickened at the plant and pumped through a 5-mile long pipeline to the tailings impoundment. An earthfill starter dam, about 50 feet high and about 4,000 feet long, will be constructed across Big Thirtynine Creek, a tributary of Beaver River. The main dam, approximately 150 feet high and over 12,000 feet long, will then be constructed contiguous with this starter dam. Dikes, varying in height from 100 to 140 feet, will be constructed across three low areas along the periphery of the impoundment to limit the area covered by tailings to about 4.6 square miles. The dry cobbs dump, which will cover about 3 square miles, will be constructed in the tributary drainage area just upstream and to the north of the impoundment. Two diversion dams will be constructed across streams that would otherwise discharge across the dry cobbs dump area to minimize the amount of water flowing into the impoundment. All rain falling on the cobbs dump area and adjacent tributary runoff will discharge into the tailings impoundment. Seepage emanating from the dam and dikes and the foundation soils will be collected and returned to the impoundment so that the water in contact with the tailings will, in the future, be contained in the disposal facility. During the operating period, all storm waters will be retained in the impoundment. Since the plant operation will consume some water, discharges will probably not be required. If there is a need to discharge water it will have to be filtered to prevent emission of fiber laden water to the lake. The water remaining in the reservoir when operations are suspended will have to be filtered and released to permit final grading and construction of abandonment provisions.

Surface and subsurface investigations of the dam and dike sites have not yet been completed. The areas which have been explored indicate that the foundations will consist of lacustrine soils and glacial till overlying bedrock. The lacustrine clays and silts are saturated and the dams and dikes will have to be constructed in easy stages to minimize the probablility of construction delays due to temporary embankment instability. Sand drains have been proposed in the dam foundation to permit faster construction of the starter dam. There are several pervious zones in the impoundment foundation and rim. These consist of fractured bedrock, talus, and sands and gravels. Care will have to be exercised to see that all of these zones that may be exposed are adequately filtered and covered by constructed membranes and/or controlled slurry disposal techniques. Although the foundation conditions must be taken care of in the fill design to assure stability and preclude excessive or unfiltered seepage, there are no apparent site conditions that cannot be handled or which would otherwise preclude construction of the proposed impoundment.

The impoundment design includes a provision for minimizing erosion of the dam and dike structures. During operation, the water level in the impoundment will be operated so as to minimize wind erosion and asbestiform particle dust formation. The abandonment plan envisions creation of a few small lakes or ponds on the tailings surface and discharge of the stream runoff over a riprapped spillway. This plan has some questionable aspects and in our opinion requires more thought and consideration for precluding erosion and sediment pickup from the cobb dump as well as the tailings impoundment area. We believe that the surface area can be protected from excessive wind erosion by vegetation but are concerned about future rainfall on the cobb dump picking up Cummingtonite asbestiform fibers as it seeps through the fill and emerges on top of the natural ground level to flow into the impoundment area as spring water to feed the surface streams that will eventually be discharged into the Beaver River. We believe that the proposed provisions for this eventuality are inadequate and that the basic design will have to provide filtration zones (possibly constructed of filtered tailings and cobbs) to eliminate the fibers emerging from these springs, and that adequate mineral ground cover will have to be placed over the tailings area to preclude future erosion from picking up fibers from the tailings and their inclusions in the outflow to the Beaver River.

We believe that the disposal design and abandonment plan can be modified to minimize the maintenance needed to keep the asbestiform fibers contained, but that some maintenance will be perpetually required to preclude eventual breaching of the facility by relentless erosion over a long period of time. Continuous maintenance may not be required. The record during operations will provide an adequate basis for defining a final requirement in this regard.

With the above considerations adequately taken care of, it is our opinion that a safe dump and impoundment structure can be built at Mile Post 7.

B. <u>SITE CONDITIONS</u>

1. <u>Surface Conditions</u>

a. <u>Topography</u> - The Mile Post 7 land disposal site is located in a broad northeast-southwest trending valley with an average width of valley floor of about 4,000 feet. The west margin of the valley has a gentle, relatively even slope of about 4 or 5 percent while the east margin is more irregular and much steeper with an average slope of about 20 percent. The most striking feature of the east side is a linear, near-vertical "wall" in bedrock typically 10 to 12 feet high, that extends along the entire east rim at an elevation of about 1275 to 1285 feet.

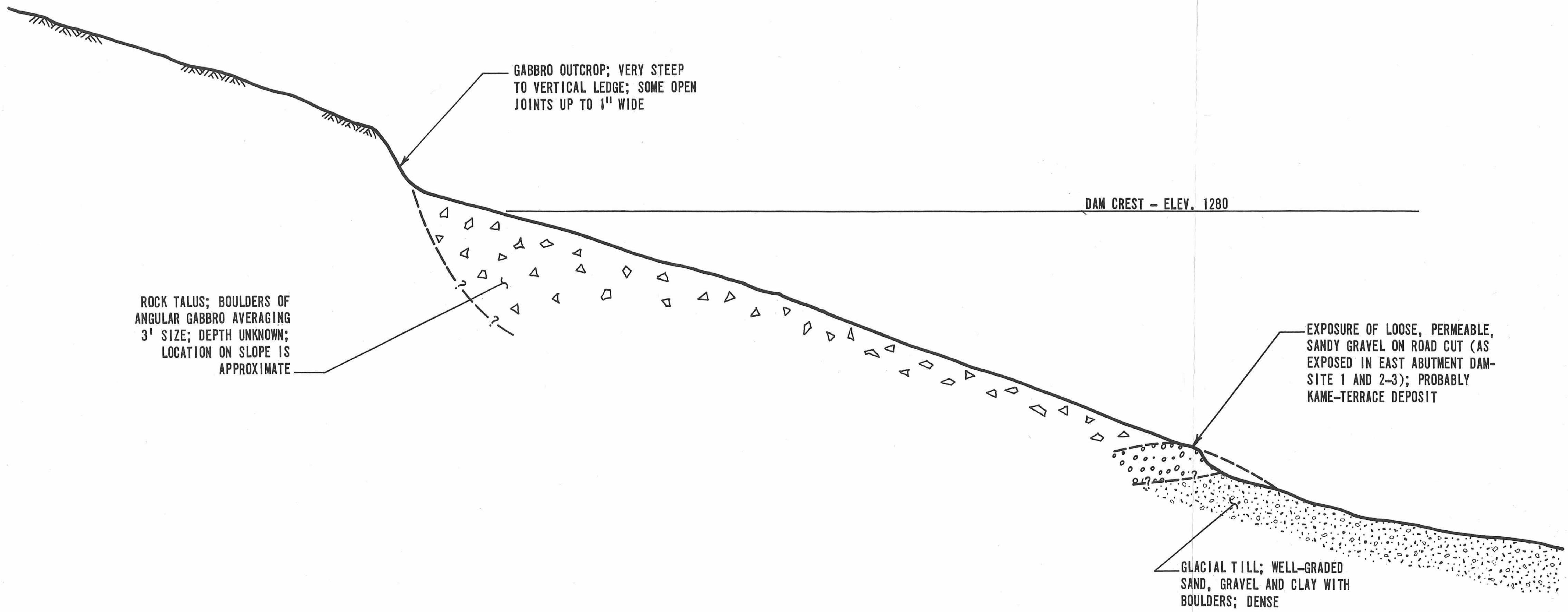
Topographic relief in the area ranges from 1,125 feet in the valley floor at Dam Site No. 1 to about 1,480 feet at the highest point on the ridge bordering the east side of the site.

The valley floor drains from northeast to southwest at an average grade of less than 0.2 percent. Big Thirtynine Creek enters the valley from near the middle of the west side of the Mile Post 7 site and then takes a meandering turn toward the southwest, joining the Beaver River some 2 miles downstream from Dam Site No. 1. The flat valley floor is poorly-drained and marshy with thick vegetation of low to moderately high tree growth and brush covering the entire valley floor, as well as most of the valley rims.

Clearly visible on air-photographs are west-northwest lineaments that cross both bedrock and recent sediments alike (Drawing I-1). These lineaments are parallel to the direction of the last glacial movement in the area and are thought to be caused by glacial scour. They were thoroughly investigated by Eugene A. Hickok and Associates; the results of this work are reported in their January 1975 report. Because of little engineering significance, they are not discussed further herein.

b. Surface Geology - Thin organic soils usually less than 2 feet thick cover most of the flat or gently sloping areas of the valley floor. Red lake clays, deposited in the glacial Lake Duluth, extend across the flat, poorly-drained portion of the valley, usually beneath the organic topsoil

A rock talus deposit is exposed in a linear band along nearly all of the west slope of the east ridge (Photo A, Photoplate III-2). The rock talus occurs at approximate elevations ranging from 1225 to 1275 feet (Drawing III-1, in pocket, and Drawing III-2). The talus area



TYPICAL SECTION

DIAGRAMMATIC—NOT TO SCALE

W. A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SKETCH OF TYPICAL SECTION WEST SLOPE - EAST RIDGE		
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	DRAWING NO. III-2

ranges in width from 100 to 200 feet with slopes averaging 30 degrees. Some of the talus area is devoid of vegetation and can be seen on aerial photographs. Vegetation grows where soil exists around the talus blocks. The rock talus consists of angular, very hard, boulders of gabbro attaining maximum dimensions of 10 feet and generally averaging 3 feet. The thickness of the talus deposit is unknown; however, it is generally greater than 10 feet. At the east abutment of Dam Site No. 1, the talus is partly covered by soil. Talus at this location occurs at approximate elevations ranging from 1220 to 1260 feet.

Lying topographically beneath the talus deposit is another linear deposit consisting of gravelly sand. This band of material was seen mostly in road cuts (Photo B, Photoplate III-2) below the talus deposit (Drawing III-2), but is believed to extend along the entire east edge of the basin parallel to the talus. The gravelly sand, because of its linear outcrop, is thought to represent an interval of deposition during glacial retreat, and has been termed a "kame terrace" deposit. The material has a low percentage of fines and appears to be generally loose and permeable.

Glacial till occurs at or very near the ground surface underlying the gently to moderately sloping terrain between the red clay and the basin rim. The till was not actually observed in exposure. Although the till may be somewhat loose and weathered near the surface, exploration indicates it has a low permeability and is relatively dense at depth. The till consists of gravel and boulders in a sandy silty clay matrix.

The only other surficial unconsolidated "unit" at the site is the occurrence of scattered boulders, which are erratics left over from the glaciation that once scoured the area. The glacial boulders are commonly seen scattered across the west side of the basin below Elevation 1290.

Bedrock exposed at the surface at the site is a dark, dense, fine-grained intrusive rock, herein collectively called gabbro. The bedrock is exposed over large areas on the east ridge and in scattered areas on the west side. Photo A, Photoplate III-1, shows a typical exposure of the gabbro in artificial cut.

PHOTO A. GABBRO OUTCROP AT CUT FOR GAS EASEMENT, SOUTH OF EAST ABUTMENT OF DAM NO. 1.

PHOTO B. GABBRO OUTCROP EXPOSED ON 10 TO 12 FOOT VERTICAL FACE (TYPICAL OF WEST SIDE OF EAST RIM). NOTE JOINTING (STRIKE N.70°E.; DIP 45° S).

PHOTO A. ROCK TALUS ALONG WEST SLOPE OF EAST RIM, NORTH OF EAST ABUTMENT OF DAM NO. 1.

PHOTO B. EXPOSURE OF GRAVELLY SAND IN 5-FOOT HIGH ROAD CUT, ON WEST SLOPE OF EAST RIDGE ABOUT 1000 FEET SOUTH OF EAST ABUTMENT CONTACT OF DAM NO. 1. GEOLOGIST'S PICK GIVES SCALE.

The near vertical "wall", described previously along the east rim, is formed by hard gabbro outcrops (see Photo B, Photoplate III-1). The talus along the base of the "wall" consists entirely of rock blocks derived from gabbro. Another vertical face 60 to 80 feet high occurs along the east side of the knob forming the east abutment of Dam Site No. 2-3. This dike, which does not cross a definable stream course, is designated as Dam 2-3 in the Klohn Leonoff report. This structure is a substitute for two previously considered structures, Dams No. 2 and No. 3. Rock talus also occurs at the base of this prominent outcrop. These rock faces are probably the result of deep glacial scouring which preferentially plucked the rock along zones of weakness, such as faults or alignments of closely fractured rock. Subsequently, blocks of rock gradually broke away from along and above the rock faces, forming the talus slopes.

The most prominent joint set in the area is vertical and parallel to the rock faces described above, which strike N30^{o}-N40^{o}E. One secondary joint set strikes N75^{o}E and dips vertically to steeply toward the south, and another set is subhorizontal. Other joints, many of them vertical, have random orientations. Open joints up to 1 inch wide are visible along the east wall. After rainfall, seeps occur from the joints visible in the east rim "wall" indicating that they carry ground water from the ridge above.

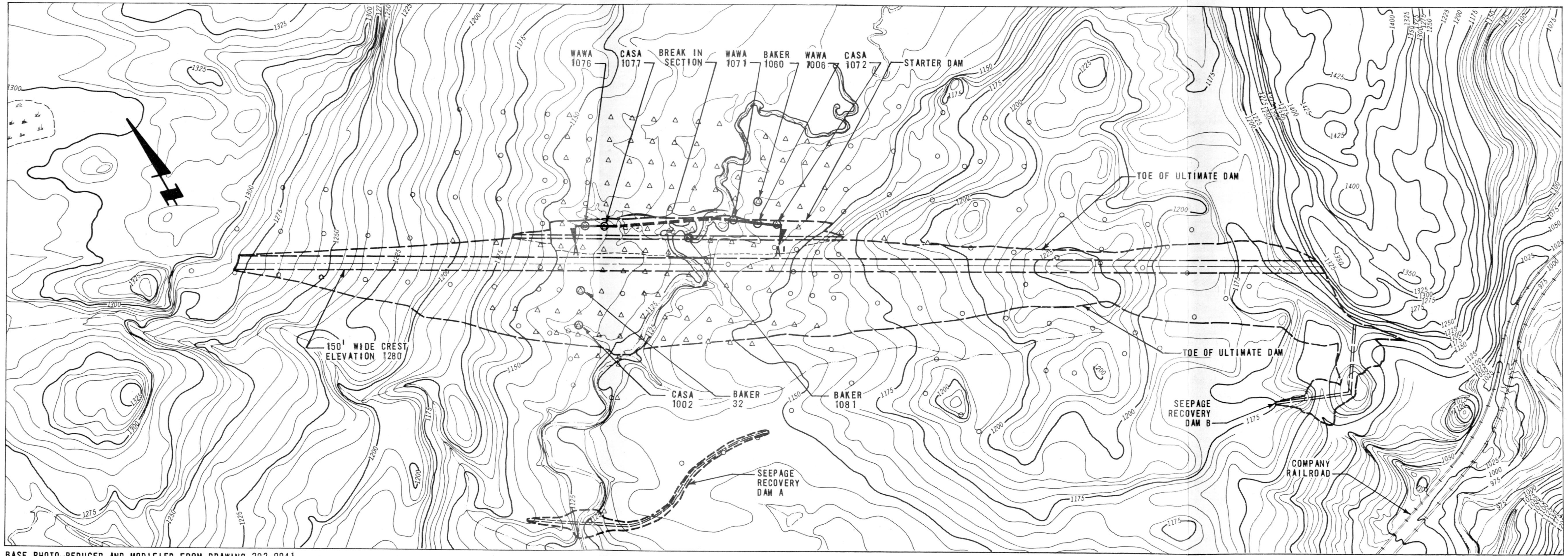
c. <u>Climatology</u> - Minnesota and the entire Great Lakes Basin lie within the northern temperate zone. Mean monthly temperatures range from a low of about 15^{o}F during the winter to a high of about 65^{o}F during the summer. Daily minimum temperatures are near or below freezing for about six months annually on the average, and prevailing wind directions are predominantly northwest or west-northwest. Precipitation averages about 28.5 inches per year, of which approximately 25 percent is snowfall. Annual surface runoff averages about 14 inches at the Mile Post 7 tailings disposal site. Thunder storm activity is common during the summer months and is often accompanied by high intensity rainfall. Evaporation from lakes in the region averages approximately 25 inches per year.

2. Subsurface Conditions

Subsurface conditions determined from drilling and trenching, and inferred from surface information are discussed below. This discussion is not intended to be all inclusive. Our remarks stress conditions and aspects of exploration work where we have the most questions, and lead to areas of the project where we believe additional exploration or information is required. We understand that additional exploration is in progress or has been completed for which we have not as yet received data. Therefore, some of the questions raised may have been answered as a result this exploration.

Included in this report, (Appendix A) are logs of four holes (WAWA holes) drilled specifically at our request and for our purposes so that we could develop as independent an opinion of foundation conditions as possible, and understand the meaning of data prepared by others. Also included are logs of six holes (CASA holes) drilled at the request of Casagrande Consultants and logged by our geologist. The holes were logged in the field using the Unified Soil Classification System; later supplemental visual data was added upon examination of the full lengths of samples in the laboratory. Laboratory classifications, when available, were also added later to the logs adjacent to field classifications. The data are limited by what the geologist could observe either in the field or laboratory. In many cases he could observe only cuttings, and could not observe a continuous section because some samples were not recovered on a continuous basis. Symbols and abbreviations used on the logs are explained in the accompanying Key for Exploration Logs in Appendix A. Additional holes were also drilled at the request of Michael Baker Jr., Inc., and were logged by their staff.

Subsurface exploration carried out at Dam Sites No. 1 and No. 2-3 by the Reserve Mining Company consultants has been very extensive. Drilling for the State's three consultants was accomplished adjacent to previous exploration by Reserve (Drawings III-3 and III-5) for verification and supplemental data purposes.



BASE PHOTO-REDUCED AND MODIFIED FROM DRAWING 292-0041, "DAMSITE NO. 1 - GENERAL ARRANGEMENT" BY KLOHN LEONOFF CONSULTANTS LTD., CIVIL AND GEOTECHNICAL ENGINEERS FOR RESERVE MINING COMPANY, FEBRUARY 1975.

SCALE

1000 — 0 — 1000 FEET

CONTOUR INTERVAL 5 FEET

KEY

△ LOCATION OF TEST DRILL HOLE BY OTHERS.

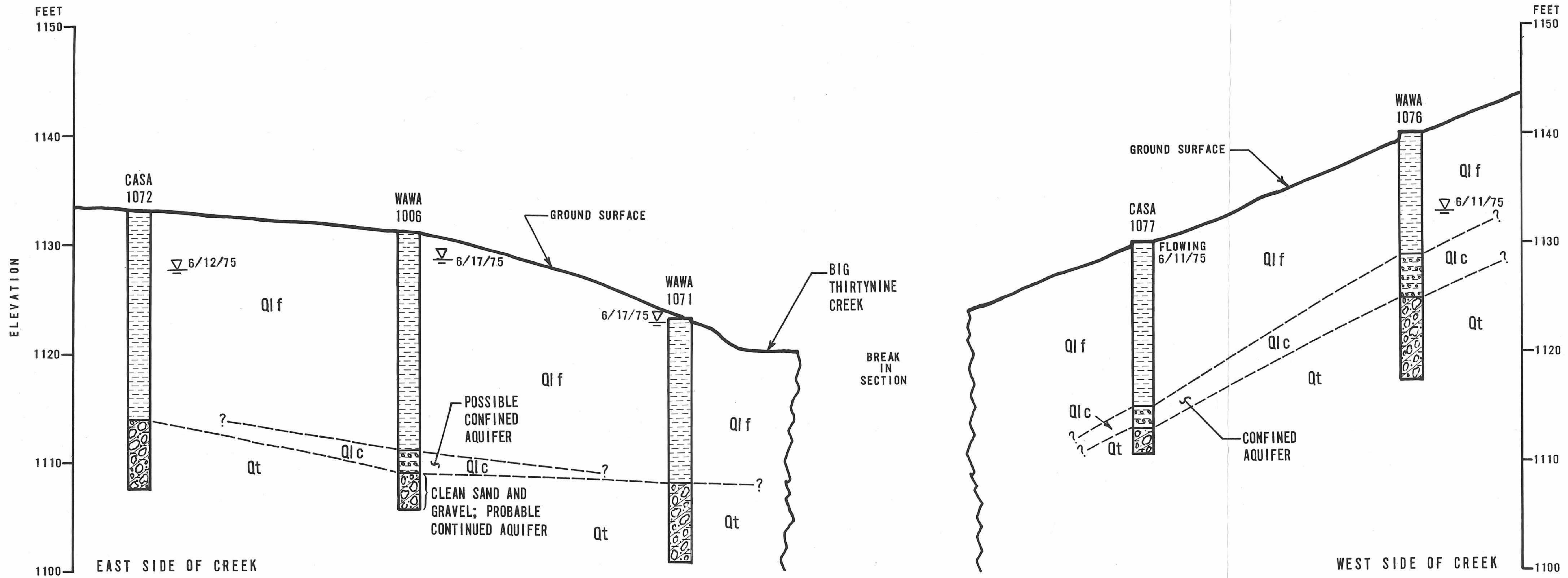
○ LOCATION OF TEST PIT BY OTHERS.

◎ LOCATION OF BAKER, CASA, AND WAWA EXPLORATION DRILL HOLES, JUNE 1975.

A A' LINE OF SECTION

NOTES:
1. SEE DRAWING NO. III-4 FOR GEOLOGIC CROSS SECTION.
2. LOGS OF BAKER HOLES ARE NOT INCLUDED IN THIS REPORT.

W. A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	EXPLORATION MAP DAM SITE NO. 1		
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	DRAWING NO. III-3



K E Y

GEOLOGIC UNITS

Ql f — LACUSTRINE DEPOSITS (FINE-GRAINED FACIES): MOSTLY THIN BEDDED SILT AND CLAY WITH SOME SAND AND GRAVEL; VERY LOW PERMEABILITY; CONFINES UNDERLYING AQUIFERS WHERE PRESENT.

Ql c — LACUSTRINE DEPOSITS (COARSE-GRAINED FACIES): INTERBEDDED, MODERATELY DENSE SAND, SILT AND CLAY WITH SOME GRAVEL; CONFINED AQUIFER; LOW TO MODERATE PERMEABILITY; NOT ALWAYS PRESENT.

Qt — GLACIAL TILL: GENERALLY DENSE, POORLY SORTED SAND AND GRAVEL WITH SILT AND CLAY BINDER; PERMEABILITY USUALLY LOW EXCEPT WHERE FINES ARE NOT PRESENT AS IN WAWA 1006.

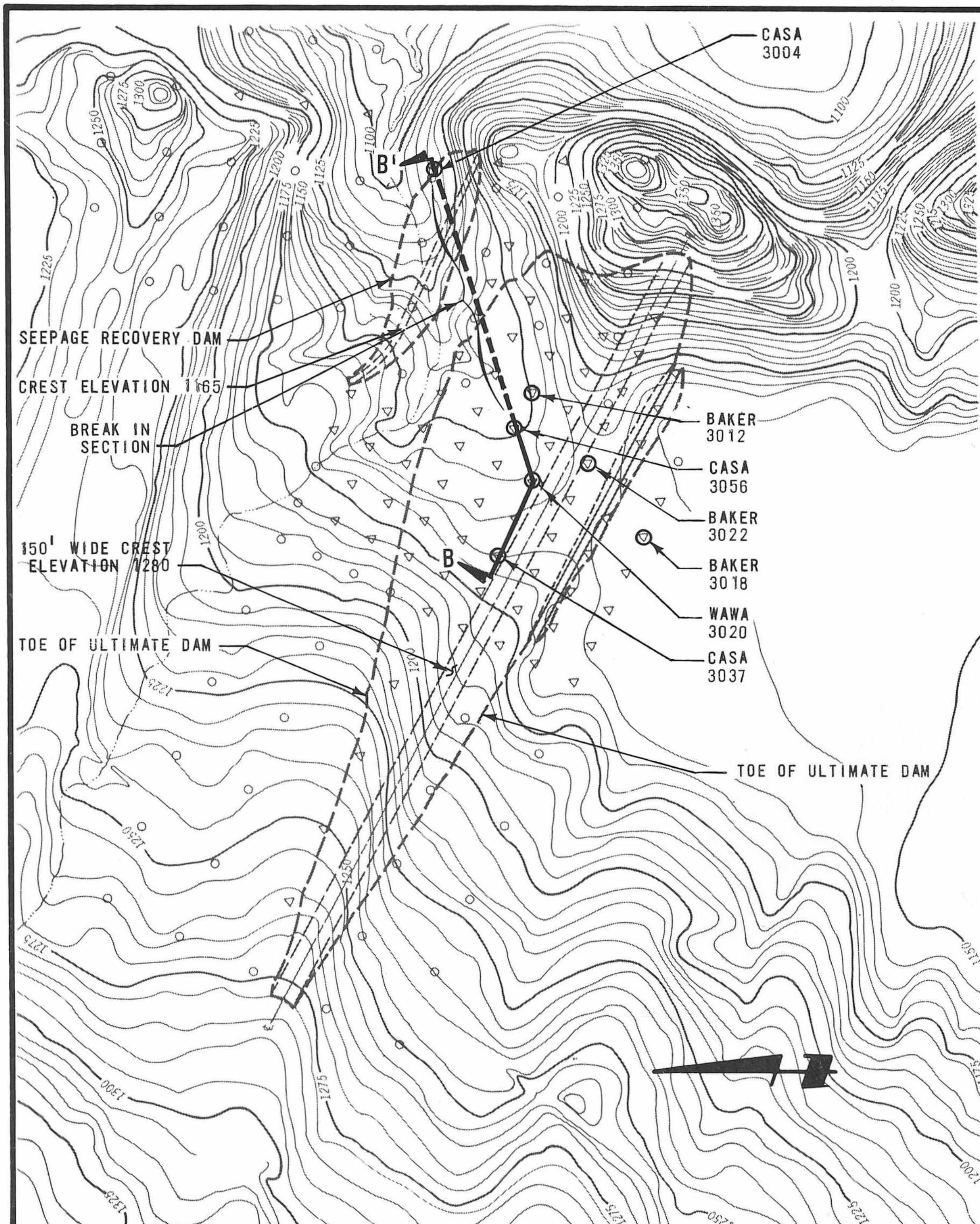
SYMBOLS

▽ PEIZOMETRIC LEVEL OF CONFINED AQUIFER WITH DATE OF MEASUREMENT.

---?- GEOLOGIC CONTACT QUERIED WHERE INFERRED

HORIZONTAL SCALE: 1" = 100'
VERTICAL SCALE: 1" = 10'

W. A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SECTION A - A' DAM SITE NO. 1		
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO	DATE	DRAWING NO.
		0829	AUGUST 1975	III-4



BASE PHOTO-REDUCED AND MODIFIED FROM DRAWING 292-0050, "DAMSITE NO. 2-3 - GENERAL ARRANGEMENT" BY KLOHN LEONOFF CONSULTANTS LTD., CIVIL AND GEOTECHNICAL ENGINEERS FOR RESERVE MINING COMPANY, FEBRUARY, 1975.

SCALE

1000 0 1000 FEET

CONTOUR INTERVAL 5 FEET

KEY

NOTES: 1. SEE DRAWING NO. III-6 FOR GEOLOGIC CROSS SECTION.

2. LOGS OF BAKER HOLES ARE NOT INCLUDED IN THIS REPORT.

△ LOCATION OF TEST DRILL HOLE BY OTHERS.

○ LOCATION OF TEST PIT BY OTHERS.

◯ LOCATION OF BAKER, CASA, AND WAWA EXPLORATION DRILL HOLES, JUNE 1975.

B B' LINE OF SECTION

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	EXPLORATION MAP DAM SITE NO. 2-3		
		PROJECT NO.	DATE	DRAWING NO.
	PALO ALTO • NEWPORT BEACH • CALIF.	0829	AUGUST 1975	III-5

Our studies of completed exploration by others and of our own exploration confirms the thickness and extent of the red lake clays. We have found that these clays are mostly, if not entirely, very thin-bedded, perhaps varved in the true "seasonal" sense. This has not been particularly stressed previously. Also a few thin, saturated silt beds were found within the clay in some drill holes. We were not able to trace the continuity of these beds. Other differences in the properties of the red clay were found in the laboratory and are discussed below under "Foundation Materials Properties."

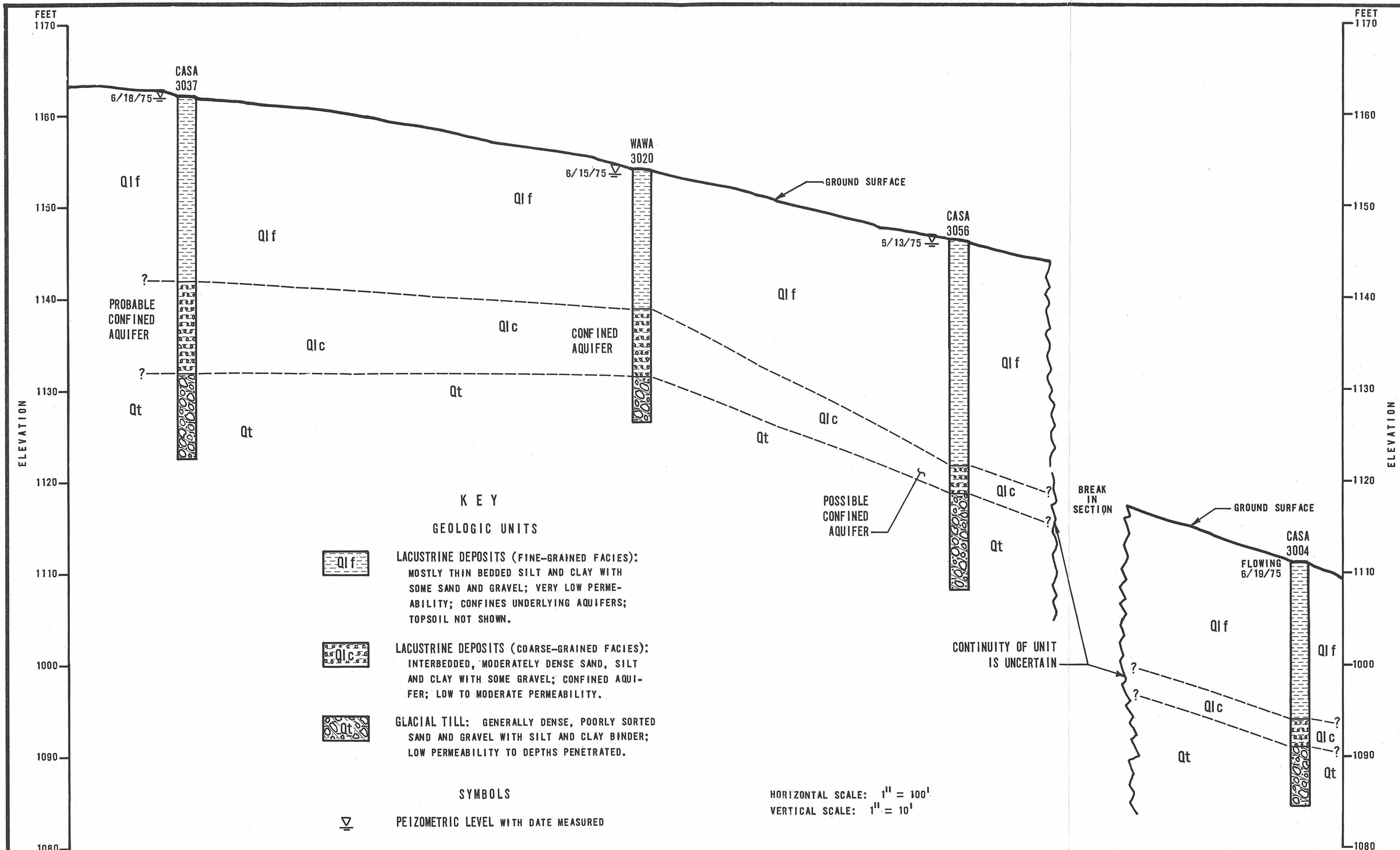
Our exploration also confirms that the glacial till, occurring at depth and consisting of gravel and boulders in a sandy silty clay matrix, is dense and has a low permeability to the depths explored.

We have found, however, that there is a zone of relatively loose and perhaps more permeable materials that sometimes occurs between the clay and the till (Drawings III-4 and III-6). The information by the Reserve consultants that we have reviewed to date does not recognize this "transitional zone" or facies change to the degree that we believe necessary. There is some evidence that the "transitional zone" is thicker and more persistent at Dam Site No. 2-3 than at Dam Site No. 1.

Our concerns related to the "transitional" material cannot be fully defined without additional exploration. Our concerns stem from the following evidence:

- Sandy-silty materials were logged and sampled in some of the holes drilled for the three State consultants, including holes WAWA 3020 and WAWA 1076. These materials attained a thickness of 7-1/2 feet at Dam Site No. 2-3 in WAWA 3020.

- Similar materials, with abundant associated water, were observed at Dam Site No. 2-3 in trenches being excavated under the supervision of Klohn Leonoff.



W. A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SECTION B – B' DAM SITE NO. 2-3		
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	DRAWING NO. III-6

- Rapid rise in water in drill holes and flow out of some holes was observed when the "transitional" materials were penetrated.

- Geologic mapping indicates that relatively clean, sand, "kame terrace" materials extend along the east side of the tailings basin. In addition, highly permeable talus deposits appear to be in contact with the "kame terrace" materials. "Transitional" materials found in exploration may be exposed on the surface along the fringes of the lacustrine deposits. Thus, relatively permeable materials may tend to be present on both sides of the tailings basin.

- Borrow removal may expose areas of "transitional" materials, and thus increase their exposure to subsurface seepage.

This evidence suggests that there is a possibility that interconnected, permeable deposits pass beneath Dam Sites No. 1 and No. 2-3, as well as the seepage recovery dam sites, and that seepage rates could be considerably higher than presently anticipated where such deposits may be exposed to the surface (either naturally or by construction operations). Also water under head could possibly be developed and could exert uplift pressures greater than anticipated. Sealing of the permeable "transitional" and "kame terrace" deposits by tailings may not be effective unless very special care is exercised because these deposits tend to occur at relatively high elevations on slopes. Tailings spigoted on the rims of the basin will tend to segregate leaving fines in the flat where the clays occur and the coarser fraction over the permeable materials along the rim.

Exploration to further evaluate the extent of interconnection and permeability of "transitional" deposits should be performed. Samples for laboratory testing should be taken and field permeability tests should be performed. Trenching across the feather contact between the lacustrine clays and "transitional" deposits might also be useful. All exploration should be carefully logged by an engineering geologist or soil engineer trained and experienced in this type of exploration.

Because the silty-sandy material of the "transitional zone" is poorly graded and saturated, these materials need to be evaluated for liquefaction potential. We believe, however, that the potential for liquefaction is very low because of the low seismicity of the area and because the "transitional" materials are usually well confined below the clay.

However, examination of the logs developed by Klohn Leonoff shows that in one area near the west side of Dam Site No. 1, silty sandy materials occur near the surface to a depth of about 15 feet. These materials were encountered in holes 1089 and 1011. This area could be a near-surface occurrence of the "transitional" materials, as discussed above. Liquefaction potential in this area may be relatively higher than where these materials are confined. We have made no laboratory tests to evaluate liquefaction potential of these materials. Additional exploration and laboratory testing may be necessary to evaluate liquefaction potential in at least this area.

Our observations indicate that conditions on the east abutments at Dam Sites No. 1 and No. 2-3 may afford considerable potential for seepage, if the foundation is not adequately treated (Drawing III-2). Additional exploration should be directed toward defining the depth of talus and underlying glacial deposits, as well as the degree of openness and extent of fractures in the wall rock. This information is needed for two primary purposes: (1) to permit selection of the types and extent of measures necessary to adequately control seepage, and (2) to aid in developing filters to preclude piping of fine-grained embankment fill materials through coarse, relatively open foundation materials over which or against which they are to be placed. Exploratory drilling in the talus material will likely be extremely slow and difficult, and the results of drilling may be inconclusive; this suggests that drilling should be done sparingly. Seismic refraction surveying in conjunction with trenching may be more satisfactory. Long and deep trenches on the abutments parallel to the dam centerlines and excavated by bulldozer or dragline, may provide the most useful information. Such trenches might be later incorporated into the design as cutoff provisions, as we do not believe that grouting of the talus would be a feasible way to construct a cutoff. Drilling and trenching in the "kame terrace" materials adjacent to and below the talus should be directed toward finding the relationships between the talus, "kame terrace", lacustrine clays, and "transitional" materials. Drilling, along with water testing in the wall rock, will be needed to determine the need for special blanketing or possibly grouting, or some other treatment of fractures.

Because access to the sites has not been available, no exploration has been accomplished to date at Dam Sites No. 4 and No. 5. For this reason, it is impossible, at this time, to evaluate the suitability of the dams proposed at these sites, even on a conceptual basis. However, we believe that the site conditions are basically amenable to the design of safe dams if the needed investigation and final design studies are carried out, although the designs may have to be different from what is now shown. An exploratory program needs to be developed and implemented to define the foundation characteristics at these two sites. For the reasons discussed in the above paragraph, the investigations must include provisions to define the extent of the talus and "kame terrace" deposit at these sites, in addition to the general site characteristics. Investigation of bedrock fracturing and jointing at the abutments of Dam Sites No. 4 and No. 5 is also important, because the east ridge is particularly thin at these two sites.

Comments for Dam Sites No. 4 and No. 5 also apply to the vicinity of the seepage recovery dams. In addition, exploration for the seepage recovery dams should be carefully integrated with exploration for the "transitional" silty sand material.

3. Seismicity and Subsidence--Uplift

a. Regional Seismicity--In Minnesota and adjacent areas, including Canada, most of the earthquakes that have occurred in the historical past are described according to the effects of ground shaking or degree of damage. This is done by assigning an intensity number from the

Modified Mercalli Scale (Appendix C), which ranges from Roman number I--ground motion not felt by anyone--to XII--total damage. It is obviously not a precise engineering measure of the severity of ground shaking. Magnitude, on the other hand, is a quantitative measurement of the size of an earthquake based on total energy release and is measured instrumentally. Gutenberg and Richter[1], in their study of California earthquakes, established an empirical formula relating magnitude and intensity. The equation $M = 1 + \frac{2\ I}{3}$, where the letter M is the magnitude and the letter I is the maximum intensity, was applied in this analysis to determine estimated magnitude.

Drawing III-7 shows the location of earthquake epicenters in Minnesota and adjacent areas during time intervals indicated on the map. The earthquake information was obtained from references listed in this report.[2,3] Most of the epicenters shown were noninstrumentally located and were based primarily on intensity studies; they are, therefore, approximately located on the seismicity map. A few earthquakes in recent years were instrumentally recorded and have known magnitudes.

The Minnesota and Lake Superior region is one of low seismic activity. Many of the earthquakes historically felt in northeastern Minnesota have occurred outside the state. Recent seismic risk maps of the United States put Minnesota in Zone 1 (minor damage, distant earthquakes may cause damage to structures with periods greater than 1.0).[4] The seismic zoning map of Canada shows the Minnesota border area in Zone 0 (no damage).[5]

The earliest known earthquake within the State of Minnesota was a "fairly strong" shock of unknown intensity in the central portion of the state in 1860.[6] In 1917, an Intensity VI shock was located at Brainerd, Minnesota,[6] and one of Magnitude 5 was reported at Morris, Minnesota, on July 9, 1975. These areas are about 175 miles and 250 miles, respectively, southwest of Silver Bay. According to newspaper reports, the earthquake at Morris shook an area of approximately 60,000 square miles.

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[1]All references appear in Appendix E

KEY

MODIFIED MERCALLI INTENSITY		RICHTER MAGNITUDE		SYMBOL	
▲	V			⁄ ⁄	FAULT
■	VI	□	5.0–5.9		
■	VII–VIII				

NOTE: THIS MAP SHOWS ALL HISTORICALLY AND INSTRUMENTALLY RECORDED EARTHQUAKE EPICENTERS OF INTENSITY (M.M.) V AND GREATER, AND MAGNITUDE (RICHTER) 4.0 AND GREATER THROUGH 1969 EXCEPT FOR MINNESOTA. SEISMICITY FOR MINNESOTA IS SHOWN THROUGH JULY 1975.

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SEISMICITY MAP		
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Three earthquakes of lesser intensity have occurred in the state and are listed as follows:

1. December 23, 1928 - light shock at Bowstring, $47.4^{o}N$, $94.0^{o}W$. House swayed.[7]
2. January 28, 1939 - Intensity IV, Detroit Lakes. Felt over a 50-mile radius.[7]
3. February 15, 1950 - Sharp shock at Alexandria, awakened residents and startled workers. Two 136-foot wells at a creamery were damaged.[7]

Earthquakes in the eastern and mid-continent regions of the United States and Canada have a zone of influence much greater than in the western region. As a result, major seismic events as far away as southeastern Canada and Illinois have been felt in the eastern portion of Minnesota. A Magnitude 7 earthquake in 1925 in the St. Lawrence River Valley and one of Magnitude 6.25 in Timiskaming, Quebec in 1935 were felt as far west as the Mississippi River and Duluth.[7,8] An Intensity VII earthquake in 1909 on the Illinois-Wisconsin border was reportedly felt in eastern Minnesota.[5] The closest shock of note to Silver Bay was at Hancock, on the Michigan Peninsula, in 1955. This Intensity V event was about 125 miles east of the Reserve Mining site.

The two faults shown on Drawing III-7 that trend toward the south shore of Lake Superior are shown on the Tectonic Map of North America[9]. Seismic activity has not been shown to be associated with these faults and they are believed to be inactive bedrock structures.

b. Design Earthquake - Although distant earthquakes may have been weakly felt at Silver Bay, the effects were probably minor or nonexistent.

Since the seismic events of Minnesota and the western Great Lakes Region are located more or less randomly, with no obvious clusters of activity, consideration should be given to the possibility that the project site could be shake by an earthquake centered nearby. The shocks of Intensity

VI at Brainerd and Magnitude 5 at Morris probably represent the maximum to be expected throughout the region.

c. Subsidence-Uplift - Differential vertical movement of the land surface, which is probably caused by isostatic recovery of the earth's crust from previous glacial loading, has been recognized and observed throughout the Hudson Bay-Great Lakes region. The center of uplift appears to be in the Hudson Bay area. Early observations by Gilbert[10] using water level gauge records and leveling showed that the Great Lakes region was rising on the north side and subsiding on the south with the canted plane tilted to the south-southwest. Gilbert deduced a mean rate of elevation change of 0.42 feet in 100 miles for each 100 years.

Gutenberg[11] used gauge readings on both sides of Lake Superior to find the precise axis of tilt. Mapping of points of equal changes of level produced an axis of tilt of N71.5°W. The line of zero movement passes from the lake outlet to the western shoreline just slightly south of the international border. To the north of this line, the land surface is rising; to the south the surface is subsiding. In the later study Gutenberg, using gauge station comparisons over a 52 year time span, obtained a subsidence of 12 cm. (0.39 ft) per century at Duluth.[12]

Moore[13] showed from gauge readings that the rate of subsidence increases to the south. One hundred-year projected movements, with respect to sea level, were calculated by Moore for the west shore of Lake Superior. Calculated values of subsidence from north to south are:

Isle Royal	-0.23 feet
Grand Marais	-0.37 feet
Two Harbors	-0.83 feet
Duluth	-1.02 feet

Because the land movements described are small and occur over a broad regional area, they can have little significance to the Mile Post 7 disposal area.

C. FOUNDATION MATERIALS PROPERTIES

1. General

A limited testing program was undertaken by W. A. Wahler and Associates to provide data with which to examine the reasonableness of the engineering properties of the foundation materials at Dam Sites No. 1 and No. 2-3 as assumed in the design report.

The laboratory investigation was directed toward assessing the shear strength, permeability, compressibility, and pore pressure dissipation characteristics of the foundation materials overlying the glacial till deposit. Of primary concern was the identification and determination of the nature of the reddish-brown lacustrine clay. The engineering properties determined in this testing program are not intended to represent final design values, because only a limited number of test borings were drilled, and thus we did not have a sufficient number of representative samples covering a large enough area. However, the test results presented appear reasonable for the samples tested and are considered adequate for purposes of assessing the reasonableness of values cited in the design report prepared by Klohn Leonoff Consultants, Ltd.

This section of our report summarizes the test results obtained in our laboratory. Specific correlations between those results and the basic data presented in the Klohn Leonoff design report are also included, where appropriate, in this section. Also included is a discussion of the nature of the foundation materials, and of the engineering behavior of those materials.

2. Engineering Properties

a. Introduction - The following laboratory tests were performed on representative samples in order to assess the properties of these materials:

1. Classification and Index Properties Tests
2. Consolidation Tests
3. Pore Pressure Dissipation Tests
4. Permeability Tests
5. Shear Strength Tests

The details of the test procedures used and results of all individual tests are contained in Appendix B. Summaries and discussion of the test data are presented below.

b. Classification and Index Properties - Gradation and hydrometer analyses, natural water content, dry density, and Atterberg Limits tests were conducted on samples of the lacustrine clay foundation soils at Dam Sites No. 1 and No. 2-3. Natural water content, dry density, and Atterberg Limits from our tests are summarized in Table III-1, below, for the lacustrine clay deposits.

TABLE III-1

CLASSIFICATION AND INDEX PROPERTIES

Parameter	Dam No. 1 Range	Dam No. 1 Average	Dam No. 2-3 Range	Dam No. 2-3 Average
Moisture Content (%)	22.2-52.5	41.0	21.8-32.5	26.5
Dry Density (pcf)	68.5-104.7	83.7	89.6-105.6	98.4
Total Density (pcf)	---	118.0	---	124.5
Atterberg Limits - LL(%)	25-88	65	35-48	44
- PL(%)	18-26	23	16-22	18

Considering the fact that classification tests such as Atterberg Limits can yield widely varying results for varved clays, depending on the relative percentage of the clay and silt layers, the average values determined are apparently well within the range of values reported and reasonably close to the selected design values shown on Drawing 292-0030 of the design report.

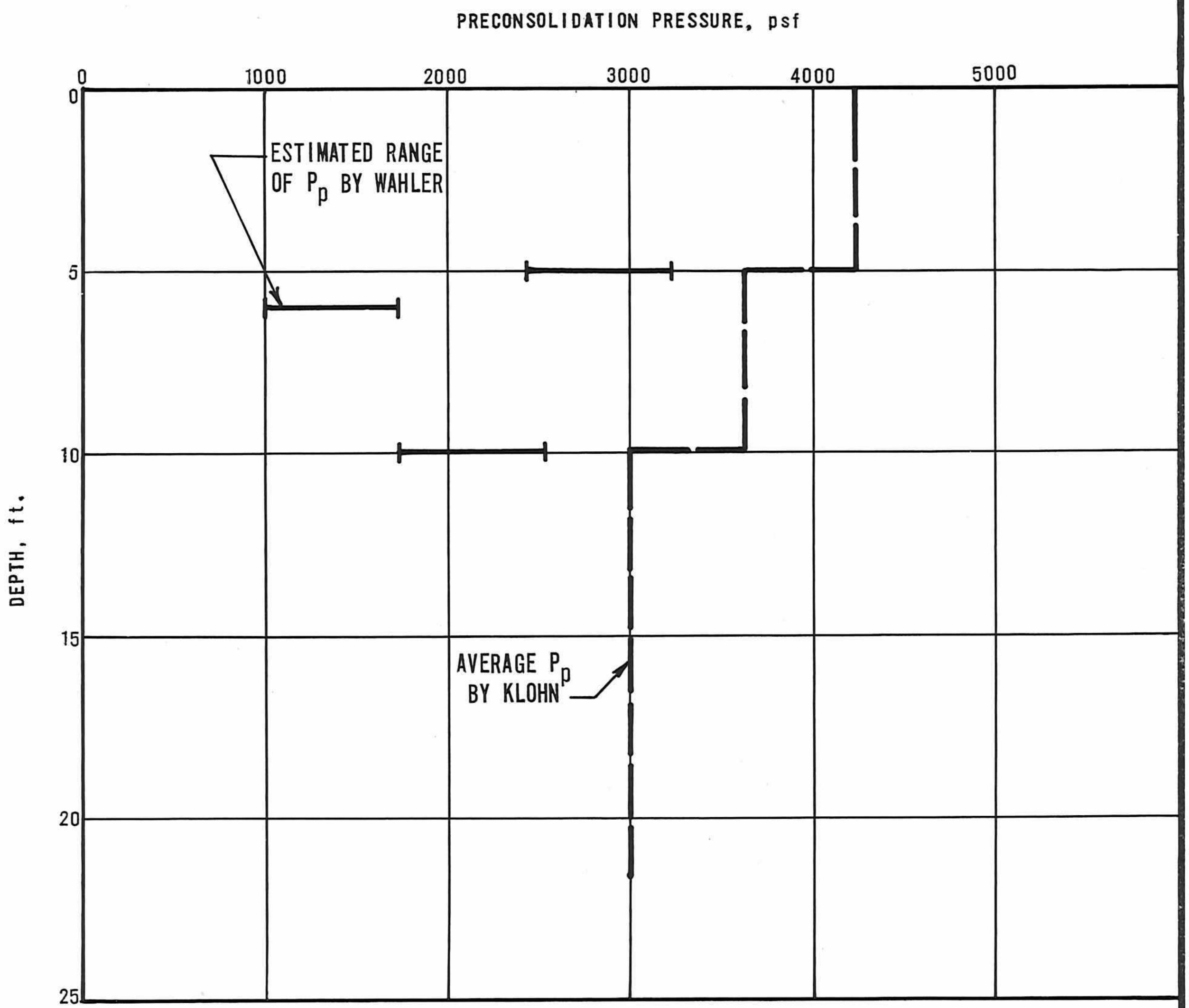
Similar classification and index properties data were developed for a very limited number of samples of the sandy-silty "transitional zone" materials (discussed in Section B.2. of this chapter). These test results are presented in Appendix B, but are not summarized here. Certain engineering properties of these materials are, however, significantly different from those of the overlying lacustrine clays, and will be presented and discussed as appropriate in this section of the report.

c. <u>Compressibility</u> - Computations of the magnitude of settlements require estimates of the existing net overburden stress, maximum past pressure (preconsolidation pressure), and the compression and recompression indices of the various compressible materials within the foundation.

Maximum past pressure and compression indices are estimated from the results of oedometer tests. Three such tests were performed on the lacustrine clay in our laboratory, and the values of the preconsolidation pressure determined from those tests are plotted on Drawing III-8, superimposed over the design values presented in the Klohn Leonoff report. Large uncertainties are inherent in any estimate of preconsolidation pressure (uncertainties in this case created by the varved nature of the materials, the always unknown degree of sample disturbance and other factors) and, therefore, in our opinion, the differences between our values and those presented by Klohn Leonoff are well within this range of uncertainty.

Values of compression index (C_c) and recompression index (C_r) from the three tests are also summarized and compared to the values of Klohn Leonoff on Drawing III-8. These values are in reasonably good agreement.

d. <u>Coefficients of Consolidation and Permeability for Vertical Drainage (C_v) and K_v)</u> - These coefficients, which are used in the estimation of time rate of consolidation of compressible materials, were determined in our laboratory from both oedometer tests and pore pressure dissipation



COMPRESSION INDEXES

PROPERTY	WAHLER		KLOHN
	RANGE	AVERAGE	DESIGN VALUE
Compression Index, C_c	0.21–0.37	0.29	0.34
Recompression Index, C_r	0.04–0.11	0.06	0.08

W. A. WAHLER & ASSOCIATES

REVIEW OF MILE POST 7 PLAN
FOR STATE OF MINNESOTA

PALO ALTO • NEWPORT BEACH • CALIF.

PRECONSOLIDATION PRESSURES AND COMPRESSION INDEXES OF LACUSTRINE CLAY

PROJECT NO.	DATE	DRAWING NO.
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tests on a limited number of samples. A summary of the average values for the lacustrine clay, and for the transition materials at both Dam Sites No. 1 and No. 2-3 are shown in Table III-2, below.

TABLE III-2

SUMMARY OF COEFFICIENTS OF CONSOLIDATION (C_v) AND PERMEABILITY (K_v) FOR VERTICAL DRAINAGE

	Dam No. 1		Dam No. 2-3	
Material	PPDT/PERM*	OED**	PPDT/PERM	OED
Lacustrine Clay				
C_v (ft ^{2}yr)	17	39	--	34
K_v (ft/min)	1.2×10^{-8}	4×10^{-8}	6×10^{-9}	10×10^{-9}
Transition Zone				
C_v (ft ^{2}/yr)	2,000	--	290,000	--
K_v (ft/min)	1.2×10^{-6}	--	4×10^{-4}	--

*PPDT/PERM - Average values of C_v from the Pore Pressure Dissipation Test, and average values of K_v from the Permeability Test. All values are for consolidation to in-situ stresses.

**OED - Average values as determined from the Oedometer Test in the normally loaded range.

The values for the lacustrine clay fall well within the range of values measured by Klohn Leonoff and shown on Drawing 292-0030 of the design report. No comparison is possible for our tests run on the "transitional materials," because we have not been able to identify any Klohn Leonoff data on such materials, but the magnitude of the coefficients can be seen to be many times that of the lacustrine materials, which indicates that the "transitional materials" can be expected to consolidate much faster than the lacustrine clays.

e. Coefficient of Permeability for Horizontal Drainage (K_h) - This coefficient, which is used in the estimation of time-rate of consolidation of compressible materials, was estimated in our laboratory from horizontally oriented samples as described in Appendix B. The results, which are presented in Appendix B, were unfortunately inconclusive because the samples available for these tests were not significantly varved and behaved essentially in an isotropic fashion (i.e., K_h approximately equal to K_v). In our experience, however, thinly-bedded or varved clay materials, if tested, would have horizontal permeabilities at least four or more times greater than their vertical permeabilities.

f. Undrained Shear Strength - The in-situ undrained shear strength of the lacustrine clay deposit was estimated in our laboratory from the results of unconsolidated-undrained (UU) triaxial and one unconfined compression test on undisturbed specimens.

Several attempts were made to orient quick direct shear test specimens so that the failure would take place among the clay laminae. Unfortunately, these results were inconsistent and inconclusive, and are not further discussed herein.

The results of our UU and unconfined compression tests are summarized in Table III-3, below, and compared to Klohn Leonoff's values.

TABLE III-3

IN-SITU UNDRAINED SHEAR STRENGTH

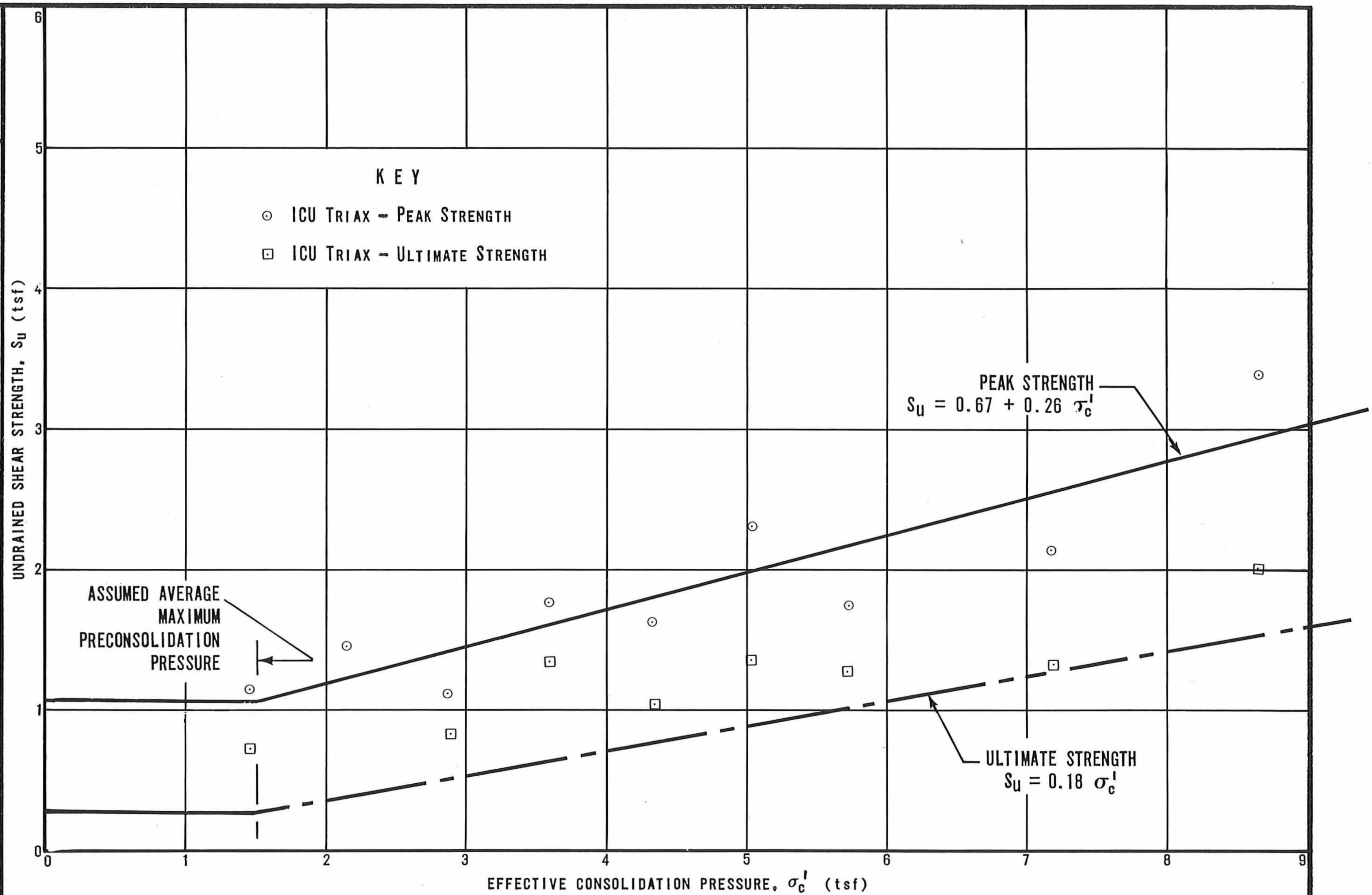
Strength	Wahler	Klohn
Peak (tsf)	0.08 - 1.25	0.8 - 3.4
Ultimate (tsf)	0.08 - 1.04	0.3 - 0.7
Design (tsf)	---	0.3

In evaluating the results of these tests, peak strength was defined as the maximum deviator stress. Ultimate strength was arbitrarily defined as the strength at high strain and, in the case of relatively brittle soil such as these, strengths will, in fact, generally decrease after reaching peak values.

In-situ undrained shear strength of clays is one of the most difficult properties to evaluate, and generally should be based on a large number of tests on high quality undisturbed samples. S_u also varies with depth, but for the purpose of simplification, a constant value is often assumed.

Two of the seven unconsolidated-undrained shear tests which we performed indicated lower in-situ peak and ultimate shear strengths than any of the corresponding results presented in the Klohn Leonoff design report. A careful review of our test results did not reveal any apparent basis for rejecting the lower strength values. However, possible sample disturbance or other undetectable factors could have adversely influenced these results. Klohn Leonoff's foundation design value of 0.3 tons per square foot seems to be conservative when compared to their overall test results presented in the design report. However, our test results could raise the question as to whether any significant volume of materials with undrained strengths lower than that assumed for design might exist in the starter dam foundation. On the basis of the limited number of tests which we performed, it does not seem possible to resolve such a question at this time. We, therefore, can only recommend that the designers re-examine their data, consider the possibility suggested above, and take the appropriate course of action with regard to stability analysis of first-stage construction of the starter dam.

g. Increase in Undrained Shear Strength - Klohn Leonoff's stability analyses of the starter dams and main embankment at Dam Site No. 1 were based on the assumption that the undrained shear strength of the foundation will increase with time due to consolidation under the weight of the embankment, an assumption which we consider reasonable. In order to evaluate the increase in undrained shear strength, a series of consolidated undrained triaxial (ICU) tests were performed. A convenient method of showing the results of those tests is to plot the undrained shear strength, S_u vs. the effective consolidation pressure σ_c'. Those results from our test data are shown on Drawing III-9. The use of this relationship is discussed more fully in Section C.3., which follows.



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REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA

UNDRAINED STRENGTH RELATIONSHIPS FOR LACUSTRINE CLAY

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h. Effective Stress-Strength Parameters - Stability analyses performed in terms of effective stresses to approximate long-term stability, require knowledge of the Mohr-Coulomb failure envelope, which is usually expressed in terms of the effective friction angle ϕ', and the unit cohesion c'.

These parameters can be obtained by plotting the results of our ICU tests in an alternate form as summarized on Drawing III-10. The resulting effective strength parameters obtained from our testing program are compared with design values proposed by Klohn Leonoff in Table III-4, below.

TABLE III-4

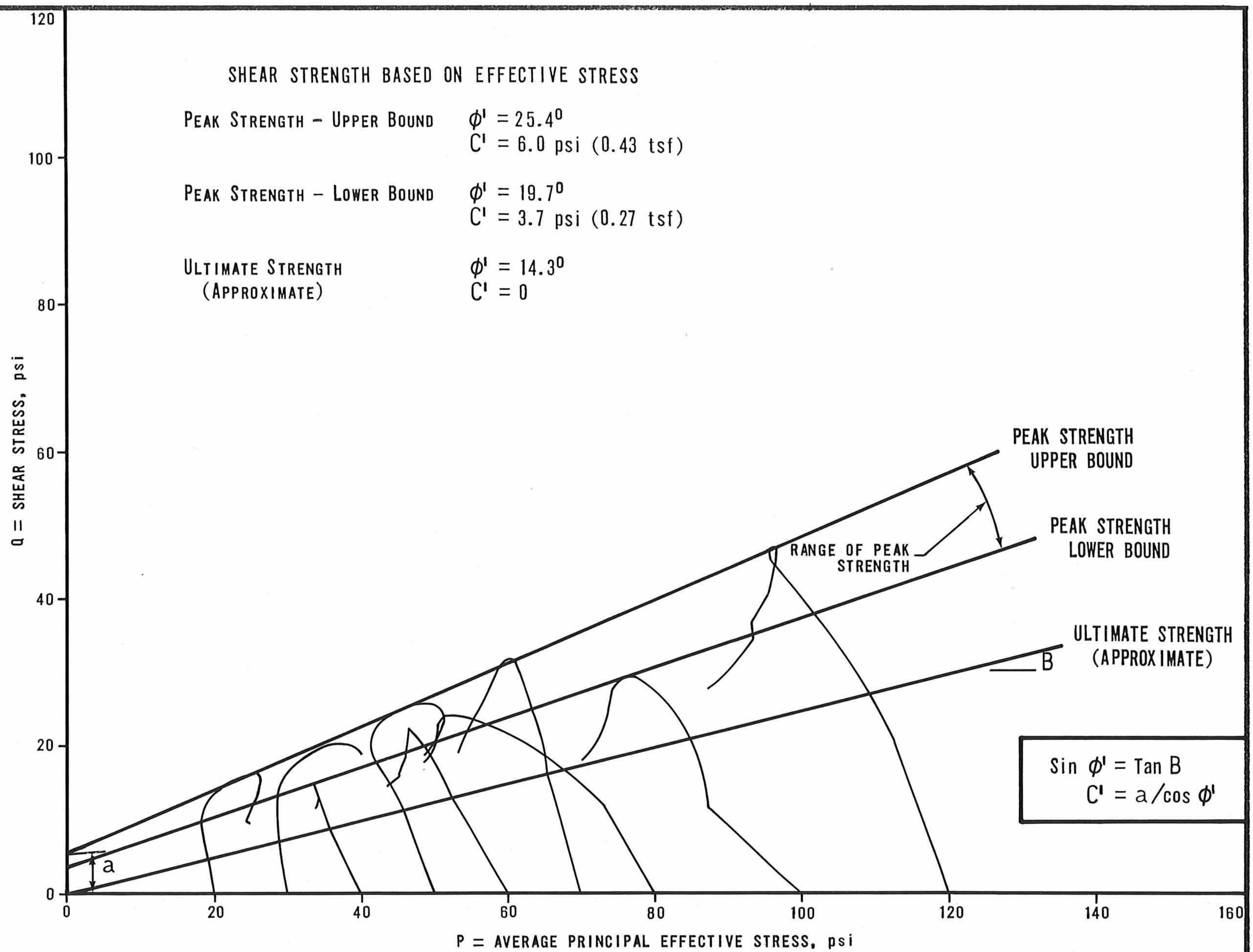
EFFECTIVE STRESS PARAMETERS

	Wahler		Klohn	
Strength	ϕ'	c'(tsf)	ϕ'	c'(tsf)
Peak - Upper Bound	25.4°	0.43		
Lower Bound	19.7°	0.27		
Design			17°	0.0
Ultimate	14.3°	0.0		
Design			13°	0.0

The values of effective stress parameters presented by Klohn Leonoff seem to be in reasonable agreement with our results.

3. Engineering Properties of the Lacustrine Foundation as Related to the Stability of Dam No. 1

The Klohn Leonoff report indicates, and we agree, that the critical foundation material beneath the tailings retention dams will be a deposit of "varved" lacustrine clay, overlying glacial till. Laboratory test results presented in the design report indicate that the lacustrine clay is relatively impermeable, highly compressible, and has low shear strength characteristics relative to the underlying glacial till.



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REVIEW OF MILE POST 7 PLAN
FOR STATE OF MINNESOTA

EFFECTIVE STRESS PATHS
FROM TRIAXIAL TESTS ON LACUSTRINE CLAY

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Based upon the results of our own limited laboratory testing, which was discussed earlier, it appears that the in-situ shear strength properties assumed in the design report for use in analyzing the stability of the first-stage construction of the starter dam at Dam Site No. 1 should be re-examined by the designer. It should, however, be noted that even if in-situ foundation strength, and thus stability of the starter dam during the first-stage construction, may be somewhat overestimated in the design report, the stability of the completed starter dam and later construction of the main dam is predicated not on an estimate of in-situ strength (based upon UU test), but from assumed increases in strength (relationships based upon CU data). The CU triaxial test data, which we feel is reasonably conservative, is then reasonably valid and since it controls the estimates of foundation strength, it should also make valid the resulting stability analysis for completion of the starter dam and the main dam. The discrepancy between our data and the Klohn Leonoff data regarding the measured values of in-situ strength is, therefore, of concern only with respect to first-stage construction of the starter dam.

The analyses of stability of the completed starter dam and of various stages of construction of the main dam, however, are predicated upon an estimated increase in the undrained shear strength of the foundation due to consolidation accelerated by the sand drains. The stability of the downstream slope of the ultimate dam is contingent upon an estimated increase in strength due to consolidation without sand drains. Estimates of the rate of foundation consolidation, and the resulting rate of increase of shear strength are, therefore, of critical importance in slope stability analysis.

Time-rate of consolidation is extremely difficult to predict, due to the complex drainage conditions that exist at any site. In the case of more homogeneous and isotropic clays (where horizontal permeability is nearly equal to vertical permeability) the rate of consolidation of a layer can be estimated rather imprecisely by assuming that dissipation (drainage) of excess pore pressure is primarily in the vertical direction. When varved clays are involved, as they appear to be at the Mile Post 7 project, the time-rate of consolidation of the thin clay layers is based upon the assumption that dissipation of excess pore pressure through drainage is predominantly in the horizontal direction. In the case where sand drains are relied upon, the estimate of horizontal permeability of the varved clay becomes critical, and must be carefully, and conservatively, arrived at for the purposes of review. Since the stability of the embankments of the Mile Post 7 project relies upon assumed increases in shearing strength that are directly related to estimates of the time-rate of consolidation of the lacustrine foundation materials, we feel that, for purposes of review, conservative estimates should be made concerning the time-rate of consolidation.

Beneath the downstream portion of Dam No. 1 and outside of the zone of influence of the sand drain installation, we believe that it is entirely reasonable and appropriately conservative to neglect the effects of horizontal drainage on consolidation estimates, unless investigations can conclusively demonstrate a high coefficient of permeability in the horizontal direction, because the horizontal width of the embankment is very large compared to the thickness and degree of anisotropy of the compressible lacustrine layer. Furthermore, the assumption of vertical drainage in only one direction (toward the overlying pervious embankment materials) seems appropriate, because of the uncertain extent of the pervious transition zone materials, which were discussed previously in Section B.2. Therefore, for purposes of our review, only upward vertical drainage has been assumed in our estimates of the increase in foundation shear strength beneath the downstream portion of the completed main dam.

Beneath the starter dam and a major portion of the upstream part of Dam No. 1, we feel that, for purposes of review, conservative estimates of the horizontal drainage characteristics of the lacustrine materials are in order. Our laboratory results were not conclusive toward estimating the horizontal drainage characteristics of the lacustrine materials or for comparison with the values quoted in the Klohn Leonoff report. Additional conservatism is in order because of the fact that during installation of sand drains, "smearing" can cause the influence of horizontal drainage to be significantly reduced, as will be discussed in Section E.2. of this chapter. Therefore, we have assumed very conservatively that the lacustrine materials are only about 4 times more permeable in the horizontal direction than in the vertical direction.

Estimates of the change in undrained shear strength that accompany changes in effective consolidation stress have been presented on Drawing III-9. This relationship, combined with consolidation theory (which provides the means by which to estimate the time-rate of consolidation) has been used to derive the relationships shown on Drawing III-11, which relates the average undrained shear strength of the foundation to construction schedule presented on Drawing 292-0026 of the design report.

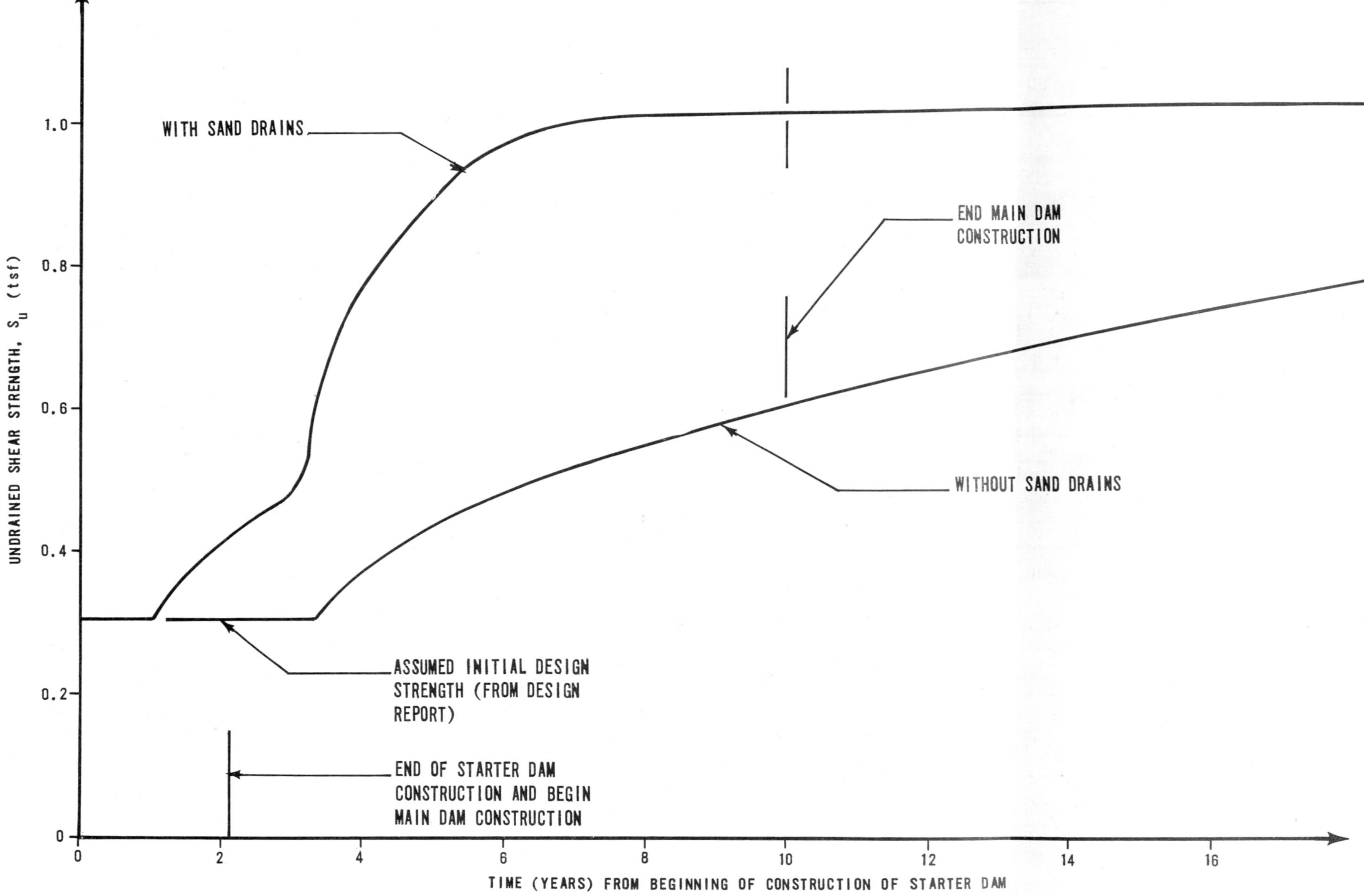
The Klohn Leonoff design report does not include the details used in the stability analysis, therefore, we can only speculate as to the other assumptions and procedures used. Our computations serve only to check the basic strength assumptions input to the Klohn Leonoff stability analyses.

D. ENGINEERING PROPERTIES OF REFUSE AND CONSTRUCTION MATERIALS

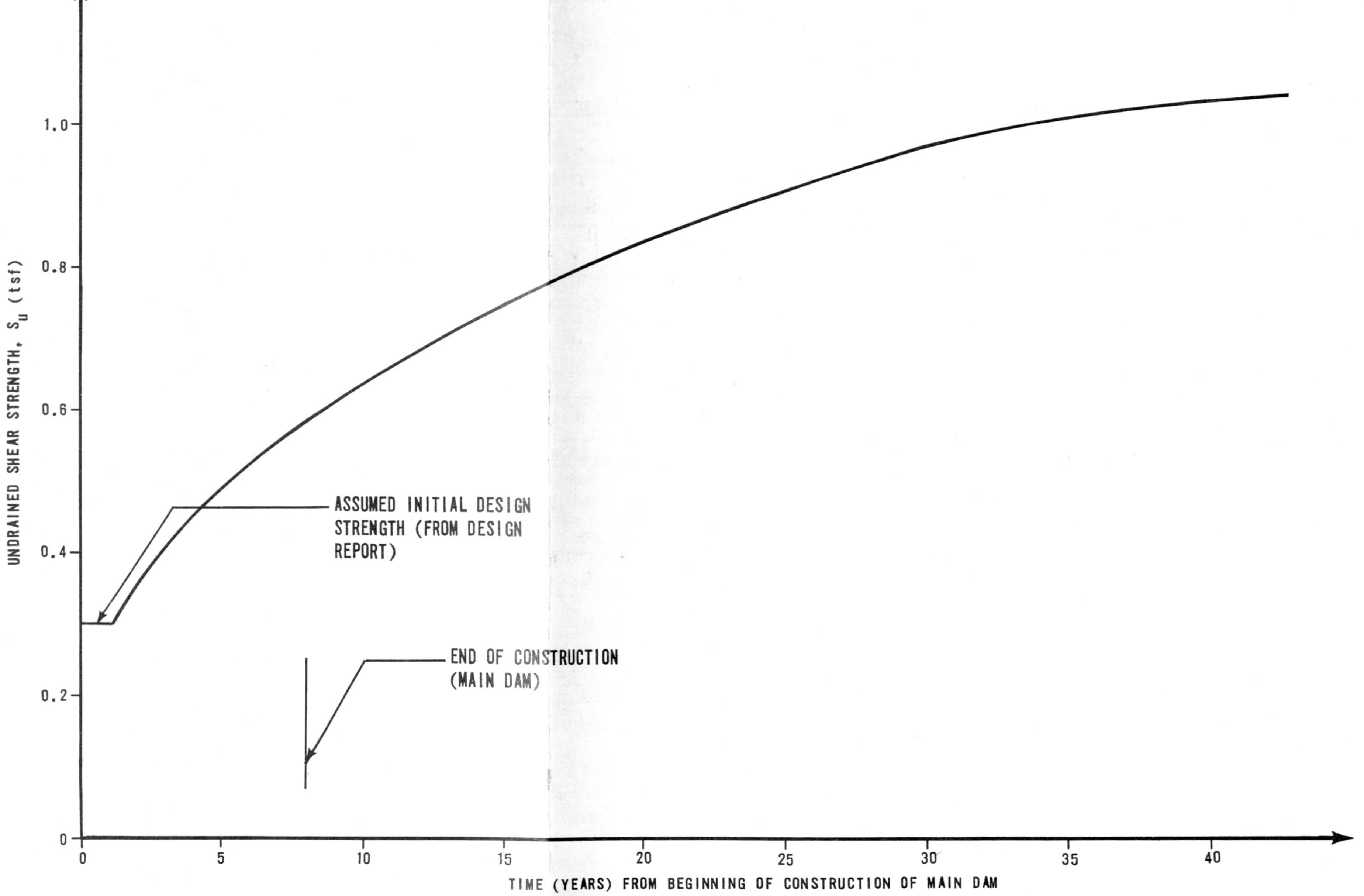
1. General

Basically, all the construction material proposed to be used in the various embankments at Mile Post 7 will come from two sources. First, the naturally occurring glacial till which will be excavated from borrow areas adjacent to Dam Sites No. 1 and No. 2-3 and used for the construction of the starter dams, and secondly, the wasted solids from the taconite milling process, or simply "tailings." The "tailings" materials are mechanically separated during different stages of the milling process, producing various groups of tailings materials which are distinguished mainly by their grain-size characteristics. From coarse to fine, the different types of materials are known as "dry cobbs," "filtered tailings" or "cycloned middlings," and "fine tailings." For the purposes of embankment construction, the "dry cobbs" and "filtered tailings" are to be recombined to form another type of material which is referred to as the "coarse tailings" which will be used to construct the major portions of the various dams. The "spigotting" method of depositing the fine tailings into the pond is intended to produce a zone of material typically referred to as the "beach" or "beach tailings."

FOUNDATION STRENGTH INCREASE UNDER STARTER DAM



FOUNDATION STRENGTH INCREASE UNDER DOWNSTREAM PORTION OF MAIN DAM



STARTER DAM

ASSUMES:

- Instantaneous Loading
- Average In-situ Pressure, $P_o \simeq 0.71$ tsf
- Average Pressure from Starter Dam $\simeq 2.47$ tsf
- Average Pressure from Main Dam $\simeq 2.96$ tsf
- Coefficient of consol. (vertical drainage) = 13.6 ft^2/yr
- Coefficient of consol. (horizontal drainage) = 54.4 ft^2/yr
- Strength Increase Predicted using Ultimate Strength Curve from Drawing No. III-9
- 18" Sand Drains on 20' Centers.

MAIN DAM

ASSUMES:

- Instantaneous Loading
- Average In-situ Pressure, $P_o \simeq 0.71$ tsf
- Average Pressure from Main Dam, $\Delta p \simeq 5.43$ tsf
- Coefficient of Consol. (vertical drainage only) = 13.6 ft^2/yr.
- Strength Increase Predicted using Ultimate Shear Strength Curve from Drawing No. III-9.

NOTES: (1) PORE PRESSURE DISSIPATION BEHAVIOR FOR THE CASE WITH SAND DRAINS NEGLECTS VERTICAL DRAINAGE, AND IS COMPUTED USING CHARTS PRESENTED BY JOHNSON, 1970, "FOUNDATION PRECOMPRESSION WITH VERTICAL SAND DRAINS", JSM & FD, ASCE, pg. 153.

(2) DIFFERENT TIME (HORIZONTAL) SCALES HAVE BEEN USED FOR THE STARTER AND MAIN DAM CURVES.

W. A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	INCREASE OF UNDRAINED SHEAR STRENGTH DURING EMBANKMENT CONSTRUCTION		
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Our laboratory received samples of the three basic groups of tailings materials, as they would be produced during the milling process. A limited number of tests were performed in our laboratory on these materials in order to confirm their basic properties, and to aid in evaluating their anticipated performance as construction materials. No samples of the glacial till were taken or received; however, based upon our experience with this type of material, certain observations can reasonably be offered.

2. Glacial Till Borrow Materials

The glacial till material is to be used for the construction of starter dams, diversion dams, seepage reclaim dams, and impervious elements of Dams No. 4 and No. 5.

Based upon our experiences elsewhere, we would expect that glacial till will make a good dam construction material, possessing reasonably high shear strength and reasonably low compressibility and permeability characteristics, if compacted properly.

The glacial till, according to data presented in the design report, appears to be a well-graded material containing particles varying up to fine gravel sizes and between approximately 30 to 60 percent silt and clay-sized particles. The coarser sizes should result in considerably higher frictional strength of the material than indicated by Klohn Leonoff's effective strength parameters of $\phi' = 31^o$ and $C' = 0$; these are considered to be conservative values for material of this type. The silt and clay fraction, on the other hand, generally will result in relatively low permeability characteristics of the till. With this type of material, it will be desirable to compact the material at a water content at or slightly wet of optimum by a method of compaction such as pneumatic rollers, so as to put the clay portion of the matrix into a dispersed type of structural arrangement. With the clay particles in a dispersed condition, the coefficient of permeability of the total material will be minimized and the flexibility of the material will be maximized.

The properties of the till indicated in the design report appear to be entirely reasonable provided careful compaction control is exercised, because it should be noted that this material could exhibit markedly different and perhaps undesirable properties, if inadequately moisture-conditioned and compacted improperly.

3. Other Embankment Materials

a. Dry Cobbs - Although not proposed in the design report for use in the embankments without blending with other materials, the dry cobbs would appear to make an excellent construction material. The dry cobbs are hard, sound, durable, and angular particles of approximately fine gravel sizes. Gradation analysis on the material we received is shown on Figure B-1 of Appendix B, and is basically similar to that shown by Klohn Leonoff. The material is well-graded, with a median size of approximately 8 to 10 mm. The hard, angular nature of the particles should give it good strength due to interlocking, even when combined with the cycloned middlings.

b. Filtered Tailings - These are the second coarsest mill byproduct. The sample of this material that we received is basically a medium-to-fine silty sand (SM) with a median size approximately equal to 0.15 mm (see Figure B-1, Appendix B). This material is close in gradation to, but slightly finer than, the material referred to as "cycloned middlings" by Klohn Leonoff.

c. Coarse Tailings - Coarse tailings refers to the mixture of dry cobbs and filtered tailings (cycloned middlings) which are proposed to constitute the main construction material for most of the dams. The design report often quotes the uses of "coarse tailings" but, unfortunately, presents data for two somewhat different mixtures of "coarse tailings;" one mixture composed of 66% dry cobbs and 34% middlings (data shown in Tables 1 and 2 of Klohn Leonoff's Appendix B); and another mixture composed of 75% dry cobbs and 25% middlings (data shown on Drawing 292-0030).

We did not attempt to blend together various "coarse tailings" mixtures for permeability testing; however, regardless of which of the two mixtures is selected, the range of values of permeability (varying from 2 to 8 x 10^{-2} ft/min) for the two mixtures as reported by Klohn Leonoff is not unreasonable. We believe that the coarse tailings will make an excellent basic construction material of high strength.

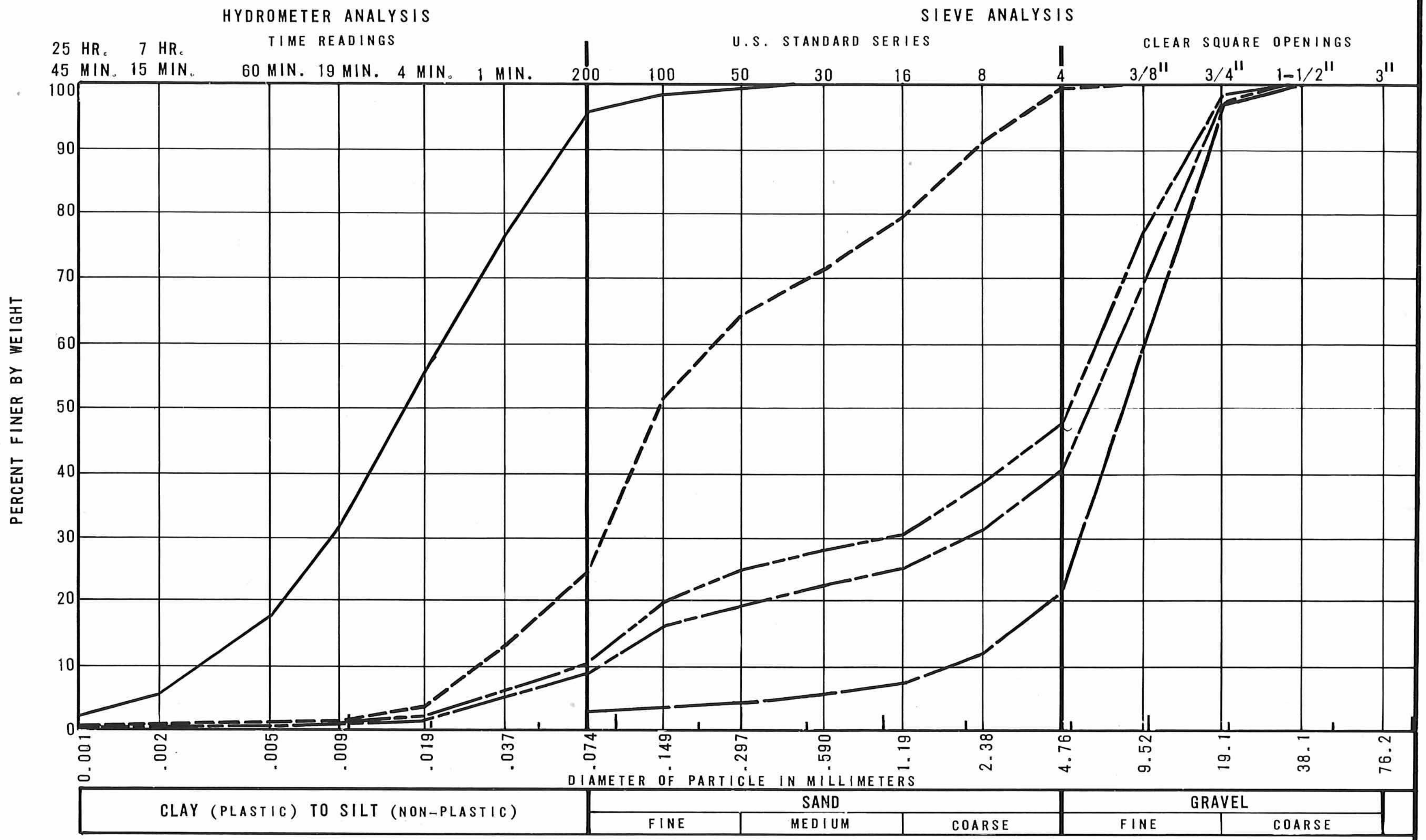
4. Fine Tailings

The fine tailings as tested in our laboratory are equivalent to a uniform silt (ML) with a median size of approximately 0.02 mm and a specific gravity of 2.99, indicative of the iron ore parent material from which they come. A test was performed in the laboratory to determine the approximate density to which the fine tailings would settle in the pond. A compaction test was also performed to determine the approximate degree of relative compaction of the settled material. The settled dry density measured 92 pcf, which was 81% of the maximum dry density of 115 pcf determined in accordance with ASTM Designation D1557, modified to provide 20,000 foot-pounds per cubic foot of compactive effort.

The values of settled density and specific gravity determined in our laboratory are very nearly the same as reported by Klohn Leonoff. However, our "settled density" value of 92 pcf does not reflect any possible increase in density which may occur in a tailings pond due to consolidation from the weight of overlying tailings materials.

Three permeability tests performed in our laboratory on the fine tailings at a density equivalent to their "settled density" measured an average coefficient of permeability of 8 x 10^{-5} ft/min, exactly the design value used by Klohn Leonoff. No determinations were made in our laboratory of the strength characteristics of settled fine tailings.

GRADATION OF PROPOSED TAILINGS



KEY

—— FINE TAILINGS FROM SLURRY — — — FILTERED TAILINGS —— —— DRY COBBS

—— - —— 75% COBS, 25% FILTERED —— - - —— 66% COBS, 34% FILTERED

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REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA

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E. LAYOUT AND DESIGN OF DAMS AND STRUCTURES

1. General

This section of the report presents our comments on the proposed siting of the various structures, the proposed details of the designs, and the methods and results of design analyses, including design criteria and assumptions.

The proposed general arrangement of dams and other tailings basin structures for the Mile Post 7 project is shown in plan on Drawing 292-0021 of the design report prepared by Klohn Leonoff. Generalized plans and cross sections of the proposed tailings retention dams, the seepage recovery dams, the diversion channels and dikes, the east side access road, and the reclaim area dikes are presented on Drawings 292-0041, 0050, 0060, 0070, 0081, 0083, and 0092 of that report.

2. Dam No. 1 and Related Structures

a. Description - As proposed in the design report by Klohn Leonoff, Dam No. 1 will be constructed over a 10-year period to a maximum height of approximately 150 feet. At ultimate crest Elevation 1280, the crest width will be 150 feet and the crest length will be about 12,600 feet, with upstream slopes of 2 horizontal to 1 vertical and downstream slopes of 6 horizontal to 1 vertical. Dam No. 1 is designed as a structure constructed primarily of a mixture of filtered tailings and dry cobbs (this mixture is referred to as coarse tailings which are intended to be pervious). A horizontal drainage blanket (indicated in the report to also consist of coarse tailings) will be placed on the downstream foundation of the dam to control the phreatic line within the downstream portion of the dam, and the upstream portion of the dam will incorporate a starter dam with a maximum height of about 50 feet and a crest elevation of 1170 feet. The starter dam is intended to be a homogeneous and impervious fill constructed of compacted glacial till derived from nearby borrow pits. Acceptable stability of the starter dam is apparently predicated upon the use of a sand drain installation to promote foundation consolidation and improved foundation shearing strength during construction.

The design provides for the establishment of a 200- to 300-foot wide impervious beach of settled fine tailings against the upstream face of the dam (by spigotting the fine tailings in slurry form from points on the upstream face of the dam) to minimize leakage from the tailings pond through the pervious materials of the dam.

The design provides for the control of stream flow during starter dam foundation preparation and sand drain installation by means of a diversion of stream flow through the left abutment portion of the starter dam foundation area through a gated 36-inch diameter diversion culvert. This culvert is intended to be sealed by grouting following completion of the starter dam.

Recovery of seepage through Dam No. 1 is provided for at two locations downstream of the dam by seepage recovery dams which are intended to be homogeneous and impervious structures of compacted glacial till. The small reservoirs created by the recovery dams are intended also to serve as sedimentation basins during initial starter dam construction and one or both dams are intended to be provided with spillways.

b. Initial Diversion Scheme - The proposed scheme for control of surface water during the early stages of construction of this dam has one major deficiency which, in our opinion, must be adequately addressed by the final design. The present concept recognizes the possibility that the 36-inch diameter diversion culvert may not be able to control storm runoff until the starter dam reaches approximately Elevation 1140. For that reason, the designers contemplate maintaining a depressed section, about 5 feet lower than the remaining embankment, to serve as a "spillway" over which flood flows in excess of available storage and culvert capacity would be discharged. Thus, any excess water would flow over the top of the glacial till starter dam. Although it is contemplated that this dam will be constructed to Elevation 1150 in a single construction season, during the early stages the available capacity will not be adequate to store large flood inflows. Furthermore, should it be necessary (for the purpose of promoting foundation stability, or for any other reason) to slow down the rate of starter dam construction, the period of "calculated" risk would be correspondingly longer.

We do not consider it safe practice to allow excess flood waters to overtop an earth dam which stores a significant amount of water. The glacial till will make an excellent embankment material, but it can be seriously eroded by substantial uncontrolled flows. The width of the depressed section is obviously an attempt to distribute the flow over a broad area, thus minimizing erosive effects. However, should erosion become more concentrated in one area of the overpour section, it could provide a preferential area for continued, more rapid erosion, with eventual release of a large quantity of water. The possible consequences of such an event are discussed in Section G of this chapter. Admittedly, such a failure would probably occur over a somewhat longer period of time than some of the other modes discussed in that section. Nevertheless, history provides some unfortunate lessons on the effects of overtopping of earth dams. In fact, until the advent of modern hydrologic techniques, this was the most common cause of dam failures.

We recommend that the final design include a more conservative provision for handling this situation, and that the information presented for final design review present a detailed analysis of the degree of risk involved in the scheme presented.

Other important details, which are not discussed in the design report or included on the drawings, should be addressed by the final plans and specifications:

1. Although not shown in the design report, we assume that the construction drawings and technical specifications will specify the gradation and compacted density of backfill materials to be placed around the culvert.

2. The details, procedures, and materials to be used for grouting the culvert pipe after completion of the starter dam must be strictly specified and enforced to ensure that the pipe is completely sealed. Fine tailings migrating through an improperly grouted culvert would probably not be prevented from migrating also through the downstream horizontal drainage blanket, which is discussed later in Section D.2.3. of this chapter and which we assume will consist of dry cobb tailings placed in contact with the downstream end of the culvert.

3. Consideration must be given to the method of sealing the culvert. Cement grouting will make this a long stiff tube traversing the dam. Because the embankment will be in a settling state, with greater settlement beneath the crest than towards the slopes, major stresses will develop in the soil adjacent to the pipe, as well as in the pipe itself. These stresses might develop shears that could lead to piping adjacent to the pipe. This consideration merits attention because a significant period of time could conceivably lapse between the sealing of the culvert and the placement of embankment materials over the downstream end in sufficient quantities to preclude the further possibility of piping. Perhaps construction of a reverse filter over the downstream end of the culvert would be warranted.

c. Foundation Treatment - Foundation treatment at the site of Dam No. 1, in addition to normal clearing, grubbing, and stripping, also contemplates the installation of an elaborate layout of sand drains as discussed in Section 7.3.4 and shown on Drawing 292-0044 of the design report. We have evaluated the proposed sand drain layout (drain diameters and spacing) in terms of the laboratory determined permeability, consolidation, and shear strength properties of the foundation materials, and it appears that the rates of foundation consolidation and gain in shearing strength shown on Drawing 292-0032 (Figures 3 and 5) and Drawing 292-0033 (Figures 8 and 9) of the design report are adequately conservative.

It is necessary to recognize, however, that any method of installation of sand drains (including nondisplacement methods such as are proposed in the design report) will result in a "smearing" action of the soil around the periphery of each hole and may also result in some disturbance or "remolding" of the soil for some unknown distance around each drain. The tendency to "smear" the soil around a drain can significantly reduce the horizontal permeability of the soil adjacent to the drain and result in slower rates of foundation consolidation. Disturbance or remolding of adjacent materials can result in local zones of appreciably lower shearing strength, and a slower rate of consolidation.

Design of sand drain installations is largely theoretical at this time and there is unfortunately very limited field data available on the performance of actual sand drain installations, invariably resulting in large and often-debated differences in professional opinions as to the best method of installation and design details for any given situation. The point to be made here is that, even though reasonably conservative assumptions and widely accepted design and installation techniques are involved, the actual performance of the sand drain installation must be very cautiously and critically observed throughout the period in which the drains are to be relied upon. Reliance upon the sand drain installation for stability of the starter dam at Dam site No. 1 of the Mile Post 7 project must recognize and provide for a contingency plan such that, if the actual performance of the sand drains falls below expectations, then the construction schedule for the starter dam and possibly later construction of the ultimate dam can be adjusted.

We do not presume to usurp the position of the designers in this project. However, in view of the above-stated unknowns, and possible economies to be achieved, additional detailed studies to evaluate the degree of anisotropy of the foundation and its effect upon consolidation (and, therefore, strength increase) may have merit. If it could be conclusively shown that subsurface conditions would, in themselves, promote sufficient gain in strength, a revised starter dam construction schedule, together with flatter slopes is an alternative solution to be considered.

The gradation proposed on Drawing 292-0044 for sand drain material, although on the coarse side of normal practice, appears to provide reasonably adequate protection against plugging by the silty layers included in the bedded lacustrine deposits. Sampling and laboratory testing, however, should be carried out to confirm the availability and permeability of the proposed material.

There is some confusion, in the design report, as to the intended thickness of the horizontal blanket over the sand drains. The text indicates that this blanket will be constructed by end-dumping and spreading in one 5-foot lift, whereas Drawing 292-0044 indicates a blanket thickness of 3 feet. Since contamination of the lower part of this blanket in contact with the fine lacustrine materials is inevitable, with a resulting loss of effective thickness of the blanket, and since spreading of that thick a layer may encourage segregation, we recommend that the required thickness of the layer be at least 5 feet and that it be placed and compacted in lifts no thicker than about 16 inches.

d. Starter Dam - The proposed starter dam for Dam No. 1 is described in Section 7.3.6 of the design report and shown on Drawings 292-0041 and 292-0042. As proposed, the starter dam will be constructed over a 2-year period to a maximum height of approximately 50 feet. At crest Elevation 1170, it will have a 40-foot wide crest and 80-foot wide berms on both the upstream and downstream slopes, with outer slopes of 3 horizontal to 1 vertical above and below these berms (the equivalent average slope will thus be about 4.8 horizontal to 1 vertical which is not extraordinarily flat for a soft clay foundation). The dam will be constructed entirely from compacted glacial till which is expected to be impervious. As indicated earlier, it is proposed to install vertical sand drains in the foundation for the starter dam to promote consolidation and improve shearing strength and stability during its construction.

Stability analyses of the starter dam have been carried out by Klohn Leonoff and the results presented on Drawing 292-0032 (Figures 2 and 3). As indicated earlier, we independently calculated the probable rates of consolidation and gain in shearing strength due to the sand drains, for comparison with values calculated by Klohn Leonoff. These calculations, and the conservative assumptions involved, are shown on Drawing III-11, indicating that the undrained strength parameters assumed by Klohn Leonoff for the stability analysis at completion of the starter dam are reasonably conservative. Klohn Leonoff, using undrained strength parameters (referred to as "total stress" analysis), computed factors of safety of 1.4 and 1.5, respectively, for both upstream and downstream slopes of the starter dam at the end of partial construction to Elevation 1150 and at the completion of construction to Elevation 1170. The range of common practice in earth dam design is to require minimum factors of safety during construction and prior to reservoir filling of up to about 1.3, depending upon the level of uncertainty and the risks involved. On that basis, it appears that the factors of safety calculated for the starter dam at the completion of construction to Elevation 1170 are within acceptable limits. As discussed in Section C of this chapter, we do recommend that the strength data utilized in stability analyses, for the case of partial completion to Elevation 1150, be re-examined.

e. Ultimate Dam - The main part of Dam No. 1 is described in Section 7.3.8 of the design report and shown on Drawing 292-0041. The main part of Dam No. 1 is to consist of "coarse tailings" transported to the dam site by rail and placed in horizontal stages in the dam over the 8-year period immediately following completion of the starter dam. Compaction requirements are varied for the coarse tailings, with the upstream portion of the dam and a 10-foot thick strip on the downstream face to be compacted by vibratory rollers, while the remaining downstream portion of the dam will only be compacted by routing construction equipment over the fill surface. The downstream foundation of the dam is to be covered by a 3-foot thick "drainage" layer of "coarse tailings" placed in one lift for the stated purpose of carrying any seepage from the tailings pond.

Stability analyses have been carried out by Klohn Leonoff and the results presented on Drawing 292-0032 (Figures 4, 5, and 6). Reference is again made to our conservative calculations of shear strength as a function of time shown on Drawing III-11 which indicate that the undrained strength parameters assumed by Klohn Leonoff for stability analysis of the ultimate dam are reasonably conservative. Based upon the Klohn Leonoff analysis using undrained strength parameters (referred to as "total stress" analysis), factors of safety of 1.6 and 1.4, respectively, were computed for the upstream and downstream slopes of the completed dam with an assumed tailings pond level of 1182 feet. It is fairly common practice in earth dam design to require minimum factors of safety of 1.5 or greater for <u>full</u> reservoir nonseismic conditions, again depending upon the level of uncertainty and the risks involved. Judged against this criterion, the factor of safety calculated for the upstream slope appears to be acceptable. The computed factor of safety for the downstream slope appears to us to be reasonably acceptable even though it is somewhat lower than 1.5. The tailings pond level at the completion of construction is almost 100 feet lower than the dam crest and, with the considerably lesser risk involved, it appears to us justifiable to accept computed factors of safety between that for end-of-construction conditions (normally required minimum factor of safety of 1.3) and full reservoir conditions (normally required minimum factor of safety 1.5). As the tailings pond level rises, the factor of safety could also be expected to increase (due to continued consolidation of the downstream foundation and increased shear strength resulting therefrom), such that it would appear that a factor of safety of 1.5 could probably be calculated for the undrained strengths developed at a point in time about 3 years following completion of the dam. We recommend, however, that the final design analyses address the relationships between tailings pond level, configurations of critical failure surfaces, and factors of safety.

The question of probable stability in the event of future seismic activity within the region should be more thoroughly covered during final design. It would be appropriate to include in the design report an evaluation of the probable stability of the dam in the event of the maximum credible earthquake. Design analysis of seismic stability of the dam is commonly performed in any number of different ways ranging from the extremely complex dynamic finite element method to the very simplistic application of a seismic coefficient in the limit equilibrium method, often referred to as "pseudo-static" analysis. Selection of the method of analysis, and of the parameters to be included in the analysis, is the province of the designer, subject to later review by the applicable regulatory entity. Based on the historical seismicity of this region, our experience leads us to believe the analyses will indicate that earthquake effects will be modest and will probably not require significant modifications to the design.

The design report indicates the thickness of the proposed horizontal drain blanket to be 3 feet, and makes no distincion in material type between the main portion of the dam and the blanket. For the reasons discussed under "Foundation Treatment," we recommend that the required thickness of the blanket be at least 5 feet and that it also be placed and compacted in thinner lifts. Further, the final design should address the characteristics of the material to be used, and should specify a gradation or source of assured drain material.

We have evaluated the gradation characteristics of the coarse tailings proposed for use in the dam for their compatibility (i.e., filtering characteristics) with the fine tailings in terms of preventing the migration of the fine tailings from the tailings pond through the coarse tailings comprising the embankment. We conclude that the two-thirds cobbs-one-third filtered tailings mixture of "coarse tailings," as defined previously, generally satisfies commonly accepted filter criteria.

The permeability of the coarse tailings and their piping resistance (i.e., ability to prevent the migration of fine tailings through the embankment) are expected to be very sensitive to the proportion of filtered tailings added to the dry cobbs. For example, a mixture of 75 percent cobbs to 25 percent filtered tailings while having slightly better permeability, would appear to provide marginal conformance with generally accepted filter criteria. On the other hand, any mixture which resulted in increasing the fines (minus #200 sieve fraction) much above 8 to 10 percent would be acceptable as a filter, but would drastically decrease the permeability of the "coarse tailings." It should be obvious, then, that extremely careful control of the gradation of the "coarse tailings" during construction is essential. If the design gradation cannot be assured, then an embankment of widely varying permeability and piping resistance could result. The final design studies, and the information presented to the State for final design review, should thoroughly cover the question of gradation control. The degree to which the ability to control the uniformity of the coarse tailings can be demonstrated will govern the final design studies and considerations. If there is some concern on this point, it may be appropriate to conduct special laboratory filter tests to assess the material's ability to preclude migration of fines.

An obvious question would arise regarding the uniformity and permeability of the proposed fine tailings beach to be formed upon the upstream face of the dam by spigotting (as described in Section 2.6 of the design report). The design is currently predicated on this beach becoming the impervious element of Dam No. 1 and all of the dikes except Dam No. 4. Reliance is also being placed on a similar beach, to be formed by spigotting off the access road, providing an impervious blanket along the east side of the tailings basin. The Klohn Leonoff test data, and our experience with such processes in general, suggest that the beaches thus formed will be "semi-pervious," and that a certain amount of seepage must be expected. To some extent, the design accounts for this, in that seepage recovery dams and pump-back facilities are appropriately planned. However, as discussed in Section B of this chapter, our geologic mapping has identified several features along the east ridge of the basin which would afford the opportunity for seepage to bypass the various dam abutments and seepage recovery facilities, if ameliorative measures are not employed. Therefore, we recommend that the final design investigations thoroughly address the relationships of these various features and the spigotted beaches, with the goal of locating just where seepage cutoff measures must be implemented. We also recommend that laboratory tests be performed on the proposed spigotted tailings to provide information on their horizontal permeability, since sedimented materials can be expected to exhibit some degree of anisotropy.

f. <u>Seepage Recovery Facilities</u> - The proposed seepage recovery facilities are described in Section 7.3.7 of the design report and shown on Drawing 292-0041. As proposed, two separate recovery ponds are defined, each created by an earth embankment composed of compacted glacial till with outer slopes of 6 horizontal to 1 vertical. Pumping stations are to be installed at each pond to return seepage to the tailings pond. The design also provides that an 18-inch thick downstream drainage blanket of material similar to that used for the sand drain blanket will be placed and that a layer of fine rock (of unspecified thickness) will be placed on the surfaces of each dam as protection against erosion.

The scheme generally appears functional and since the proposed dam for area "A" appears to have a maximum height of about 40 feet, and, as stated in the design report, the dam may serve as a rail access over the creek, we assume that stability analyses have been carried out to show that the 6:1 design slopes are, in fact, adequate.

We did not carry out extensive hydrologic studies. However, based on our review of data and an approximate evaluation, it appears that the small seepage recovery ponds have sufficient capacities to contain the flood inflows from their small drainage basins provided that adequate freeboard is maintained. This should be easily accomplished since the water contained in the ponds will normally be intercepted seepage and this water will be pumped periodically back into the tailings pond.

Once deposition of tailings has ceased and the site is abandoned, these ponds will most likely require spillway facilities, or regrading to permit runoff without impoundment. Based on average hydrologic conditions, there will be a net excess of water for most years. Eventually the storage capacities of the ponds will be exceeded and discharge capabilities will be required, unless seepage and possibly some transpiration losses offset the net gain. Any water released from these reservoirs containing cummingtonite asbestiform fibers will have to be filtered before released. Abandonment cannot be made until the water seeping from the reservoir meets emission standards.

3. Dam No. 2-3 and Related Structures

As proposed in Section 7.4 of the design report and shown on Drawing 292-0050, Dam No. 2-3 will have a maximum height of approximately 120 feet and a crest length of 5200 feet. The proposed design details for Dam No. 2-3 and related structures are generally similar to Dam No. 1 and our comments for those features generally apply here.

There may be one important exception, however, in that a sand drain installation is not contemplated for the very low starter dam for Dam No. 2-3. Stability of the relatively steep upstream slope of the ultimate dam may be more critical than at Dam No. 1 and must be carefully analyzed, and more extensive instrumentation should be installed than is presently proposed.

4. Dam No. 4

As very briefly proposed in Section 7.5 of the design report and shown on Drawing 292-0060, Dam No. 4 will have a maximum height of approximately 100 feet and is to be a conventionally zoned structure with an impervious central core of compacted glacial till flanked by shells of coarse tailings with outer slopes of 2.5 horizontal to 1 vertical, both upstream and downstream.

Site exploration has not been accomplished and reported for this dam, and the proposed layout and structural arrangement form little more than a conceptual design. Therefore, it is impossible to evaluate the adequacy of the dam as proposed. It is our view that the site is amenable to the design and construction of a safe dam, provided that the necessary exploratory investigations are carried out and the embankment is designed, in accordance with contemporary design practice, to adequately account for site conditions.

The relatively steep downstream slope presently shown for this dam dictates that the engineering characteristics of the foundation at this site be thoroughly evaluated and incorporated in stability analyses during final design. Without such an evaluation, the appropriateness of constructing a dam, of the dimensions shown, essentially on the ground surface is open to question. The design analyses will also have to determine whether internal drainage will be necessary to provide assured interception of seepage through the impervious core, thus enhancing slope stability.

Only upon completion of a comprehensive exploration program, which also must include an evaluation of the character of the abutments, can the necessary design details, foundation treatment and specifications be developed for this dam. At that time the adequacy of the proposed seepage collection provisions can also be better assessed. It is possible that site conditions may dictate a more sophisticated seepage collection system.

5. Dam No. 5

As very briefly proposed in Section 7.6 of the design report, and shown on Drawing 292-0070, Dam No. 5 will have a maximum height of approximately 120 feet and is to be constructed essentially of coarse tailings with an impervious beach of spigotted fine tailings to be established upon the upstream face of the dam similar to that described and discussed for Dam No. 1. The portion of Dam No. 5 up to Elevation 1200 will be constructed as part of the east side access road.

Since site exploration has not been accomplished and reported for this dam either, it is also impossible to evaluate the adequacy of the dam as proposed. Again, however, we consider that a safe dam can be designed and constructed if the necessary investigations and analyses are carried out. In particular, we believe that thorough, well-planned site investigations to assess the character of the dam abutments and the east ridge in the vicinity of Dam No. 5 will be necessary before an adequate seepage control and recovery scheme can be devised to protect Bear Lake. Until these site investigations are completed, it is impossible to comment on the adequacy of any proposed seepage recovery scheme.

6. Water Course Diversion Channels and Related Structures

The proposed tailings disposal scheme for Mile Post 7 requires that the drainage area above the site be reduced so that the water entering the disposal area will be maintained at a more manageable level. This reduction is to be accomplished by the construction of two diversion facilities which will intercept the natural watercourse channels and divert the drainage flow around the site.

Diversion No. 1, as proposed, will divert Little Thirtynine Creek into Big Thirtynine Creek. A low earthfill dam will be constructed across the creek and will be composed of locally borrowed glacial material buttressed by mine stripping rock, as required. The principal diversion channel will be about 4,000 feet long with an invert width of 25 feet and a slope of about 8 feet per mile. The diversion facility has been designed for a maximum flow of approximately 4,000 cfs.

Diversion No. 2 will divert the runoff from Big Thirtynine Creek, including the flow from Little Thirtynine Creek, into Beaver River. A low dam, similar to that for Diversion No. 1, will be constructed across the creek. The principal channel will be about 2,000 feet long with an invert width of 100 feet and a slope of 8 feet per mile. This facility has been sized for a flow of approximately 10,000 cfs.

Our analyses have confirmed these values, 4,000 cfs and 10,000 cfs, to be the approximate maximum capacities which could be diverted by the proposed facilities. Any substantial additional flow would overtop the small diversion dams and create sizable breaches in the embankments.

The design report indicates that the diversions were designed to pass flood runoff from storms up to a 10,000-year frequency. To provide a basis for comparison, our firm computed the estimated runoff which would be expected from a Probable Maximum Flood (PMF). Conservative runoff values were used to reflect the heavy vegetation and ground cover conditions of the watershed. The PMF for Diversion No. 1 was determined to be approximately 13,000 cfs, and for Diversion No. 2 the PMF value was found to be about 40,000 cfs.

The 10,000-year flood frequency diversion design is reasonably conservative regarding the proposed 40-year operating life of the Mile Post 7 disposal site. However, following abandonment of the site perhaps a PMF design should be considered since overtopping the small diversion dams would create a breach in the dam embankment. Unless all breaches were repaired, much of the previously diverted flow would pass directly into the tailings disposal area.

Regardless of the final channel capacity designs, periodic inspections and maintenance will probably be necessary for an indefinite period to verify that the diversion channels have not become restricted in some manner due to the accumulation of debris, unanticipated vegetational growth, landslides, or other obstacles which could substantially reduce the discharge capabilities of the channels.

F. CONSTRUCTION, OPERATION, INSPECTION, AND MONITORING

1. General

This section of the report presents our comments on methods of construction, construction control requirements, embankment instrumentation details and procedures, and those aspects of tailings basin operation that would affect the funtionality and safety of the project.

2. Designer's Memorandum

One of the most important steps of the design process, and often the one to which the least attention is given, is the preparation of detailed instructions from the designers to the field engineer and construction inspection staff. The design of any dam is by no means complete after the final design report and drawings and specifications are prepared. Even though detailed field and laboratory investigations are conducted, and the most advanced analytical techniques are employed to arrive at the final design, it is obvious that natural variations in subsurface conditions and construction materials make it impossible to exactly define or predict every aspect of a given site or every variation in the construction materials that might affect the actual performance of the intended project. Only during construction, when the dam foundation area is completely exposed, can the geological and soil engineering properties that were assumed in the design be verified, and only when construction materials are excavated and placed in the embankment, can the variations in materials and techniques of construction be fully evaluated for suitability and economy of construction.

A field engineer or inspector, well qualified in earthwork construction techniques, will often be able to recognize foundation or embankment materials which are definitely unsuitable for a given structure. However, he may have difficulty in recognizing and making decisions on marginal foundation or embankment materials. His difficulties will be even greater if he does not know what the dam designers intended to be accomplished with the design, or has not been involved in the background investigations which have been carried out, such as field exploration and laboratory testing. The information contained in the designer's memorandum is intended: 1) to provide the field engineers and inspectors of the project with a clear understanding of the intent of the dam design; 2) to provide guidance in methods and criteria for testing and evaluating embankment materials to assure that proper placement and compaction will be achieved; 3) to provide guidance in determining acceptable dam foundation conditions; 4) to explain the details and use of the embankment instrumentation system, and provide guidelines for interpreting instrumentation readings in terms of how they relate to design assumptions; and 5) to identify those items that are expected to require extra attention during construction. Although the memorandum is always intended to be as comprehensive as possible, it should be obvious that the field engineer and his staff should maintain close liaison with the dam designers throughout construction so that unforeseen developments, not anticipated or discussed in the memorandum, can be quickly solved. The information provided in the designer's memorandum is thus a supplement to the drawings and specifications.

We consider that the complexity of this project requires preparation of a document such as that discussed above. Furthermore, this memorandum should be provided to the State regulatory entity during the period when plans and specifications are being reviewed. This will permit the reviewers to fully understand how the designers intend to control construction to achieve the intent of the design, and will also provide a base against which State representatives can gauge results being achieved during construction.

3. <u>Required Quantities of Embankment Construction Materials Vs. Proposed Construction Schedule</u>

The estimated production rates of dry cobbs and filtered tailings materials available for embankment construction are indicated in the design report by Klohn Leonoff as 6.6 million long tons per year and 2.0 million long tons per year, respectively. Assuming that coarse tailings will be two-thirds dry cobbs and one-third filtered tailings and that the average in-place density of coarse tailings in the embankments will be about 140 lb/ft^3 or 1.7 long $tons/yd^3$, the resulting maximum possible production of coarse tailings will be approximately 3.5 million cubic yards of compacted embankment material per year.

As indicated on Drawing 292-0027 of the design report, the required total volumes of coarse tailings embankment materials for the dams are:

1.	Dam No. 1	-	25.0 million cubic yards
2.	Dam No. 2-3	-	7.8 million cubic yards
3.	Dam No. 4	-	0.5 million cubic yards
4.	Dam No. 5	-	3.2 million cubic yards
	TOTAL		36.5 million cubic yards

Using the Klohn Leonoff figures, approximately 10 years of filtered tailings production will be required to provide the required quantity of coarse tailings (two-thirds dry cobbs, one-third filtered tailings) to complete Dams No. 1, No. 2-3, No. 4 and No. 5. Comparing this with the proposed construction schedule shown on Drawing 292-0026, indicates that it represents about the absolute maximum rate at which these dams can be constructed;

however, in any case, there is no apparent problem in keeping the embankment surfaces well above the rising tailings pond. An interesting point can also be made that about 2.6 million long tons of dry cobbs per year would be "left over" for placement in the coarse tailings storage area on the west side of the tailings pond or for other uses.

4. Glacial Till Borrow Area Operations

Impervious borrow materials for the various starter dams, for the diversion dams, for the seepage reclaim dams, for the central core zone of Dam No. 4, and for the impervious section of Dam No. 5 are proposed to be derived from the borrow areas shown on Drawing 292-0039 of the design report.

The impervious borrow is a dense glacial till, the physical properties of which were discussed earlier in Section D of this chapter. The till was originally deposited in contact with the bedrock underlying the proposed tailings pond, and varies in thickness up to about 100 feet. Based upon information from drill holes and exploratory trenches, Drawing 292-0039 indicates that after removing up to about 3 to 3½ feet of topsoil, silt and clay materials, an average excavation depth of 10 feet into the till in Borrow Areas 1, 2, and 3 would make available up to about 4.3 million cubic yards of material for construction. Ground water appears to be relatively high (generally within a depth of between 0 and 10 feet) and peripheral ditches are proposed to lower these levels and control any surface water inflow.

Even relatively moderate compaction (as proposed) of the fine-grained, dense, and practically impervious till is almost impossible to achieve economically at natural moisture contents greater than about 2 to 3 percent wet of optimum.

The confirmed quantity of material from the three proposed borrow areas would appear to be well in excess of the required quantities (roughly 2 million cubic yards). However, the very high natural moisture content that can be expected in materials below the ground-water table will make them impossible to properly compact unless air drying can be accomplished to lower the moisture content. If air drying the materials is not practical, and we suspect that it is not, generally shallower borrow operation will result over much larger areas.

If bedrock or the so-called "transitional" materials between the bedded lacustrine deposits and glacial till, or other pervious strata, are exposed in any of the borrow areas, they may have to be blanketed with impervious material to guard against the possibility of reservoir leakage through them. Details to account for such a contingency should be provided in the plans and specifications, with the understanding that they may have to be modified during construction.

5. Embankment Construction and Control

a. General - The construction of high quality embankments, that fulfill the intent of the designers, requires the preparation of detailed and comprehensive construction drawings and technical specifications, which we assume will be done.

Our comments here are confined to a few of the aspects of construction and control that are normally most critical during construction.

b. Construction Requirements for Impervious Elements of Dams and Other Structures - As stated in the design report, glacial till placed in starter dams (and we assume all other seepage reclaim dams, diversion dikes, and embankment zones) will be placed at near-optimum water content in about 9-inch lifts and compacted with 4 to 6 coverages of a "heavy" sheepsfoot or pneumatic roller. We are not certain what is intended by the term "heavy," but suggest that if a sheepsfoot roller is used, 4 to 6 coverages may not be adequate. In any event, whatever compaction equipment and procedures are finally selected should be backed up by documented evidence that the desired results can be achieved (either by historical performance records on similar materials, or by construction of a test fill). Because of expected variations in the proposed borrow materials, we suggest that technical specifications provide not only gradation limits but also more definite limits of acceptable moisture content and maximum particle size.

The fill surface during construction, and particularly during the wet months of the year, should be kept sloped to drain to prevent infiltration of rain water and trafficability problems and, at times of impending rain, should be sealed by rolling. Any moisture conditioning of the materials (other than minor final correction), notably drying, should be accomplished off the dam embankment.

c. <u>Construction Requirements for Coarse Tailings Zones in Dams and Other Structures</u> - As stated in the design report, coarse tailings will be placed in all main dam embankments and in the east side access road embankment. In zones where compaction is called for, it is proposed to spread the materials in 24-inch lifts and compact them by six coverages of a vibratory steel drum roller. Based upon our experience with vibratory compaction of coarse materials, we would expect that two or three coverages by a vibratory roller on 12- to 15-inch thick lifts would be more economical and produce better results, as well as minimize the chances of segregation of fine and coarse particles accompanying thick lifts.

In zones where less compaction is required, it is proposed to spread the material in "thin" lifts and compact the material with "construction equipment." We assume that specifications will adequately define "thin lifts," and that the hauling and spreading equipment or "construction equipment" will be required to be methodically routed over the entire surface of the fill.

The gradation of the "coarse tailings" in terms of piping resistance, permeability, and other critical engineering properties was discussed in Section E of this chapter. In that section, it was indicated that coarse tailings, composed of about two-thirds dry cobbs and one-third filtered tailings, appear to satisfy commonly accepted filter criteria, and we are assuming that this gradation will, in fact, be used to construct the compacted coarse tailings zones of all embankments and other earth structures. Since the proposed total output of crushed coarse material from the concentrating plant, if mixed at the mill, would result in coarse tailings containing approximately 76 percent dry cobbs and 24 percent filtered tailings, it should be obvious that only approximately 93 percent of the dry cobbs output is required to be mixed with the entire filtered tailings output; thus the rate of production of filtered tailings will control the rate of production of acceptable coarse tailings for embankment production. We assume that careful control of the mixture can be assured at the plant, and that the excess of dry cobbs will be placed directly in the disposal area or used for other purposes. No attempt should be made to blend these individual tailings materials on the fill.

d. Construction Requirements for Spigotted Tailings - Since the mechanical and hydraulic details of the fine tailings disposal system must be known, and since the system will essentially control the probable vertical and horizontal variation of gradation and other important characteristics of the spigotted materials, it will be necessary to review the specific proposal when available. The basic requirements can only be described rather broadly as objectives; i.e., directed to producing a thick, semi-impervious and relatively uniform deposit in immediate contact with the upstream faces of Dam Sites No. 1 and No. 2-3 and the east side access road for the purpose of limiting seepage to the capacity of the various seepage reclaim ponds.

e. Construction Inspection and Field and Laboratory Testing - Full time and competent field inspection will be essential in the glacial till borrow area during all foundation excavations for structures, during all placement of embankment dike and road materials, and during trench backfilling to ensure compliance with the requirements of the construction drawings and technical specifications that will be prepared.

The first requirement for proper construction control will be the establishment of survey control at all structure sites.

Field and laboratory testing of all embankment materials must be carried out at least periodically according to a prearranged minimum schedule and, of course, whenever doubtful situations are noted by the inspection staff.

At about the time plans and specifications are prepared, the designers will specify the tests to be used for control of construction. The test standards, and their frequency, are usually proposed by the designer, consistent with problems anticipated and the needs of the design. For example, the number of density tests normally necessary will depend on the type of construction specification--an "end result" type specification requiring much more frequent testing than a "method" type. The frequency of gradation tests will depend on an assessment of how difficult it may be to control this factor on critical zones. Furthermore, even when a frequency is specified, actual construction performance often either dictates increasing, or permits relaxing, test schedules. In addition, during the early stages of construction, much more frequent testing is normally necessary until procedures become established and test results demonstrate consistently satisfactory performance. For the above reasons, we do not intend to preempt the responsibility of the designers and reviewers by recommending test standards and frequencies. However, we recognize the State's desires to have, at this time, some idea of what the control test program might be. Therefore, Table III-5 is included herein as an example of what might be regarded as a typical program for this size and type job. It is nothing more than that, and should not be regarded as a firm recommendation at this time--we leave that to the designers and reviewers.

6. Instrumentation and Monitoring

a. General - As proposed in the design report, an instrumentation array will be installed within the foundation of the starter dam of Dam Site No. 1 to monitor and evaluate the response of the lacustrine deposits to applied loads and to compare this response with the design assumptions. This process is standard design practice, although, as will be indicated later, we think that instrumentation layouts should be developed for all of the dam structures. Since the designers indicate that additional instrumentation will be added during the final design stage, we assume that they have this in mind.

b. Layout, Types, and Purpose of Starter Dam Instrumentation - The array proposed for the starter dam at Dam Site No. 1 is explained in Section 7.3.5 and shown on Drawing 292-0044 of the design report and is proposed to consist of:

TABLE III-5

TYPICAL TESTING SCHEDULE FOR CONSTRUCTION CONTROL

Routine or Special Control Tests	Embankment Control Test Frequency Indicators				
	Compacted Impervious Materials	Compacted Coarse Tailings	Drainage Blanket Materials	Uncompacted Coarse Tailings	Slope Protection for Seepage Recovery Dams
Maximum-Minimum Density	--	3	2	3	--
Compaction	5	--	--	--	--
In-Place Density	1	3	2	3	--
Gradation (+#200 Sieve) Analysis	5	2	2	2	4
Percolation	--	3	2	--	--

Frequency Indicators

1. Each lift placed or 1 per 1,000 yd^3, whichever is more frequent
2. Each 10,000 yd^3
3. Each 100,000 yd^3, or if materials change significantly
4. As necessary
5. Each lift placed or 1 per 5,000 yd^3, whichever is more frequent

NOTE: Additional testing will be required whenever changes of material type occur in the borrow areas, or whenever necessary to check suspect conditions during fill placement

1. Electric (strain gage, vibrating wire, etc.) total pressure cells oriented vertically on the foundation to measure applied loads resulting from starter dam and later coarse tailings construction.

2. Settlement (mercury or other type) gages installed on the foundation and steel rods set in bore holes into the glacial till and extending up through the embankment, in combination to measure the change in thickness of the lacustrine deposits under applied loads and pore pressure dissipation.

3. Electric (strain gage, vibrating wire, etc.) pore pressure transducers or piezometers installed in bore holes in the foundation between the sand drains as well as within the sand drains and the horizontal sand blanket over the drains, to measure pore pressure response in the foundation and to judge the effectiveness of the sand drains.

We are fully in agreement with the intent and in general agreement with the tentative layout; however, we have had very unfortunate experiences with the long-term stability of electrical-type instruments under hydrostatic conditions. We, therefore, would very strongly recommend the use of pneumatic or hydraulic type piezometers and total pressure cells for more dependable long-term stability.

c. Recommended Other Instrumentation - We recommend that pneumatic piezometers be installed in bore holes within the foundations and in the embankments using vertical tubing risers and that settlement plates with vertical risers be installed on top of the foundations beneath the coarse tailings portions of all four tailings retention dams. This additional instrumentation would minimize interference with the construction operations, offer reasonable dependability, and minimize the lengths of tubing runs, while providing valuable information on foundation uplift pressures, flow through the embankments and foundation settlements, for comparison with the design assumptions for the completed dams.

d. Sampling and In Situ Strength Testing Prior to and After Starter Dam Construction - Sections 7.3.5.5 and 7.3.5.6 in the design report discuss proposed semi-continuous drill sampling and vane shear testing to be carried out before and after construction of the starter dam for Dam Site No. 1. This program could produce extremely valuable data for future dam construction on red clays and it will, of course, produce "record" type data for the Mile Post 7 project. The proposal is commendable, but we suggest that the part of the program dealing with the proposed vane shear testing perhaps should be more carefully considered before it is attempted. The experience of others (for example, Ladd at M.I.T. working with the varved clays of the Connecticut Valley) have resulted in a conclusion that the field vane test leads to unreliable and misleading results in certain types of varved clays.

e. Monitoring and Interpretation of Instrumental Data - A specific schedule of "reading out" instrumental data, interpreting it and comparing it with the various design assumptions must be delegated to a specific individual. Any deviations from the design assumptions must be promptly analyzed in depth to determine whether modifications are necessary to the design or construction schedule. We recommend that the designer's memorandum discussed earlier include a section which presents how specific instrumentation readings relate to the design assumptions, and identifies "early warning" conditions.

7. Storage Capacity of the Tailings Pond During Project Operations

Our analyses (utilizing a topographic map provided by Reserve Mining Company) indicate that the disposal site will have sufficient capacity to store the fine tailings refuse as proposed, provided that the projected annual quantities of refuse material are reasonably accurate and that the schedule of construction is adhered to.

After the initial starter dams have been completed, the proposed tailings pond should also have sufficient available capacity to store the inflow of any magnitude of flood during the operating life of the project as long as the stated minimum freeboard requirements above free water levels for storing a Probable Maximum Flood (PMF) are equaled to exceeded. The storage capacity at Elevation 1170 is about 12,000 acre-feet. Our estimated PMF volume for the 8.7 square mile tailings site is 8,500 acre-feet and is based on a conservative assumption that the total probable maximum precipitation (adjusted value of 18 inches) will be converted to surface runoff and stored. Above Elevation 1170, the available storage capacity increases, and so it is apparent that flood inflows thereafter can be adequately contained.

On the basis of available data, the water balance evaluation presented by Reserve Mining Company appears reasonable with regard to runoff conditions into the tailings basin and the water requirements for operations during the 40-year life of the project.

G. FAILURE ANALYSES AND FACTORS OF SAFETY

1. General

Because large reservoirs have the possibility of creating havoc if they fail, modern dam sites are very thoroughly investigated and the dams are conservatively designed. As a result, such dams are quite safe as a class. Since the possible failure of the on-land tailings dams at Mile Post 7 has been publicly identified as a concern, perhaps the safety of modern dams should be put in proper perspective so that this concern will be correctly directed towards the solution to this problem.

The history of dam failures is too long and unfortunate to ignore. Dam failures have occurred and still do occur at an unfortunate rate. Dam failures occur because of inadequate investigations, design, construction, or operation. Recent failures caused the U.S. Congress to pass a National Dam Safety Law in 1972. This law is in the process of being implemented throughout the country at the present time. It is the intent of this law to make dam engineering, construction, and operational practice in those states which do not now have adequate regulatory capability conform in the future to minimum national standards that will put these states on a par with the states already having adequate safeguards. These safeguards consist of requiring thorough and competent use of modern technology for dam design. The techniques used to assure safer dams are discussed in Chapter IV. Concern over dam safety will be better directed at seeing that these provisions work, rather than at the concept of dam utilization, per se.

Modern dams developed using current investigation, design, construction inspection, and operational monitoring technology are among the safest structures built by man. Present technology provides a sound basis for minimizing accidents and failures. Where the site subsurface information or rainfall data, for instance, must be interpolated or extrapolated, conservative techniques are used to define the condition to be addressed, and conservative design provisions are then made to assure the safest practical design for each factor. In addition to using conservative interpretations and assumptions, modern dam design practice is to use factors of safety for all aspects of the design to provide a margin of tolerance for variance, unknowns, and changes of conditions. Thus, the probability of a properly designed dam failing is extremely remote.

Although the probability of failure is remote, failure analyses and analyses of the consequences of possible failures are made. These studies are made in order to identify the possible mode of failure to be sure that it is considered in the design, and to assess the consequences of a possible failure to evaluate the adequacy of the factors of safety used in the design, as well as to identify areas of possible hazard in the event of a failure. Various types and levels of assessment can be made. An assessment of the possible types of failures of the Mile Post 7 tailings dams and the possible consequences of their failure has been made below. This assessment has been made to identify areas of concern and assess risk in order to put the safety of these structures in general perspective. The types of failures that we have identified represent, in our opinion, the range of failure modes that are reasonably possible for these types of dams at this site.

Both the degree of risk and consequences of failure vary for each of the dams and dikes proposed for the tailings impoundment; therefore, each must be assessed separately. The dam (Dam 1 as designated by Klohn Leonoff) and the three dikes (Dams 2-3, 4, and 5) each vary somewhat because of: 1) the foundation conditions, which vary from site to site; 2) the length of time each structure would be in service; 3) the height of each structure with regard to the volume of waste which its failure could release; 4) the topographic conditions which pertain to each individual dam site with regard to the route which impounded waste would follow if released; and 5) the nature and numbers of structures, development, and people who might be downstream at the time of the failure. We do not have sufficient data at this time to evaluate all of these factors; therefore, we must confine our assessment and comment to the factors for which we have data.

The analyses made below should in no way be construed to imply that adequately safe structures cannot be designed and constructed at each of the four sites. They simply mean that each site, with its own individual characteristics and problems, must be dealt with individually in order to arrive at a safe design for each. Important individual problems must first be recognized and resolved, a final design completed in accordance with proper standards and current engineering practice, and proper construction controls, and monitoring, operating, and maintenance procedures followed that are compatible with the design.

2. Modes of Failure

The most probable modes of failure include surface sloughs, slope erosion, local seepage, and other minor problems. These types of failure, however, have no serious consequence beyond the cost of correction; therefore, they will be ignored in this discussion, leaving only major failure modes to consider. In considering all of the conceivable (even though less probable) major modes of critical instability which could reasonably pertain to the dams in this development, we have narrowed the possibilities to five major categories which we feel merit consideration, as follows:

(1) Static load-induced foundation failure, followed by strain-induced liquefaction in the impounded tailings.

(2) Earthquake-induced foundation or embankment failure, accompanied by liquefaction in the impounded tailings.

(3) Embankment overtopping by impounded water, due to inadequate storage, diversion and/or flow bypass facilities, and accompanied by erosion and strain-induced liquefaction of the impounded tailings.

(4) Sliding failure of embankment due to excessive pore pressures resulting from inadequate internal drainage features, followed by strain-induced liquefaction in the impounded tailings.

(5) Piping or internal erosion of embankment due to cracking and/or concentrated seepage, combined with erosion and strain-induced liquefaction in the impounded tailings.

Each of these possible modes will be discussed in more detail below:

(1) Static load-induced foundation failure, followed by strain-induced liquefaction in the impounded tailings.

This mode of failure envisions a situation where, for whatever reason, the superimposed embankment load at a given time would become too great for the clay foundation to resist and a shearing failure would occur through the foundation and part of the embankment. Under these conditions, a sliding failure would occur, part of the embankment and some of the foundation would slide downward and outward, and if the slide takes part of the crest with it, the dam might be breached, and the water stored in the impoundment and a portion of the impounded tailings would be released as a viscous fluid through the breach.

At the sites where we have foundation information, this type of failure would probably occur due to construction of the embankment proceeding at too fast a rate for the foundation to consolidate and mobilize sufficient strength to carry the weight of the fill safely. Because the foundation materials are relatively impervious, this is a concern principally in the construction of the starter dam, but probably is not a serious concern for the dam as a whole because construction of the main structure will be relatively slow. Planned provision of sand drains in the starter dam foundation, if needed, should preclude this type of failure if they are properly constructed. If properly constructed sand drains are too expensive, sand drains should not be considered, as inadequate drains will not perform the required function. Because the main body of the tailings dam is planned for completion well ahead of the need for its full height and resultant storage capacity, the provision of piezometers in the foundation should permit the detection of any excessive pore water pressure buildup and a management of the phasing of construction to preclude this type of failure in the main dam. Thus, design and construction procedures can minimize and probably preclude failures of this type. However, if failure were to occur, it would have to be a massive enough failure to breach the dam down to the water level for the consequences to affect the public. Failure of the starter dam would (if it were to occur at all) be expected to occur during or soon after its completion; thus, even if it were to fail, it may not release enough water to be critical. Additionally, at that time, the water would probably still be clear of Cummingtonite fibers because tailings disposal will probably not have been initiated, so the environmental damage would also be minimal with this type of failure. As soon as construction of the tailings zones of the dam is started, the probability of failure will be reduced by placement of coarse tailings in the downstream portion of the dam making foundation pore pressures less critical. Although it is possible that the tailings zone of the dam could fail at any time if its height were too great for the foundation support, the failure could not affect the public unless it happened when the tailings basin were nearly full, some 35 or 40 years hence. A failure before that time would probably occur during the 10-year construction period or just following completion. Such a failure would not breach the dam and cause loss of the reservoir; therefore, the public would not be involved. After the foundation has been able to readjust to the fill load, this type of failure will be extremely unlikely.

(2) Earthquake-induced foundation or embankment failure, accompanied by liquefaction in the impounded tailings.

This mode envisions a foundation or embankment failure due to overstressing during an earthquake. As in case (1), above, the forces tending to cause instability would become too great for the foundation and/or embankment to resist, and a shearing failure would occur through the foundation and part of the embankment. Also, as in case (1), a sliding failure would occur, part of the embankment would slide downward and outward, and if the failure proceeds far enough, the retained water and a portion of the impounded tailings would be released through the breach. The probability of this type of failure at this site is very low because of the low seismicity of the area. However, the probability that a failure, if it were to occur, would breach the dam is very much higher than for case (1) above. The volume of tailings involved in the liquefaction phenomenon would also probably be very much larger than in case (1) because of the more wide-spread effects of the earthquake forces on the impounded tailings. This type of failure would be precluded by thorough foundation and construction materials investigation, a conservative assessment of the largest earthquake which might affect the site, proper consideration and incorporation of the materials properties and "design earthquake" in the design, proper construction monitoring and control, and postconstruction monitoring to confirm that design parameters are not exceeded. The probability of this type of failure can, therefore, be reduced to practically zero for this site by use of current design procedures.

(3) Embankment overtopping by impounded water, due to inadequate storage, diversion, and/or flow bypass facilities, and accompanied by erosion and strain-induced liquefaction of the impounded tailings.

This mode, as defined, envisions overtopping of the embankment at some stage of completion, due to inadequate storage, diversion, and/or flow bypass facilities. A fairly rapid erosional failure would occur, releasing the stored water and a portion of the impounded tailings through the breach. The amount of water stored and released in this mode would probably be considerably greater than in any of the other modes discussed, because the water level at the time of overtopping would be abnormally high due to one or more unusual conditions not associated with normal operation. Events which might cause such abnormally high water levels could be:

(a) Failure during a period of heavy runoff of one or both of the diversion facilities designed to convey runoff around the reservoir.

(b) Plugging of the 36-inch diameter conduit designed to act as an outlet during construction of the starter dam during heavy runoff by debris and/or sediment.

(c) Insufficient capacity of the unrestricted 36-inch diameter outlet conduit to convey excessive flood flows during construction of the starter dam.

Situation (a) presumably could occur at any stage of the facility construction or operation. Situations (b) and (c) apply only to the starter dam.

Reserve's consultants, in their design report, state that ". . . The diversion culvert can pass average stream flows during a construction season, but storms and unusual runoff conditions may not be handled until the starter dam provides sufficient head (about Elevation 1140'). Therefore, the starter dam will be constructed with a section 200 feet wide kept about 5 feet below the rest of the embankment. In the event of an unusual storm while the embankment is below Elevation 1140, excess water will go over the lower, control section. Any erosion resulting from this flow would be repaired as soon as the area dried."

Since the data indicate overtopping to be a possibility, and the designers have made provision for controlled overtopping of the fill while it is below Elevation 1140, there appears to be a reasonably good chance that such an event could occur, and that events (b) or (c), described above, must be considered as realistically possible occurrences. Should such an event occur when the starter dam is at or near Elevation 1140, there could be over 5,000 acre-feet of water stored behind the dam. Such a large volume, if released in a short period of time by a relatively rapid erosional embankment failure, could cause severe damage downstream.

The safety aspects of the probable inability of an unprotected glacial till embankment to withstand overpour are discussed in Section E of this chapter, and will not be elaborated upon further in this discussion.

However, unless the current provisions for handling excess flood flows below Elevation 1140 are modified, we believe that a relatively high risk situation would be created during the early construction period and until sufficient reservoir storage space were available to safely contain such flows. Once the required reservoir storage becomes available, and provided that adequate freeboard design criteria are followed, the chances for events (a), (b), or (c) to occur would become progressively more remote as the dam elevation increases, as the reserve reservoir storage area would become even larger. At a later stage, event (a) again becomes a possibility when the ultimate crest of the dam is being approached by the tailings and water level; therefore, the freeboard will have to be maintained at a safe level to permit storing the probable maximum flood.

This type of failure would be precluded by providing a more conservative means to convey excess flood flows past the starter dam during its construction, and thereafter, by maintaining adequate freeboard to safely contain any excess flows which enter the reservoir, regardless of source. Overtopping of the dam in the final stage of the impoundment life then becomes the final critical stage for this type of failure. Freeboard must be provided to store the water from any possible flood without spillway operation (to preclude environmental damage) and breaching to preclude public hazard. The necessity for precluding discharge of contaminated slurry water into the lake makes provision of a normal type of spillway to handle floods unacceptable.

(4) <u>Sliding failure of embankment due to excessive pore pressures resulting from inadequate internal drainage features, followed by strain-induced liquefaction in the impounded tailings.</u>

This failure mode envisions a situation where the embankment drainage system would be unable to freely drain the volume of water seeping through the embankment, regardless of source. This condition would, in turn, create a local or more widespread increase in internal pore water pressure, thus reducing the shearing resistance of the embankment and foundation materials within the area of influence. Should the reduction in shearing resistance become large enough, a failure could occur which, as in cases (1) and (2), would cause the embankment to move downward and outward and could release the stored water and a portion of the impounded tailings if it were a large enough slide. This type of failure could be precluded by a conservative internal drainage system consisting of coarse cobbs which could safely handle almost any unexpected, as well as the expected, seepage conditions. Thus, since the safety of the structure depends on the bulk of the tailings embankment being pervious, it is necessary for construction inspection to assure that the structure is built as designed.

(5) <u>Piping or internal erosion of embankment due to cracking and/or concentrated seepage, combined with erosion and strain-induced liquefaction in the impounded tailings.</u>

Historically, overtopping of the embankment by flood flows exceeding storage and/or spillway capacity was the major cause of dam failures. In recent years, since hydrology has been developed to its present state, piping is one of the greatest single causes of earth dam failures. This mode of failure envisions the formation of a path of significant concentrated seepage which might develop through the dam embankment or its foundation due to such causes as differential embankment settlement or inadequate fill compaction around the starter dam outlet conduit. Because of the long seepage paths involved and the inherent self-healing properties of the starter dam and tailings dam materials (provided gradation control is maintained), this mode, as a general consideration, is deemed to be a less likely possibility than some of the others discussed. However, one hypothetical situation involving the starter dam seems worthy of mention. Basically, this condition would require transverse cracking through the starter dam, due to differential settlement during construction, combined with a high reservoir behind the starter dam due to one or more of the excessive inflow conditions discussed in case (3) above, which would cause temporary full ponding in the reservoir. Should the reservoir rise above Elevation 1150 (the top of the broad upstream and downstream berms) under such conditions, the seepage path through which water could escape and cause internal erosion of the embankment would be considerably shorter than below that elevation. Any failure and release of water which might be caused by this unlikely, but possible, combination of circumstances, would probably occur over a longer period of time than would the failures envisioned under cases (1), (2), (3), and (4) above, because of the time needed for development of the erosion to breach the dam. This would reduce the probability of tailings liquefaction.

This type of failure would be effectively minimized by adoption of careful construction procedures, controls, and monitoring of starter dam embankment behavior. Evidence of differential settlement should be recognized by review of instrumentation and survey data obtained during construction, or by direct visual observation of any transverse cracks which might develop through the starter dam embankment. Evidence of inadequate compaction would be recognized by review of earthwork control data developed as construction proceeds.

In each of the cases above, there is a very low probability of failure if the structures are properly designed, constructed, and maintained. Furthermore, to be dangerous to the public, the reservoir must be coincidentally in a critical condition, further reducing the probability of a catastrophic type of failure at the Mile Post 7 site. As remote a possibility as there is for failure, it could happen. Therefore, it is instructive to consider the consequences of such failure regardless of probability.

It will be noted that each of the five modes described above includes the probability of an accompanying occurrence of liquefaction in the impounded tailings. Just as a water storage dam would release its impounded reservoir during a major failure, a tailings storage dam would release at least a portion of its impounded water and tailings during a major failure. The major differences between the two would be principally in the nature of stored substance which would be released, the distance which the released substance would flow, the velocity at which the flow might occur, and the environmental consequences of the resulting flood in the deposition of tailings in the wake of the flood.

When fine-grained tailings settle out from the slurry in which they are transported to the impoundment, they come to rest in a fully saturated, loosely formed, low density state. The tailings particles do not usually reach a stable, compact state unless the tailings mass is vibrated, loaded, and consolidated, or the pore water is drained from the mass. When these forces are applied to the tailings slowly enough to permit the pore water to seep away, thereby making space for a closer grain spacing as a result of the force, the mass consolidates and becomes denser. When a considerable force is applied faster than drainage can permit the volume reduction to take place, much of the force is transmitted to the pore water rather than through the tailings particle structure, thereby reducing the strength of the mass, sometimes to the degree that the mass will behave like a liquid (at least until it moves a sufficient amount for the water to escape from the tailings grain pores and the mass comes to rest due to an increase in shear strength). Liquefaction due to earthquake shaking or mechanical vibration is relatively well known. In addition, liquefaction can be induced in saturated, loose, uniformly graded, fine-grained relatively equidimensional tailings by the sudden release of confinement and/or the occurrence of excessive pore pressures, such as can exist with the sudden drawdown attendant with a rapid embankment failure. The tailings then "liquefy" and flow in combination with the stored water from the reservoir, to settle out somewhere along the way or finally in a lake or the ocean depending on the relative volume of accompanying water. It is therefore necessary, in evaluating the consequences of a failure of a tailings impoundment, to recognize that the volume of material that can pose a potential threat can exceed the volume of water in storage if the failure is rapid enough. If the failure is slow enough, the loss of tailings will be limited to that which is eroded out by the outflow of the reservoir water.

From the above discussion, it is obvious that the mode of failure would have a major role in determining the volume of tailings which might liquefy; the possible condition of an earthquake-induced failure would probably involve the largest potential volume of "liquefied" material. There are several well documented case histories of inadequately designed and constructed tailings dams which failed in Chile during a major earthquake in March of 1965. In one instance, more than 2 million tons of tailings liquefied and flowed from an impoundment, traveled 12 kilometers (more than 7 miles) in a few minutes, destroyed part of the town of El Cobre, and killed more than 200 people. Despite this catastrophic occurrence, all of the tailings did not liquefy and flow from the reservoirs involved. Where the material was held in place long enough for enough drainage to take place or where the tailings had been previously consolidated from dessication, tailings retained their original location on near-vertical slopes, many feet high.

W. A. Wahler and Associates have investigated the Chile failures and several other, fortunately noncatastrophic, cases of tailings dam failures which occurred under nonearthquake conditions here in the United States, but which also involved the release of some portion (proportionately much less than at El Cobre) of the impounded tailings. In some cases, the tailings were eroded from the reservoir, while in other cases, they "liquefied" due to drawdown stresses and strains. In each case, the released tailings flowed for some distance downstream, depending upon all the physical conditions which prevailed in each case.

The above discussion is not meant to draw a parallel between the inadequately or nondesigned dams which failed and those proposed by Reserve

Mining Company, which are being designed, and will be constructed and operated, using modern technology. Additionally, there will be adequate review of the plans and specifications before construction commences and the construction inspection and operational monitoring will be regulated by competent State authorities. The principal point to be made is that <u>should</u> a dam failure occur for <u>any</u> reason, it <u>must</u> be anticipated that most of the water in storage and at least a portion of the impounded tailings would be released and could flow for considerable distances downstream, causing destruction in the path of flow. The remainder of the discussion which follows is based upon this probability.

3. Potential Consequences of Failure

A generalized assessment has been made of the potential consequences of failure of Dams 1, 2-3, 4, and 5 to determine, in a qualitative way, the physical features which might be seriously affected by such a failure. As implied earlier in this report, the assumption of a major failure is also accompanied by the assumption that such a failure would be relatively rapid. Under these conditions, the volume of released water and tailings materials would be expected to be of such magnitude that normal downstream channel capacities would be greatly exceeded, and significant damage could occur.

For purposes of clarity, the major features which could be affected by a failure of each of the four dams are listed individually below, along with the dam to which they refer. After the listing for each dam, a brief narrative discusses, in a general way, the extent to which damages might be expected to occur from the worst conceivable type of failure postulated above. The assessments presented below are approximate only, but each assumes release of a large quantity of water through a breach in the embankment large enough to involve the impoundment pool. More precise analyses would be needed if more finite answers must be obtained. For this reason, no attempt will be made herein to discuss the details, but rather only the broad probable ramifications of such a failure event. In general, the listings below of the potentially affected major features will proceed from each dam in a downstream direction toward Lake Superior.

a. <u>Dam No. 1</u> - The following structures and/or facilities are located downstream in the path of a possible failure of Dam No. 1.

(1) Reserve Mining Company Railroad
(2) Power line to Silver Bay
(3) Road between towns of Silver Creek and Beaver Bay
(4) Beaver River
(5) Outskirts of the town of Beaver Bay
(6) U.S. Highway 61
(7) Lake Superior

The flow distance between Dam No. 1 and Lake Superior is approximately 7 to 8 miles. Should a major failure of Dam No. 1 occur, it is anticipated that released water, combined with tailings, would flow all the way into Lake Superior. Sections of the power line, roads, and railway crossing and adjacent to the stream channel would probably be destroyed. The streams themselves would be choked with tailings and debris. Low-lying structures along the streams and in the town of Beaver Bay would be destroyed or severely damaged. Tailings and debris would likely flow into Lake Superior. Dam No. 1, being the highest of the four, would have the greatest potential for release of a large volume of impounded material. The loss of life would probably be minimal, but would depend upon the number of people in the affected area at the time and on the amount of warning time available for evacuation. Diligent construction and operation procedures should minimize the probability for loss of life in this possible but improbable event.

b. <u>Dam No. 2-3</u> - The following structures and/or facilities are located downstream in the path of a possible failure of Dam No. 2-3.

(1) Road between Lax Lake and Beaver Bay
(2) Cedar Creek and East Branch Beaver River
(3) Power line to Silver Bay
(4) Beaver River
(5) Outskirts of the town of Beaver Bay
(6) U.S. Highway 61
(7) Lake Superior

The flow distance between Dam No. 2-3 and Lake Superior is approximately 6 to 7 miles. Should a major failure of Dam No. 2-3 occur, it is anticipated that, as with Dam No. 1, the released water, combined with tailings, would flow into Lake Superior. Sections of the power line, roads, and railroad crossing and adjacent to the stream channel would probably be destroyed or severely damaged. The streams would be choked with tailings and debris.

Low-lying structures along the streams and in the outskirts of the town of Beaver Bay would be destroyed. Tailings and debris would flow into Lake Superior. Dam No. 2-3, being the second highest of the four, would have the second greatest potential for release of a large volume of impounded material. However, since the saddle upon which the dam would be constructed has its low point at approximately Elevation 1155, the outflow of water or tailings material impounded below that elevation would be impossible.

In addition to the most probable path of the flood resulting from a failure, there is a possible route for some of the water and debris through the town of Silver Bay and the Reserve Mining Company mill site. This route is longer and topographically 20 to 25 feet above the lower valley heading to the Beaver River, but there is precedent for such flood bifurcations. This route would be over the topographically low saddle that exists near the junction of the East Branch of Beaver River and the stream which flows from Bean Lake. The stream course below this juncture is steep, narrow, and rocky. It is conceivable that this reach of the stream could become blocked by debris, trees, etc., backing the water and tailings upstream to, or beyond, the saddle. The saddle, being at approximately Elevation 1075, may or may not preclude part of the flow from spilling out of the East Branch drainage into the town of Silver Bay. A detailed study would have to be performed to accurately predict this. If the flow were to spill out, it would undoubtedly continue on downstream into the mill site area and Lake Superior.

c. <u>Dam No. 4</u> - The following structures and/or facilities are located downstream in the path of a possible failure of Dam No. 4.

(1) Road between Lax Lake and Beaver Bay
(2) Cedar Creek and East Branch Beaver River
(3) Power line to Silver Bay
(4) Beaver River
(5) Outskirts of the town of Beaver Bay
(6) U.S. Highway 61
(7) Lake Superior.

Dam No. 4, being directly adjacent to Dam No. 2-3, but on the east side of the reservoir, would have a similar and only slightly shorter flow path to Lake Superior than would Dam No. 2-3. The topographic saddle upon which Dam No. 4 would be constructed has its low point at approximate Elevation 1195, thereby limiting the outflow of any significant volume of tailings impounded below that elevation. As with Dam No. 2-3, it is uncertain whether flowing material would back up and spill out of the East Branch drainage and down into the town of Silver Bay and the mill site, but it would be less probable because the maximum volume of outflow should not be as large as that from Dam No. 2-3.

d. <u>Dam No. 5</u> - The following structures and/or facilities are located downstream in the path of a possible failure of Dam No. 5.

(1) Bear Lake
(2) Power line to Silver Bay
(3) Reserve Mining Company Railroad
(4) Roads between town of Beaver Bay, Lax Lake, and town of Silver Creek.
(5) Beaver River
(6) Outskirts of the town of Beaver Bay
(7) U.S. Highway 61
(8) Lake Superior

Dam No. 5 would have the shortest potential flow path to Lake Superior. Being located on a topographic saddle with its low point slightly above Elevation 1200, it would probably have the lowest volume discharge potential of the four dams. However, should a failure of Dam No. 5 occur, Bear Lake, being immediately adjacent to the dam site, would probably have most of its impounded water displaced by tailings. This displaced water, along with the water and tailings released from the impoundment, could destroy sections of the power line, roads, and railroad crossing and adjacent to the stream channels. The stream channel areas would be choked with tailings and debris. Low-lying structures along the streams and in the outskirts of the town of Beaver Bay would be destroyed or severely damaged. Tailings and debris would flow into Lake Superior. The consequences would probably be much less severe than from the failure of Dam No. 1, but would encompass the same type of damage.

4. Techniques for Mitigation of Potential Downstream Damages

From the standpoint of a major failure of any of the four dams, there are few practical actions which could be taken in advance to mitigate potential damages. Power lines, roads, streams, and the railroad as presently located could not be protected from damage. On the basis of a detailed study which would have to be performed to predict approximate high flow line elevations which might result from potential failure of each of the dams, it would be possible to move low-lying dwellings or other structures to higher ground, if this were deemed desirable. The probability of flow into the town of Silver Bay could be better ascertained and it would be possible to devise measures to prevent such an occurrence. There do not appear to be any feasible means of preventing flows resulting from failure of any of the four dams from reaching Lake Superior other than, of course, precluding failure.

5. Conclusions

We have tried here to put the dam safety and failure potential into perspective on the basis of a limited study. We have presented our assessment of the potential consequences of major embankment instability at each of the four damsites proposed for Reserve Mining Company's Milepost No. 7 site. Since no one can guarantee the absolute permanence of anything done in this world, we consider that this assessment has realistic significance in weighing all of the pros and cons of the project. However, perhaps the single most important conclusion that can be presented concerning this assessment is to try to emphasize the proper perspective in which the entire problem of earth dam and tailings dam safety should be viewed. There is no denying the fact that an earth dam or tailings dam, if it fails catastrophically, can be a cause of widespread damage and loss of life. However, in the course of history, there have been many thousands of these types of structures built throughout the world. Despite the fact that many of these structures received little or no benefit of modern engineering design and construction practice, there have been surprisingly few major failures recorded, particularly major failures which involved widespread damage.

With the advent of modern soils and hydrologic engineering practice, it has been possible to design and construct even safer structures than ever before. With the application of modern design technology and exertion of proper controls and safeguards during construction and operation, the physical risks involved in this type of venture can be reduced to an absolute minimum. The degree of conservatism involved in each project can be adjusted to be compatible with the potential consequences of an unforeseen failure. Following this line of reasoning, one would expect that a major earth dam poised above a large metropolitan center would normally require a greater amount of design technology and conservatism than would a farmer's small irrigation pond in the country. Such, in fact, is usually the case for modern day structures. The sophistication of the design can be tailored to suit the needs of the project.

Tailings dams, until recent years, have involved little modern soils engineering technology. They were built by trial-and-error, rule-of-thumb, or whatever other nontechnical criteria happened to suit the builder's fancy. Unfortunately, such an approach is still not all that rare today, even though modern technology is available to solve many of the problems which have traditionally been associated with tailings dam construction and operation.

In the case of Reserve Mining Company's Mile Post 7 project, we see a very strong attempt being made by the owner and the State to fully utilize available technology and to produce a well-engineered end product which will be functional, conservative, and safe. Provided this attitude is followed through final design, construction, and operation (regulatory reviews and controls can be invoked to see that it is), we see no reason why any doubts concerning dam safety should prevent construction of the four dams in the Mile Post 7 project. See Chapter IV for a discussion of the regulatory controls that should be applied to maximize the safety of the structures used for the tailings impoundment.

H. ABANDONMENT AND RECLAMATION

A review was made of the Reserve Mining Company's proposed plans for abandonment and reclamation of the disposal area, as presented in Volume I of the Environmental Report prepared by Arthur D. Little, Inc., and dated April 30, 1975. Since many aspects of the rehabilitation program remain to be resolved through planned and ongoing research efforts, it is not possible at this time to provide comprehensive comments relating to a "final" course of action proposed by the Company. For this reason, our comments at this time will be limited to some aspects of the proposed plan which we believe require further attention while the final details are being resolved and some suggestions for consideration in final design.

The proposal, as it is now, for formation of a new "lake," or series of small ponds on top of the abandoned waste area, accompanied by a spillway cut through rock to discharge excess flows into Bear Lake or the Beaver River, seems worthy of comment. It is not clear how such a plan could be environmentally acceptable if the water flowing across the top of the tailings and then discharging from such a lake were likely to be able to take Cummingtonite asbestiform materials in suspension from anywhere in the drainage area. Since the proposed spillway would presumably operate only during periods of high runoff when available settling time would be minimal, it would seem to be very difficult, if not impossible, to claim without further research and adequate documentation that discharged water would be free of this contaminant. Perhaps the percentage of contaminants would be low enough as to not be objectionable, but it seems that this question should be resolved before such a plan could be approved.

If the downstream slopes of the tailings dams and the completed areas of dry cobb disposal dumps are adequately protected against long-term erosion as the structures are constructed, this part of the project abandonment will be completed when the mining operation is terminated. Other major aspects of the abandonment plan, however, will just begin to be undertaken at that time.

Assuming that abandonment is to be carried out as planned, the capacity of the tailings impoundment and cobb dump will have to be adequate for the volume of material mined and processed on a by-weight basis. In addition to an impoundment or reservoir volume adequate to store the refuse volume, we believe that there will have to be capacity provided at the end of operations for at least the minimal amount of operational water and unsettled tailings, plus the maximum potential precipitation or storm accumulation and inflow, plus a reasonable capacity for a second storm before the reservoir excess can be treated and discharged. After cessation of operations, the water in storage will have to be filtered before it can be pumped out of the reservoir and into any stream leading to Lake Superior. The treatment facility required for this operation should be available for the last couple of years for disposal of excess storm water to minimize the excess storage capacity that would otherwise be required.

After unwatering the reservoir and dewatering the surface tailings to the degree practical, final grading, shaping, and surface preparation of the tailings impoundment area will begin. Meanwhile, the dry cobbs disposal area can be prepared. The remaining surface can be vegetated in order to stabilize this mass. Proper vegetative cover will probably be adequate to stabilize the surface of these very porous deposits against wind erosion, and control of erosion from that source may suffice because most of the excess water falling thereon will seep into the mass, minimizing erosion of its surface. The two creek diversion dams may have to be reinforced or made part of the disposal dump so that they will continue to perform this function long into the future with little or no maintenance. The availability of coarse dry cobbs makes this an economical process, if planned properly. The question not yet answered--and that must be answered in order to make adequate provisions in the design--is what will be the quality of the infiltrated rain and other seepage water that courses its way through the cobbs waste dump to emerge as springs on top of the natural ground surface and to flow into the impoundment drainage areas as surface water? Will this water be clean enough to discharge into Lake Superior? It may be necessary to construct reverse filters at exit points to clarify the seepage. It is possible that such could be constructed using tailings. This would necessitate a leaching cleanup process but may not be too serious a problem as it might be accomplished during the 40-year operational period.

After this seepage water emerges from the cobbs dump and the tributary areas on the periphery of the impoundment, it must mingle with the rain water falling directly on the impoundment surface and cross the surface to the outlet without being degraded to an unacceptable degree so that it can flow into the local streams without polluting them. We believe that this may take more than a vegetative cover, since although such a cover may be adequate to control wind erosion and dust, or even normal soil erosion, it may not be able to keep Cummingtonite asbestiform fibers from being picked up by water flowing over its surface.

We believe that the proposed abandonment plan is deficient in that it does not prove that the proposed scheme will limit the Cummingtonite asbestiform fibers liberated from the storage area to an acceptable amount. We believe this must be proved. This is in addition to meeting normal water quality standards.

Based on the present state-of-the-art, and on research being conducted by Reserve Mining Company's consultants, there is little doubt that a satisfactory program of vegetation can be developed for the disposal areas to preclude dust problems. However, in addition to not proving that vegetative cover is the whole answer, the cited report states that approximately three years will be required to construct the tailings dams to the point that a revegetation program can be initiated. During this period of time, it seems that a certain amount of erosion and erosion-required-maintenance of borrow areas and embankment slopes would have to be anticipated. Siltation of the seepage collection pond below each dam could prove to be a maintenance problem until such time as vegetation can be established on the downstream face of each dam to minimize potential erosion problems. Everyone's interests will be served if such cover is placed where needed at the earliest point in time.

Reserve's concept of conducting a vigorous reclamation program throughout the 40 years of the tailings disposal facility operation represents a sound approach that undoubtedly will minimize the amount of final cleanup grading and vegetation, and the ongoing maintenance work after abandonment. During that long period of operation, a great deal of experience will be gained through coping with the operational problems. This experience should add to the knowledge now available to assure an even better final solution than can be assured on the basis of present or additional short-term research. Therefore, it would seem to be desirable to utilize this experience to upgrade the abandonment provisions to minimize maintenance after abandonment. Other operational observations and monitoring results may be of use to make final abandonment easier.

For example, some local runoff and seepage from the tailings dams will continue to occur. If this water can be proved to be acceptable for safe discharge into local streams, maintenance problems will probably be minimal. However, if this water, because of its quality, could not be safely released, the facilities that will have to be developed to care for it will have to be greater and ongoing maintenance may have to be more intensive and be required for a very long time into the future. A better understanding of the final abandonment needs will be gained as the program progresses. Therefore, plans must provide not only a tentative solution, but also for needed monitoring and research to provide for the final solution. Present regulations require that at least a tentative plan must now be submitted, even for stages that must be carried out in 40 years, and approved in order to permit the project to be initiated. However, it is obvious that no final unalterable plans can be acceptable at this time and unconditionally approved for all time. It is not possible to prevent a reassessment from being made just before abandonment; therefore, it seems prudent to proceed on the basis that such will be required and to expect to keep adequate records for evaluation as operations are carried out and to assure that improvements are being made as experience shows them to be necessary or to prove the adequacy of the program to assure its ultimate acceptability.

The Reserve abandonment plan includes consideration of early termination of disposal due to early cessation of mining for reasons as yet unknown. We believe that this plan will work as long as the water from the reservoir then in storage is removed, treated to remove Cummingtonite asbestiform fibers, and released to Lake Superior, and the embankment is breached so that it cannot impound water under any circumstances, thus forever changing its status from "impoundment" to "dump." After this has been done, the final grading and environmental protection plan work can be implemented.

We believe that there is another early termination situation that merits consideration. This is a reverse type of situation that may come about if the storage capacity of the tailings impoundment is found to be inadequate. This could terminate the mine life. This may come about for one of the two reasons listed below:

1. The weight-volume relationships of the various refuse materials may be different than estimated because of less than expected deposited or "settled" densities of the cobbs or tailings with the result that the planned capacity of the storage area might be inadequate. Adequate storage could only be gained at a late date by costly enlargement or area supplementation; therefore, a conservative reserve or over-capacity potential, or a potential for planned enlargement would be a wise investment easier made at the planning stage than later.

2. The discovery of supplemental ore within the technical capability of the plant and within an economical haul distance may be discovered. Plant and operational expansion may be justified if refuse handling capability does not preclude desired expansion. Current plans could be altered to provide for future expansion in the event that such were warranted at some time for whatever the reason.

In conclusion, Reserve Mining Company appears to be making a concerted effort to develop a sound abandonment and reclamation plan which will require a minimal amount of extra effort to phase out when tailings disposal operations cease. However, we believe that a serious reassessment of the abandonment plan is needed and that either justification should be given to the present plan or it should be modified to assure discharge of acceptable surface drainage water into the local streams. A certain amount of research is being done now, and it is obvious that, over the 40-year operating period, new information will be gained which could significantly affect reclamation and final abandonment plans, particularly those which involve the handling of water from the abandoned waste area. It is therefore concluded that any permits issued by the State of Minnesota will have to be conditional, and that an ongoing program of monitoring, coordination, and cooperation will have to be conducted between the State and Reserve Mining Company so that progress approvals can be given by the State as new information develops and plans are formulated utilizing this information. Reserve Mining Company should not be expected to submit a rigid "final" abandonment plan for approval prior to receiving conditional approval to proceed with the development. However, plans for a minimal ongoing vegetation program should be firm before beginning development, and the State should establish certain time checkpoints to verify that the Company is meeting its commitments.

CHAPTER IV

REGULATORY CONTROL

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REGULATORY CONTROL

A. INTRODUCTION

An essential element of any system for enforcing regulations covering refuse disposal is the review and approval of final detailed design, plans, and specifications for all critical facilities by a designated regulatory entity prior to initiation of construction. The approval of the plans and specifications is then made contingent on their being carried out during construction. For mine refuse projects, the construction phase is largely an operational process; therefore, it is extended over a long period of time. During this time, new factors may be developed or conditions may change. Therefore, the inspection process must be able to assure not only that the work is carried out in accordance with the approved plans and specifications, but also that the conditions assumed in the design are consistent with conditions actually encountered during construction, and that all new factors and conditions encountered are taken care of by properly designed and approved modifications to the plans.

To make the regulatory system work, the review procedure must be well understood by all concerned and systematically carried out to the maximum extent possible to assure that standards or requirements are applied uniformly and effectively.

The objectives of review and approval of plans and specifications are to:

1. Assure that at least minimum safety standards are met.

2. Assure that at least the minimum investigations and analyses are undertaken for proper design and construction planning.

3. Assure compliance with the required standards and accepted engineering principles and criteria for design and construction.

4. Enable the regulating agency to evaluate the need for and, if necessary, request additional analyses and/or investigations, commensurate with the degree of hazard or concern involved, in order to properly safeguard persons and property.

5. Provide an overview, or second opinion, on the adequacy of the design of the facility, thereby minimizing the possibility for serious oversights of critical aspects.

6. Provide fair and equitable enforcement of regulations and standards.

Approval of plans and specifications for construction does not, however, imply that a completed project will automatically be approved if construction is not performed in accordance with plans and specifications. Even though a regulatory agency may have reviewed plans and specifications and issued approval for construction to proceed, the approval is by necessity conditional; the review and approval function must thereafter be a continuing process. This is true because the design itself is a continuing process, which is not completed with the preparation of plans and specifications. During construction of any major project, and particularly a project involving extensive earthwork and subsurface construction operations, conditions are often discovered which differ from those projected on the basis of the design level investigations and which, if not treated by design or specification modifications, can have a detrimental effect on the operational success of a project, or even its safety. Obviously, the more extensive a preconstruction investigation can be made, the better are the chances of limiting the occurrence of unanticipated conditions during construction. However, no preconstruction investigation can be all-inclusive enough to guarantee precluding such deviations, and designers, owners, and regulatory agencies must formulate their plans and operational principles on the basis that modifications to designs will probably be necessary. The degree to which modifications during construction may be expected will usually be inversely proportional to the level of confidence that can be placed in the preconstruction investigations (whether this level of confidence stems from the adequacy of the investigations themselves or from the complexity of site conditions).

Because the regulation of mine refuse facilities is relatively new in the United States, procedures, technology, standards, and guidelines generally must be borrowed from other fields where longer experience has permitted their development, rather than take the time to develop procedures and technology from scratch. The field with the most applicable technology is the regulation of dam safety as practiced in those states having a large number of major dams and a history of problems. Perhaps a discussion of standard practice in the regulation of dam safety in those areas where it has been developed into a science would be useful in the context of the current project considerations.

Agencies having regulatory authority over the safety of dams have long recognized the above considerations, and have developed procedures, backed by the necessary legislation, to deal with them. In addition to the review of final design investigations and studies and of plans and specifications, these agencies actively follow up during construction and after the facility is placed in operation.

During construction, the agencies make continuous or periodic inspections--and special inspections at such times as critical items of the work are being accomplished--to assure that construction is being performed in conformance with the approved plans and specifications, and that exposed conditions which might adversely affect the facility as designed are not being overlooked. The intensity of inspection is a function of the nature and complexity of the elements under construction and the confidence the agency has in the construction supervision. The owner is required to perform, at his expense, such work or tests as are necessary to assist the agency in determining that conformance is being secured. If, at any time during construction, the agency finds that safety considerations require modifications to the work, the agency will instruct or order the owner to revise the plans and/or specifications and submit the revisions for approval. Should the agency find that the construction is not being done in accordance with the conditions of approval for construction or with the approved plans and specifications (or revisions thereto), the agency will order, in writing, immediate compliance and may order that no further work be done until such compliance is effected and the corrective action thus taken is approved. Cases are on record where control of a dam construction job has become so lax that the regulatory agency has had to order removal and replacement of substantial amounts of completed work.

Upon completion of a dam or reservoir, the owner is required to give notice of completion to the regulatory agency, and to then file with the agency supplementary drawings and information which describe the project as constructed, and any other data and construction records bearing on the safety and permanency of the dam and reservoir. Upon a finding by the agency that the dam and reservoir are safe to impound water, the agency will issue a certificate of approval to store water subject to any limitations that are included on the certificate.

Once a dam has been placed in operation, the agency monitors its maintenance and operation to the extent necessary to safeguard life and property. The agency may require the owner to maintain records on operation and maintenance of the facility and to submit periodic reports. If conditions warrant, the owner may be required to conduct a formal surveillance program including periodic measurements of internal pore pressures, displacements, drain flows and other performance indicators and to analyze and interpret the facility's performance and submit formal reports to the agency at periodic intervals. The frequency and extent of such a program will, of course, depend on individual site conditions and performance history. The agency itself makes periodic inspections (their frequency depending on the individual case) and also makes special inspections if unusual circumstances or occurrences dictate. The owner is required to promptly notify the agency of any unusual or alarming circumstance affecting the dam or reservoir. In the event conditions are discovered which may bear on the safety of the facility, the agency may order the owner to conduct special geologic or engineering investigations and/or to effect remedial action if warranted. In the extreme, the agency may revoke a certificate of approval to store water whenever it determines that a dam or reservoir constitutes a danger to life and property, or it may amend the terms and conditions by issuing a new certificate containing revised limitations.

It should be noted that the procedures and sequence discussed above, which are generally applicable and time-tested for water storage projects, contain one important factor which does not exist for most tailings disposal impoundments. Normally, the construction of a dam for the purpose of storing water is completed before any significant impoundment (other than possible temporary impoundment during flood periods) occurs. Thus, implicit in the review and approval process is the possibility that, if compliance with the conditions of approval and requirements of safety cannot be secured from the owner, a certificate of approval to operate the facility will not be issued. Furthermore, if conditions are discovered that necessitate modifications to the design or special remedial treatment, the opportunity exists to accomplish this before the project is put into service and becomes a potential hazard. On the other hand, implementation of a tailings impoundment facility is usually (at least for a substantial portion of its life) a dynamic process--that is, dam construction and project operation occur simultaneously. Therefore, the need for identification of, and timely response to, conditions that necessitate modifications to the design cannot be overemphasized. The owner or his designated representative must promptly advise the regulatory entity of any conditions discovered which bear on the adequacy of the facility, so that any necessary modifications can be proposed, evaluated, and disposed of in a cooperative and timely manner.

B. FACTORS PERTAINING TO MILE POST 7 PROJECT

Any consideration of the probable scope of regulatory agency involvement in monitoring a project must address certain specific factors which pertain for that project. Such factors as physical conditions, potential consequences of inadequate performance, extent, and adequacy of investigations conducted prior to the start of construction, and the degree to which the owner or constructor demonstrates reliable performance, will all influence the extent to which the regulatory agency must become involved. Thus, the degree of agency involvement and the agency's manpower requirements cannot be generalized, but rather must be tailored to the circumstances surrounding a given project.

To date, the information that has been presented for review falls far short of being final design-level documentation. Chapters II and III identify a number of major areas of concern for which specific investigations or studies still have to be made. As the investigations proceed, it is likely that other areas of concern will also be identified. As more information is gathered during these investigations, the designers will (assuming that a permit is granted for implementation of a project at the Mile Post 7 site) be developing the design to the level where plans and specifications are prepared. This must, of course, include proposals for treating specific problem areas, as well as more firm proposals for instrumentation and for evaluating the effectiveness of the various proposed details and treatments. At that time, it will be possible to establish a more definite idea of the areas that the review entity will have to monitor and the extent of involvement and record review that may be required. However, to provide a basis for the State of Minnesota to begin planning how it will discharge its review responsibility, the following section presents, to the extent we are able to do so with the information now available to us, recommended guidelines for the review process.

We consider it essential to re-emphasize here that all parties to this case must understand the importance of the State's regulatory function. In the event that a permit is granted for the Mile Post 7 site, the State's jurisdictional authority must be supported in a manner that will permit it to discharge its task and secure responsible compliance with the demands of public safety.

C. RECOMMENDED GUIDELINES

In the event Reserve Mining Company's application for implementation of the Mile Post 7 plan is disposed of favorably, it will be necessary that plans and specifications for construction be developed and presented to the State of Minnesota for review. By that time, it will be essential that a well-conceived and coordinated process for the technical review of the final designs be in effect. The review should be conducted for the State by a team of professionals embracing the various required disciplines--as a minimum, geology, earth dam engineering, hydrology and hydraulics, soil mechanics, and coastal engineering (although the need for the latter discipline may not exist until somewhat later, depending on the progress of studies related to the delta). Some state agencies having regulatory authority over large numbers of facilities of similar nature employ experienced staffs embracing a broad spectrum of disciplines. The broad-based workload of such an agency justifies maintaining a permanent technical staff, so that a concentrated final design review for any specific project can be undertaken by the existing staff. Agencies which do not have long-term workloads demanding permanent employment of such professionals have to take a different approach in meeting short-term requirements. We recommend that the State of Minnesota solve this problem by retaining a Board of Consultants to assist in the review of the final design and the plans and specifications, as well as to provide an overview of construction and provide advice on specific problem areas discovered during construction. Where specialized studies or calculations are necessary as a check on any specific features of the design, this can be accomplished by backup technical personnel of consulting firms. We believe it necessary, however, that one State employee be assigned as Review Coordinator. This person, along with the Board of Consultants, would make up the Technical Review Team, which could be augmented as necessary by backup consultant firm personnel, specialized consultants at such times as they are needed to assist in resolving a specific issue, and State personnel when likewise needed.

The need for any special evaluations, and a conclusion as to who should perform them, should be developed by the Board of Consultants and the State's Review Coordinator, and recommend to the applicable State administrative officer for approval.

As the project moves into the stage of review of final design and plans and specifications, we consider it essential that direct dialogue be had between the Technical Review Team and the project designers. It is not possible to accomplish an effective review of the final design of a complex project such as this by obtaining information, design criteria and results through intermediaries only. The opportunity must exist for the designers and reviewers to discuss, in conference, the data, assumptions, methods of investigation and the intent of the design. This will permit the information developed to be directly presented and explained by the designers, and to be better understood by the reviewers. It will also permit the reviewers to better communicate ideas and areas of concern to the designers. This cannot help but be of benefit to all parties concerned, and lead to a more timely execution of the entire review process. By this recommendation we do not intend that other interested parties be excluded from the review process or that formal transmittal of necessary documents be precluded. Certainly, it is to be expected that Reserve Mining Company and the State of Minnesota may want to have representation at important review conferences, and it will still be necessary to formally transmit documents such as plans, specifications, and special reports (both for the record and so that the Technical Review Team members can have them to study in advance of any conferences). It will also be desirable to place on the record any requests for additional information or important comments and conclusions that are made at such review conferences. However, we do not believe it will be possible to have an effective and timely review of the final design without such direct contact between designers and reviewers.

In order that the State may adequately plan and exercise its regulatory function during construction, it will be necessary that it have in hand a construction schedule, in sufficient detail to show when critical activities or items of work are planned. In this way, the State will be alerted to periods when relatively heavy site inspection demands can be expected, and to the approximate times when specific features or items of work will have to be inspected. We recommend that one condition of any approval to construct be the requirement that a detailed construction schedule be provided to the State before construction of the project starts. This will not obviate the need for Reserve's representative on site to give the State shorter-term advance notice as to when specific items of work are to be done, so that the State can arrange to have its inspector available. Additionally, from time to time as work progresses, an updated overall schedule should be transmitted to the State. We recommend that Reserve Mining Company be required to designate an on-site representative with whom the State's inspector can communicate to obtain any needed information and to discuss resolution of any apparent problem areas. This representative must have the position and authority to discuss these matters with the State's representative and to carry out any and all agreements made.

With the information available to date, it is difficult to predict if full time inspection will be needed or, if not, how often it will be necessary for State representatives to inspect the work. To a large extent, the frequency of inspections will depend on specific problems encountered, rate of construction, and the degree of confidence the State is able to place in the control being exercised over the work. However, it should be anticipated that, in the early stages of construction, when the starter dam foundation is being prepared for embankment placement or special foundation treatment is being carried out, inspections will have to be quite frequent--possibly on a weekly basis. During the early stages of starter dam placement, frequent inspections will also probably be necessary, since dam construction often requires a period of time before procedures are properly "shaken down" and construction control becomes adequate.

The following guidelines, which cannot be all-inclusive because so many of the details of the project are yet to be resolved, suggest when inspections of the work should be made by State representatives:

1. Periodic inspections of all project work, the frequency depending on several factors as discussed above.

2. Inspections of prepared foundations just prior to embankment being placed upon them.

3. Inspections of special operations, such as drain installation, pipeline and culvert installation, grouting (if done), blanket placement, installation of monitoring devices, and any other critical elements of work.

4. Inspections of any completed cuts made for borrow materials that are within the confines of the proposed tailings storage area, prior to their being covered up or inundated.

5. Special inspections of the project area after storms to determine that diversion works and drainage channels and ditches are functioning adequately, and that erosion is being controlled.

A complete written record must be made of each inspection and photographs should be taken of critical items, as well as general site pictures and operations. If any deficiencies are observed during the inspection process, they must be recorded and reported to Reserve's representatives. It is the operator's responsibility to devise a method of correcting the deficiency. The regulatory agency must make certain the deficiencies are corrected, but cannot usurp the operator's authority or liability by dictating the method of correction. It should also be noted that the fact that State representatives will be inspecting the project from time to time in no way can relieve the owner of the responsibility to provide adequate control of the work, or to notify the State of any unusual conditions discovered and develop corrective action.

In addition to making inspections, the State should monitor the effectiveness of construction and performance of the facilities by reviewing critical data which should be developed by Reserve's representatives. Typical data which should be submitted to the State for review would include (but not be limited to) the following:

1. Summaries of soil test results, such as construction control tests for gradation, moisture content, and density, as well as record tests of engineering properties. A separate summary should be prepared for each embankment zone or element (such as glacial till, coarse tailings compacted with spreading equipment, heavily compacted coarse tailings, drain zones, and blankets), so that the reviewer can readily evaluate the trend for each element. It is not necessary, or desirable, that the State be furnished copies of individual test results (as long as such results are maintained available for perusal if necessary for some special purpose). If the summaries indicate the dates and locations of the tests, along with the basic results, and if they are furnished on an agreed-upon periodic schedule, they will form an excellent basis for evaluating trends with time and flagging any impending loss of quality control, or change in material properties.

2. Results of instrumentation readings or measurements of any other monitoring devices, together with the designer's comments on how the results relate to the design assumptions. The State should also use the portion of the "Designer's Memorandum" (see Chapter III) which discusses the interpretation of instrumentation readings as an aid to evaluating the meaning of specific results.

3. Geologic maps of exposed foundations or at other key features, as soon as these maps are compiled and reviewed. We do not suggest that this should involve submittal of maps of very small areas at extremely frequent intervals, because proper interpretation of rock and soil conditions at a given location often

requires information from adjacent areas. However, unlike the case of a water storage dam, where compilation of geologic maps at the end of construction and before the project is put into operation is usually sufficient, we believe that the "dynamic" nature of this project requires that such information be compiled and reviewed regularly as the work proceeds. In this way, if problems develop in an area that has already been covered up or inundated, information will be available, in useful form, to assist in making an immediate determination of the source of the problem and in effecting corrective action.

4. Records of grouting operations, in the event such treatment is undertaken. In addition to tables summarizing grout hole locations, sequence of grouting, and mixes, pressures and grout takes for intervals of holes, we recommend that sections along any grout curtain be plotted showing diagrammatically the grout takes for the various holes and depth intervals. These should be furnished to the State at regular intervals, or as reaches of the curtain are completed. Such sections will provide an excellent interpretive summary of the overall grouting operation.

5. Records of sand drain construction, in the event such is undertaken. In addition to the location and vital statistics for each hole, a record of any unusual findings or construction condition must be recorded.

6. Logs of any drill holes made for special operations and installations, as well as logs of any holes made for the purpose of acquiring any additional exploratory information during construction. The locations of the drill holes should also be indicated.

All of the above data are typical of what is required to be compiled and submitted to regulatory agencies for the construction of any major dam. Usually, much of this data is presented in a construction report upon completion of the work, although the agency's representatives will have reviewed records from time to time during their inspections of the work. The major difference in regard to the Mile Post 7 project (and the reason why compilation of data cannot await completion of construction) is that impoundment will be occurring as the project is constructed. Thus, it will be necessary to have at hand, and to have reviewed and evaluated, the critical construction and performance records so that corrective actions can quickly be implemented when needed. Because this project will probably involve matters beyond the experience of the State's inspector and may involve the State's consultants, certain data may be required to be submitted periodically. The State should designate this data as early as possible to facilitate obtaining the data necessary for continuing adequate review.

APPENDIX A

SITE INVESTIGATION

APPENDIX A
SITE INVESTIGATION

Site investigation methods and activities are described in this appendix. Logs of the four holes drilled for our purposes are included herein, as are logs of the six holes drilled for Casagrande Consultants and logged by us.

Geologic mapping, shown on Drawing III-1 (in pocket) was performed on June 7, 9, 18, and 19, 1975, by A. S. Buangan of W. A. Wahler and Associates and Mr. John Rapp of Michael Baker, Jr., Inc. The geologic mapping data was compiled and drawn by Michael Baker, Jr., Inc. on the Mile Post 7 site plan at a scale of 1" = 1000'.

The drilling and sampling program requested by Casagrande Consultants, W. A. Wahler and Associates, and Michael Baker, Jr., Inc. was performed from June 10 to June 21, 1975. A. S. Buangan of W. A. Wahler and Associates supervised and logged test borings requested by Casagrande Consultants and W. A. Wahler and Associates. John Rapp of Michael Baker, Jr., Inc. supervised and logged test borings requested by that firm. Field logs of drill holes and other information on the Casagrande and Wahler test borings were transmitted to the State of Minnesota and other consultants in June 1975. The holes were logged using the Unified Classification System.

The drilling was accomplished using a truck-mounted CME-75 rig (Photo A, Photoplate A-1), where access was relatively easy, and a crawler-mounted CME-55 rig (Photo B, Photoplate A-1), where access was relatively difficult. The equipment was furnished and operated by Braun Engineering Testing, Inc. from Minneapolis under contract with the State of Minnesota.

The typical procedure used in advancing the holes was to take Shelby tube samples using a stationary piston sampler in the red lake clays. Some holes were nearly continuously sampled in the clay while others were sampled at 2-foot intervals. The "transitional" materials were also sampled using the piston sampler when possible. After glacial till was encountered, Standard Penetration Tests (SPT) were usually performed to evaluate penetration resistance. Samples taken during the drilling program were shipped to the respective consultants upon completion of the program.

PHOTO A. TRUCK-MOUNTED CME 75 RIG ON DRILL HOLE CASA-1077.

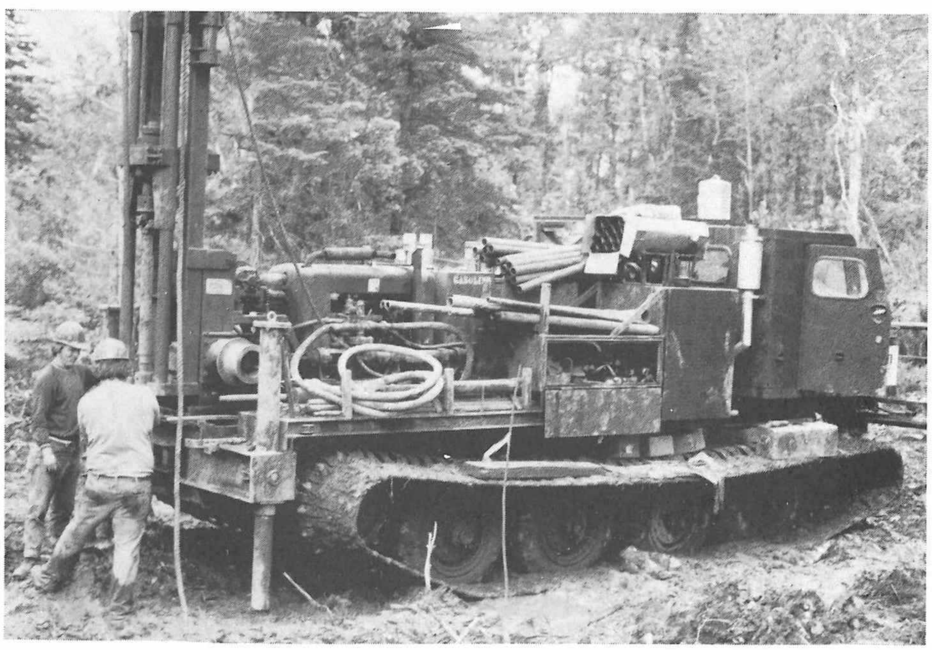

PHOTO B. CRAWLER-MOUNTED CME 55 RIG ON DRILL HOLE CASA-3056.

DRILL RIG	TRUCK MOUNTED CME 75	HOLE ELEVATION	1131'	LOGGED BY	ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE)	2.3' (6/17/75)	HOLE DIAMETER	6-1/2"	DATE DRILLED	JUNE 16, 1975

NOTE: Wahler hole drilled within 10' of Klohn hole 1006.
*RECOVERY RATIO INDICATED BY FRACTION.

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
0–2	CH	CH	0-22.0 LACUSTRINE DEPOSITS; generally thinly bedded or varved CLAY w/silty to sandy layers. Upper 2' probably disturbed by road traffic.		AD	DRILLED WITH HOLLOW STEM AUGER TO 2.0' (AD).
2–4			Black organic clay layers at depth 2'. Red CLAY; highly plastic; stiff; damp.	PS-1 2.0-4.0'	PS 2.0*/2.0	SAMPLED WITH THIN WALL STATIONARY PISTON SAMPLER (PS); 0-200 PSI APPLIED HYDRAULIC PRESSURE.
4–6					AD	EASY DRILLING. RED CLAY CUTTINGS.
6–8		CH	Red CLAY; highly plastic; stiff; damp.	PS-2 6.0-8.0'	PS 1.2/2.0	100-200 PSI. PART OF SAMPLE SLIPPED OUT OF TUBE AND WAS LEFT IN HOLE.
8–10					AD	EASY DRILLING. REDDISH BROWN CLAY CUTTINGS.
10–12	CL-CH (EST)	CH	Brown, silty CLAY; highly plastic; stiff; damp; partially varved.	PS-3 10.0-12.0'	PS 1.2/2.0	100-300 PSI; PART OF SAMPLE SLIPPED OUT OF TUBE AND WAS LEFT IN HOLE.
12–14					AD	EASY DRILLING; RED CLAY.
14–16		CH	Red CLAY; highly plastic; stiff; damp; included rock fragments.	PS-4 14.0-16.0'	PS 1.8/2.0	100-300 PSI; DENTED TIP OF TUBE.
16–20		CL	Reddish brown to brown, silty CLAY w/sand as indicated by cuttings.		AD	EASY DRILLING IN REDDISH BROWN, SILTY CLAY WITH LITTLE SAND.

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SOIL EXPLORATION DRILL HOLE LOG			HOLE NO. WAWA 1006
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 1 OF 2	

DRILL RIG	TRUCK MOUNTED CME 75	HOLE ELEVATION	1131'	LOGGED BY	ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE)	2.3' (6/17/75)	HOLE DIAMETER	6-1/2"	DATE DRILLED	JUNE 16, 1975

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
20			LACUSTRINE DEPOSITS--CONT. ? FACIES CHANGE TO COARSER MTL			EASY DRILLING TO 22.0'.
		ML	Brown, sandy SILT to clayey SILT as indicated by cuttings.		AD	ROUGH DRILLING IN GRAVELLY MATERIAL FROM 22.0-24.0'.
22		GP	22.0-25.5 GLACIAL TILL; GRAVEL-SAND; little fines; brown; medium dense; wet.			
24				SPT-1 24.0-25.5'	DR 1.0/1.5	DROVE STANDARD SPLIT SPOON WITH 140 LB. HAMMER FALLING 30" (DR). 8/0.5, 12/0.5, 10/0.5
26			BOTTOM OF HOLE = 25.5 FEET			WATER LEVEL IMMEDIATELY AFTER PULLING OUT AUGER-8.4'. WATER LEVEL 20 MINUTES AFTER PULLING AUGER-5.0'. WATER LEVEL, 8:00 A.M., 6/17/75-2.3'.

W.A. WAHLER & ASSOCIATES

REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA

PALO ALTO • NEWPORT BEACH • CALIF.

SOIL EXPLORATION
DRILL HOLE LOG

PROJECT NO.	DATE	SHEET NO.	HOLE NO.
0829	AUGUST 1975	2 OF 2	WAWA 1006

DRILL RIG	TRUCK MOUNTED CME 75	HOLE ELEVATION	1123'	LOGGED BY	ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE)	HOLE LOCATED IN MUD POOL.	HOLE DIAMETER	6-1/2"	DATE DRILLED	JUNE 16, 1975

NOTE: Wahler hole located about 50' East of Klohn hole 1071.
*RECOVERY RATIO INDICATED BY FRACTION.

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
0			0-2.0 RESIDUAL SOIL; CLAY, sandy; dark brown; soft; wet; organic topsoil.		AD	DRILLED WITH HOLLOW STEM AUGER (AD).
2			2.0-15.0 LACUSTRINE DEPOSITS; mostly clays with poor or indistinct bedding.	PS-1 2.5-4.5'	PS 2.0*/2.0	SAMPLED WITH THIN WALL STATIONARY PISTON SAMPLER (PS). 100 TO 200 PSI APPLIED HYDRAULIC PRESSURE.
4		SC	Medium clayey SAND at tip of tube; brown; medium dense; damp.		AD	
6	CL-CH			PS-2 5.0-7.0'	PS 1.9/2.0	100 TO 200 PSI.
		CH	CLAY; reddish brown with rounded fine gravel and sand; highly plastic; stiff; damp; contains carbonized twigs and other organic material.		AD	DRILLED TO 8.0'. CLEANED OUT BY JETTING TO OBTAIN SAMPLE THROUGH HOLLOW STEM AT 8.5'.
8		CH	Reddish brown CLAY; highly plastic; firm; damp; some included rock fragments.	PS-3 8.5-10.5'	PS 1.0/1.5	100 PSI INCREASING TO 400 PSI IN LAST 2". BENT TIP OF TUBE PROBABLY DUE TO ROCK.
10					AD	
	CH	CH	Reddish brown CLAY; highly plastic; stiff; damp; included fine gravels.	PS-4 10.5-12.5'	PS 2.0/2.0	100 TO 200 PSI APPLIED PRESSURE.
12					AD	DRILLED TO 14.0'. SLIGHTLY ROUGH DRILLING.
14					PS	100 TO 600 PSI. 3" ROCK AT TIP OF TUBE; NO RECOVERY.
		GP-SP	15.0-22.5 GLACIAL TILL; SAND and GRAVEL with some fines. Boulders from 15.0-16.5'.		AD	DRILLED TO 15.0'. BOULDERS AND COBBLES FROM 15.0-16.5'. PULLED OUT AUGER TO SAMPLE AT 16.5'. SLOUGH IN HOLE TO 14.0'. WENT DOWN WITH AUGER AND JETTED TO 16.5' TO CLEAN OUT BEFORE SAMPLING. CUTTINGS OF RED BASALT AND GRAY DIABASE.
16				SPT-1 17.0-18.5'	DR 1.0/1.5	DROVE STANDARD SPLIT SPOON WITH 140 LB. HAMMER AND 30" FREEFALL (DR). 26/0.5, 17/0.5, 46/0.5
18			GRAVEL and SAND; little fines; red; dense; moist.		AD	ROUGH DRILLING IN BOULDERY MATERIAL FROM 18.5-21.0'.
20						

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SOIL EXPLORATION DRILL HOLE LOG			HOLE NO. WAWA 1071
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 1 OF 2	

DRILL RIG	TRUCK MOUNTED CME 75	HOLE ELEVATION	1123'	LOGGED BY	ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE)	HOLE LOCATED IN MUD POOL.	HOLE DIAMETER	6-1/2"	DATE DRILLED	JUNE 16, 1975

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
20			GLACIAL TILL--CONTINUED			SEVERAL ATTEMPTS TO DRIVE SAMPLE AT 21.0'. JETTED HOLE WITH SPLIT SPOON TO REACH 21.0'.
22		GP-SP	SAND and GRAVEL; little fines; brown; dense; wet.	SPT-2 21.0-22.5'	DR 1.0/1.5	24/0.5, 15/0.5, 21/0.5
			BOTTOM OF HOLE = 22.5 FEET			AUGER BROKEN 10' FROM THE BOTTOM. ATTEMPTED TO FISH AUGER BUT UNSUCCESSFUL BECAUSE OF CAVING GROUND ABOVE AUGER.
24						WATER LEVEL 8:00 A.M. 6/17/75 - 0'

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SOIL EXPLORATION DRILL HOLE LOG			HOLE NO.
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 2 OF 2	WAWA 1071

DRILL RIG: TRUCK MOUNTED CME 75	HOLE ELEVATION: 1140'	LOGGED BY: ASB	
GROUNDWATER DEPTH (BELOW GROUND SURFACE): 7.0' (6/11/75)	HOLE DIAMETER: 6-1/2"	DATE DRILLED: JUNE 10-11, 1975	

NOTE: Wahler hole 1076 located within 10' of Klohn drill hole 1076.
*RECOVERY RATIO INDICATED BY FRACTION.

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
0		CH	0-15.0 LACUSTRINE DEPOSITS; generally varved or thinly bedded silt and clay with some sand.		AD	DRILLED WITH 6-1/2" HOLLOW STEM AUGER (AD).
2	CH		Red CLAY from 0-1.5' from auger cuttings.	PS-1 1.5-3.5'	PS 2.0*/2.0	SAMPLED WITH THIN WALL STATIONARY PISTON SAMPLE (PS). APPLIED HYDRAULIC PRESSURE AT 300 PSI. (TEN SECOND SAMPLING).
		CH	Red CLAY at tip of tube; stiff; damp; highly plastic.			
4					AD	DRILLED TO 4.0'.
	CH	ML	Varved silty CLAY at tip of tube; reddish brown.	PS-2 4.0-6.4'	PS 2.4/2.4	300 PSI APPLIED HYDRAULIC PRESSURE (5 SECOND SAMPLING).
6	CH		Change in tube		AD	DRILLED TO 6.5'.
	CH		CLAY, sandy; little gravel; reddish brown; plastic; clayey SAND at tip of tube.	PS-3 6.5-8.0'	PS 1.8/1.5	300 PSI; PIECE OF ROCK AT 8.0'. DENTED TUBE.
8			Change in tube		AD	WATER INITIALLY ENCOUNTERED AT 8.0'.
10	CH		SILT and CLAY; interlayered at tip of tube; reddish brown and red; firm; damp; varved.	PS-4 8.5-10.5'	PS 2.0/2.0	300 PSI APPLIED PRESSURE. DENTED TIP OF TUBE.
			? FACIES CHANGE TO COARSER MTL		AD	DRILLED TO 10.5'. ROCKY MATERIAL AT 10.5'.
12	ML	CL-ML SC	Varved CLAY, silty; some sand; interlayered w/SILT and SAND, clayey; horizontal layers; some angular pieces of gravel; firm.	PS-5 11.0-13.0'	PS 1.4/2.0	100-300 PSI APPLIED PRESSURE. DENTED TIP OF TUBE AT 12.5'.
14						ROUGH DRILLING IN ROCK AT 13.5'. ATTEMPTED PISTON SAMPLER AT 14.0'. UNABLE TO SAMPLE IN GRAVELLY MATERIAL.
				NO RECOVERY	DR 0/1.0	DROVE STANDARD SPLIT SPOON FROM 14.0-15.0' (DR). 5/0.5, 9/0.5
			15.0-22.5 GLACIAL TILL; poorly sorted silty to clayey sand and gravel.	SPT-1 15.0-16.0'	DR 0.5/1.0	ONLY ONE PIECE OF ROCK RECOVERED.
16		GP-SP	GRAVEL and SAND; some clay and silt in split spoon; red; moist; medium dense.		AD	REDRILLED TO 15.0'. DROVE STANDARD SPLIT SPOON. 13/0.5, 16/0.5
18			GRAVEL and SAND; some silt and clay; red; very dense; moist.	SPT-2 18.0-19.0'	DR 0.5/0.9	11/0.5, 100/0.4
20					AD	STOPPED 6/10/75. RESUMED 6/11/75. WATER LEVEL BEFORE DRILLING-7.0'.

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SOIL EXPLORATION DRILL HOLE LOG	HOLE NO. WAWA 1076
PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 1 OF 2

DRILL RIG TRUCK MOUNTED CME 75	HOLE ELEVATION 1140'	LOGGED BY ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE) 7.0' (6/11/75)	HOLE DIAMETER 6-1/2"	DATE DRILLED JUNE 10-11, 1975

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
20			GLACIAL TILL--CONTINUED		AD	SLOW AND ROUGH DRILLING FROM 18-22'; TOOK 15 MINUTES TO DRILL IN FIRST GEAR AND 100 TO 600 PSI APPLIED PRESSURE.
22			Hard pieces of rock in split spoon sampler.	SPT-3 22.0-22.5'	DR 0.2/0.5	180/0.5
			BOTTOM OF HOLE = 22.5 FEET			BACKFILLED HOLE WITH CUTTINGS.
24						

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SOIL EXPLORATION DRILL HOLE LOG			HOLE NO. WAWA 1076
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 2 OF 2	

DRILL RIG CME 55 MOUNTED ON FN 160	HOLE ELEVATION 1154'	LOGGED BY ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE) 0.5' (6/15/75)	HOLE DIAMETER 6-1/2"	DATE DRILLED JUNE 13, 1975

NOTE: Wahler hole drilled 8' S.15°E. of Klohn Drill Hole 3020 on center of access road.
*RECOVERY RATIO INDICATED BY FRACTION. **SAMPLE EXTRUDED IN THE FIELD AND PLACED IN JAR.

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
0			0-1.0 RESIDUAL SOIL; CLAY, sandy; brown; roots; disturbed topsoil.		AD	DRILLED WITH HOLLOW STEM AUGER (AD).
2	CL	CH	1.0-22.5 LACUSTRINE DEPOSITS; generally thinly bedded or varved sand, silt, and clay. Red CLAY, w/sand and a little gravel at tip of tube; stiff; damp; highly plastic.	PS-1 1.0-3.0'	PS 1.9*/2.0	SAMPLED WITH THIN WALL STATIONARY PISTON SAMPLER (PS). 100 TO 300 PSI APPLIED HYDRAULIC PRESSURE.
					AD	EASY DRILLING.
4	CL	CH	Reddish brown CLAY at tip of tube; some included rock fragments; stiff; damp; highly plastic.	PS-2 4.0-5.5'	PS 1.5/1.5	200 PSI APPLIED PRESSURE INCREASING TO 500 PSI IN LAST 3". DENTED TIP OF TUBE.
6					AD	ROUGH DRILLING IN ROCK AT 5.0'.
		CH	Red CLAY at tip of tube; included rock fragments; highly plastic; damp w/distinct varving.	PS-3** 6.5-8.0'	PS 1.0/1.5	200 PSI INCREASING TO 600 PSI IN LAST 6". BOTTOM 8" OF TUBE CRUMBLED, APPARENTLY BY BOULDER.
8					AD	DRILLED TO 8.5'. ROUGH IN COBBLES FROM 7.5-8.5'.
	CL		Change in tube	PS-4 8.5-10.6'	PS 2.1/2.1	200 PSI GRADUALLY INCREASING TO 500 PSI.
10	CL	ML	Brown, sandy SILT at tip of tube; very stiff; damp.			
					AD	
12	CL (EST)	CH	Red CLAY at tip of tube; very stiff; damp; highly plastic; varved.	PS-5 11.0-13.0'	PS 2.0/2.0	200 PSI GRADUALLY INCREASING TO 400 PSI.
					AD	EASY DRILLING.
14		ML	PS-6; BROWN, SANDY SILT; FIRM TO STIFF; MOIST.	PS-6** 14.0-14.8'	PS 0.6/0.8	200 PSI INCREASING TO 500 PSI IN LAST 2". SAMPLE LOOSE IN TUBE. BENT TIP OF TUBE.
		SM-ML	? FACIES CHANGE TO COARSER MTL. SAND, silty to SILT, sandy; brown; dense; wet; poorly bedded.	PS-7** 15.0-15.8'	PS 0.6/0.8	DRILLED TO 15.0'. ROUGH IN ROCKY MATERIAL FROM 14.5-14.8'.
16			PS-7; BROWN, SILTY SAND; WET; DENSE.		AD	200 PSI INCREASING TO 500 PSI IN LAST 3".
				NO RECOVERY	PS	200 TO 600 PSI. NO SAMPLE RECOVERED. TUBE TIP BENT.
					AD	
18	SM		Brown, fine, silty SAND; dense; wet.	PS-8 17.5-18.7'	PS 1.0/1.2	200 PSI INCREASING TO 400 PSI IN LAST 2". DENTED TIP OF TUBE. SAMPLE LOOSE IN TUBE.
					AD	
20	SM		Brown, fine, silty SAND; dense; wet.	PS-9 19.0-20.0'	PS 1.0/1.0	200 PSI INCREASING TO 500 TO LAST 2". SAMPLE LOOSE IN TUBE.

DRILL RIG CME 55 MOUNTED ON FN 160	HOLE ELEVATION 1154'	LOGGED BY ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE) 0.5' (6/15/75)	HOLE DIAMETER 6-1/2"	DATE DRILLED JUNE 13, 1975

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
20			LACUSTRINE DEPOSITS--CONTINUED		AD	EASY DRILLING.
	ML	SM	Brown, silty SAND at tip of tube; medium to coarse sand; dense; wet.	PS-10 21.0-22.2'	PS 0.9/1.2	200 PSI INCREASING TO 500 PSI. DENTED TUBE. SAMPLE LOOSE IN TUBE.
22	SM (EST)		Silty SAND (light brown)			
		GP-SP	22.5-27.5 GLACIAL TILL; GRAVEL-SAND, clayey, silty; reddish brown; boulders as indicated by drilling; dense; some silty sand lenses.		RD	ROUGH DRILLING AT 22.5'. BOULDER AT 23.0'. ATTEMPTED STANDARD SPLIT SPOON; REFUSAL IN BOULDER. REFUSAL WITH HOLLOW STEM AUGER. DRILLED WITH TRICONE ROCK BIT AND WATER. VERY ROUGH AND SLOW DRILLING FROM 23.0-24' IN DIABASE BOULDER. ROUGH IN GRAVELLY MATERIAL FROM 24.0-25.5'. RELATIVELY EASY DRILLING FROM 25.5-26.0'. CUTTINGS OF DIABASE AND RED BASALT.
24						
26			Reddish brown, silty SAND w/included rock fragments; dense.	SPT-1 26.0-27.5'	DR 0.8/1.5	DROVE STANDARD SPLIT SPOON WITH 140 LB. HAMMER WITH 30" FREEFALL (DR). 16/0.5, 18/0.5, 23/0.5
			BOTTOM OF HOLE = 27.5 FEET			WATER LEVEL AFTER PULLING OUT AUGER-5.0'. WATER LEVEL - 8:00 A.M., 6/15/75-0.5'.
28						

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SOIL EXPLORATION DRILL HOLE LOG	HOLE NO. WAWA 3020
PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 2 OF 2

LOGS OF HOLES DRILLED AT THE REQUEST OF CASAGRANDE CONSULTANTS (CASA HOLES), AND LOGGED IN THE FIELD BY A REPRESENTATIVE OF W. A. WAHLER AND ASSOCIATES

The logs that follow (Holes with the CASA prefix numbered 1002, 1072, 1077, 3004, 3037, and 3056) were typed from our field logs. Laboratory classifications have not been added because we did not have complete laboratory data. However, minor editorial changes have been made in the logs for clarity or because of information gained after the holes were drilled. Laboratory classifications presented by Casagrande Consultants in their August 1975 report may differ from field classifications shown on the logs, because our field logs were made using field judgment and field classification techniques, and because our representative sometimes logged from cuttings and did not always see complete samples that were contained in sample tubes.

DRILL RIG TRUCK MOUNTED CME 75	HOLE ELEVATION 1134'	LOGGED BY ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE) 5.0' (6/16/75)	HOLE DIAMETER 6-1/2"	DATE DRILLED JUNE 13, 1975

NOTE: Casagrande hole drilled about 20' N of Klohn drill hole 1002.
*RECOVERY RATIO INDICATED BY FRACTION.

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
0			0-28.5 LACUSTRINE DEPOSITS; thinly bedded or varved; CLAY, SILT and SAND w/some rock fragments.		AD	DRILLED WITH HOLLOW STEM AUGER (AD).
2		CH	Red CLAY; firm; highly plastic; damp; varved.	PS-1 1.0-3.0'	PS 1.6*/2.0	SAMPLED WITH THIN WALL STATIONARY PISTON SAMPLER (PS). 100 TO 300 PSI APPLIED HYDRAULIC PRESSURE.
					AD	
4		CH	Red CLAY; stiff; highly plastic; damp; varved.	PS-2 3.5-5.5'	PS 2.0/2.0	100 TO 300 PSI. GROOVE ALONG SIDE OF SAMPLE, PROBABLY CAUSED BY HARD ROCK FRAGMENT.
					AD	
6			Interval resampled, see below.			
		CH	Red CLAY; stiff; highly plastic; damp.	PS-3 6.0-8.0'	PS 1.9/2.0	100 TO 300 PSI. SIDES OF TUBE SQUEEZED ON BOTTOM 8", PROBABLY BY ROCK IN THE CLAY.
8					AD	
10		CH	Reddish brown, silty CLAY; probably some included hard rock fragments; highly plastic; stiff; damp.	PS-4 8.5-10.5'	PS 1.7/2.0	100 TO 300 PSI. DENTED TIP OF TUBE.
12		ML	Brown, sandy SILT; firm; moist.	PS-5 11.0-12.8'	PS 1.8/1.8	100 TO 400 PSI. DENTED TIP OF TUBE.
			Change in tube		AD	
14		CH	Reddish brown CLAY; highly plastic; stiff; damp.	PS-6 14.0-16.0'	PS 1.9/2.0	100 TO 300 PSI.
16					AD	
18		SM-CL	Brown, silty SAND and reddish brown, silty CLAY at tip of tube; dense; firm; wet.	PS-7 17.0-18.1'	PS 1.1/1.1	100 TO 500 PSI. WATER LEVEL AFTER SAMPLING PS-7 - 12.5'.
					AD	WATER LEVEL 1/2 HOUR AFTER PREVIOUS READING - 5'.
20				PS-8 18.5-20.5'	PS 2.0/2.0	100 TO 400 PSI. BENT TIP OF TUBE.

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SOIL EXPLORATION DRILL HOLE LOG	HOLE NO. CASA 1002
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829 / DATE AUGUST 1975 / SHEET NO. 1 OF 2	

DRILL RIG	TRUCK MOUNTED CME 75	HOLE ELEVATION	1134'	LOGGED BY	ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE)	5.0' (6/16/75)	HOLE DIAMETER	6-1/2"	DATE DRILLED	JUNE 13, 1975

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
20			LACUSTRINE DEPOSITS--CONT.			
		CH	Reddish brown CLAY; included coarse sand to fine gravel; angular rock fragments; highly plastic; firm to stiff; damp.		AD	
22		CH	Reddish brown CLAY at tip of tube; highly plastic; stiff; damp at 22.4'.	PS-9 21.5-23.5'	PS 2.0/2.0	100 TO 300 PSI APPLIED PRESSURE. TIP OF TUBE SLIGHTLY DENTED.
24					AD	
		CL	CLAY at tip of tube; little fine and included coarse, angular sand fragments; brown; stiff.	PS-10 24.5-26.5'	PS 2.0/2.0	100 TO 200 PSI.
26					AD	EASY DRILLING TO 27.0'. ROUGH IN GRAVELLY MATERIAL FROM 27.0-27.5'. CLEANED OUT AUGER CUTTINGS INSIDE HOLLOW STEM BY JETTING TO 27.5'.
28			Red CLAY in split spoon to 28.5'.	SPT-1 27.5-29.0' (GRAVEL-SAND)	DR 0.6/1.5	DROVE STANDARD SPLIT SPOON WITH 140 LB. HAMMER AND 30" FREE FALL (DR). 5/0.5, 7/0.5, 10/0.5
			28.5-33.0 GLACIAL TILL; GRAVEL and SAND; clay binder; red; dense.			
30					AD	ROUGH DRILLING IN GRAVELLY MATERIAL TO 32.0'.
32			Gravelly, sandy CLAY; red; dense.	SPT-2 32.0-33.5'	DR 1.0/1.5	5/0.5, 37/0.5, 21/0.5 WATER LEVEL AFTER PULLING OUT AUGER, 5:30 P.M., 6/15/75 - 5.0'.
0			BOTTOM OF HOLE =33.5 FEET			
			Shallow hole drilled 1.5'NW of main hole to resample depth interval from 4.0-8.5'.			
4			Red CLAY; highly plastic; stiff; damp.	PS-11 4.0-6.5'	PS 1.3/2.5	SAMPLED WITH THIN WALL PISTON SAMPLER; 100 TO 200 PSI. PART OF SAMPLE LEFT IN HOLE. DRILLED TO 6.5'.
8			Red CLAY; highly plastic; stiff; damp.	PS-12 6.5-8.5'	PS 1.3/2.0	100 TO 200 PSI APPLIED PRESSURE; PART OF SAMPLE LEFT IN HOLE.
12						

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SOIL EXPLORATION DRILL HOLE LOG			HOLE NO. CASA 1002
PALO ALTO • NEWPORT BEACH • CALIF.		PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 2 OF 2	

DRILL RIG	TRUCK-MOUNTED CME 75	HOLE ELEVATION	1133'	LOGGED BY	ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE)	5.3' (6-12-75)	HOLE DIAMETER	6-1/2"	DATE DRILLED	JUNE 11-12, 1975

NOTE: Casagrande hole located within 10' of Klohn drill hole 1072.
*RECOVERY RATIO INDICATED BY FRACTION.

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
0		CH	0-19.0 LACUSTRINE DEPOSITS; thinly bedded or varved (?) CLAY w/silty and sandy layers.		AD	DRILLED WITH 6" HOLLOW STEM AUGER (AD).
2			CLAY; red; firm to stiff; damp; highly plastic; upper 2.0' probably disturbed from road traffic.	PS-1 1.0-3.0'	PS 2.0*/2.0	SAMPLED WITH THIN WALL STATIONARY PISTON SAMPLER; 3" O.D. APPLIED HYDRAULIC PRESSURE FROM 100-200 PSI (PS).
		CL-CH (ML)	?		AD	DRILLED TO 3.5'.
4			Change in tube Moderate reddish brown, silty CLAY to clayey SILT; firm to stiff; moist; moderately to highly plastic.	PS-2 3.5-5.5'	PS 2.0/2.0	100 TO 200 PSI APPLIED PRESSURE.
6					AD	
			Moderate reddish brown, silty CLAY to clayey SILT; firm to stiff; moist; moderately to highly plastic.	PS-3 6.0-8.0'	PS 1.8/2.0	100 PSI APPLIED PRESSURE.
8					AD	
		CL	? Change in tube Grayish brown, silty CLAY at tip of tube; firm to stiff; damp; moderately plastic.	PS-4 8.5-10.5'	PS 2.0/2.0	100-200 PSI APPLIED PRESSURE.
10					AD	
12			Brown, silty CLAY at tip of tube; some included rock fragments.	PS-5 11.0-13.0'	PS 2.0/2.0	200-300 PSI APPLIED PRESSURE; DENTED TIP OF TUBE DUE TO ROCK FRAGMENT.
					AD	
14		CH	Change in tube ? CLAY; red; stiff; moist; highly plastic; some included hard rock fragments at 16.0'.	PS-6 14.0-16.5'	PS 2.5/2.5	200 PSI APPLIED PRESSURE INCREASING TO 400 PSI IN LAST 2". DENTED TIP OF TUBE DUE TO ROCK FRAGMENT.
16					AD	
18		CL	? FACIES CHANGE (?) IN TUBE CLAY, sandy; some angular, hard rock fragments; stiff; damp.	PS-7 17.5-19.5'	PS 2.0/2.0	200-300 INCREASING TO 500 PSI IN LAST 2". WATER AT 16.0'.
20		GP-SP	19.0-24.0 GLACIAL TILL; GRAVEL, SAND, AND CLAY; red; dense.		AD	ROUGH DRILLING IN GRAVELLY MATERIAL FROM 19.0-20.0'.

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SOIL EXPLORATION DRILL HOLE LOG			HOLE NO. CASA 1072
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 1 OF 2	

DRILL RIG	TRUCK-MOUNTED CME 75	HOLE ELEVATION 1133'	LOGGED BY ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE)	5.3' (6-12-75)	HOLE DIAMETER 6-1/2"	DATE DRILLED JUNE 11-12, 1975

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
20			GLACIAL TILL--CONTINUED			ROUGH DRILLING FROM 20.0' TO 21.0' IN ROCKY MATERIAL.
22		GP-SP	Medium to coarse, angular SAND and sandy CLAY in split spoon; red; medium dense.	SPT-1 21.0-22.0'	DR 0.5/1.0	DROVE STANDARD SPLIT SPOON (DR) WITH 140 LB. HAMMER FALLING 30" (DR). 7/0.5, 15/0.5
					AD	ROUGH DRILLING WITH HOLLOW STEM AUGER FROM 21.0-24.0' IN GRAVELLY MATERIAL. CLEANED OUT BOTTOM 3' OF HOLLOW STEM BY JETTING WITH CHOPPING BIT.
24			Reddish brown GRAVEL and silty CLAY.	SPT-2 24.0-25.5'	DR 1.0/1.5	STOPPED 5:30 P.M., 6-11-75. RESUMED 9:00 A.M., 6-12-75. WATER LEVEL BEFORE DRILLING - 0.3'.
26			BOTTOM OF HOLE = 25.5 FEET			WASHED OUT HOLE TO 24.0'. DROVE STANDARD SPLIT SPOON FROM 24-25.5'. 0/0.5, 18/0.5, 18/0.5. WATER LEVEL AFTER PULLING AUGERS - 5.3'.

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SOIL EXPLORATION DRILL HOLE LOG			HOLE NO. CASA 1072
PALO ALTO • NEWPORT BEACH • CALIF.		PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 2 OF 2	

DRILL RIG TRUCK-MOUNTED CME 75	HOLE ELEVATION 1130'		LOGGED BY ASB
GROUNDWATER DEPTH INITIALLY ENCOUNTERED AT 9.5' (BELOW GROUND SURFACE) FLOWING (6-11-75)	HOLE DIAMETER 6-1/2"		DATE DRILLED JUNE 10, 1975

NOTE: Casagrande hole located on center of access road within 10' of Klohn drill hole 1077. *RECOVERY RATIO INDICATED BY FRACTION.

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
0			0-17.0 LACUSTRINE DEPOSITS; thinly bedded or varved SILT and CLAY w/some sand and gravel.		AD	DRILLED WITH HOLLOW STEM AUGER (AD). SAMPLED WITH THIN WALL STATIONARY PISTON SAMPLER (PS). 100 TO 200 PSI APPLIED HYDRAULIC PRESSURE.
2		CH	Upper 2' probably disturbed from road traffic. Red CLAY at tip of tube; stiff; damp; highly plastic; varved.	PS-1 1.5-3.5'	PS 2.0*/2.0	
					AD	EASY DRILLING.
4				PS-2 4.0-6.5'	PS 2.5/2.5	150 PSI APPLIED PRESSURE.
6		CH	Red CLAY at tip of tube; stiff; damp; highly plastic; varved.			
					AD	EASY DRILLING.
8			Horizontal stratification at tip of PS-3; some thin (1/8" thick) fine sand lenses.	PS-3 7.0-9.0'	PS 2.0/2.0	200 PSI APPLIED PRESSURE.
					AD	EASY DRILLING.
10		CL	Water encountered at 9.5'. Sandy CLAY at tip of tube at 11.5'; reddish brown; stiff; damp.	PS-4 9.5-11.5'	PS 1.9/2.0	300 PSI APPLIED PRESSURE. TIP OF TUBE SLIGHTLY DENTED, PROBABLY DUE TO SMALL ROCK FRAGMENTS.
12					AD	EASY DRILLING.
			Change in tube. CLAY w/little sand at tip of tube.	PS-5 12.0-14.0'	PS 2.0/2.0	300 PSI APPLIED PRESSURE. DENTED TIP OF TUBE DUE TO ROCK.
14			1-1/2" angular, hard rock fragments in auger cuttings.		AD	EASY DRILLING.
		ML	? FACIES CHANGE TO COARSER MTL. SILT, sandy; some coarse sand; moderate brown; firm; wet. Sandy SILT at tip of tube.	PS-6 14.5-16.5'	PS 2.0/2.0	200 PSI APPLIED PRESSURE. AFTER SAMPLING PS-6, WATER LEVEL ROSE FROM 9.5' TO GROUND SURFACE FLOWING AT APPROXIMATELY 3 GPM.
16					AD	DRILLED TO 17.0'. ROUGH DRILLING IN GRAVELLY MATERIAL AT 17.0'.
		GC			AD	ATTEMPTED PISTON SAMPLER AT 17', BUT HIT REFUSAL (600 PSI APPLIED PRESSURE).
18			17.0-19.3 GLACIAL TILL; GRAVEL and SAND; some clay; mostly angular gravel; reddish brown; very dense.	SPT-1 18.0-18.2'	DR 0.2/0.2	DRILLED TO 18.0'. DROVE STANDARD SPLIT SPOON WITH 140 LB. HAMMER AND 30" FREE FALL (DR); 150/0.2.
					AD	
				SPT-2 19.0-19.3'	DR 0.3/0.3	ROUGH DRILLING TO 19.0'. 100/0.3
20			BOTTOM OF HOLE = 19.3 FEET			

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SOIL EXPLORATION DRILL HOLE LOG		HOLE NO. CASA 1077
PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 1 OF 1	

DRILL RIG CME 55 MOUNTED ON FN 160	HOLE ELEVATION 1111'	LOGGED BY ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE) FLOWING (6/19/75)	HOLE DIAMETER 6-1/2"	DATE DRILLED JUNE 18, 1975

NOTE: Casagrande hole located 12' W of Klohn hole 3004.
*RECOVERY RATIO INDICATED BY FRACTION.

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
0		CH	0-0.5 TOPSOIL; CLAY; dark brown; organic; boulder near surface.		AD	DRILLED WITH HOLLOW STEM AUGER (AD).
2			0.5-20.0 LACUSTRINE DEPOSITS; thinly bedded to varved (?) CLAY, silt and sand. Red CLAY, silty; some coarse sand; stiff; damp.	PS-1 1.5-3.5'	PS 1.8*/2.0	SAMPLED WITH THIN WALL STATIONARY PISTON SAMPLER (PS). 100 TO 300 PSI APPLIED HYDRAULIC PRESSURE.
4					AD	
			Moderate, red, silty CLAY, sandy; fine to coarse sand; some fine gravel; moderate to highly plastic; stiff; damp.	PS-2 4.0-6.0'	PS 2.0/2.0	100 TO 250 PSI; DENTED TIP OF TUBE. ROUGH DRILLING IN BOULDER AT 5.7'.
6					AD	
			Red CLAY; highly plastic; stiff; damp; block structure.	PS-3 6.5-8.5'	PS 1.8/2.0	100 TO 250 PSI.
8					AD	
			Change in tube			
10		CL	? Brown, silty CLAY; slightly sandy; moderately plastic; firm; moist.	PS-4 9.0-11.0'	PS 2.0/2.0	100 TO 200 PSI; LITTLE WATER AT TOP OF TUBE.
					AD	
12		ML	Brown, clayey SILT to sandy SILT; low to moderate plasticity; firm; moist.	PS-5 12.0-14.0'	PS 2.5/2.0	100 TO 200 PSI; TOP 6" OF SAMPLE IS CAVED MATERIAL. WATER LEVEL IN HOLLOW STEM AUGER AT 10:00 A.M.-12.4'.
14						
		SC	Moderate, red, clayey SAND; fine to coarse sand; medium dense; moist.	PS-6 14.5-16.5'	PS 2.0/2.0	100 TO 250 PSI; TUBE TIP SLIGHTLY DENTED. DROVE STANDARD SPLIT SPOON, WITH 140 LB. HAMMER AND 30" FREE FALL (DR). 5/0.5, 8/0.5, 10/0.5
16		SC	? FACIES CHANGE TO COARSER MTL Red, gravelly, clayey, SAND; medium dense; wet.	SPT-1 16.5-18.0'	DR 0.3/1.5	MOST OF SAMPLE FELL DOWN HOLE. DRILLED TO 18.0'. WATER ROSE TO SURFACE AND FLOWING 5 MINUTES AFTER DRILLING TO 18'. JETTED HOLE TO WASH OUT CAVED MATERIAL BEFORE PISTON SAMPLING. 100 TO 600 PSI APPLIED PRESSURE. BENT TIP OF TUBE. SAMPLE EXTRUDED IN THE FIELD. ARTESIAN FLOW AFTER SAMPLING ABOUT 1 GPM. 7/0.5, 8/0.5, 15/0.5
18			Red, clayey, sandy GRAVEL; dense; (sample extruded in the field).	PS-7 18.0-18.5'	PS 0.4/0.5	
20			Red GRAVEL and SAND; little clay; medium dense; wet.	SPT-2 18.5-20.0'	DR 0.6/1.5	

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SOIL EXPLORATION DRILL HOLE LOG		HOLE NO. CASA 3004
PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 1 OF 2	

DRILL RIG	CME 55 MOUNTED ON FN 160	HOLE ELEVATION	1111'	LOGGED BY	ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE)	FLOWING (6/19/75)	HOLE DIAMETER	6-1/2"	DATE DRILLED	JUNE 18, 1975

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
20			20.0-26.5 GLACIAL TILL; poorly sorted SAND and GRAVEL w/variable fines.	SPT-3 20.0-21.5'	DR 1.0/1.5	DRILLED TO 20.0'. ROUGH DRILLING JETTED HOLE TO WASH OUT CAVED MATERIAL. DRIVE SAMPLE. 13/0.5, 21/0.5, 35/0.5
22		GP-SP	GRAVEL and SAND w/clay binder; red; very dense; damp.		AD	VERY ROUGH DRILLING FROM 22.0-22.5'. NO ARTESIAN FLOW AFTER DRILLING TO 22.5'. 38/0.5, 100/0.5
			GRAVEL and SAND; little fines; red; very dense; damp.	SPT-4 22.5-23.5'	DR 1.0/1.0	
24						ROUGH DRILLING TO 25.0'.
26			GRAVEL and SAND; little fines; red; very dense; damp.	SPT-5 25.0-26.5'	DR 1.0/1.5	18/0.5, 42/0.5, 58/0.5
28			BOTTOM OF HOLE = 26.5 FEET			WATER LEVEL AFTER PULLING AUGER, 1:30 P.M.-ARTESIAN FLOW. WATER LEVEL AT 5:00 P.M.-ARTESIAN FLOW 1-2 GPM. WATER LEVEL AT 8:00 A.M., 6/19/75-ARTESIAN FLOW.

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SOIL EXPLORATION DRILL HOLE LOG			HOLE NO. CASA 3004
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 2 OF 2	

DRILL RIG CME 55 MOUNTED ON FN 160	HOLE ELEVATION 1162'	LOGGED BY ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE) 0' (6/18/75)	HOLE DIAMETER 6-1/2"	DATE DRILLED JUNE 17, 1975

NOTE: Casagrande hole drilled 6' S20W of Klohn hole 3037.
*RECOVERY RATIO INDICATED BY FRACTION.

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
0			0-1.0 <u>RESIDUAL SOIL</u>; <u>CLAY</u>; dark brown; organic material; topsoil.		AD	DRILLED WITH HOLLOW STEM AUGER (AD).
			1.0-30.0 <u>LACUSTRINE DEPOSITS</u>; thinly bedded <u>CLAY</u> and <u>SILT</u> w/sand and some gravel; possibly varved in part.			
2		CH	Red <u>CLAY</u> at tip of tube; some sand and included hard gravel; firm to stiff; damp; highly plastic.	PS-1 2.0-3.7'	PS 1.3*/1.7	SAMPLED WITH THIN WALL STATIONARY PISTON SAMPLER. 100 PSI APPLIED HYDRAULIC PRESSURE INCREASING TO 400 PSI IN LAST 2". DENTED THE TIP OF TUBE DUE TO ROCK. ROUGH DRILLING IN BOULDERY MATERIAL FROM 4.0-5.0'.
4					AD	
6		CH	Red <u>CLAY</u>; included gravels or boulders; stiff; damp; highly plastic.	PS-2 5.0-6.8'	PS 1.8/1.8	100 TO 400 PSI INCREASING TO 600 PSI IN LAST 1". BOTTOM 12" OF TUBE CRUMPLED PROBABLY BY BOULDERS. DROVE ALONG SIDES OF SAMPLE.
8		CL-ML	Reddish brown, silty <u>CLAY</u> and <u>SILT</u>; little fine sand; very stiff; damp; varved.	PS-3 7.5-9.0'	PS 1.3/1.5	100 TO 400 PSI INCREASING TO 600 PSI IN LAST 1". TIP OF TUBE SLIGHTLY DENTED.
			Change in tube		AD	ROUGH DRILLING IN COBBLE AT 9.0'.
10		ML	? Brown, clayey, sandy <u>SILT</u>; included rock fragments; stiff; damp.	PS-4 10.0-12.0'	PS 2.0/2.0	100 PSI GRADUALLY INCREASING TO 600 PSI. BOTTOM 6" OF TUBE SQUEEZED IN PROBABLY BY ROCK.
12			Change in tube		AD	ROUGH DRILLING IN ROCK AT 11.5'.
14		CH	? Red <u>CLAY</u>; stiff; damp; highly plastic.	PS-5 13.0-15.0'	PS 2.0/2.0	100 TO 300 PSI.
16			Change in tube			
		CL	? Brown, silty <u>CLAY</u>; stiff; damp.	PS-6 16.0-18.0'	PS 2.0/2.0	100 PSI GRADUALLY INCREASING TO 300 PSI.
18			Moderate, reddish brown, silty <u>CLAY</u>; a little sand; some included rock fragments; stiff; damp.		AD	EASY DRILLING.
20				PS-7 19.0-20.0	PS 1.0/1.0	100 TO 200 PSI INCREASING TO 400 AT LAST 1". PROBABLY IN ROCK FRAGMENT.

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA PALO ALTO • NEWPORT BEACH • CALIF.	SOIL EXPLORATION DRILL HOLE LOG PROJECT NO. 0829 · DATE AUGUST 1975 · SHEET NO. 1 OF 2	HOLE NO. CASA 3037

DRILL RIG CME 55 MOUNTED ON FN 160	HOLE ELEVATION 1162'	LOGGED BY ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE) 0' (6/18/75)	HOLE DIAMETER 6-1/2"	DATE DRILLED JUNE 17, 1975

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
20			LACUSTRINE DEPOSITS--CONT. ? FACIES CHANGE TO COARSER MTL		AD	EASY DRILLING.
22		ML	Brown, sandy SILT; some fine sand lenses and gravel; stiff; damp.	PS-8 22.0-22.8	PS 0.8/0.8	100 TO 300 PSI INCREASING TO 600 PSI AT BOTTOM 1". PROBABLY IN ROCK. BENT TIP OF TUBE. SAMPLE LOOSE INSIDE TUBE.
					AD	ROUGH DRILLING 22.5-24.0'.
24			Brown, sandy SILT, clayey; some fine gravel; stiff; moist.	PS-9 24.0-24.5'	PS 0.5/0.5	100 TO 200 PSI INCREASING TO 600 PSI AT BOTTOM 1". DENTED TIP OF TUBE. SAMPLE LOOSE INSIDE TUBE.
					AD	SLIGHTLY ROUGH DRILLING TO 26.0'.
26			Brown, sandy SILT, clayey; some clean sand pockets and fine gravel; dense; moist.	SPT-1 26.0-27.5'	DR 1.0/1.5	DROVE STANDARD SPLIT SPOON WITH 140 LB. HAMMER AND 30" FREE FALL (DR). 5/0.5, 16/0.5, 22/0.5
28					AD	
		CL	Reddish brown, sandy CLAY w/included fine gravel at tip of tube.	PS-10 28.5-30.5'	PS 1.2/2.0	100 TO 300 PSI. ROUGH SAMPLING. DENTED TIP OF TUBE.
30			? Change in tube			
		GP-SP	30.0-39.5 GLACIAL TILL; poorly sorted SAND and GRAVEL w/silt and clay.	SPT-2 30.5-32.0'	DR 1.5/1.5	42/0.5, 54/0.5, 110/0.5
32			Reddish brown, SAND and GRAVEL, clayey; very dense; damp.		AD	ROUGH DRILLING FROM 32.0-34.0'.
34		SP	Reddish brown, gravelly SAND, clayey; very dense; damp.	SPT-3 34.0-35.5'	DR 1.2/1.5	5/0.5, 32/0.5, 48/0.5
36					AD	VERY ROUGH DRILLING FROM 35.5-38.0' IN GRAVELLY MATERIAL.
38		SP	Reddish brown, gravelly SAND, clayey; very dense; damp.	SPT-4 38.0-39.5'	DR 1.0/1.5	11/0.5, 36/0.5, 100/0.5 WATER LEVEL AFTER PULLING AUGER. 3:30 P.M., 6/17/75-10.0'. WATER LEVEL AFTER 1/2 HOUR-10.0'. WATER LEVEL, 6/18/75-0.0'.
40			BOTTOM OF HOLE = 39.5 FEET			

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	SOIL EXPLORATION DRILL HOLE LOG			HOLE NO. CASA 3037
PALO ALTO • NEWPORT BEACH • CALIF.		PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 2 OF 2	

DRILL RIG	CME 55 MOUNTED ON FN 160	HOLE ELEVATION	1146'	LOGGED BY	ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE)	0' (6/13/75)	HOLE DIAMETER	6-1/2"	DATE DRILLED	JUNE 12, 1975

NOTE: Casagrande hole drilled 10' E of Reserve Hole No. 3056.
*RECOVERY RATIO INDICATED BY FRACTION.

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
0			0-0.5 RESIDUAL SOIL; CLAY, silty; dark brown; organic soil.		AD	DRILLED WITH 6" HOLLOW STEM AUGER (AD).
			0.5-27.0 LACUSTRINE DEPOSITS; thinly bedded or varved (?) CLAY and SILT w/some sand and gravel.			
2		CH	Red CLAY; little sand and fine gravel; highly plastic; stiff; damp at tip of tube.	PS-1 2.0-4.0'	PS 1.6*/2.0	SAMPLED WITH THIN WALL STATIONARY PISTON SAMPLER (PS). 200 TO 400 PSI APPLIED HYDRAULIC PRESSURE. TIP OF TUBE SLIGHTLY DENTED.
4					AD	DRILLED TO 5.0'; SOME ROCK FRAGMENTS.
6			Reddish brown CLAY with rock fragments; stiff; damp at tip of tube.	PS-2 5.0-6.7'	PS 1.4/1.7	200 PSI APPLIED PRESSURE INCREASING TO 600 PSI IN LAST 2". DENTED TIP OF TUBE.
					AD	DRILLED TO 7.0'; LITTLE ROCKY.
8			Reddish brown CLAY; mottled w/gray; some included rock fragments; stiff; damp; highly plastic.	PS-3 8.0-10.0'	PS 1.7/2.0	SAMPLED THROUGH HOLLOW STEM. 200 TO 600 PSI APPLIED PRESSURE. DENTED TIP OF TUBE.
10					AD	
		?	Change in tube			
12		ML	Brown, sandy SILT at tip of tube; stiff; damp.	PS-4 11.0-12.8'	PS 1.7/1.8	200 PSI APPLIED PRESSURE INCREASING TO 600 IN LAST 3". DENTED TIP OF TUBE.
					AD	LITTLE ROUGH DRILLING TO 14.0'.
14		CH	Reddish brown, silty CLAY at tip of tube; stiff; highly plastic; damp.	PS-5 14.0-16.0'	PS 1.6/2.0	200 PSI APPLIED PRESSURE GRADUALLY INCREASING TO 600 PSI.
16					AD	EASY DRILLING. NO ROCK.
18			Reddish brown CLAY mottled w/gray; some included rock fragments; stiff; damp; highly plastic.	PS-6 17.0-19.0'	PS 2.0/2.0	100 TO 300 PSI APPLIED PRESSURE.
20					AD	

DRILL RIG	CME 55 MOUNTED ON FN 160	HOLE ELEVATION	1146'	LOGGED BY	ASB
GROUNDWATER DEPTH (BELOW GROUND SURFACE)	0' (6/13/75)	HOLE DIAMETER	6-1/2"	DATE DRILLED	JUNE 12, 1975

ELEVATION (Depth)	CLASS. LAB.	CLASS. FIELD	DESCRIPTION FIELD IDENTIFICATION	SAMPLE NUMBER	MODE	REMARKS
20		CL	LACUSTRINE DEPOSITS--CONT. Reddish brown, silty CLAY at tip of tube; stiff; damp.	PS-7 20.0-22.0'	PS 1.9/2.0	200 TO 400 PSI APPLIED PRESSURE.
22					AD	WATER LEVEL AT 19.0'.
			Change in tube	PS-8 23.0-25.0'	PS 2.0/2.0	200 TO 400 PSI APPLIED PRESSURE. DIFFICULTY PULLING OUT PISTON. VACUUM BETWEEN PISTON AND SAMPLE MOVED SAMPLE. DISTURBED SAMPLE.
24		ML-CL	? FACIES CHANGE TO COARSER MTL. SILT, sandy to CLAY, sandy; brown; stiff; moist.			
			Brown, sandy SILT at tip of tube at 25'.		AD	
26			Brown, sandy CLAY at tip of tube at 26.5'.	PS-9 26.0-27.0'	PS 1.0/1.0	300 PSI INCREASING TO 700 PSI AT 27.0', APPARENTLY IN ROCK. TUBE WAS CUT WITH SAW BECAUSE OF EXTREME DIFFICULTY PULLING OUT TUBE FROM SAMPLER HEAD.
		ML-CL	27.0-37.5 GLACIAL TILL; SILT, sandy and CLAY, sandy; reddish brown to brown; included angular, coarse sand and fine gravel.		AD	ROUGH DRILLING FROM 27.0-28.0'.
28				SPT-1 28.0-29.5'	DR 1.0/1.5	DROVE STANDARD SPLIT SPOON WITH 140 LB. HAMMER AND 30" FREE FALL (DR). 10/0.5, 25/0.5, 30/0.5
30			Brown, gravelly, sandy SILT; some clay.		AD	EASY DRILLING. ROUGH DRILLING IN GRAVELLY MATERIAL AT 31.0'.
32			Reddish brown, sandy SILT w/included rock fragments.	SPT-2 32.0-33.5'	DR 1.0/1.5	13/0.5, 17/0.5, 26/0.5
34					AD	EASY DRILLING TO 36.0' IN SOME ROCKY MATERIAL. CLEANED OUT CUTTINGS IN BOTTOM OF HOLLOW STEM BY JETTING TO GET TO 36.0' FOR DRIVE SAMPLE.
36			Reddish brown, sandy CLAY; silty, angular coarse sand and fine gravel; dense; damp.	SPT-3 36.0-37.5'	DR 1.0/1.5	11/0.5, 18/0.5, 21/0.5
38			BOTTOM OF HOLE = 37.5 FEET		AD	WATER LEVEL AFTER PULLING OUT AUGERS-5.0', 5:30 P.M. WATER LEVEL AT SURFACE, 8:00 A.M., 6/13/75.

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA PALO ALTO • NEWPORT BEACH • CALIF.	SOIL EXPLORATION DRILL HOLE LOG			HOLE NO. CASA 3056
		PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 2 OF 2	

UNIFIED SOIL CLASSIFICATION SYSTEM (ASTM D-2487)

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES
COARSE GRAINED SOILS MORE THAN 50% RETAINED ON NO. 200 SIEVE*	GRAVELS 50% OR MORE OF COARSE FRACTION RETAINED ON NO. 4 SIEVE	CLEAN GRAVELS	GW	WELL-GRADED GRAVELS AND GRAVEL-SAND MIXTURES, LITTLE OR NO FINES.
			GP	POORLY GRADED GRAVELS AND GRAVEL-SAND MIXTURES, LITTLE OR NO FINES.
		GRAVEL WITH FINES	GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES.
			GC	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES.
	SANDS MORE THAN 50% OF COARSE FRACTION PASSES NO. 4 SIEVE	CLEAN SANDS	SW	WELL-GRADED SANDS AND GRAVELLY SANDS, LITTLE OR NO FINES.
			SP	POORLY GRADED SANDS AND GRAVELLY SANDS, LITTLE OR NO FINES.
		SANDS WITH FINES	SM	SILTY SANDS, SAND-SILT MIXTURES.
			SC	CLAYEY SANDS, SAND-CLAY MIXTURES.
FINE GRAINED SOILS 50% OR MORE PASSES NO. 200 SIEVE*	SILTS & CLAYS	LIQUID LIMIT 50% OR LESS	ML	INORGANIC SILTS, VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS.
			CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS.
			OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY.
	SILTS & CLAYS	LIQUID LIMIT GREATER THAN 50%	MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDS OR SILTS, ELASTIC SILTS.
			CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.
			OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY.
	HIGHLY ORGANIC SOILS		PT	PEAT, MUCK AND OTHER HIGHLY ORGANIC SOILS.

*BASED ON THE MATERIAL PASSING THE 3-IN. (75-MM) SIEVE.

DEFINITION OF TERMS

GRAIN SIZES

U.S. STANDARD SERIES SIEVES: 200, 50, 16, 4 — CLEAR SQUARE SIEVE OPENINGS: 3/4", 3", 12"

SILTS & CLAYS DISTINGUISHED ON BASIS OF PLASTICITY	SAND			GRAVEL		COBBLES	BOULDERS
	FINE	MEDIUM	COARSE	FINE	COARSE		

MOISTURE CONDITION (INCREASING MOISTURE ——→)

DRY — SLIGHTLY DAMP — DAMP (PL) — MOIST — VERY MOIST — WET (SATURATED) (LL)

SANDS & GRAVELS

RELATIVE DENSITY	BLOWS/FOOT*
VERY LOOSE	0-4
LOOSE	4-10
MEDIUM DENSE	10-30
DENSE	30-50
VERY DENSE	OVER 50

CLAYS & SILTS

CONSISTENCY	BLOWS/FOOT*	STRENGTH**
VERY SOFT	0-2	0-¼
SOFT	2-4	¼-½
FIRM	4-8	½-1
STIFF	8-16	1-2
VERY STIFF	16-32	2-4
HARD	OVER 32	OVER 4

SAMPLE NUMBER COLUMN

TYPE OF SAMPLE CONTAINER:

- BAG .... B
- JAR .... J
- SHELBY TUBE .... PS
- LINER (TUBE) L
- WRAPPED CORE .... WC
- BOX X

MODE COLUMN

METHOD OF ADVANCING HOLE:

DRILL
- FLIGHT AUGER .... AD
- BUCKET AUGER .... BA
- SPIN AUGER .... SD
- ROTARY DRILL .... RD
- CABLE TOOL .... CT

SAMPLER
- DRIVE .... DR
- PITCHER BARREL .... PB
- PISTON SAMPLER..... PS

RECOVERY RATIO INDICATED BY A FRACTION:

$$\frac{1.2}{1.5} = \frac{\text{FOOTAGE RECOVERED}}{\text{FOOTAGE SAMPLED}}$$

REMARKS COLUMN

NUMBER OF BLOWS REQUIRED TO DRIVE SAMPLER IS SHOWN FOR EACH 0.5' OF PENETRATION AS FOLLOWS: 17/.5 22/.5 29/.5

SPT — STANDARD PENETRATION TEST; 2" O.D. SAMPLER DRIVEN WITH A 140 POUND HAMMER FALLING A DISTANCE OF 30".

W — 2" O.D. STANDARD SPLIT-SPOON SAMPLER DRIVEN WITH A 250-POUND SLIP JAR FALLING A DISTANCE OF 18 INCHES.

* NUMBER OF BLOWS OF 140 POUND HAMMER FALLING 30 INCHES TO DRIVE A 2-INCH O-D. (1-3/8 INCH I-D.) SPLIT SPOON (SPT).
** UNCONFINED COMPRESSIVE STRENGTH IN TONS/SQ. FT.

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KEY FOR EXPLORATION LOGS

APPENDIX B

LABORATORY INVESTIGATION

APPENDIX B

LABORATORY INVESTIGATION

A. INTRODUCTION

This Appendix includes a discussion of test procedures and results of the laboratory investigation performed by W. A. Wahler and Associates for the On-Land Tailings Disposal Dam at the Mile Post No. 7 site of Reserve Mining Company, Silver Bay, Minnesota.

The purpose of the laboratory investigation was to perform a limited number of tests to check Reserve Mining Company's Consultants' assessment of the geotechnical engineering characteristics of the lacustrine foundation material beneath Dams No. 1 and No. 2-3 and the taconite tailings material which will be disposed of. The investigation program was carried out employing, wherever possible, currently accepted test procedures of the American Society of Testing and Materials (ASTM). Certain phases of the investigation, such as the triaxial testing and pore pressure dissipation studies, were carried out employing laboratory testing techniques which have not yet been standardized. These innovations in soil testing were carried out in accordance with methods developed by our firm or by other researchers in the field of soil engineering.

The various undisturbed foundation samples used in the laboratory investigation were obtained during the course of the site drilling program carried out under the direction of W. A. Wahler and Associates. Undisturbed thin-wall tube samples of the foundation materials were obtained with a thin-wall stationary piston sampler. Drill hole numbers are the same as previous drill holes by Klohn Leonoff Consultants, Ltd. Samples of fine tailings, concentrator tailings, filter tailings, and dry cobbs were selected by members of the Reserve Project Team and shipped to our laboratory for testing.

B. INDEX PROPERTY TESTING

In the field of soil mechanics and earth dam design, it is advantageous to have a standard method of identifying soils and classifying them into categories or groups that have similar or distinct engineering properties. The most commonly used method at present is the Unified Soils Classification System (USCS) as described by ASTM D2487-66T. The USCS is based on a recognition of the various types and significant distribution of soil constituents, considering individual grain size, magnitude and type of gradation characteristics, and plasticity of materials.

The index properties tests presented in this report include the determination of natural water content and in-place dry density for undisturbed samples, grain-size distribution, Atterberg Limits, and specific gravity determination.

1. Natural Water Content and Dry Density

Natural water content and dry density data for undisturbed foundation samples were determined, in conjunction with other tests, from 2.875-inch diameter, thin-wall tube samples. All samples were extruded, trimmed to obtain a smooth square face, accurately measured to obtain volume and wet weight, and then dried for a period of 24 hours in an oven maintained at a temperature of 105°C. The oven-dried samples were weighed and the moisture content and dry density calculated. These results are summarized in Table B-1 and are also shown with the various other index and engineering properties test results for undisturbed foundation materials.

2. Grain-Size Distribution

The gradation characteristics of selected foundation materials and tailings materials were determined in accordance with ASTM Designation D422-63 and D1140-54, except as modified below. Representative samples were quartered and prepared in accordance with ASTM Designation D421-58. The samples were soaked in water until individual soil particles were separated and washed

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& ASSOCIATES

on a No. 200 mesh sieve. That portion of the material retained on the No. 200 mesh sieve was oven-dried and then either mechanically sieved or simply weighed to determine the percent passing the No. 200 mesh sieve. A hydrometer analysis was performed on the minus No. 200 material using a constant temperature hydrometer bath. Sodium hexametaphosphate was used as a dispersing agent. The grain-size distribution tests are presented on Figure B-1, sheets 1 through 7 and sheet 9.

One sample, 1076, PS-4, 8.5'-10.5', showing very significant varve layers after drying, was manually separated into the clay and silt laminae and tested separately. These grain-size distribution test results are presented on Figure B-1, sheet 8.

The varved nature of some of the foundation materials is illustrated in the photographs reproduced on Photoplate B-1. Photo 2 is of the sample described above on which the separate grain-size distributions of the clay and silt laminae were determined. In the photographs, the darker colored laminae are clay, the lighter colored are predominantly silt.

3. Atterberg Limits

The liquid and plastic limits for the lacustrine foundation samples were determined in accordance with ASTM Designation D423 and D424. Results of the Atterberg Limits for foundation materials are summarized on Figure B-2, sheets 1 through 3, and also on the gradation, consolidation, and triaxial presentation sheets to aid in interpretation of such results.

4. Specific Gravity

Specific gravity determinations were made on selected samples of foundation material and also on the tailings material in accordance with ASTM Designation D854-58. The specific gravity test results are shown in Table B-2 and also with the various engineering properties test results.

C. ENGINEERING PROPERTIES TESTING

The engineering properties testing consisted of minimum and maximum density testing, consolidation, unconfined compression, direct shear, isotropically consolidated-undrained (ICU) triaxial shear and unconsolidated-undrained (UU) triaxial shear testing, permeability, and pore pressure dissipation.

1. Minimum and Maximum Density

The minimum dry density of the existing concentrator tailings material was determined in accordance with ASTM Designation D2049-69 after oven-drying the sample.

The minimum density of the fine tailings material was determined by allowing the sample to settle in water to its ultimate density. The material was mixed with water in a malt mixer for three minutes and was then poured into a 2.48-inch I.D., 10-inch high Lucite cylinder and the settlement *vs.* time was monitored until the ultimate density was reached.

The maximum dry density of the same material was determined in accordance with ASTM Designation D1557-70, modified to yield a compactive energy of 20,000 foot-pounds per cubic foot ($ft.lb./ft^3$) by reducing the number of layers to three and the number of blows per layer of a 10-pound hammer to 15. The minimum and maximum dry density results are presented on Figure B-3, sheets 1 through 3.

2. Consolidation Tests

Three one-dimensional consolidation tests were performed on undisturbed lacustrine foundation samples. The samples were loaded to normal pressures of 125, 250, 500, 1000, 2000, 4000, and 8000 psf, rebounded back to 1000 psf, reloaded again to 2000, 4000, 8000, 16,000, and 32,000 psf, and then rebounded back to 125 psf. Samples were allowed to consolidate for 24 hours under each applied load increment. Each consolidation test included time readings for five of the load increments. Final specimen data was calculated at 125 psf rebound. Results of the consolidation tests appear on Figure B-4, sheets 1 through 3.

3. Unconfined Compression

One lacustrine foundation sample was tested for unconfined compressive strength in accordance with ASTM D2166-66. Unconfined compressive strength vs. axial strain were monitored during the test. The results appear on Figure B-5.

4. Direct Shear Tests

Direct shear tests were performed on selected undisturbed foundation samples. Each sample was trimmed to 1.0 inch high and positioned in the shear box of the same diameter as the sample. The sample was then flooded with water, loaded with the appropriate confining pressure, and immediately sheared horizontally at a controlled strain rate of 0.05 inch per minute. The sample was not allowed to consolidate prior to shear. The horizontal displacement, shear stress, and volume change of the sample was recorded at regular strain intervals. The results of the direct shear testing appear on Figure B-6, sheets 1 through 3.

5. Triaxial Shear Tests

All triaxial shear testing was performed on undisturbed thin-wall tube samples.

a. Sample Preparation - Samples selected for testing were extruded from tubes using a hydraulically operated ram capable of exerting the minimum force necessary to free the sample from the tube. Specimens were then trimmed to an approximate 2:1 height to diameter ratio. With the aid of a special trimming device which completely supported the sample, the possibility of sample disturbance due to handling was significantly reduced.

After trimming, and the initial weight and volume measurements determined, each specimen was placed in a triaxial cell, encased in a rubber membrane and sealed to the bottom pedestal and topcap with rubber "O" rings. After securing the triaxial chamber, the cell was filled with water and fitted with a 1 inch diameter stainless steel piston for load application.

1) Unconsolidated-Undrained Tests - The UU triaxial shear tests were performed on samples at natural water content. After preparation, as described in (a) above, each sample was transported to the loading machine. The specimen was tested with the triaxial chamber pressure increased to the desired confining pressure; however, no drainage was allowed. Axial load and sample strain were monitored throughout the test, as described in (c) below. Results of the UU triaxial tests are presented on Figure B-7, sheets 1 through 7.

2) Isotropically Consolidated Undrained - The samples tested under ICU conditions were prepared as in (a) above, saturated, and isotropically consolidated as in (b) below, and then failed in an undrained condition. Pore pressure, axial load, and sample strain were monitored, as described in (c) below. Results of the isotropically consolidated triaxial shear test are presented on Figure B-8, sheets 1 through 3.

b. Sample Saturation and Consolidation - The laboratory is equipped with a panel of six bays, with individual pressure control to each bay, such that six triaxial samples can be simultaneously saturated and/or consolidated at different individual pressures. Bleeding air regulators capable of delivering air pressure up to 170 psi are used to control the top, bottom, and chamber lines leading to the triaxial cells. Each saturation bay is also equipped with constant diameter Pyrex sight tubes, each with a cross-sectional area of 0.075 square inch, which connect with the base of the triaxial cell, and thus to the sample. The sight tubes are easily read to the nearest 0.01 cubic inch.

The samples for ICU testing were saturated using a combination vacuum-back-pressure technique. The vacuum was applied to increase the initial saturation without a change in void ratio in order to preclude the need for excessively high back pressures. Nevertheless, a back pressure of at least 50 psi was necessary to obtain a sufficient degree of saturation prior to the consolidation phase of the test. In order to determine whether the back pressure applied was causing complete saturation, Skempton's "B" parameter was measured for all samples. A value in excess of 0.95 was considered to represent a fully saturated condition. After achieving complete saturation, the chamber pressure was increased to a value in excess of the back pressure equal to the designated consolidation pressure. The top and bottom drainage lines were simultaneously opened, and a total volume of water expelled from the samples was monitored as a function of time. These consolidation curves are included on the presentation sheets. In most cases, strips of filter paper, placed along the sides of the specimen during setup, were used to accelerate the consolidation process.

c. Sample Failure - All triaxial specimens were failed by compression loading at a constant rate of strain while maintaining a constant minor principal stress. The rate of strain selected for sample failure was dependent upon the material's consolidation characteristics.

The filter strips along the sides of most of the samples allowed for their failure at a faster rate. The exact rate of strain for each test is presented on the individual data sheet. The axial load readings were recorded during the test at specified axial deformations using BLH load cells (0-2,000 lb. and 0-5,000 lb.). Pore pressure measurements were obtained by Stathom pore pressure transducers (0-200 psi). The adopted failure criterion used for the presentation of the Mohr circle of stress for most triaxial tests was the point of maximum principal effective stress ratio, except for the unconsolidated tests, in which maximum deviator stress was used.

6. Permeability Tests

Permeability coefficients for selected samples of foundation material were determined in conjunction with triaxial shear tests. Also, samples of tailings material were fabricated specifically for permeability testing.

Samples were tested after saturation and consolidation by applying a constant head hydraulic gradient and monitoring the flow of water from bottom to top of the sample through the sight tubes. Horizontal coefficients of permeability were also determined for selected foundation samples by trimming undisturbed Shelby tube specimens on an axis perpendicular to the vertical. The "oriented" specimens were then saturated, consolidated, and tested in the manner described above. Permeability test results are presented on Figure B-9, sheets 1 through 4.

7. Pore Pressure Dissipation Tests

Pore pressure dissipation tests were performed on selected foundation samples. After preparing each sample and sealing it in a triaxial cell, as described in 5.a. above, a pore pressure transducer was connected to the base of the cell and thus to the bottom of the sample. The confining pressure was then increased incrementally. The sample was not allowed to drain and the resulting pore pressure at the base of the sample was monitored. After achieving the desired confining pressure, the sample was allowed to dissipate the pore pressure which had developed as a result of the increase in confining pressure. This dissipation was allowed only through the top of the approximately 4.0- to 6.0-inch high samples while its progress was monitored by the transducer at the bottom. Test results for the pore pressure dissipation tests are summarized on Figure B-10, sheets 1 through 7, in the form of buildup in pore pressure as minor principal stress and pore pressure dissipation (percent of the pressure developed as a result of the application of confining pressure versus time).

Table B-1

RESERVE MINING

IN-PLACE WATER CONTENT AND DRY DENSITY DATA

Hole No.	Sample No.	Depth, Ft.	Water Content, %	Dry Density, pcf
1006	PS-1	2 - 4	29.8	91.5
1006	PS-1	2 - 4	31.8	88.2
1006	PS-1	2 - 4	33.3	87.2
1006	PS-1	2 - 4	32.9	87.9
1006	PS-3	10 -12	52.1	68.5
1006	PS-3	10 -12	52.5	69.6
1006	PS-3	10 -12	43.9	75.0
1071	PS-2	5 - 7	42.8	76.8
1071	PS-2	5 - 7	41.2	79.0
1071	PS-2	5 - 7	48.0	72.9
1071	PS-4	10.5-12.5	42.5	78.1
1071	PS-4	10.5-12.5	48.9	72.8
1071	PS-4	10.5-12.5	44.9	74.9
1076	PS-1	1.5- 3.5	44.4	76.7
1076	PS-1	1.5- 3.5	41.7	79.0
1076	PS-1	1.5- 3.5	38.4	82.0
1076	PS-2	4 - 6.4	33.0	88.3
1076	PS-2	4 - 6.4	41.0	80.1
1076	PS-2	4 - 6.4	46.8	75.3
1076	PS-3	6.5- 8	34.3	86.0
1076	PS-4	8.5-10.5	37.7	83.6
1076	PS-4	8.5-10.5	41.0	80.1
1076	PS-5	11 -13	22.2	104.7
3020	PS-1	1 - 3	22.7	104.7
3020	PS-1	1 - 3	21.8	105.6
3020	PS-2	4 - 5.5	24.1	99.6
3020	PS-2	4 - 5.5	23.7	101.8
3020	PS-2	4 - 5.5	23.2	100.1
3020	PS-4	8.5- 9.5	27.4	97.8
3020	PS-4	9.5-10.6	25.6	100.4
3020	PS-4	9.5-10.6	22.8	104.1

TABLE B-1 (continued)

Hole No.	Sample No.	Depth, Ft.	Water Content, %	Dry Density, pcf
3020	PS-5	11 -13	32.5	89.6
3020	PS-5	11 -13	34.1	88.3
3020	PS-5	11 -13	32.3	90.7
3020	PS-5	11 -13	28.1	97.5
3020	PS-8	17.5-18.7	18.5	113.0
3020	PS-9	19 -20	18.0	111.4
3020	PS-10	21 -22	19.5	109.1

TABLE B-2

SPECIFIC GRAVITY DATA

Hole No.	Sample No.	Depth	Specific Gravity
1071	PS-2	5 - 7	2.70
1076	PS-2	4 - 6.4	2.79
3020	PS-4	9.5-10.6	2.75
3020	PS-9	19 -20	2.79
Fine Tailings			2.99
Concentrator Tailings			2.97

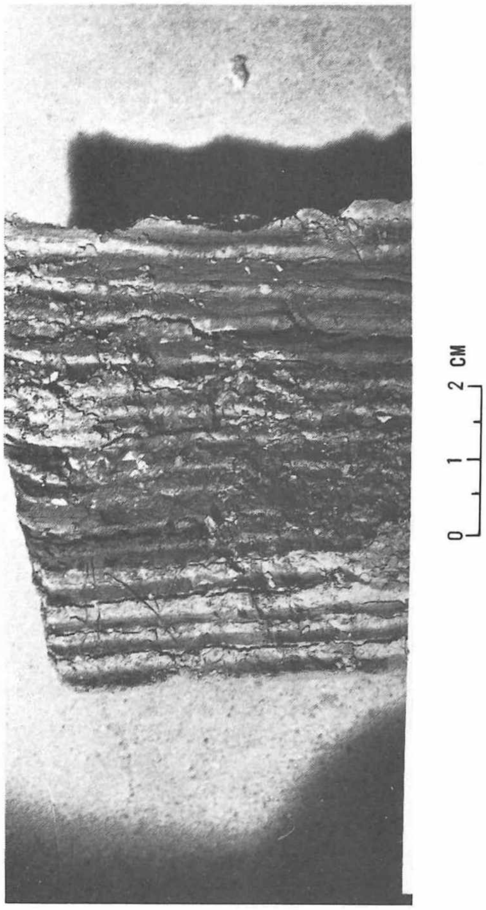

PHOTO A. PHOTO ILLUSTRATING VARVED NATURE OF FOUNDATION MATERIALS. CUT FROM SAMPLE NO. PS-2 (DRILL HOLE NO. WAWA-1076).

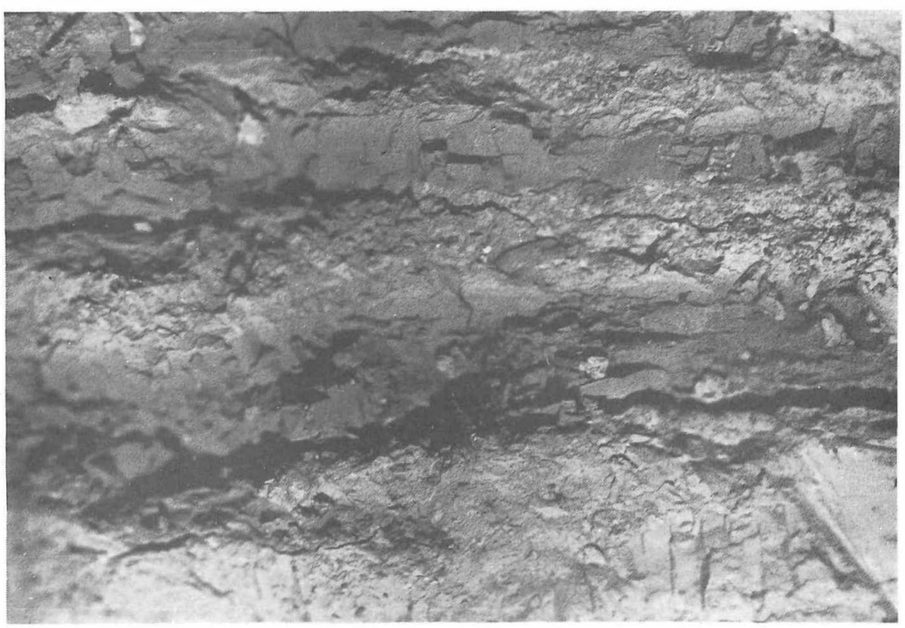

PHOTO B. CLOSEUP OF VARVED MATERIAL. CUT FROM SAMPLE NO. PS-4 (DRILL HOLE NO. WAWA-1076).

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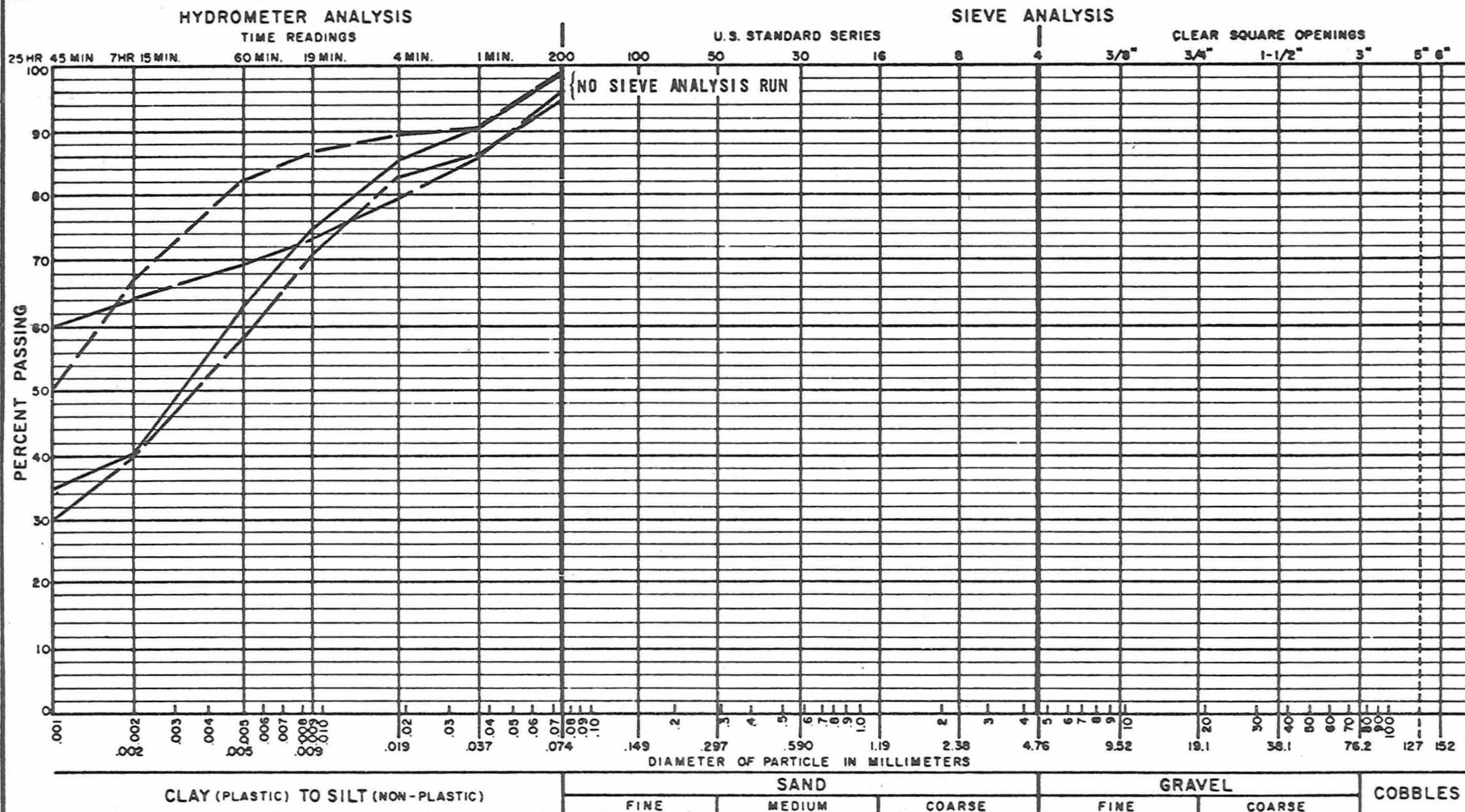
REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA

GRADATION TEST RESULTS

PROJECT NO 0829 | DATE AUGUST 1975 | DRAWING NO FIG. B-1

KEY:

LL	53	79	---	56						
PL	26	29	---	20						
PI	27	50	---	36						
NAT. W/C	29.8	36.2(AVG)	49.5 (AVG)	42.9(AVG)						
SPEC.GRAVITY	---	---	---	---						
CLASSIF.SYMB.	CH	CH	CH	CH						
SAMPLE NO.	PS-1	PS-2	PS-3	PS-4						
DEPTH, FT.	2-4	6-8	10-12	14-16						
HOLE NO.	1006	1006	1006	1006						



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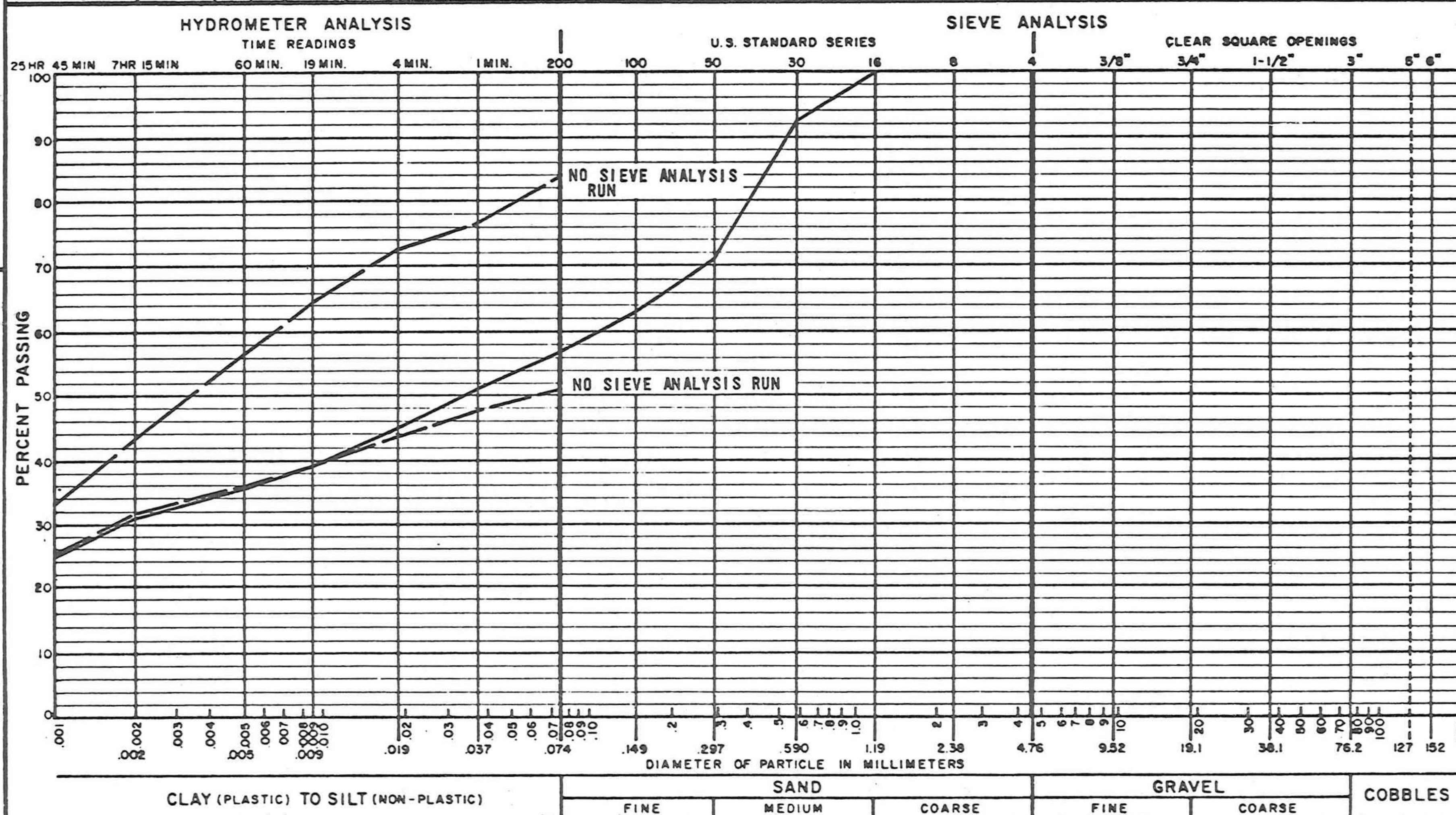
REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA

GRADATION TEST RESULTS

PROJECT NO	DATE	DRAWING NO
0829	AUGUST 1975	FIG. B-1

KEY:

LL	50	50	68						
PL	22	22	18						
PI	28	28	50						
NAT. W/C	42.8	41.2	42.5						
SPEC. GRAVITY	2.70	2.70	---						
CLASSIF. SYMB.	CL-CH	CL-CH	CH						
SAMPLE NO.	PS-2	PS-2	PS-4						
DEPTH, FT.	5-7	5-7	10.5-12.5						
HOLE NO.	1071(TOP)	1071(MIDDLE)	1071						



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REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA

GRADATION TEST RESULTS

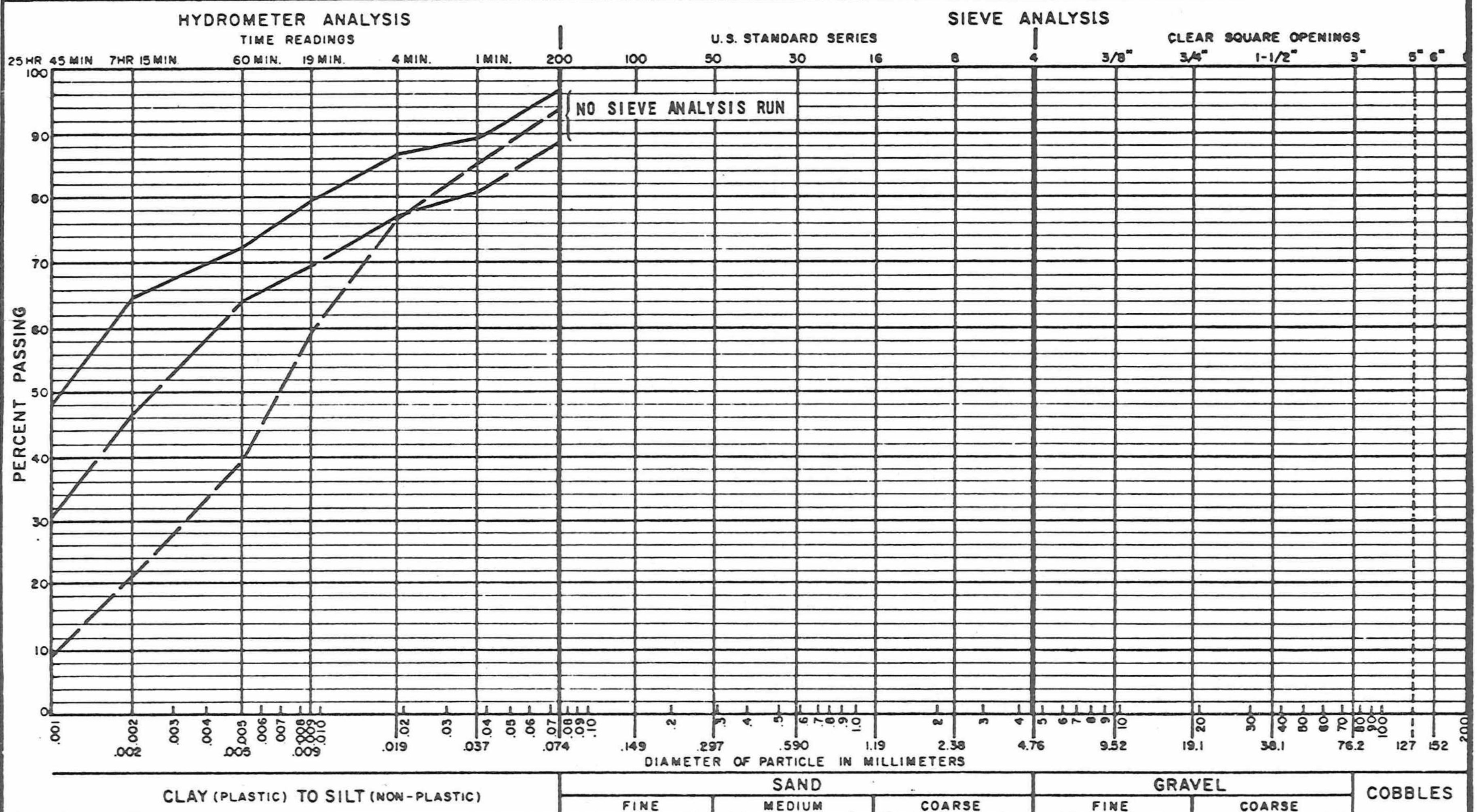
PROJECT NO 0829

DATE AUGUST 1975

DRAWING NO FIG. B-1

KEY: ——— — — — — —— — ——

LL	86	54	70						
PL	26	25	20						
PI	60	29	50						
NAT. W/C	44.4	33.0	34.3						
SPEC. GRAVITY	---	2.79	---						
CLASSIF. SYMB.	CH	CH	CH						
SAMPLE NO.	PS-1	PS-2	PS-3						
DEPTH, FT.	1.5-3.5	4-6.4	6.5-8.0						
HOLE NO.	1076	1076	1076						



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REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA

GRADATION TEST RESULTS

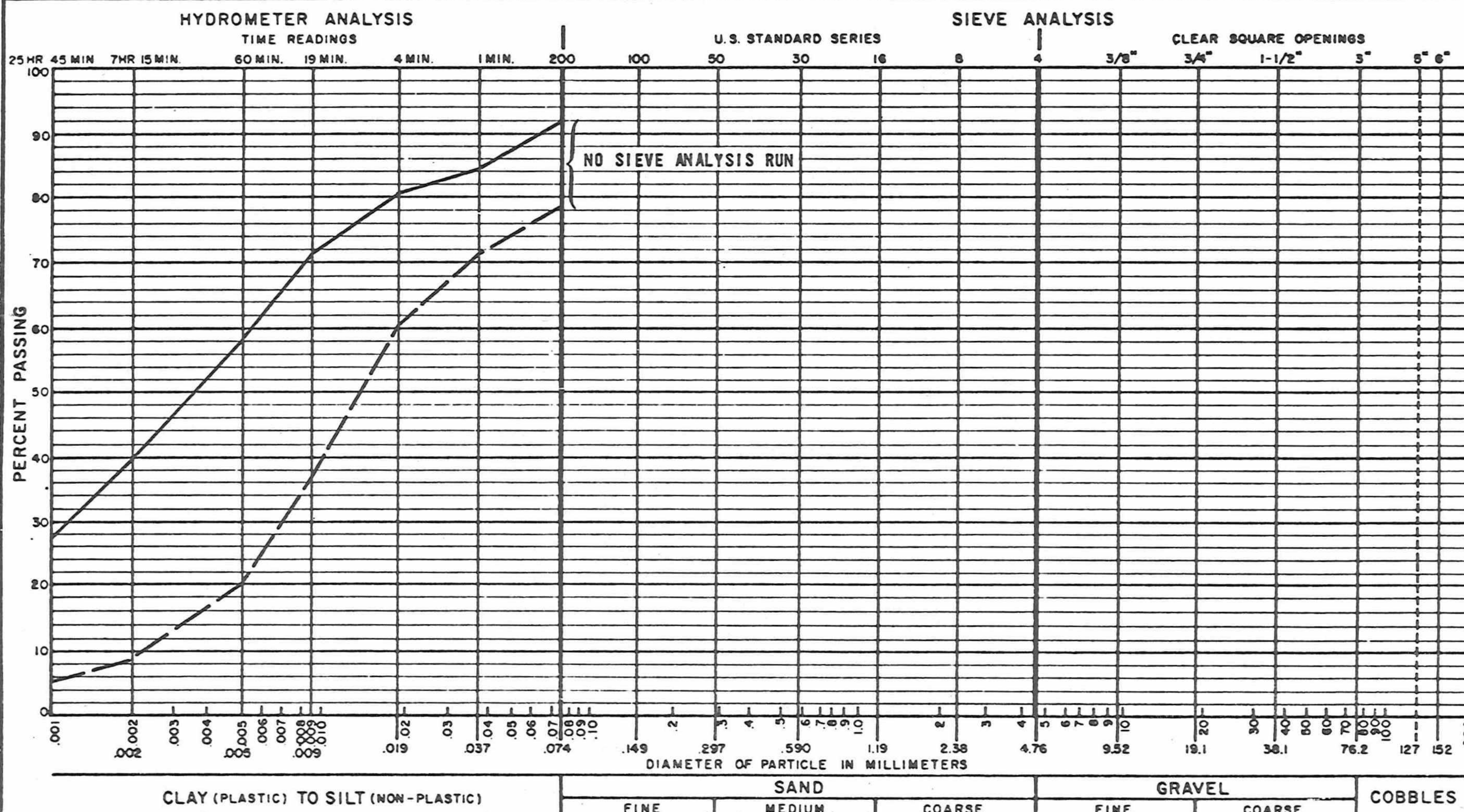
PROJECT NO: 0829

DATE: AUGUST 1975

DRAWING NO: FIG. B-1

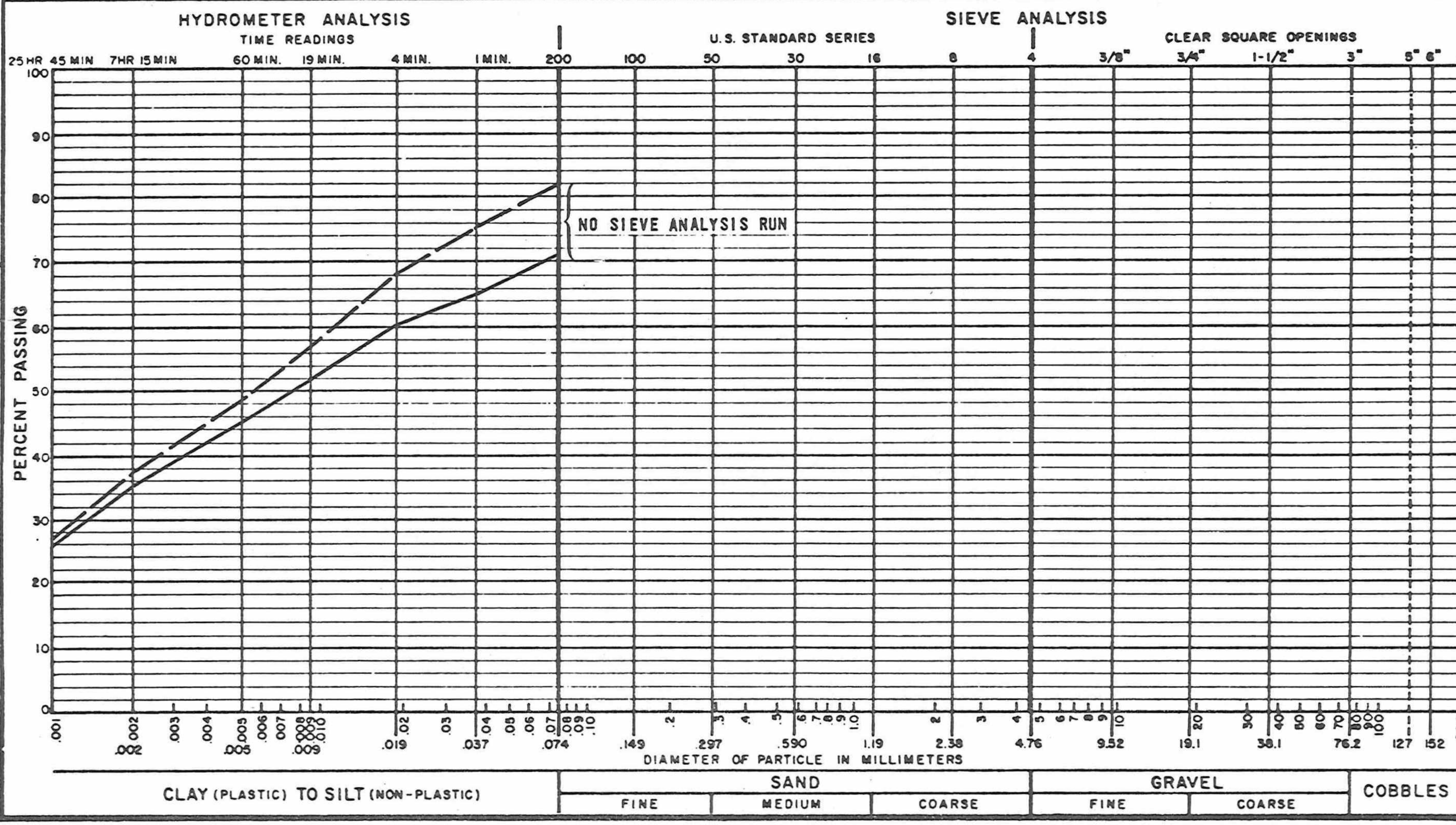
KEY: ——— (solid) - - - (dashed)

LL	73	25							
PL	25	22							
PI	48	3							
NAT. W/C	37.7	22.2							
SPEC. GRAVITY	---	---							
CLASSIF. SYMB.	CH	ML							
SAMPLE NO.	PS-4	PS-5							
DEPTH, FT.	8.5-10.5	11-13							
HOLE NO.	1076	1076							



KEY: ———— (PS-1)   — — — (PS-2)

LL	45	47
PL	22	16
PI	23	31
NAT. W/C	22.7	24.1
SPEC. GRAVITY	---	---
CLASSIF. SYMB.	CL	CL
SAMPLE NO.	PS-1	PS-2
DEPTH, FT.	1-3	4-5.5
HOLE NO.	3020	3020



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REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA

GRADATION TEST RESULTS

PROJECT NO: 0829

DATE: AUGUST 1975

DRAWING NO: FIG. B-1

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REVIEW OF MILE POST 7 PLAN
FOR STATE OF MINNESOTA

GRADATION TEST RESULTS

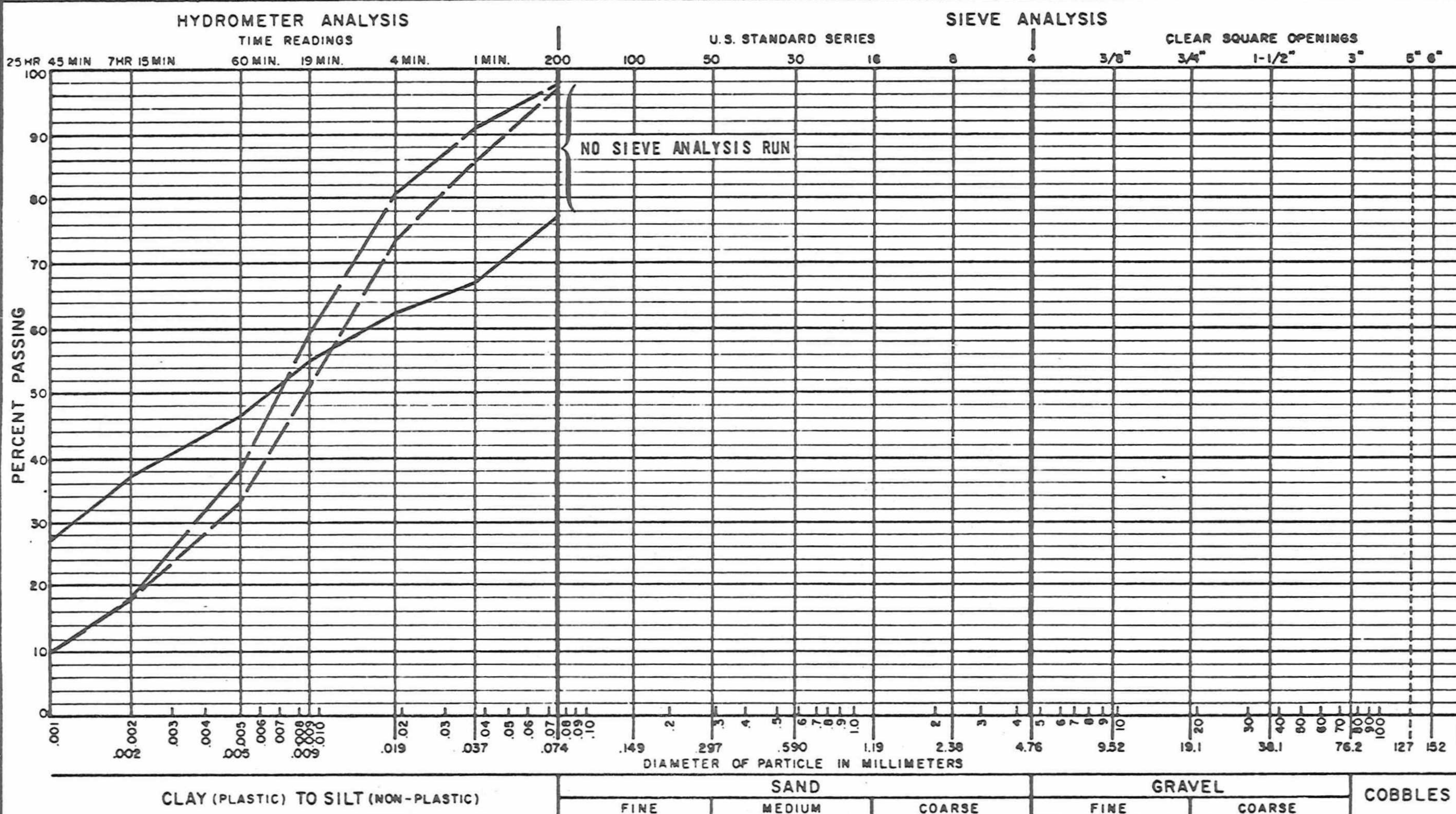
PROJECT NO 0829

DATE AUGUST 1975

DRAWING NO FIG. B-1

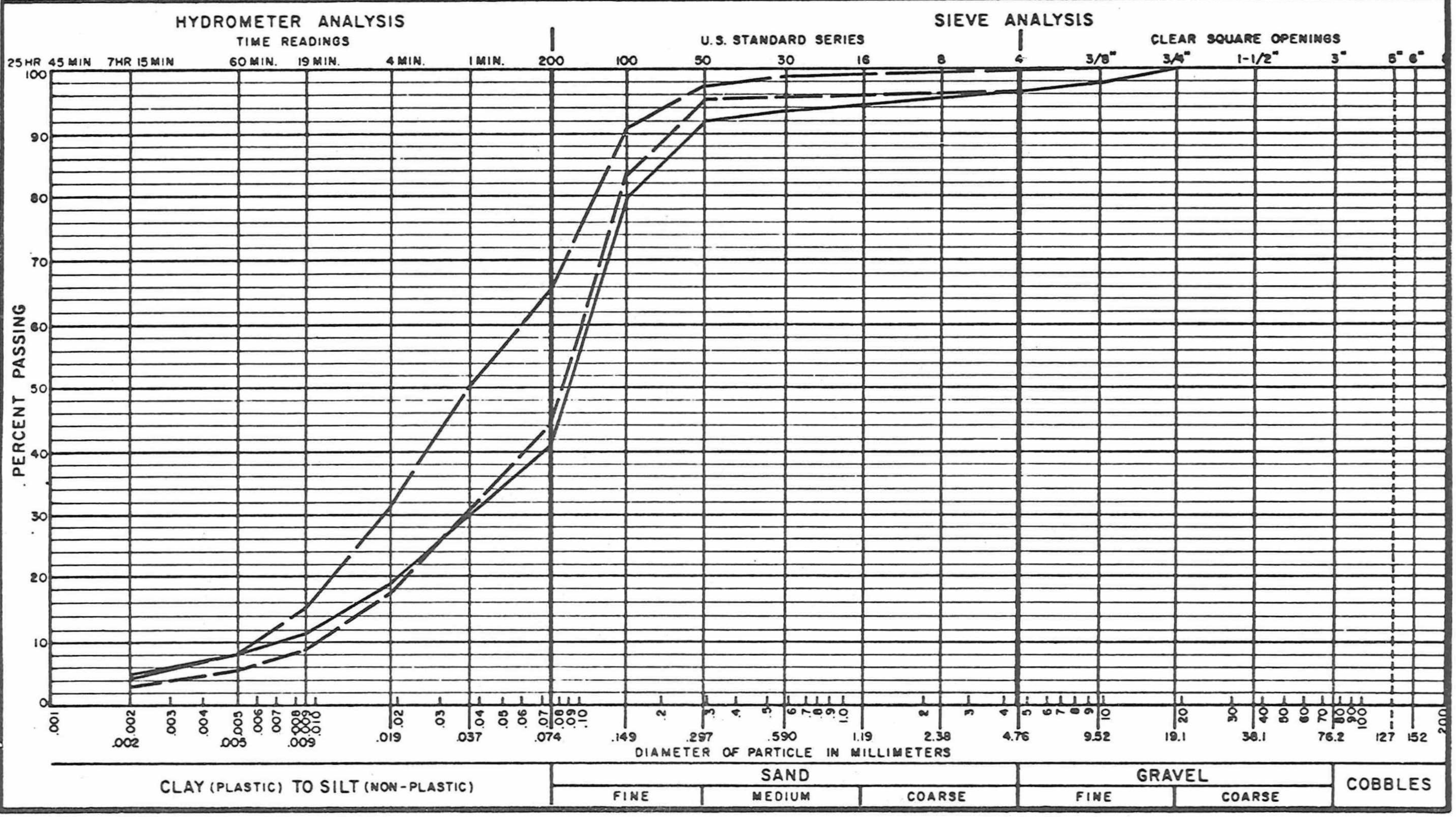
KEY: ——— — — — — — ———

LL	48	35	---							
PL	17	18	---							
PI	31	17	---							
NAT. W/C	27.4	25.6	32.5							
SPEC. GRAVITY	---	2.75	---							
CLASSIF. SYMB.	CL	CL	CL							
SAMPLE NO.	PS-4	PS-4	PS-5							
DEPTH, FT.	8.5-9.5	9.5-10.6	11-13							
HOLE NO.	3020	3020	3020							



KEY: ——— – – – — — —

LL	---		---
PL	---	---	---
PI	NP	NP	NP
NAT. W/C	18.5	18.0	19.5
SPEC. GRAVITY	---	2.79	---
CLASSIF. SYMB.	SM	SM	ML
SAMPLE NO.	PS-8	PS-9	PS-10
DEPTH, FT.	17.5-18.7	19-20	21-22.2
HOLE NO.	3020	3020	3020



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REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA

GRADATION TEST RESULTS

PROJECT NO	DATE	DRAWING NO
0829	AUGUST 1975	FIG. B-1

EXAMPLE OF VARYING

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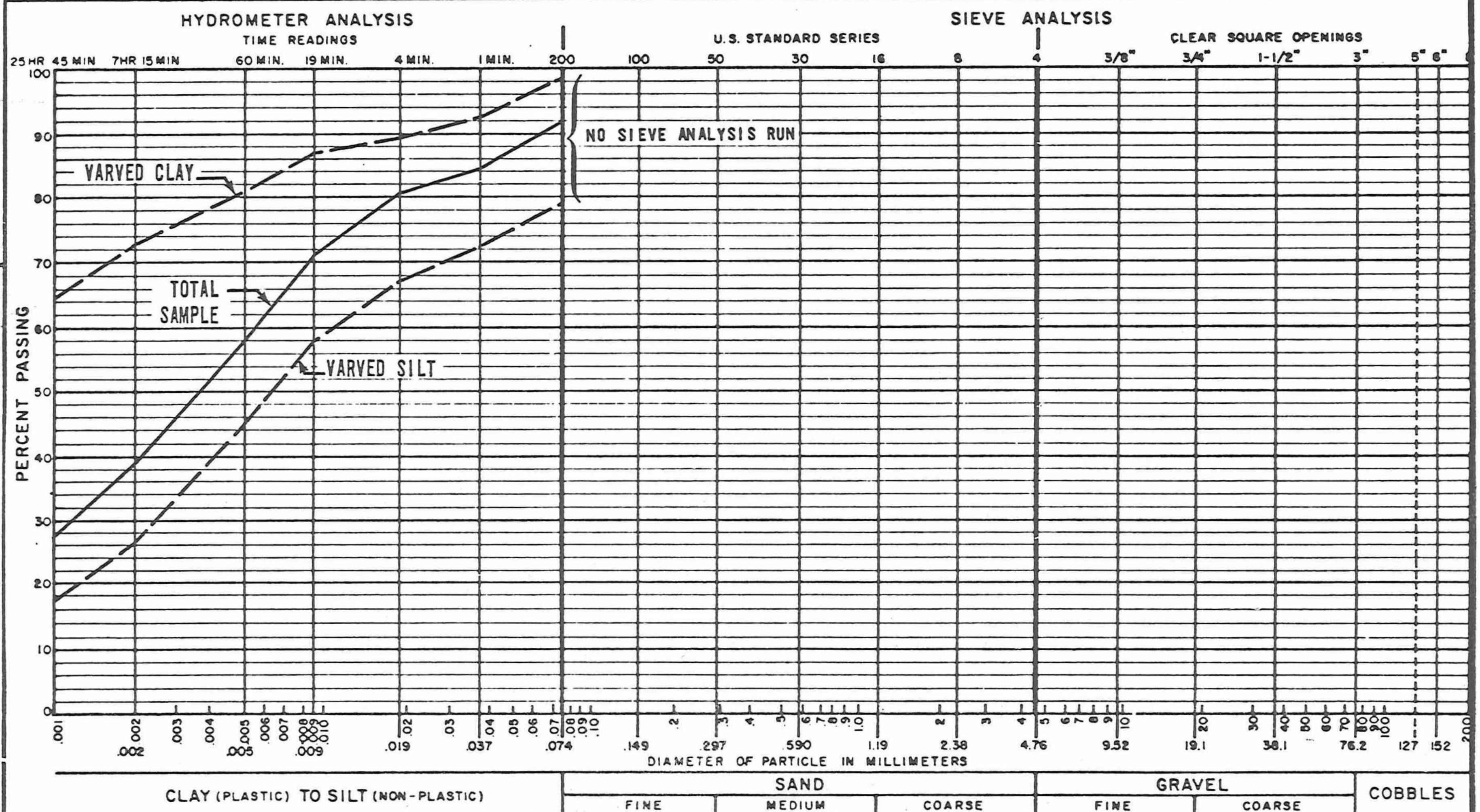
REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA

GRADATION TEST RESULTS
EXAMPLE OF VARVING

PROJECT NO	DATE	DRAWING NO
0829	AUGUST 1975	FIG. B-1

KEY: ————

LL	73									
PL	25									
PI	48									
NAT. W/C	37.7									
SPEC. GRAVITY	---									
CLASSIF. SYMB.	CH									
SAMPLE NO.	PS-4									
DEPTH, FT.	8.5-10.5									
HOLE NO.	1076									



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REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA

GRADATION TEST RESULTS

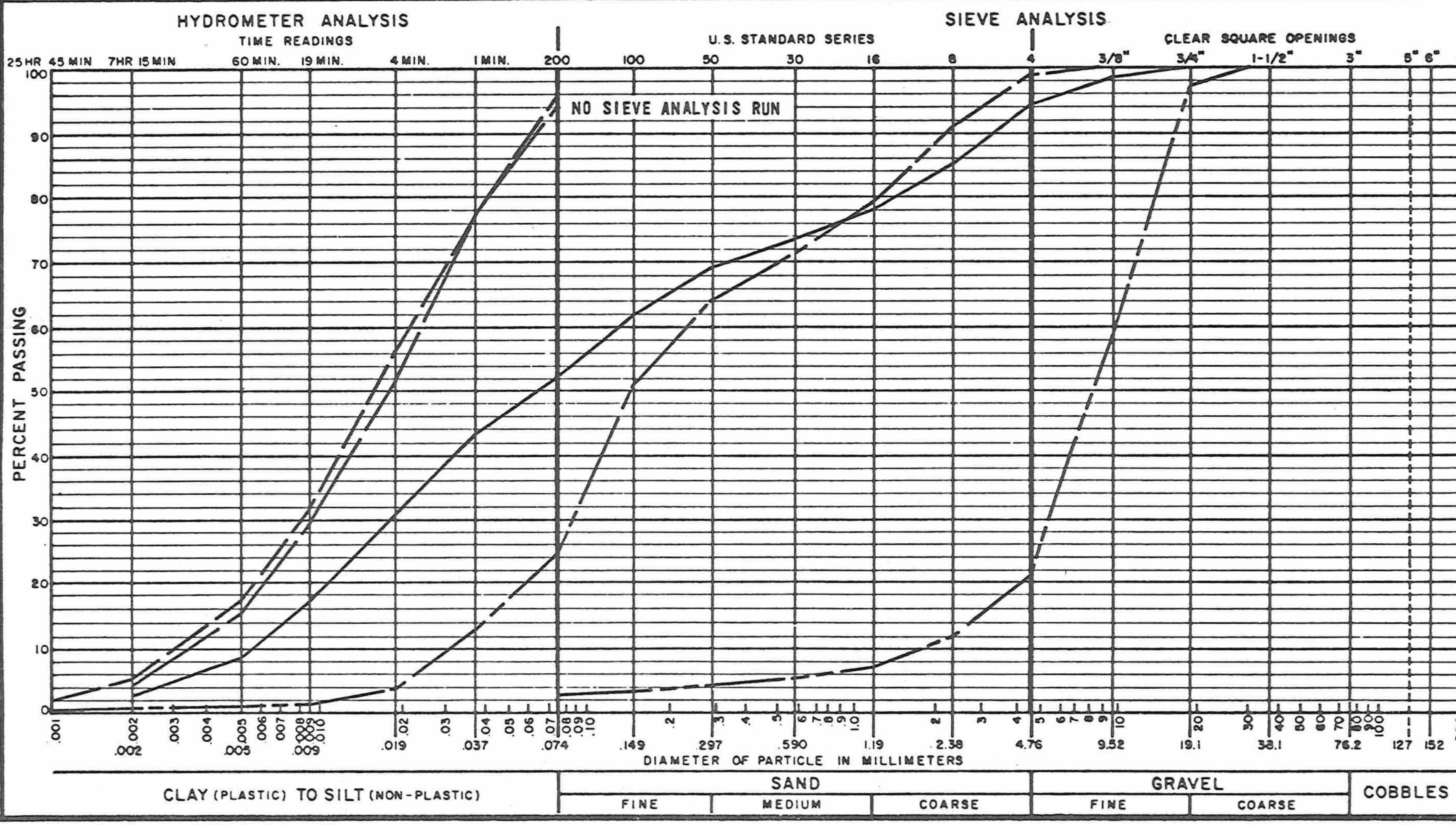
PROJECT NO: 0829

DATE: AUGUST 1975

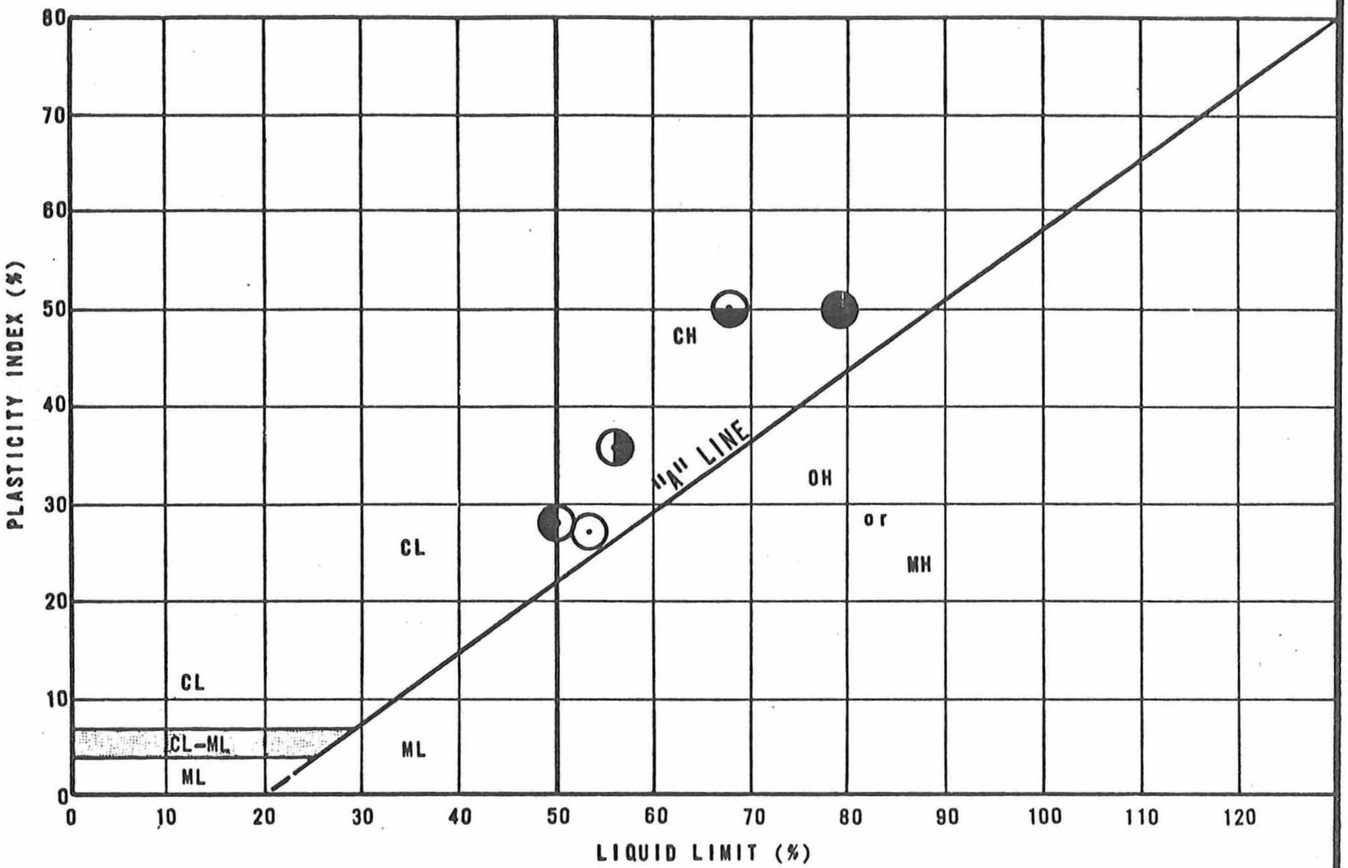
DRAWING NO: FIG. B-1

K E Y:

LL	---	---	---	---	---				
PL	---	---	---	---	---				
PI	NP	NP	NP	NP	NP				
NAT. W/C	---	---	---	---	---				
SPEC. GRAVITY	2.97	2.99	2.99	---	---				
CLASSIF. SYMB.	ML	ML	ML	SM	GW				
SAMPLE	CONCENTRATOR TAILINGS	FINE TAILINGS 1ST CONTAINER OF 6 SUBMITTED	FINE TAILINGS 2ND CONTAINER OF 6 SUBMITTED	FILTER TAILINGS 1ST CONTAINER OF 3 SUBMITTED	DRY COBBS 3 CONTAINERS COMBINED				



PLASTICITY CHART



PLASTICITY DATA

KEY SYMBOL	HOLE NUMBER	DEPTH (feet)	NATURAL WATER CONTENT W (%)	PLASTIC LIMIT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	LIQUIDITY INDEX $\left(\frac{W - PL}{LL - PL}\right)$	UNIFIED SOIL CLASSIFICATION SYMBOL
⊙	1006	2–4	32.0 (AVG)	26	53	27	0.222	CH
●	1006	6–8	36.2 (AVG)	29	79	50	0.144	CH
◑	1006	14–16	42.9 (AVG)	20	56	36	0.636	CH
◐	1071	5–7	44.0 (AVG)	22	50	28	0.786	CL–CH
◒	1071	10.5–12.5	45.4 (AVG)	18	68	50	0.548	CH

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REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA

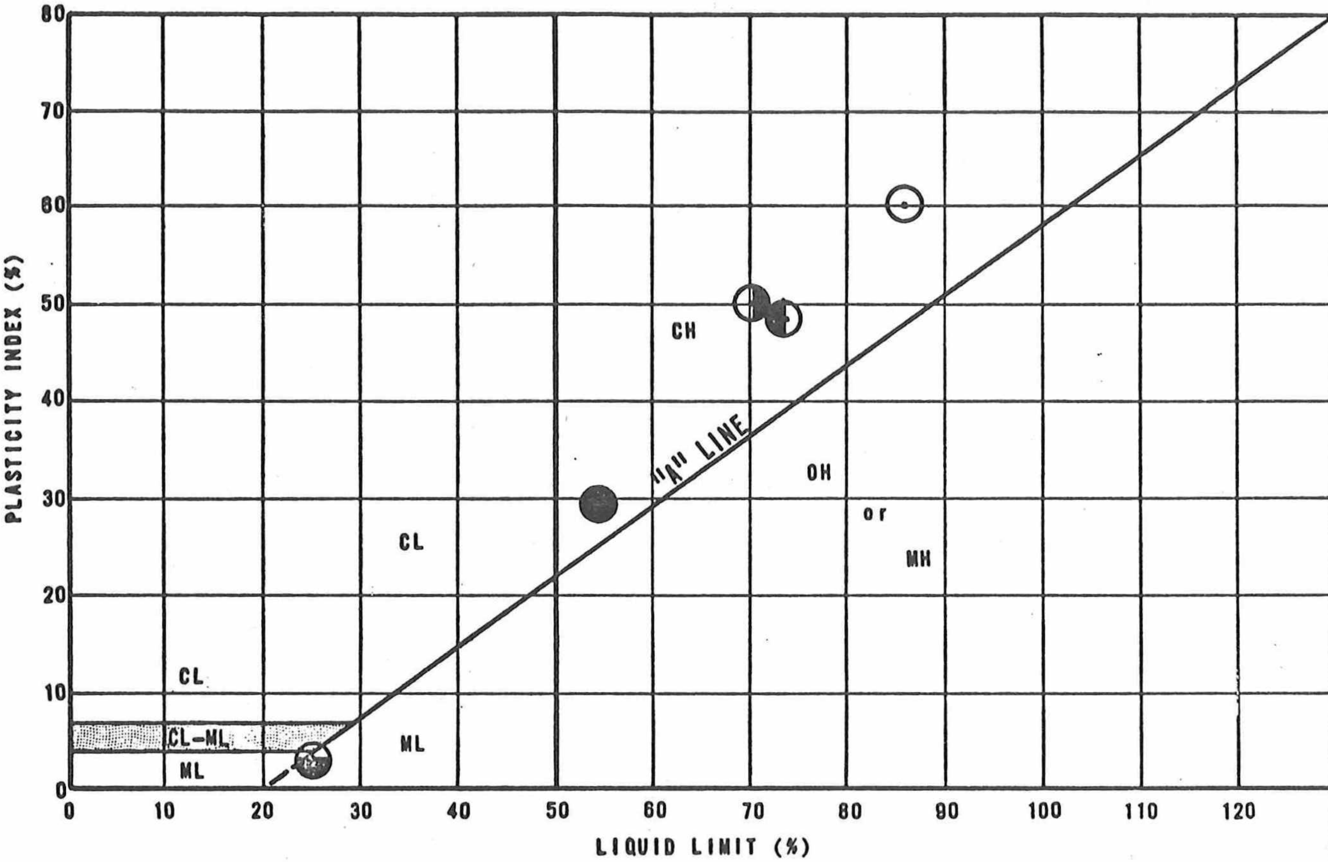
ATTERBERG LIMITS – PLASTICITY DATA

PROJECT NO.	DATE	DRAWING NO.
0829	AUGUST 1975	FIG. B-2

740-3

Sheet 1 of 3

PLASTICITY CHART



PLASTICITY DATA

KEY SYMBOL	HOLE NUMBER	DEPTH (feet)	NATURAL WATER CONTENT W (%)	PLASTIC LIMIT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	LIQUIDITY INDEX $\left(\frac{W - PL}{LL - PL}\right)$	UNIFIED SOIL CLASSIFICATION SYMBOL
⊙	1076	1.5–3.5	41.5 (AVG)	26	86	60	0.258	CH
●	1076	4–6.4	40.3 (AVG)	25	54	29	0.528	CH
◐	1076	6.5–8	34.3	20	70	50	0.286	CH
◑	1076	8.5–10.5	39.4 (AVG)	25	73	48	0.265	CH
◒	1076	11–13	22.2	22	25	3	0.067	ML

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REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA

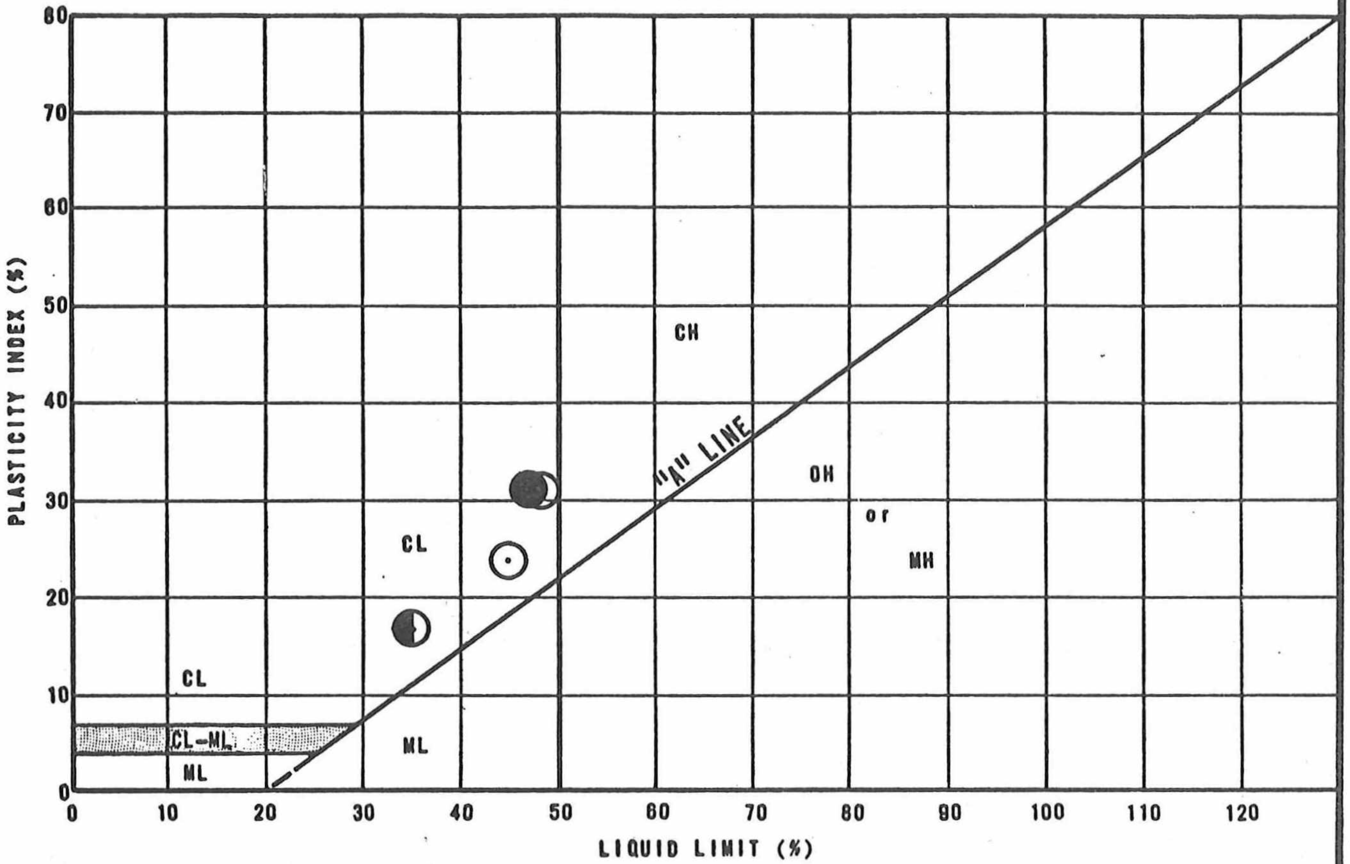
ATTERBERG LIMITS – PLASTICITY DATA

PROJECT NO.	DATE	DRAWING NO.
0829	AUGUST 1975	FIG. B-2

740-3

Sheet 2 of 3

PLASTICITY CHART



PLASTICITY DATA

KEY SYMBOL	HOLE NUMBER	DEPTH (feet)	NATURAL WATER CONTENT W (%)	PLASTIC LIMIT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	LIQUIDITY INDEX $\left(\frac{W - PL}{LL - PL}\right)$	UNIFIED SOIL CLASSIFICATION SYMBOL
⊙	3020	1–3	22.3 (AVG)	22	45	23	0.013	CL
●	3020	4–5.5	23.7 (AVG)	16	47	31	0.248	CL
◐	3020	8.5–9.5	27.4	17	48	31	0.335	CL
◐	3020	9.5–10.6	24.2 (AVG)	18	35	17	0.365	CL

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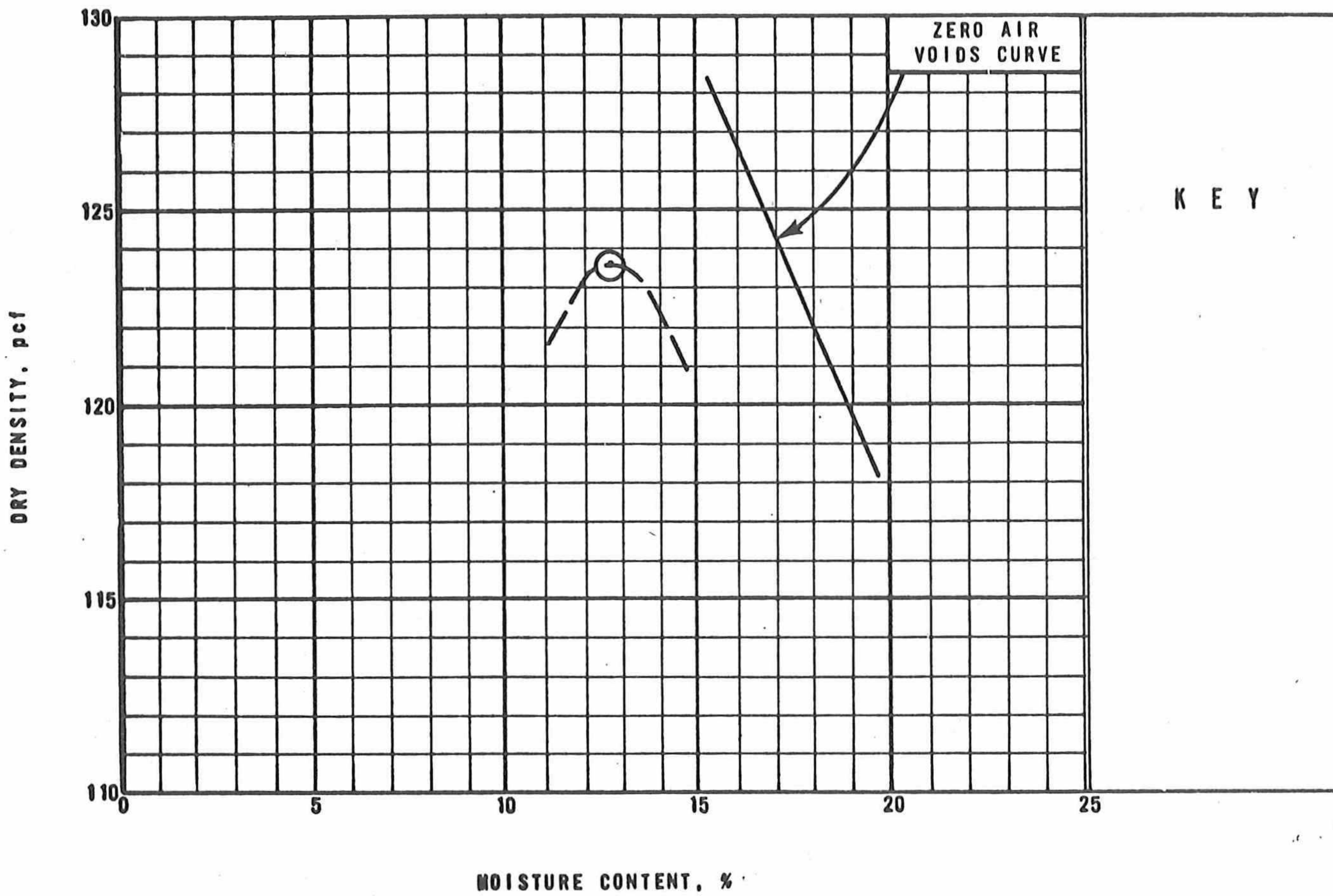
REVIEW OF MILE POST 7 PLAN
FOR STATE OF MINNESOTA

ATTERBERG LIMITS – PLASTICITY DATA

PROJECT NO.	DATE	DRAWING NO.
0829	AUGUST 1975	FIG. B-2

740-3

SAMPLE NO.	SAMPLE DESCRIPTION	SPECIFIC GRAVITY	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PERCENT PASSING NO. 4	PERCENT PASSING NO. 200
EXISTING CONCENTRATOR TAILINGS	GRAY, SANDY SILT (ML)	2.97	NP	NP	94.8	51.9



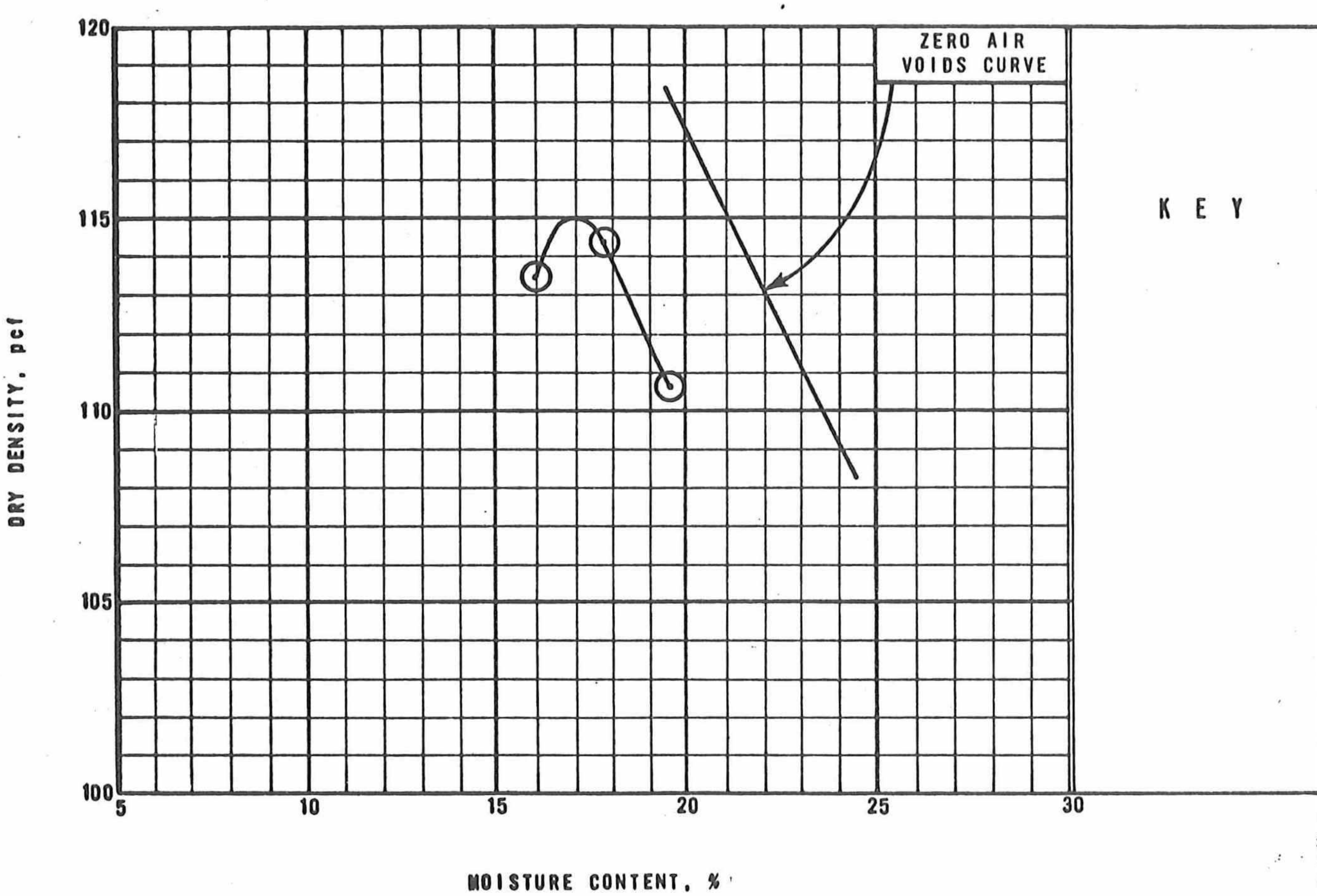
MINIMUM DENSITY AS DETERMINED BY ASTM D-2049-69 = 89.2 pcf

SAMPLE NO.	EXISTING CONCENTRATOR TAILINGS		
NATURAL WATER CONTENT, %	---		
OPTIMUM WATER CONTENT, %	(EST.) 12.7		
MAXIMUM DRY DENSITY, pcf	(EST.) 124.6		
TEST DESIGNATION — ASTM / COMPACTIVE ENERGY FT.LB./FT.^{3}	D-1557-70 / 20,000		

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	COMPACTION TEST RESULTS		
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0828	DATE AUGUST 1975	DRAWING NO. FIG. B-3

805-2

SAMPLE NO.	SAMPLE DESCRIPTION	SPECIFIC GRAVITY	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PERCENT PASSING NO. 4	PERCENT PASSING NO. 200
FINE TAILINGS	GRAY SILT (ML)	2.99	NP	NP	100	95.9



MINIMUM SETTLEMENT DENSITY = 92.8 pcf

SAMPLE NO.	FINE TAILINGS		
NATURAL WATER CONTENT, %	---		
OPTIMUM WATER CONTENT, %	17.0		
MAXIMUM DRY DENSITY, pcf	115.0		
TEST DESIGNATION ASTM COMPACTIVE ENERGY FT.LB./FT.^{3}	D-1557-70 20,000		

805-2

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REVIEW OF MILE POST 7 PLAN
FOR STATE OF MINNESOTA

COMPACTION TEST RESULTS

PROJECT NO.	DATE	DRAWING NO.
0829	AUGUST 1975	FIG. B-3

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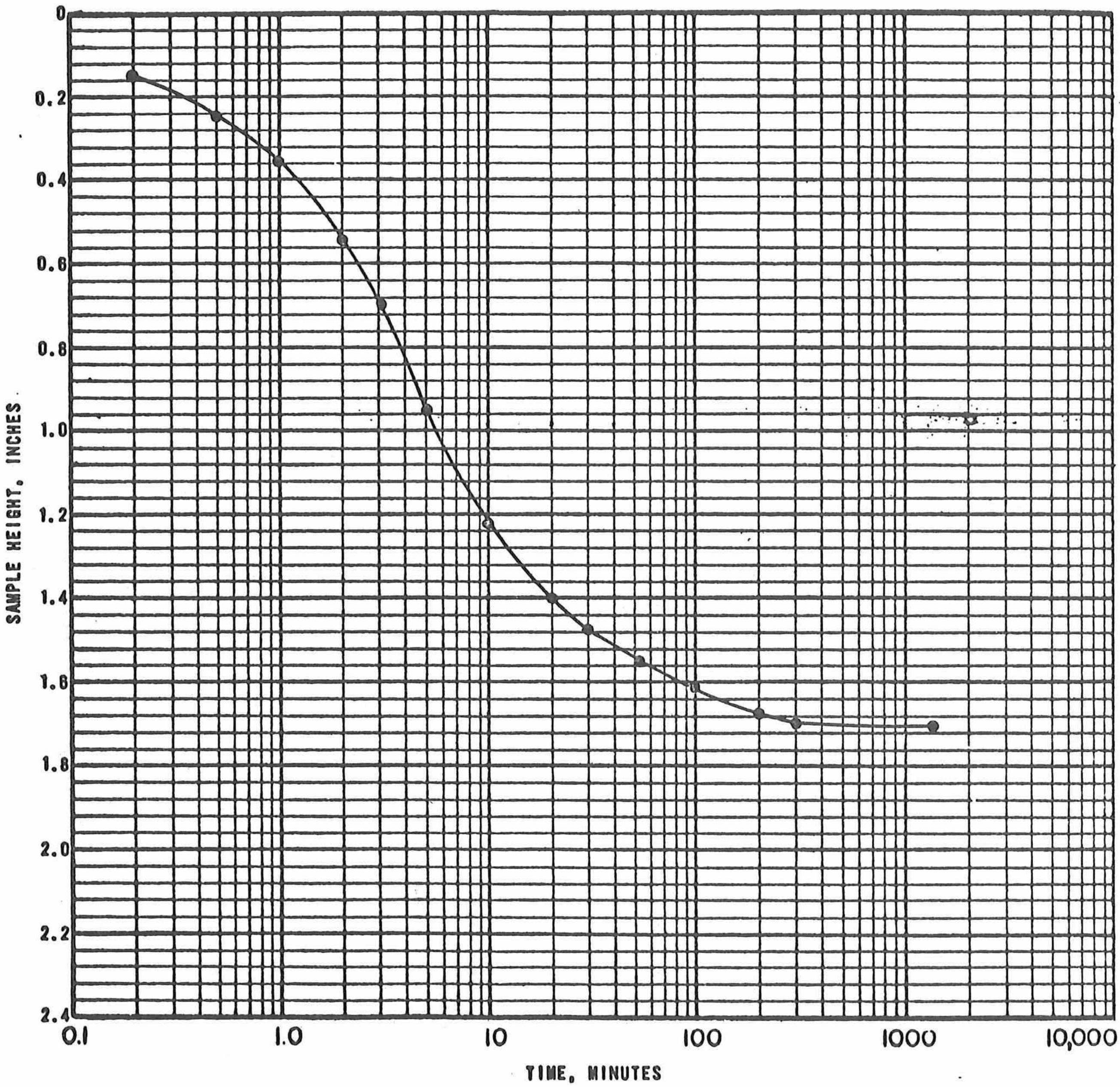
MINIMUM DRAINED SETTLEMENT DENSITY TEST

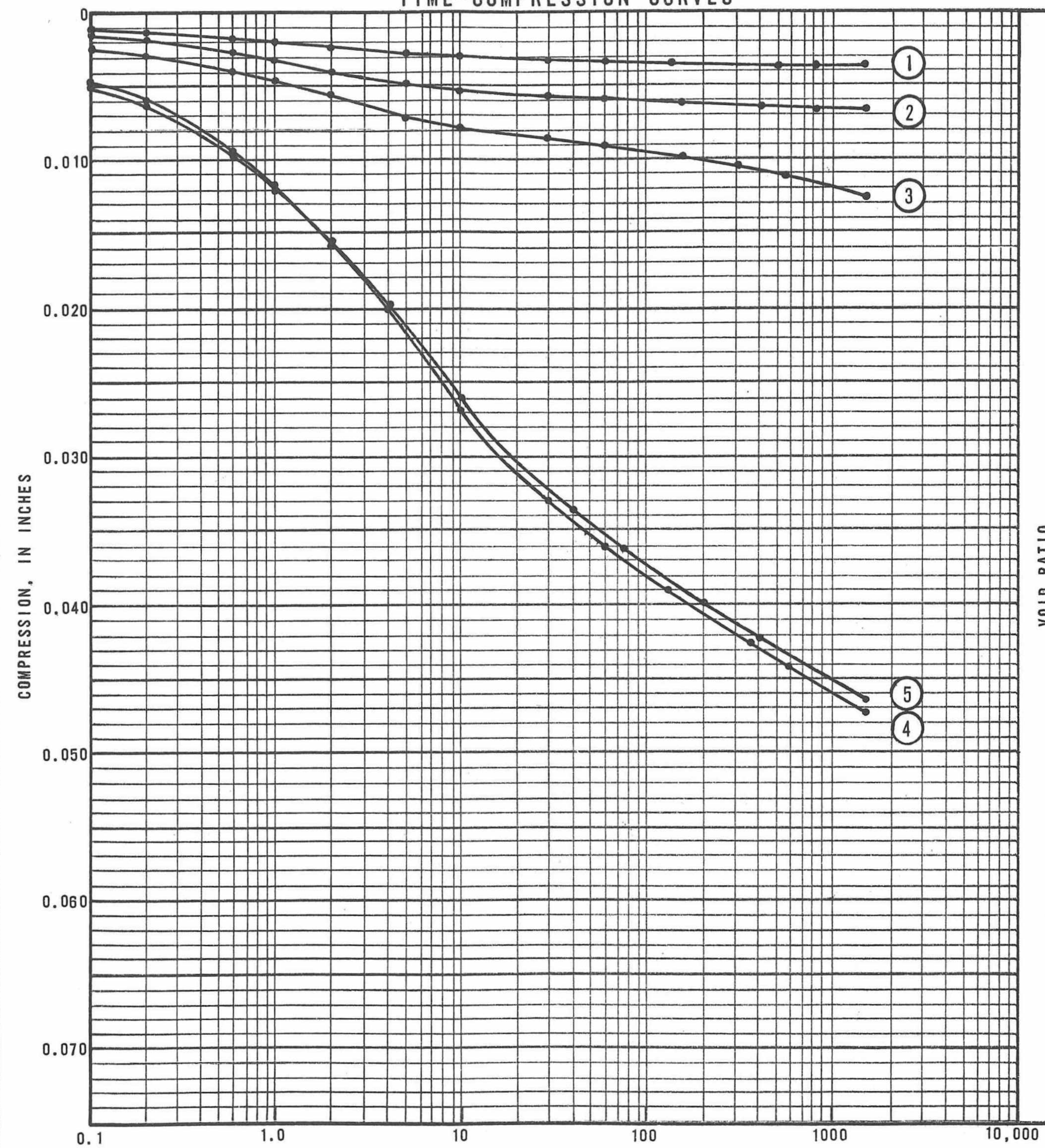
SAMPLE NO. FINE TAILING DEPTH, ft. ---



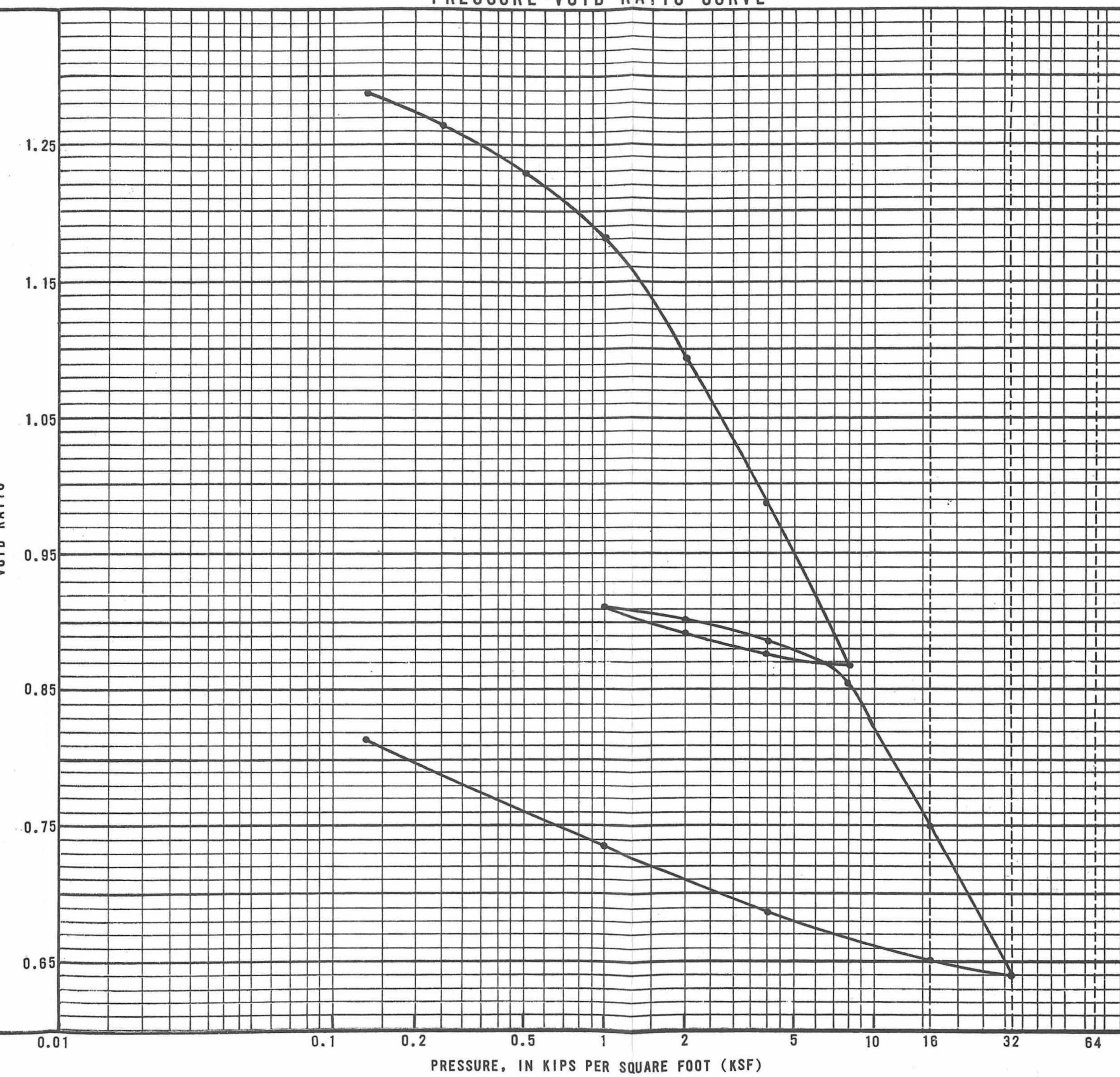
FINAL DRY DENSITY = 92.8 pcf

853

TIME-COMPRESSION CURVES



PRESSURE-VOID RATIO CURVE



NOTE: TIME READINGS WERE TAKEN AFTER SAMPLE WAS REBOUNDED FROM 8000 TO 1000 PSF.

PRESSURE INCREMENTS OF TIME-COMPRESSION CURVES

CURVE NO.	PRESSURE INCREMENT FROM (KSF)	TO (KSF)
1	1.0	2.0
2	2.0	4.0
3	4.0	8.0
4	8.0	16.0
5	16.0	32.0

DESCRIPTION OF SPECIMEN: Red Brown, Sandy CLAY (CL-CH)

ATTERBERG LIMIT SPECIMEN

STRATUM DESIGNATION	---
LIQUID LIMIT (LL)	50
PLASTIC LIMIT (PL)	22
PLASTICITY INDEX (PI)	28
NATURAL WATER CONTENT % (w)	44.0 AVG.
LIQUIDITY INDEX = (w-PL)/(LL-PL)	0.786
SPECIFIC GRAVITY (G)	2.70

CONSOLIDATION SPECIMEN

INITIAL DRY DENSITY (pcf)	72.9
FINAL DRY DENSITY (pcf)	92.9
DIAMETER OF SPECIMEN (inches)	2.875
INITIAL THICK. OF SPEC. (inches)	1.0
INITIAL WATER CONTENT %	48.0
FINAL WATER CONTENT %	30.2
INITIAL DEGREE SATURATION %	98.7
FINAL DEGREE SATURATION %	100.0

HOLE NO. 1071 | DEPTH (ft) 5-7

INITIAL VOID RATIO (e_o) ———	1.313
FINAL VOID RATIO (e_f) - - - - →	0.815
MOST PROBABLE PRECONSOL. STRESS (Ksf) SYMBOL P_c↓	1.2
EXISTING OVERBURDEN STRESS (Ksf) SYMBOL P_o↓	0.7

COMPRESSION INDEX (C_c)	0.30
COEFFICIENT OF CONSOL. (C_v) cm²/sec (VIRGIN CURVE)	0.002
COEFFICIENT OF CONSOL. (C_v) cm²/sec (RECOMPRESSION)	0.005
RECOMPRESSION INDEX (C_r)	0.04

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REVIEW OF MILE POST 7 PLAN
FOR STATE OF MINNESOTA

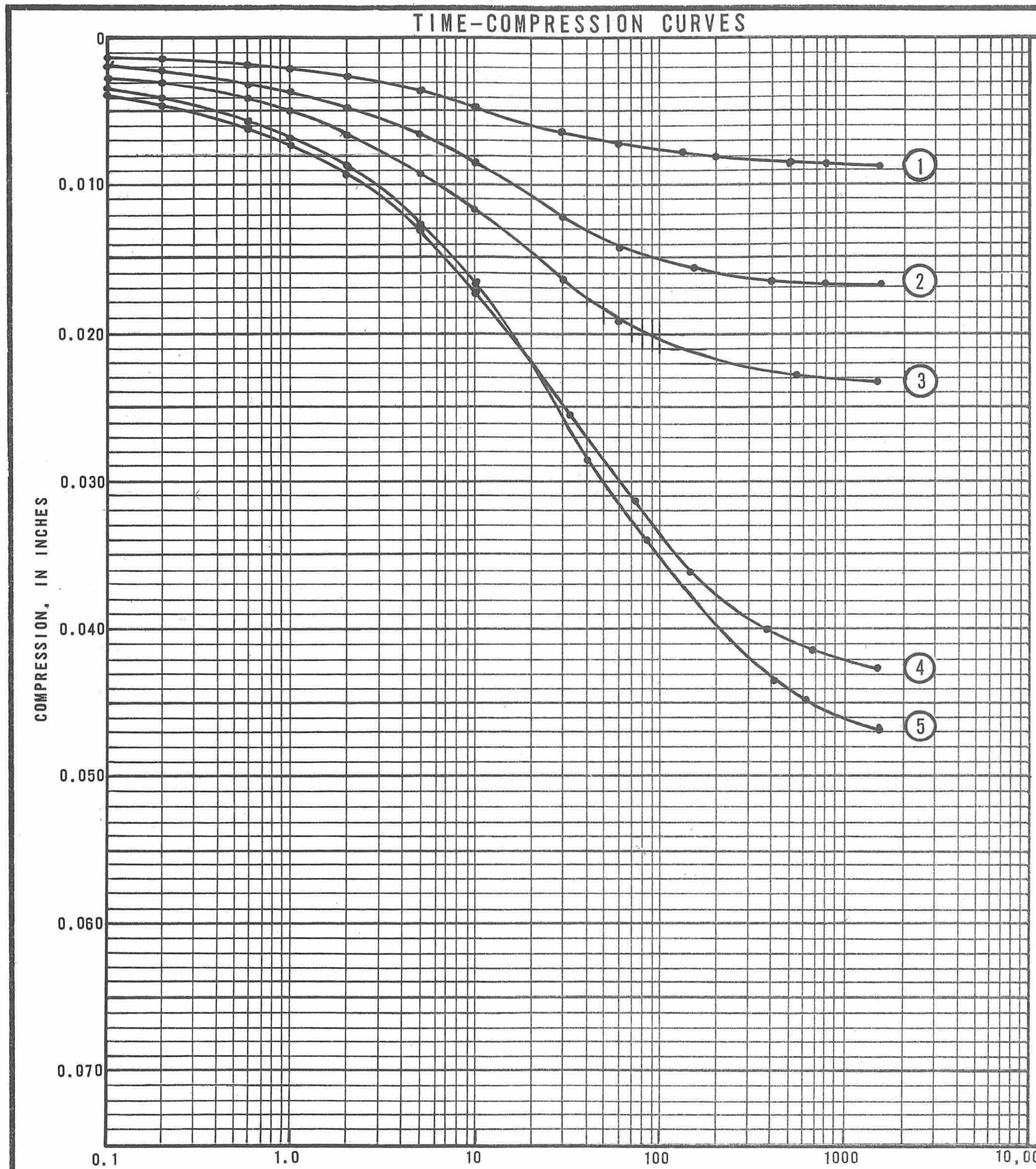
CONSOLIDATION TEST

PROJECT NO.	DATE	DRAWING NO.
0829	AUGUST 1975	FIG. B-4

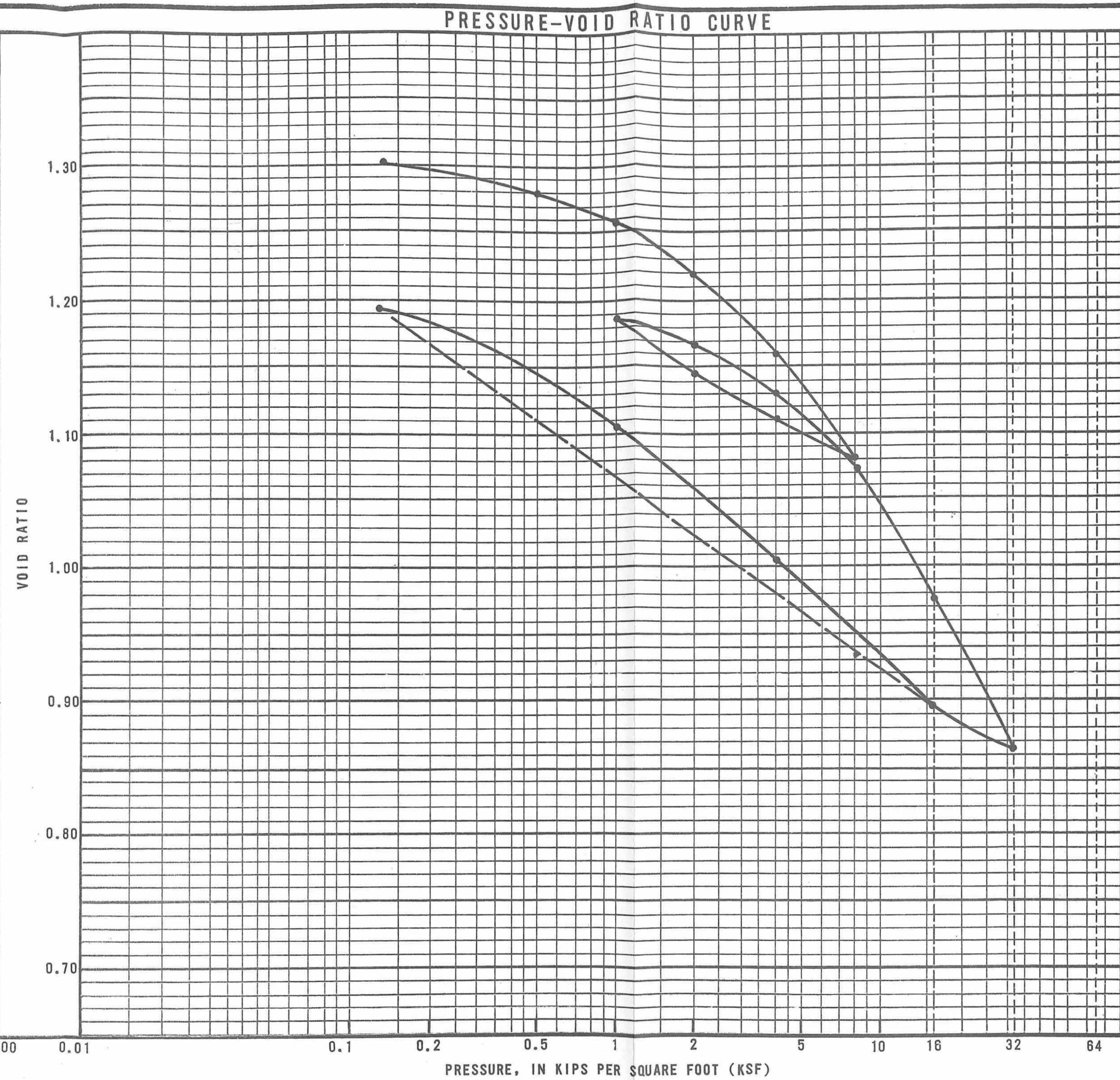
SAMPLE NO. 1071 PS-2

853A

Sheet 1 of 3



NOTE: TIME READINGS WERE TAKEN AFTER SAMPLE WAS REBOUNDED FROM 8000 TO 1000 PSF.



PRESSURE INCREMENTS OF TIME-COMPRESSION CURVES: CURVE NO.	PRESSURE INCREMENT FROM (KSF)	TO (KSF)
1	1.0	2.0
2	2.0	4.0
3	4.0	8.0
4	8.0	16.0
5	16.0	32.0

DESCRIPTION OF SPECIMEN: Red Brown, Silty CLAY (CH)

HOLE NO. 1076 — DEPTH (ft) 4-6.4

ATTERBERG LIMIT SPECIMEN	
STRATUM DESIGNATION	---
LIQUID LIMIT (LL)	54
PLASTIC LIMIT (PL)	25
PLASTICITY INDEX (PI)	29
NATURAL WATER CONTENT % (w)	40.3 AVG.
LIQUIDITY INDEX = $\frac{w-PL}{LL-PL}$	0.528
SPECIFIC GRAVITY (G)	2.79

CONSOLIDATION SPECIMEN	
INITIAL DRY DENSITY (pcf)	75.3
FINAL DRY DENSITY (pcf)	79.5
DIAMETER OF SPECIMEN (inches)	2.875
INITIAL THICK. OF SPEC. (inches)	1.0
INITIAL WATER CONTENT %	46.8
FINAL WATER CONTENT %	42.7
INITIAL DEGREE SATURATION %	99.6
FINAL DEGREE SATURATION %	100.0

INITIAL VOID RATIO (e_o) — — —	1.311
FINAL VOID RATIO (e_f) - - - - - -	1.191
MOST PROBABLE PRECONSOL. STRESS (Ksf) SYMBOL P_c↓	3.0
EXISTING OVERBURDEN STRESS (Ksf) SYMBOL P_o↓	0.6

COMPRESSION INDEX (C_c)	0.37
COEFFICIENT OF CONSOL. (C_v) cm^2/sec (VIRGIN CURVE)	0.0003
COEFFICIENT OF CONSOL. (C_v) cm^2/sec (RECOMPRESSION)	0.0006
RECOMPRESSION INDEX (C_r)	0.11

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REVIEW OF MILE POST 7 PLAN
FOR STATE OF MINNESOTA

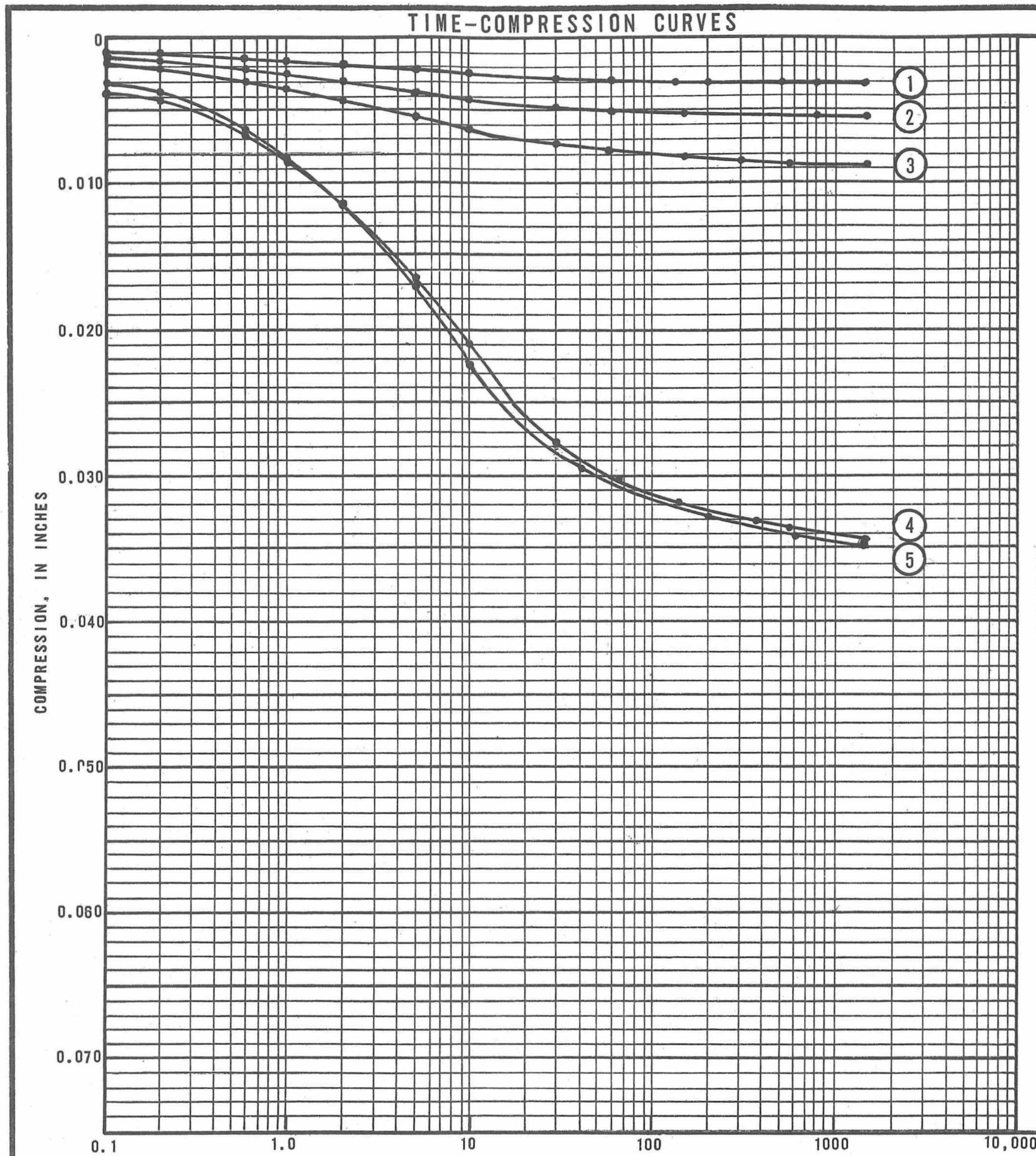
PALO ALTO • NEWPORT BEACH • CALIF.

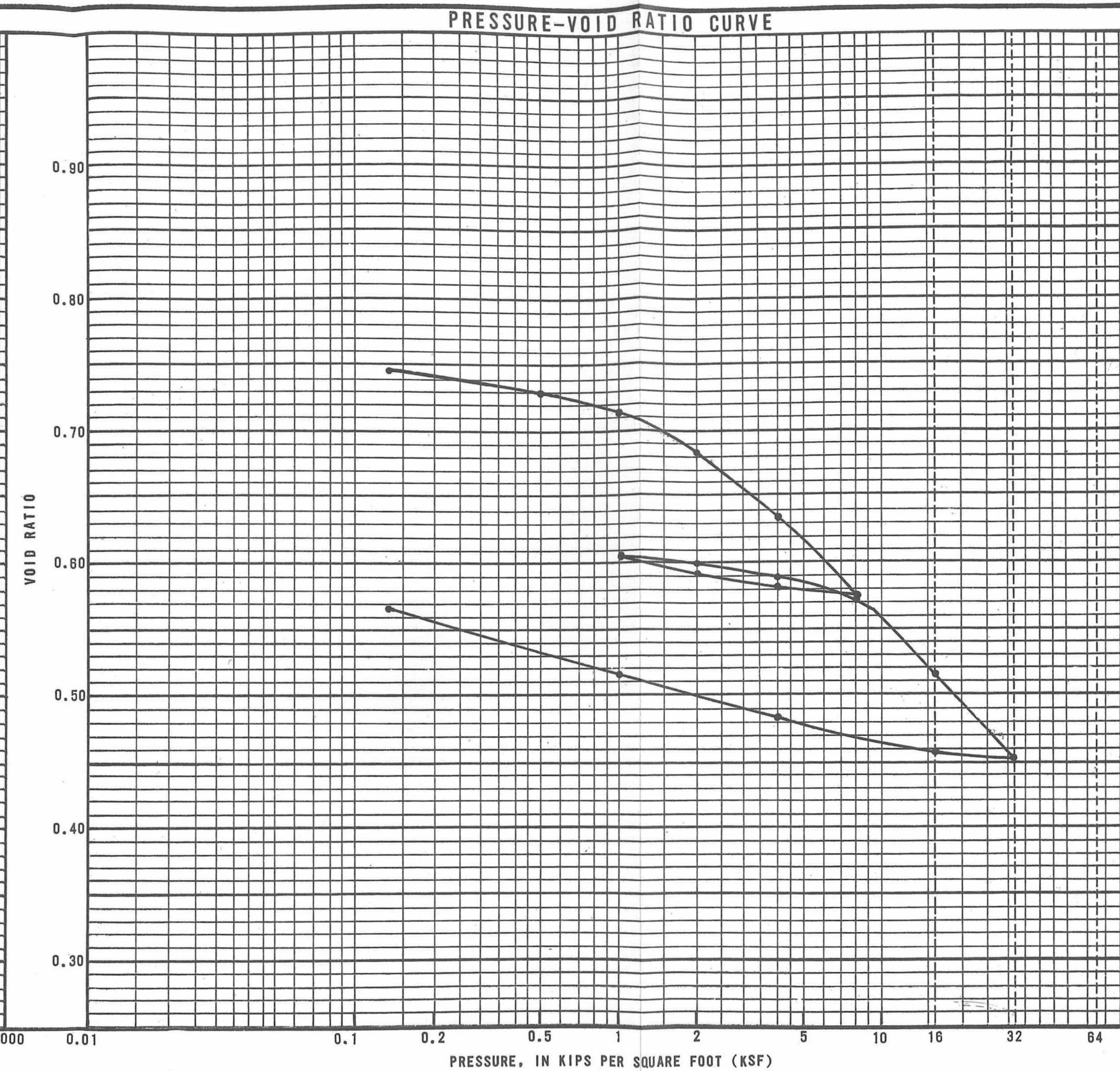
CONSOLIDATION TEST

PROJECT NO.	DATE	DRAWING NO.
0829	AUGUST 1975	FIG. B-4

SAMPLE NO. 1076 PS-2

853A





NOTE: TIME READINGS WERE TAKEN AFTER SAMPLE WAS REBOUNDED FROM 8000 TO 1000 PSF.

PRESSURE INCREMENTS OF TIME-COMPRESSION CURVES

CURVE NO.	PRESSURE INCREMENT FROM (KSF)	TO (KSF)
1	1.0	2.0
2	2.0	4.0
3	4.0	8.0
4	8.0	16.0
5	16.0	32.0

DESCRIPTION OF SPECIMEN: RED BROWN, SANDY CLAY (CL)

HOLE NO. 3020 — DEPTH (ft) 8.5-9.5

ATTERBERG LIMIT SPECIMEN

STRATUM DESIGNATION	---
LIQUID LIMIT (LL)	48
PLASTIC LIMIT (PL)	17
PLASTICITY INDEX (PI)	31
NATURAL WATER CONTENT % (w)	27.4
LIQUIDITY INDEX = (w-PL)/(LL-PL)	0.335
SPECIFIC GRAVITY (G)	2.75

CONSOLIDATION SPECIMEN

INITIAL DRY DENSITY (pcf)	97.8
FINAL DRY DENSITY (pcf)	109.5
DIAMETER OF SPECIMEN (inches)	2.875
INITIAL THICK. OF SPEC. (inches)	1.0
INITIAL WATER CONTENT %	27.4
FINAL WATER CONTENT %	20.6
INITIAL DEGREE SATURATION %	99.9
FINAL DEGREE SATURATION %	100.0

INITIAL VOID RATIO (e_o)	0.755
FINAL VOID RATIO (e_f)	0.567
MOST PROBABLE PRECONSOL. STRESS (Ksf) SYMBOL P_c↓	2.1
EXISTING OVERBURDEN STRESS (Ksf) SYMBOL P_o↓	1.0

COMPRESSION INDEX (C_c)	0.21
COEFFICIENT OF CONSOL. (C_v) cm2/sec (VIRGIN CURVE)	0.001
COEFFICIENT OF CONSOL. (C_v) cm2/sec (RECOMPRESSION)	0.005
RECOMPRESSION INDEX (C_r)	0.04

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REVIEW OF MILE POST 7 PLAN
FOR STATE OF MINESOTA

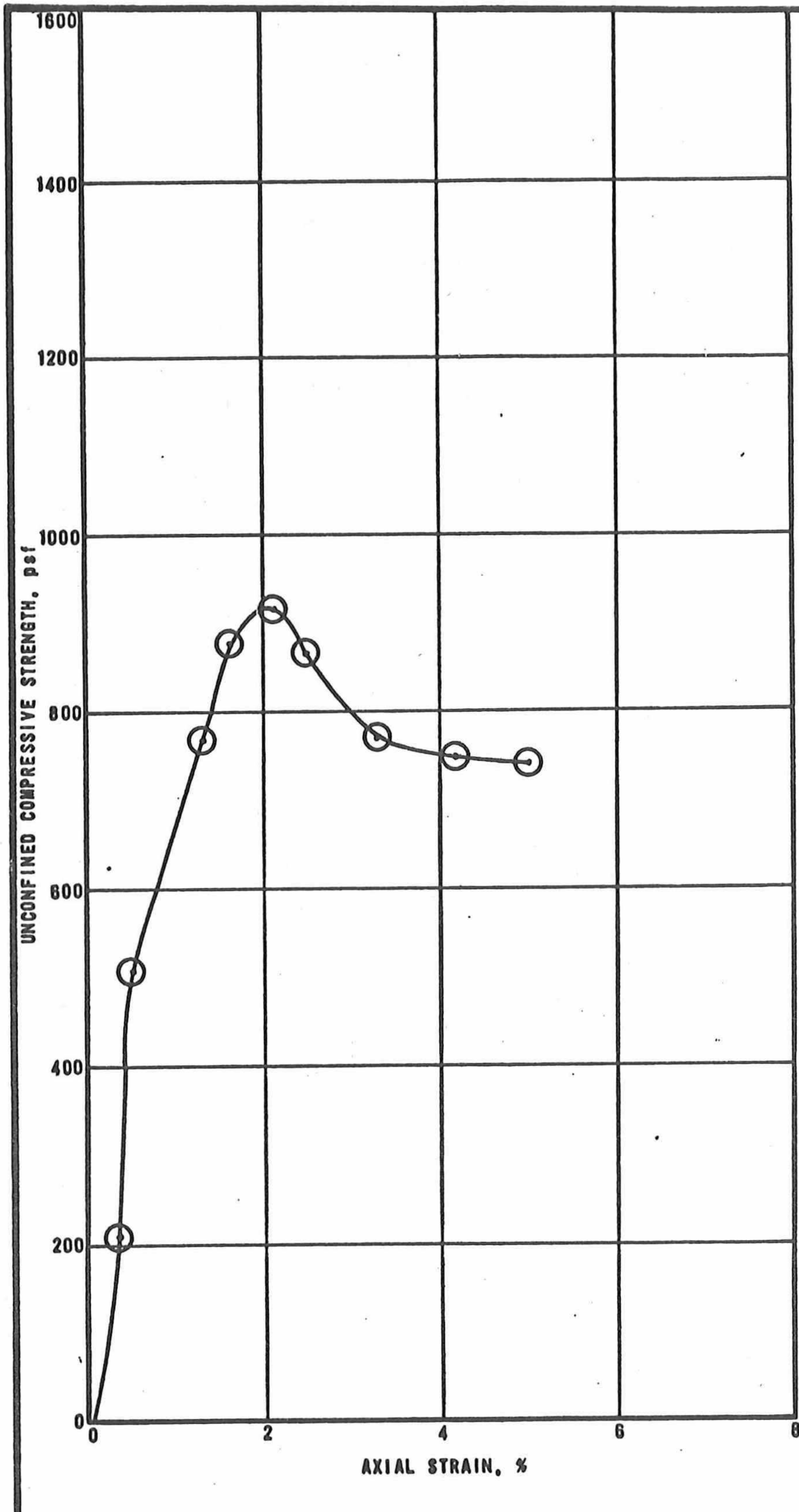
PALO ALTO • NEWPORT BEACH • CALIF.

CONSOLIDATION TEST

PROJECT NO.	DATE	DRAWING NO.
0829	AUGUST 1975	FIG. B-4

SAMPLE NO. 3020 PS-4

853A

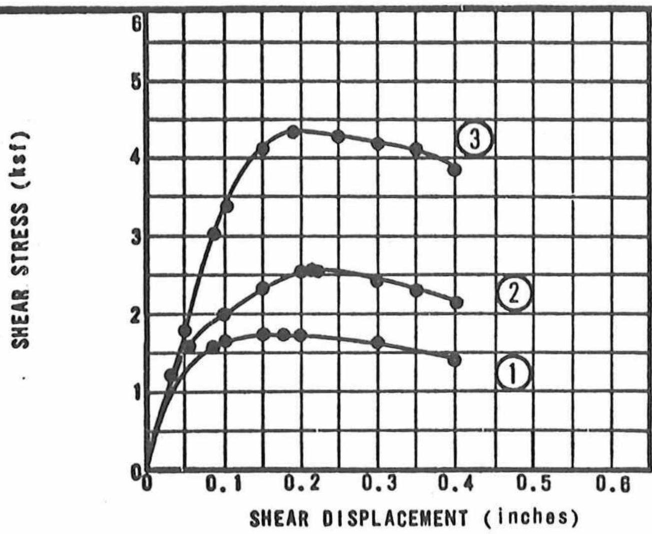


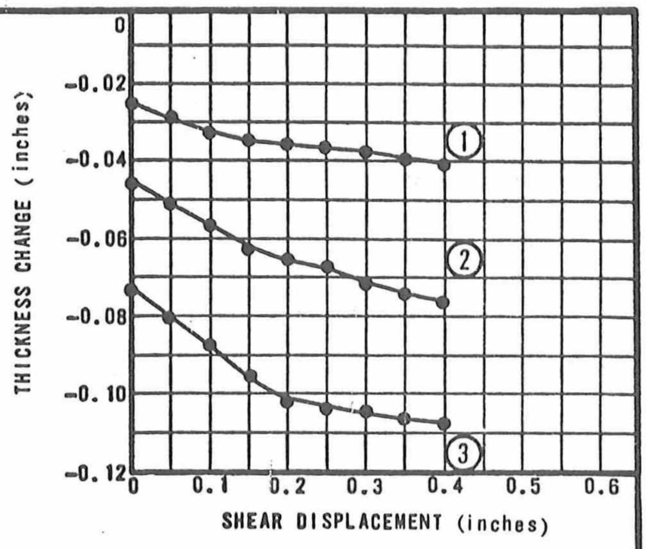
SPECIMEN NO.			
Drill Hole No.	1076		
Depth (ft)	6.5-8		
Water Cont. %	34.3		
Dry Density,pcf	86.0		
Void Ratio	99.5		
Saturation, %	94.8		

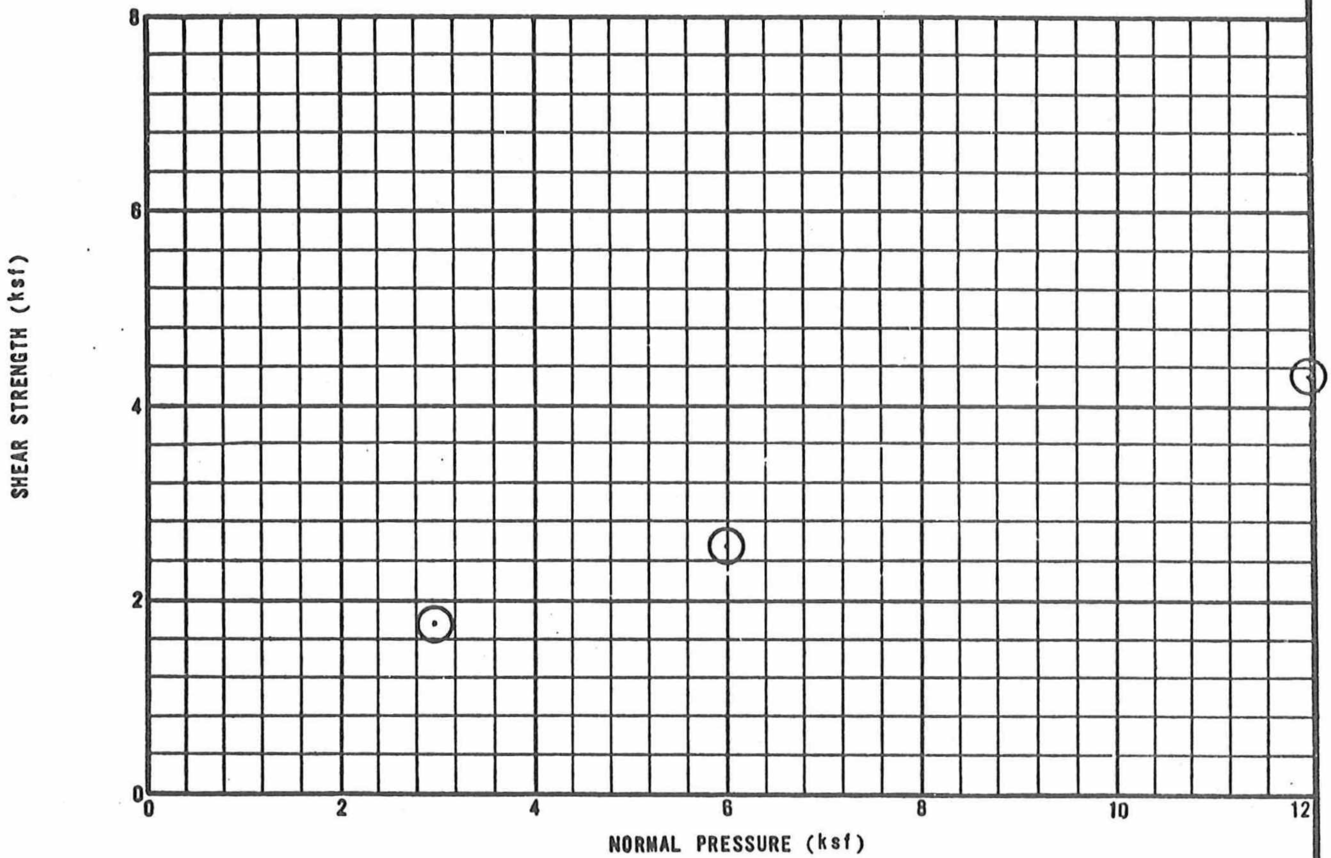
NOTE: SAMPLE DESCRIPTION:
BROWNISH RED, SANDY, SILTY CLAY.
EST. SPEC. GRAV. = 2.75

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA PALO ALTO ● NEWPORT BEACH ● CALIF.	UNCONFINED COMPRESSION TEST		
		PROJECT NO.	DATE	DRAWING NO.
		0829	JULY 1975	FIG. B-5

Sheet 1 of 1







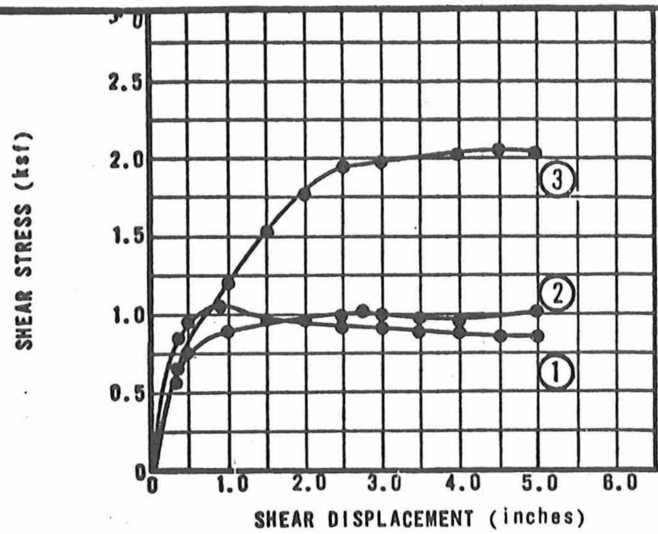
HOLE NO. 1006, PS-1
DEPTH (ft) 2-4
SAMPLE DESCRIPTION Red Brown CLAY
TEST DESIGNATION Unconsolidated-Undrained
RATE OF STRAIN 0.025 in/min.

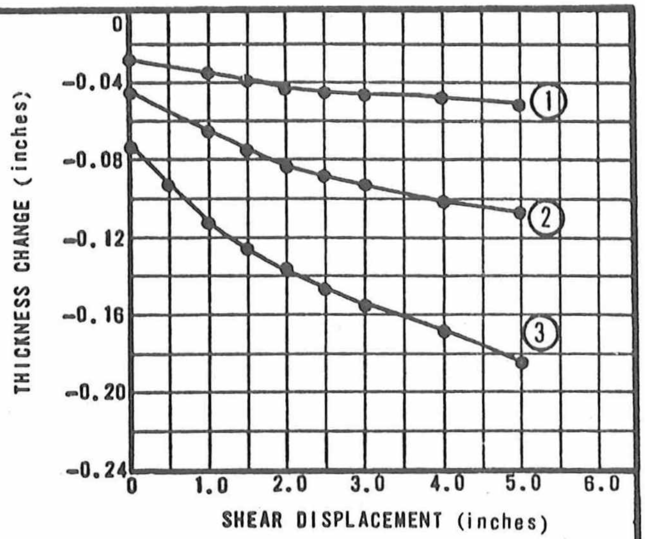
SPECIMEN NUMBER	①	②	③	
NORMAL PRESSURE (ksf)	3.0	6.0	12.0	
SHEAR STRENGTH (ksf)	1.73	2.55	4.34	
INITIAL WATER CONTENT (%)	31.8	33.3	32.9	
FINAL WATER CONTENT (%)	31.8	39.4	34.3	
DRY DENSITY (pcf)	88.2	87.2	87.9	

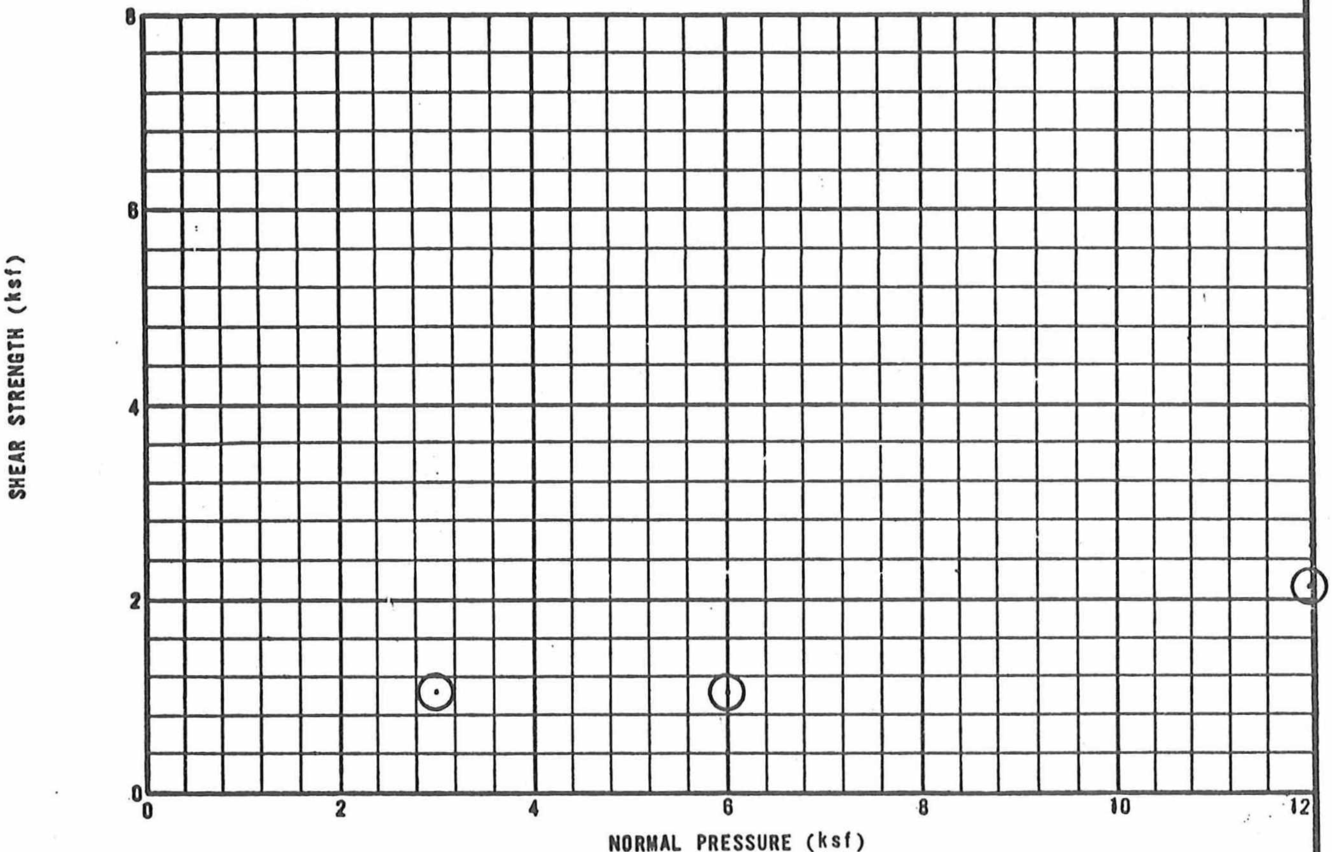
Note: Strain was started on sample immediately after application of load. Samples number 2 and 3 were flooded at start of strain with water.

611-2 Rev. 2/69

W. A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	DIRECT SHEAR TEST
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829 · DATE JULY 1975 · DRAWING NO. FIG. B-6







HOLE NO. 1006, PS-3

DEPTH (ft) 10-12

SAMPLE DESCRIPTION Red Brown CLAY

TEST DESIGNATION Unconsolidated-Undrained

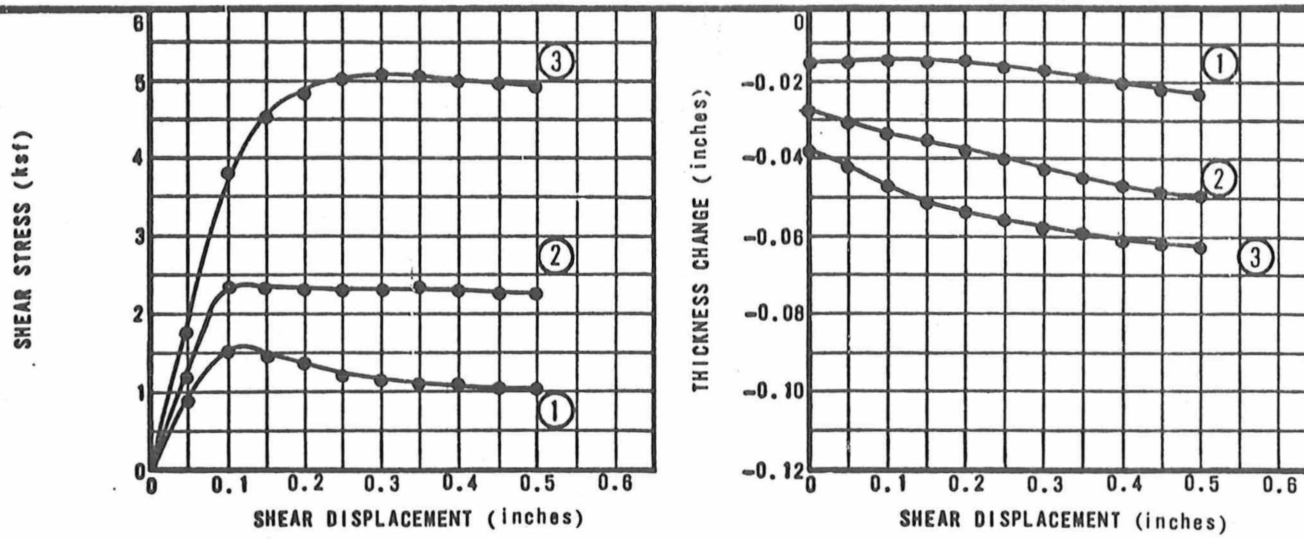
RATE OF STRAIN 0.025 in/min.

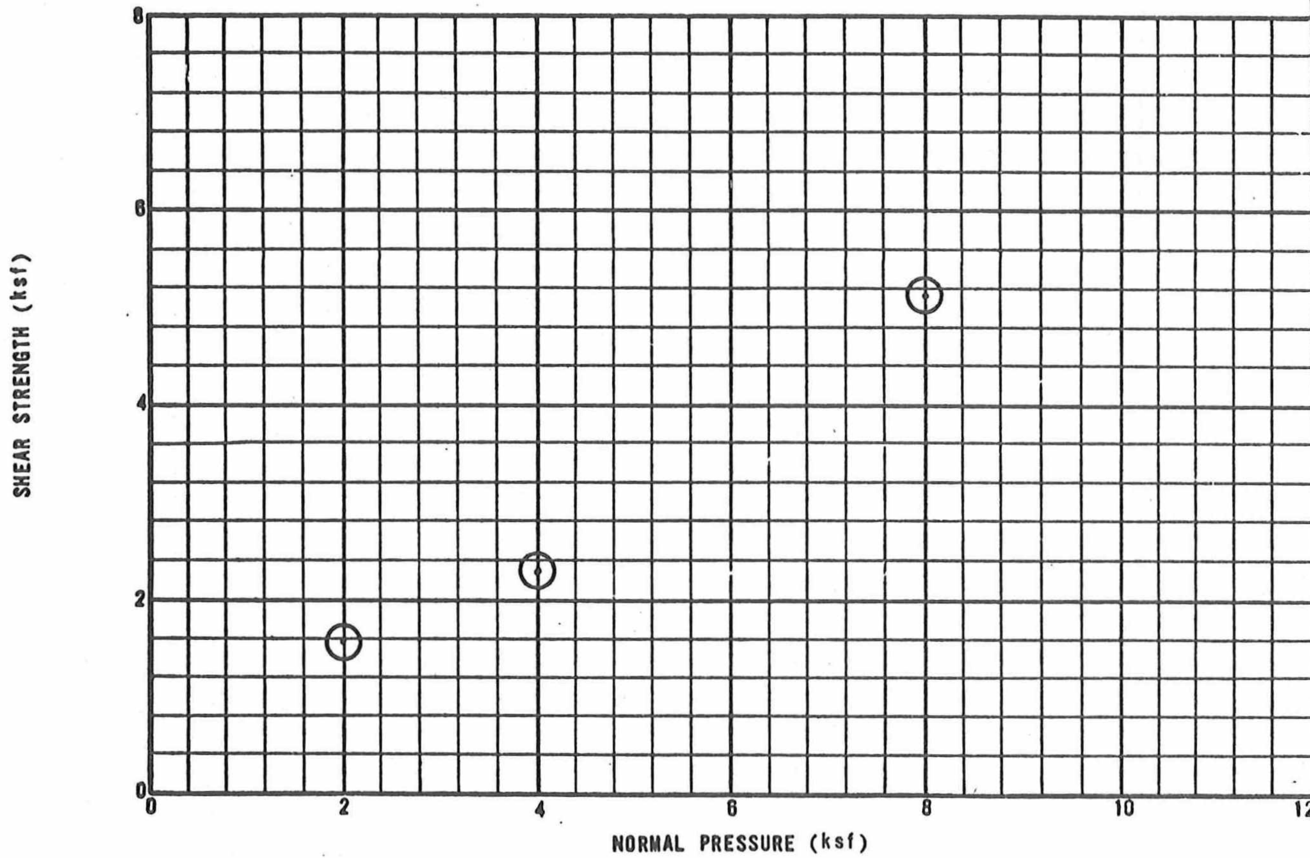
SPECIMEN NUMBER	①	②	③
NORMAL PRESSURE (ksf)	3.0	6.0	12.0
SHEAR STRENGTH (ksf)	1.06	1.02	2.13
INITIAL WATER CONTENT (%)	52.1	52.5	43.9
FINAL WATER CONTENT (%)	53.4	55.1	49.2
DRY DENSITY (pcf)	68.5	69.6	75.0

NOTE: Strain was started on sample immediately after application of load. Samples were flooded with water at start of strain.

611-2 Rev. 2/69

W. A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	DIRECT SHEAR TEST		
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE JULY 1975	DRAWING NO. FIG. B-6





HOLE NO. 3020, PS-5
DEPTH (ft) 11-13
SAMPLE DESCRIPTION RED BROWN, SILTY CLAY

TEST DESIGNATION UNCONSOLIDATED-UNDRAINED

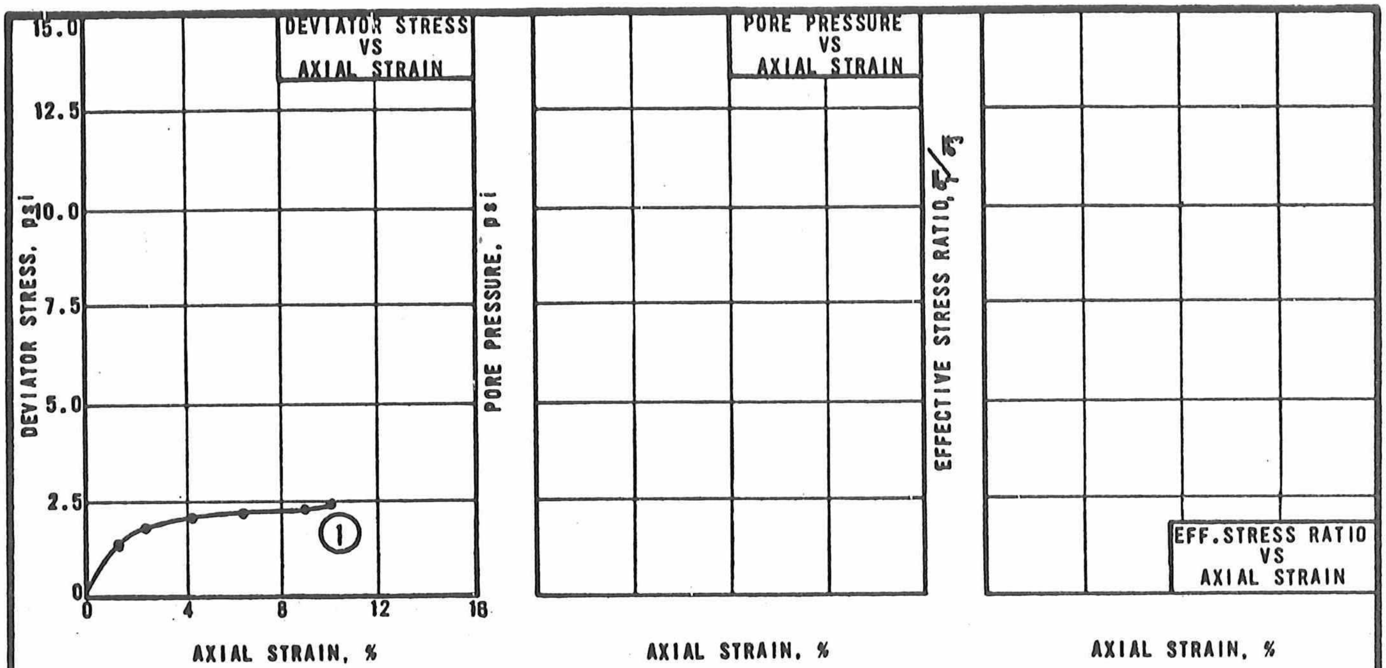
RATE OF STRAIN 0.025 in/min.

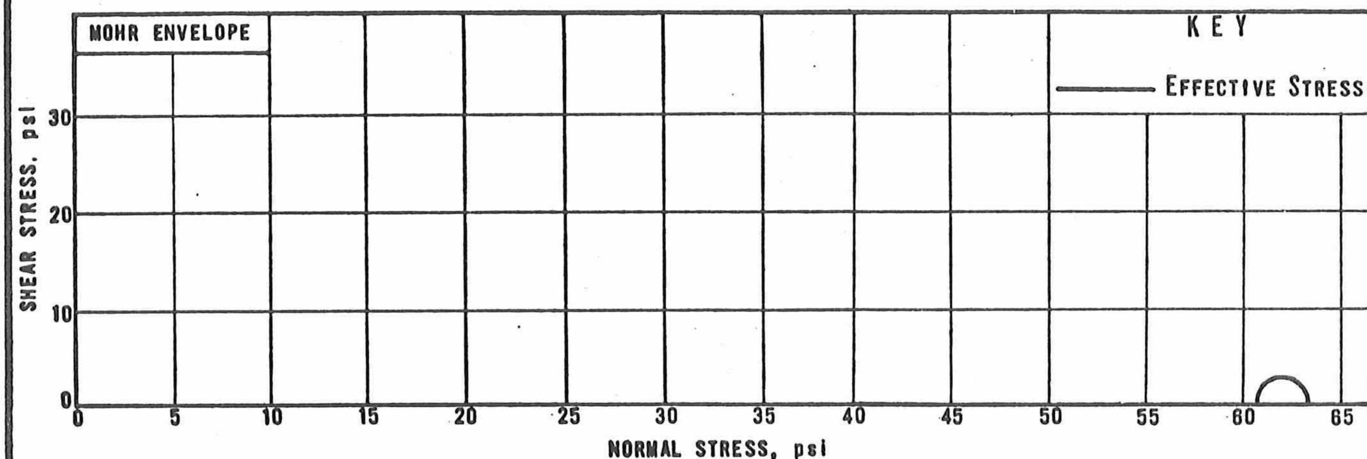
SPECIMEN NUMBER	1	2	3	
NORMAL PRESSURE (ksf)	2.0	4.0	8.0	
SHEAR STRENGTH (ksf)	1.56	2.39	5.07	
INITIAL WATER CONTENT (%)	34.1	32.3	28.1	
FINAL WATER CONTENT (%)	36.9	34.1	29.1	
DRY DENSITY (pcf)	88.3	90.7	97.5	

NOTE: STRAIN WAS STARTED ON SAMPLE IMMEDIATELY AFTER APPLICATION OF LOAD. SAMPLES WERE FLOODED WITH WATER AT START OF STRAIN.

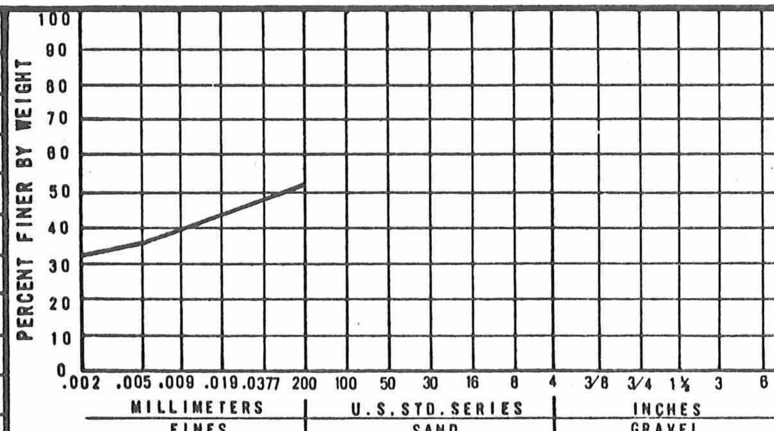
611-2 Rev. 2/69

W. A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	DIRECT SHEAR TEST		
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE JULY 1975	DRAWING NO. FIG. B-6





SPECIMEN NO.		1		
INITIAL CONDITION	Water Content,%	41.2		
	Opt.Water Content,%	---		
	Dry Density,pcf	79.0		
	Max.Dry Density,pcf	---		
	Void Ratio	1.133		
	Saturation,%	98.2		
	Confin.Pressure,psi	60.0		
FINAL CONDITION	Water Content,%	---		
	Dry Density,pcf	---		
	Void Ratio	---		
	Saturation,%	---		
GENERAL	Specimen Diameter, in.	2.875		
	Back Pressure,psi	0		
	Test Time to Failure, hrs.	1.27		
	Rate of Strain, %/hr.	7.89		

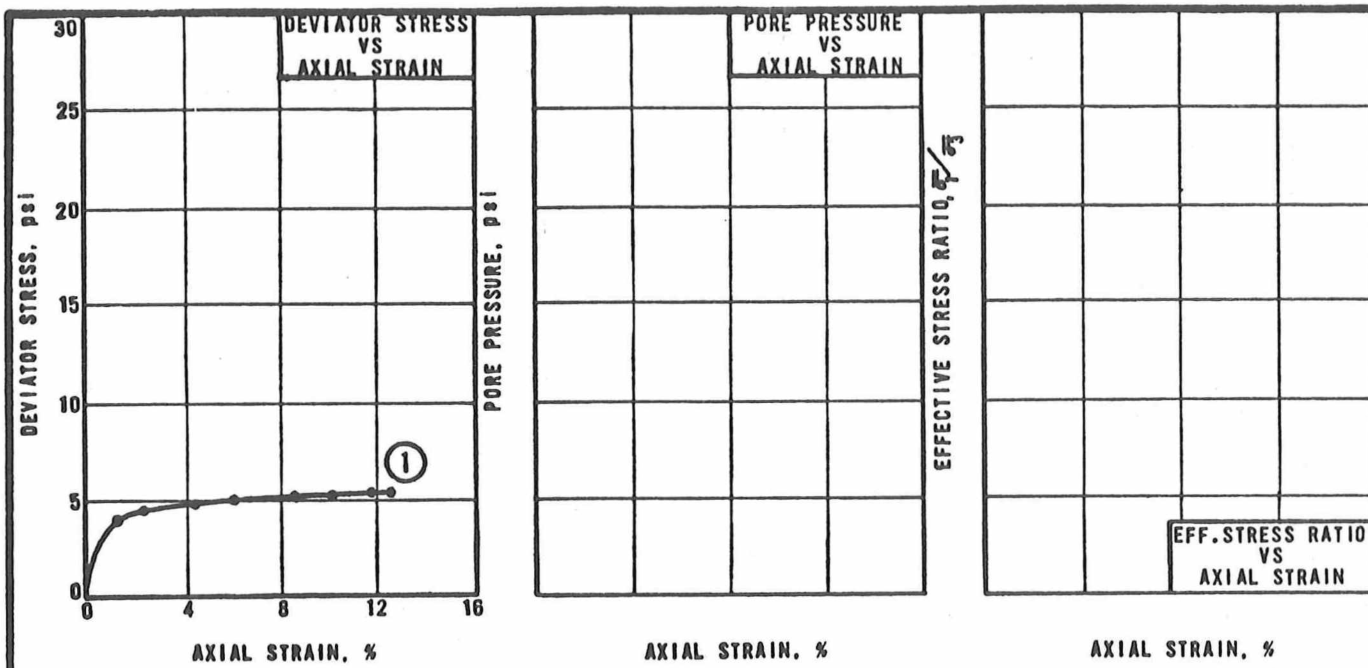


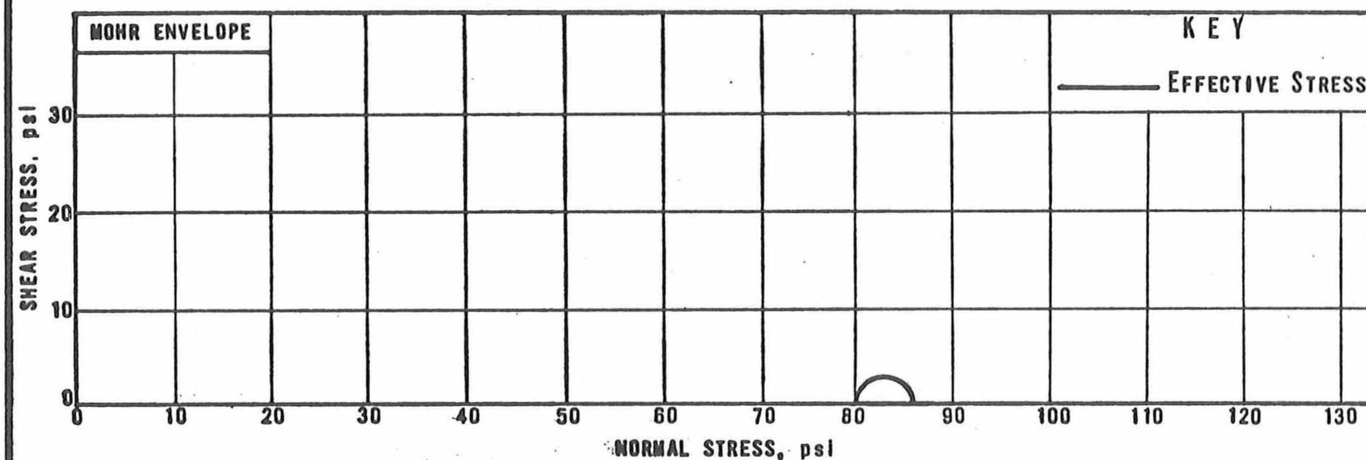
SYMB	CL-CH	SOIL CLASSIFICATION: Red Brown, Sandy CLAY
LL	50	
PL	22	SAMPLE LOCATION: Hole 1071, PS-2, 5'-7'
PI	28	
SG	2.70	N O T E:

W. A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	UNCONSOLIDATED UNDRAINED TRIAXIAL TEST RESULTS			SAMPLE NO. 1071 PS-2
	PALO ALTO · NEWPORT BEACH · CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 1 of 7	

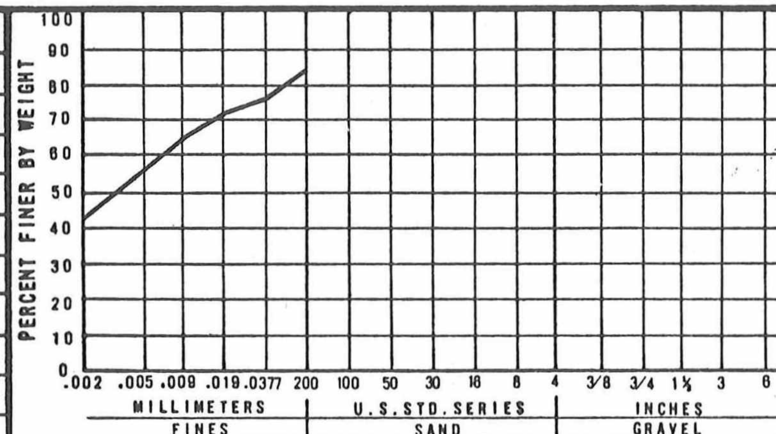
834(REV)

FIG. B-7





	SPECIMEN NO.	①		
INITIAL CONDITION	Water Content, %	48.9		
	Opt. Water Content, %	---		
	Dry Density, pcf	72.8		
	Max. Dry Density, pcf	---		
	Void Ratio	1.359		
	Saturation, %	99.1		
FINAL CONDITION	Confin. Pressure, psi	80.0		
	Water Content, %	---		
	Dry Density, pcf	---		
	Void Ratio	---		
	Saturation, %	---		
GENERAL	Specimen Diameter, in.	2.875		
	Back Pressure, psi	0		
	Test Time to Failure, hrs.	1.62		
	Rate of Strain, %/hr.	7.73		



SYMB	CH	SOIL CLASSIFICATION: Red Brown CLAY
LL	68	
PL	18	SAMPLE LOCATION: Hole 1071, PS-4, 10.5'-12.5'
PI	50	
SG	EST. 2.75	NOTE:

834(REV)

W. A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	UNCONSOLIDATED UNDRAINED TRIAXIAL TEST RESULTS			SAMPLE NO. 1071 PS-4
		PROJECT NO.	DATE	SHEET NO.	
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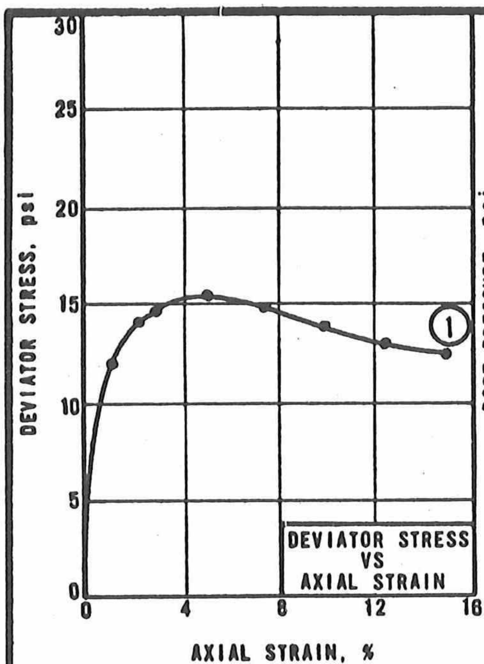
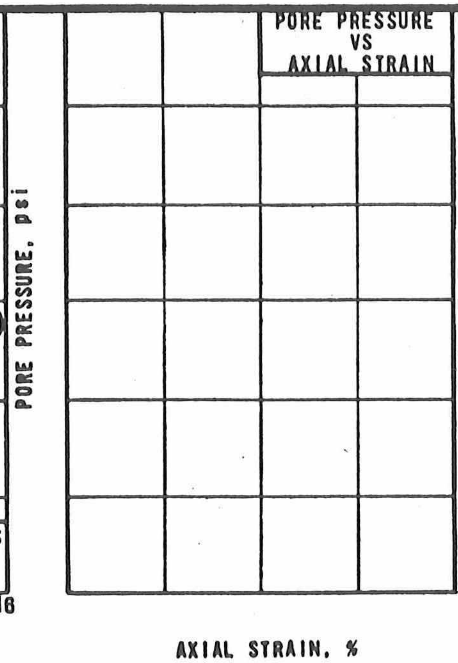
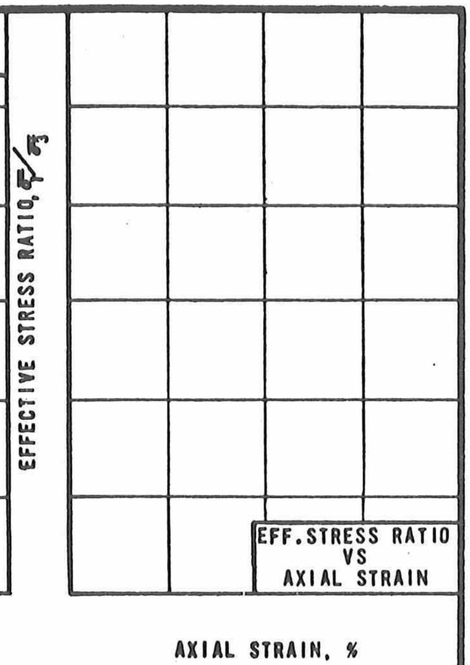
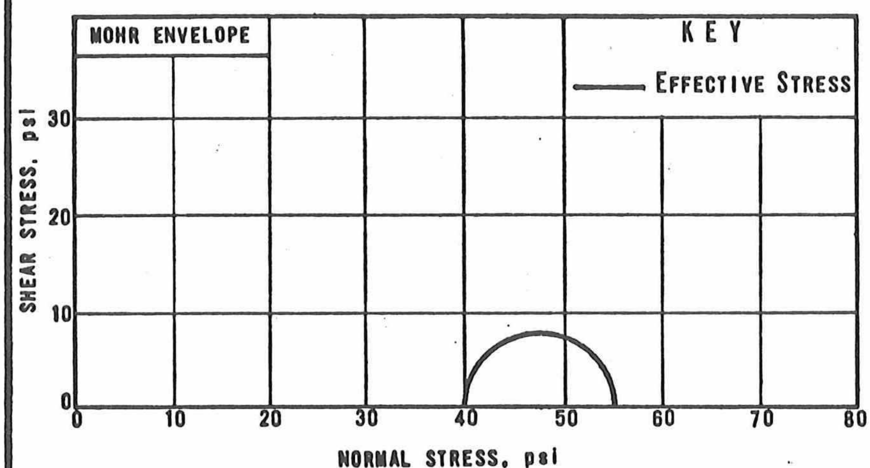
FIG. B-7

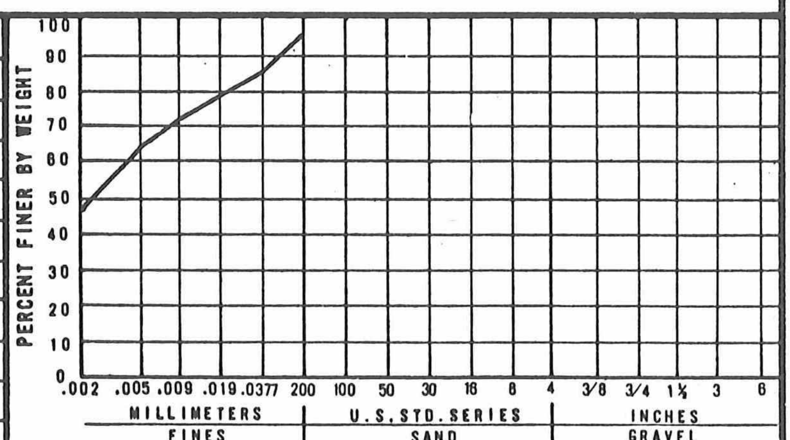








	SPECIMEN NO.	1		
INITIAL CONDITION	Water Content,%	41.7		
	Opt.Water Content,%	---		
	Dry Density,pcf	79.0		
	Max.Dry Density,pcf	---		
	Void Ratio	1.173		
	Saturation,%	97.9		
FINAL CONDITION	Confin.Pressure,psi	40.0		
	Water Content,%	---		
	Dry Density,pcf	---		
	Void Ratio	---		
	Saturation,%	---		
GENERAL	Specimen Diameter, In.	2.875		
	Back Pressure,psi	0		
	Test Time to Failure, hrs.	1.93		
	Rate of Strain, %/hr.	7.76		

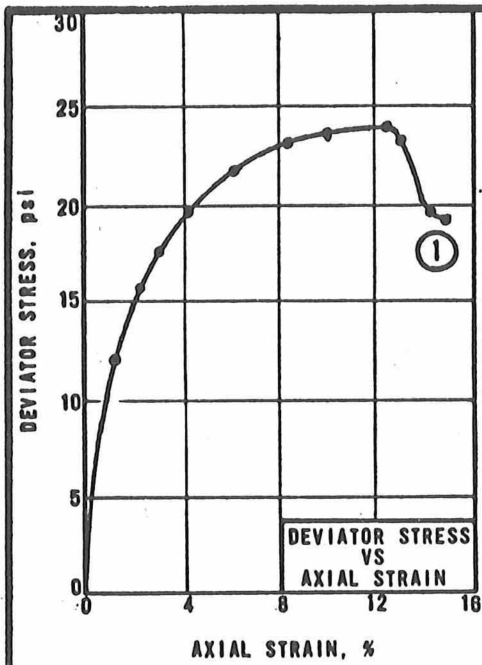


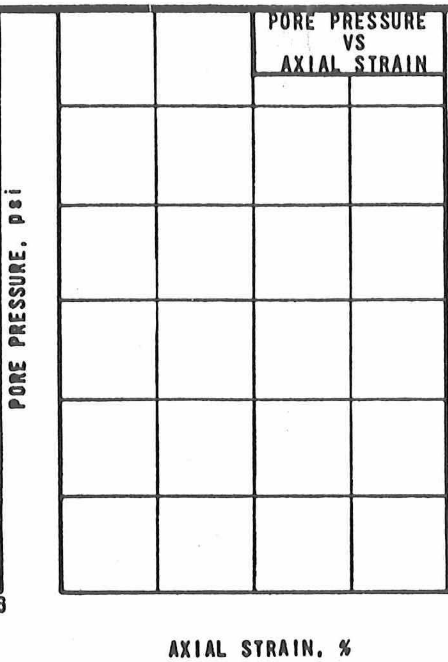
SYMB	CH	SOIL CLASSIFICATION: Red Brown CLAY
LL	86	
PL	26	SAMPLE LOCATION: Hole 1076, PS-1, 1.5'-3.5'
PI	60	
SG	EST. 2.75	NOTE:

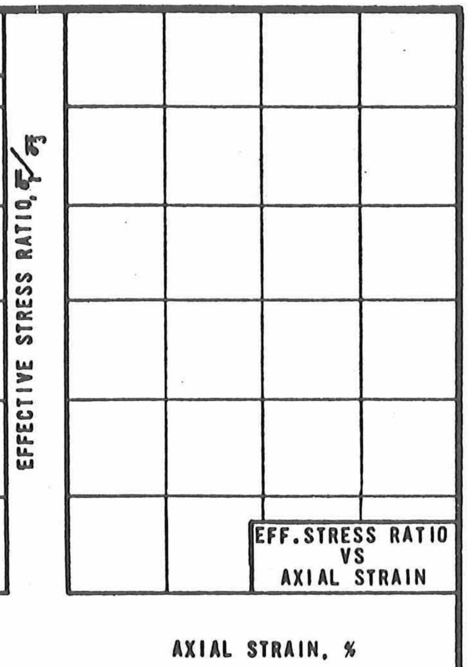
834(REV)

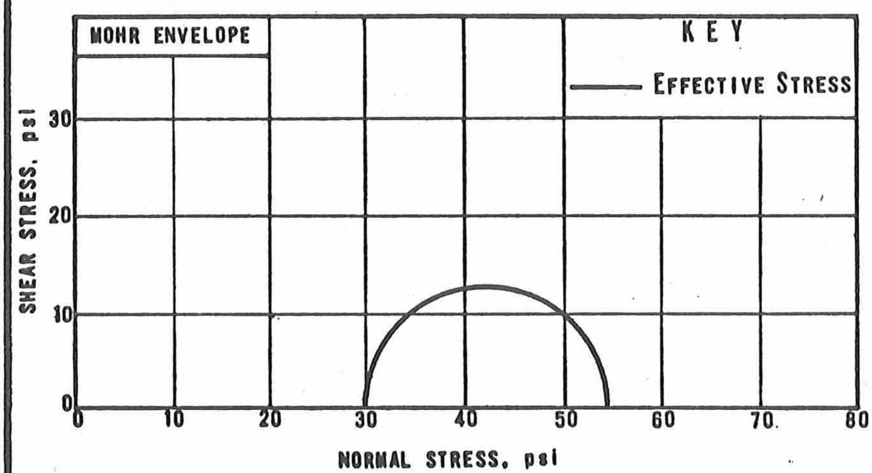
W. A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	UNCONSOLIDATED UNDRAINED TRIAXIAL TEST RESULTS			SAMPLE NO. 1076 PS-1
	PALO ALTO · NEWPORT BEACH · CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 3 of 7	

FIG. B-7

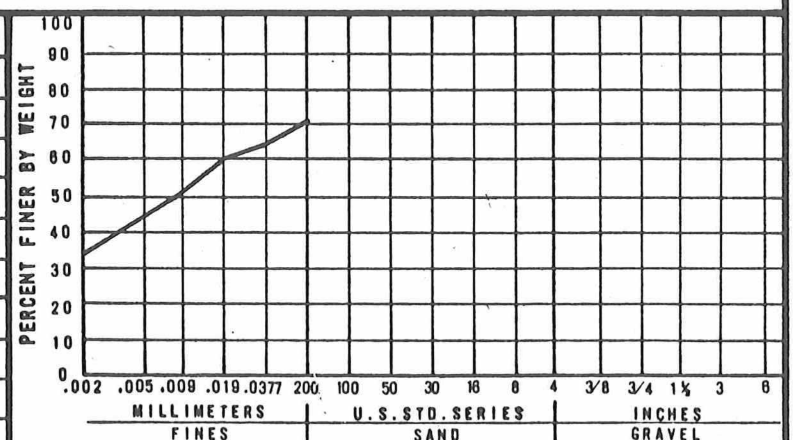








	SPECIMEN NO.	1		
INITIAL CONDITION	Water Content,%	21.8		
	Opt.Water Content,%	---		
	Dry Density,pcf	105.6		
	Max.Dry Density,pcf	---		
	Void Ratio	0.626		
	Saturation,%	96.0		
FINAL CONDITION	Confin.Pressure,psi	30.0		
	Water Content,%	---		
	Dry Density,pcf	---		
	Void Ratio	---		
	Saturation,%	---		
GENERAL	Specimen Diameter, in.	2.875		
	Back Pressure,psi	0		
	Test Time to Failure, hrs.	1.93		
	Rate of Strain, %/hr.	7.76		



SYMB	CL	SOIL CLASSIFICATION: Red Brown, Sandy CLAY
LL	45	
PL	22	SAMPLE LOCATION: Hole 3020, PS-1, 1'-3'
PI	23	
SG	EST. 2.75	NOTE:

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA PALO ALTO · NEWPORT BEACH · CALIF.	UNCONSOLIDATED UNDRAINED TRIAXIAL TEST RESULTS		SAMPLE NO. 3020 PS-1
		PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 4 of 7

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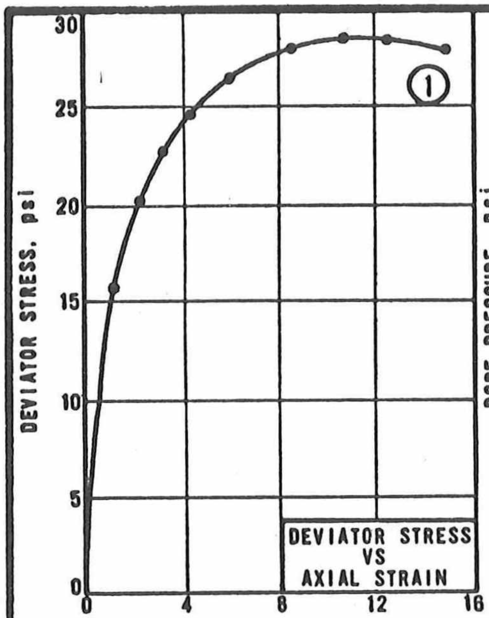
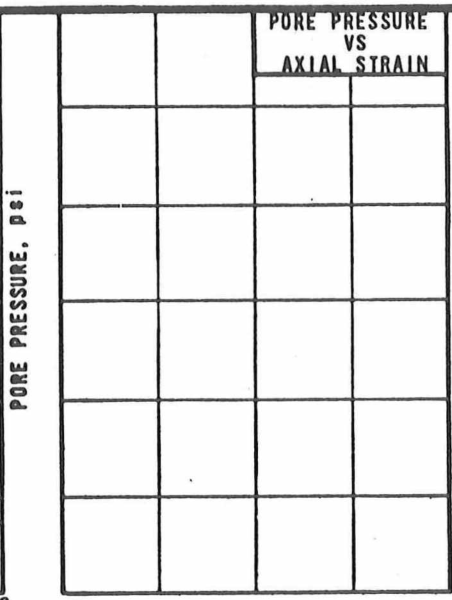
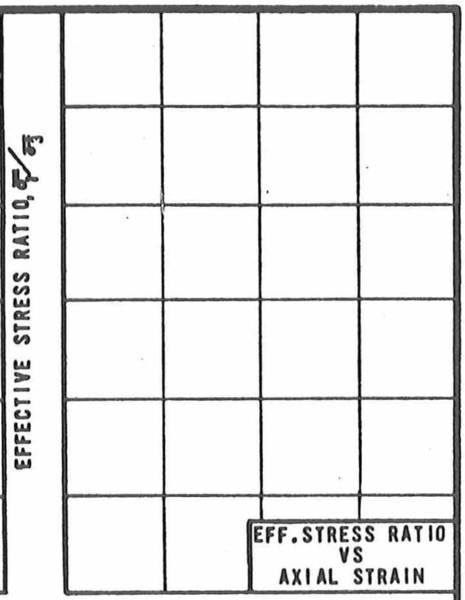
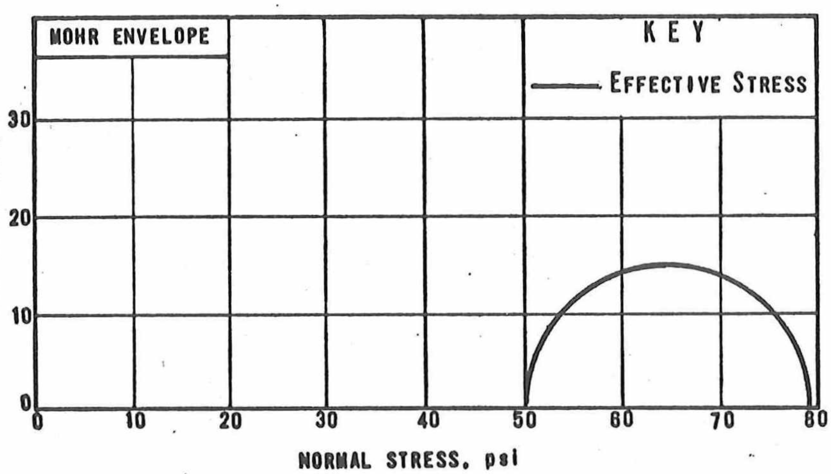
FIG. B-7

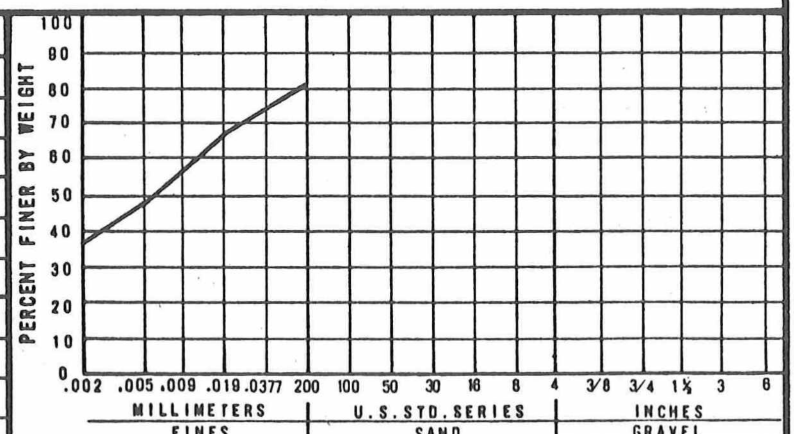








	SPECIMEN NO.	①		
INITIAL CONDITION	Water Content,%	23.7		
	Opt.Water Content,%	---		
	Dry Density,pcf	101.8		
	Max.Dry Density,pcf	---		
	Void Ratio	0.667		
	Saturation,%	95.0		
FINAL CONDITION	Confin.Pressure,psi	50.0		
	Water Content,%	---		
	Dry Density,pcf	---		
	Void Ratio	---		
	Saturation,%	---		
GENERAL	Specimen Diameter, in.	2.875		
	Back Pressure,psi	0		
	Test Time to Failure, hrs.	1.93		
	Rate of Strain, %/hr.	7.76		

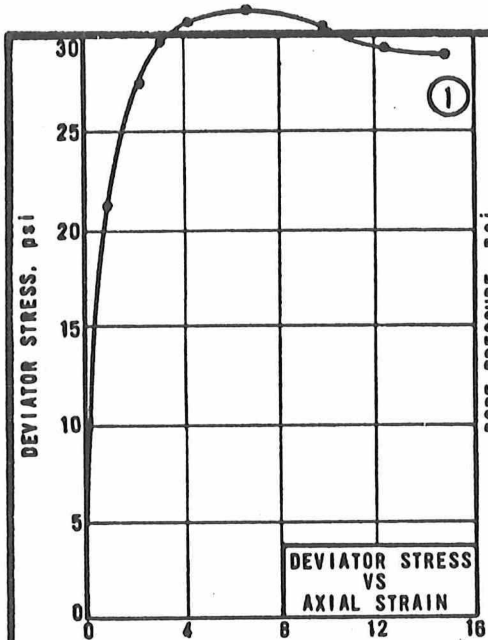


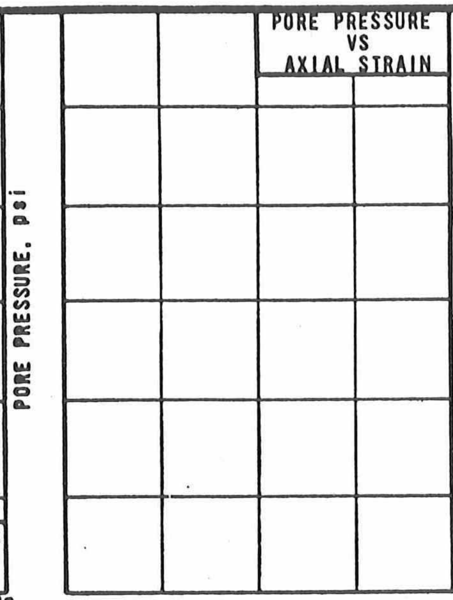
SYMB	CL	SOIL CLASSIFICATION: Red Brown, Sandy CLAY
LL	47	
PL	16	SAMPLE LOCATION: Hole 3020, PS-2, 4'-5.5'
PI	31	
SG	EST. 2.75	NOTE:

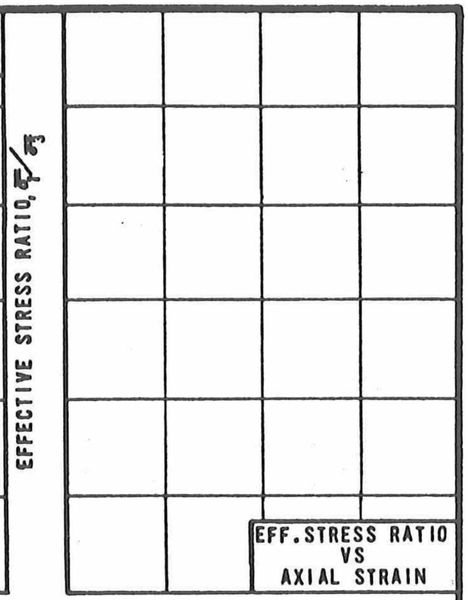
834(REV)

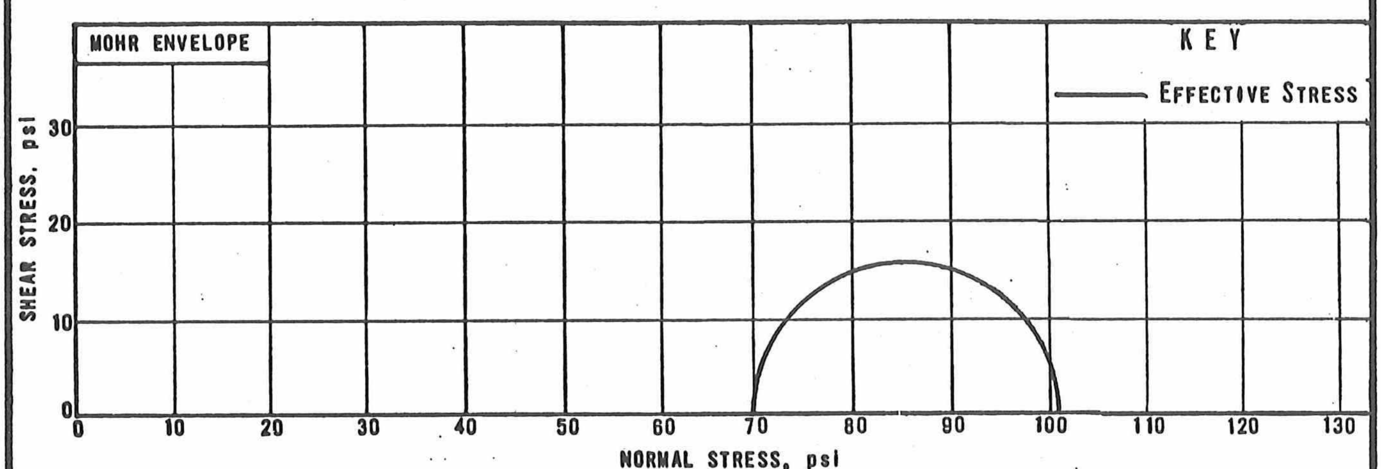
W. A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	UNCONSOLIDATED UNDRAINED TRIAXIAL TEST RESULTS			SAMPLE NO. 3020 PS-2
	PALO ALTO · NEWPORT BEACH · CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	SHEET NO. 5 of 7	

FIG. B-7

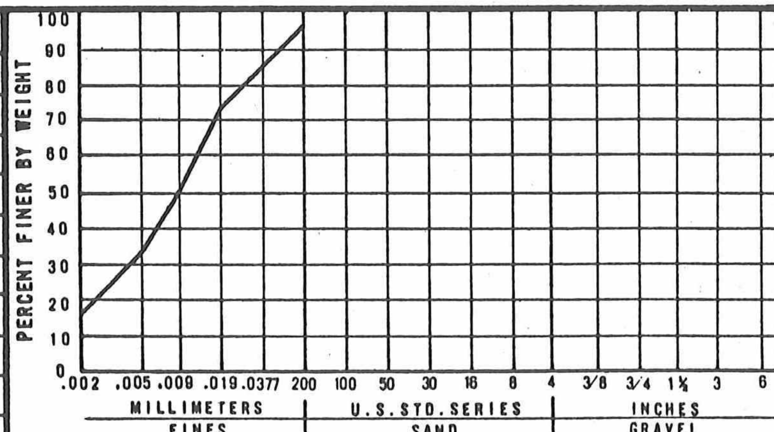








SPECIMEN NO.		1		
INITIAL CONDITION	Water Content, %	22.8		
	Opt. Water Content, %	---		
	Dry Density, pcf	104.1		
	Max. Dry Density, pcf	---		
	Void Ratio	0.649		
	Saturation, %	96.9		
FINAL CONDITION	Confin. Pressure, psi	70.0		
	Water Content, %	---		
	Dry Density, pcf	---		
	Void Ratio	---		
	Saturation, %	---		
GENERAL	Specimen Diameter, in.	2.875		
	Back Pressure, psi	0		
	Test Time to Failure, hrs.	1.93		
	Rate of Strain, %/hr.	7.76		



SYMB	CL	SOIL CLASSIFICATION: RED BROWN CLAY
LL	35	
PL	18	SAMPLE LOCATION: HOLE 3020, PS-4, 9.5'-10.6'
PI	17	
SG	2.75	NOTE:

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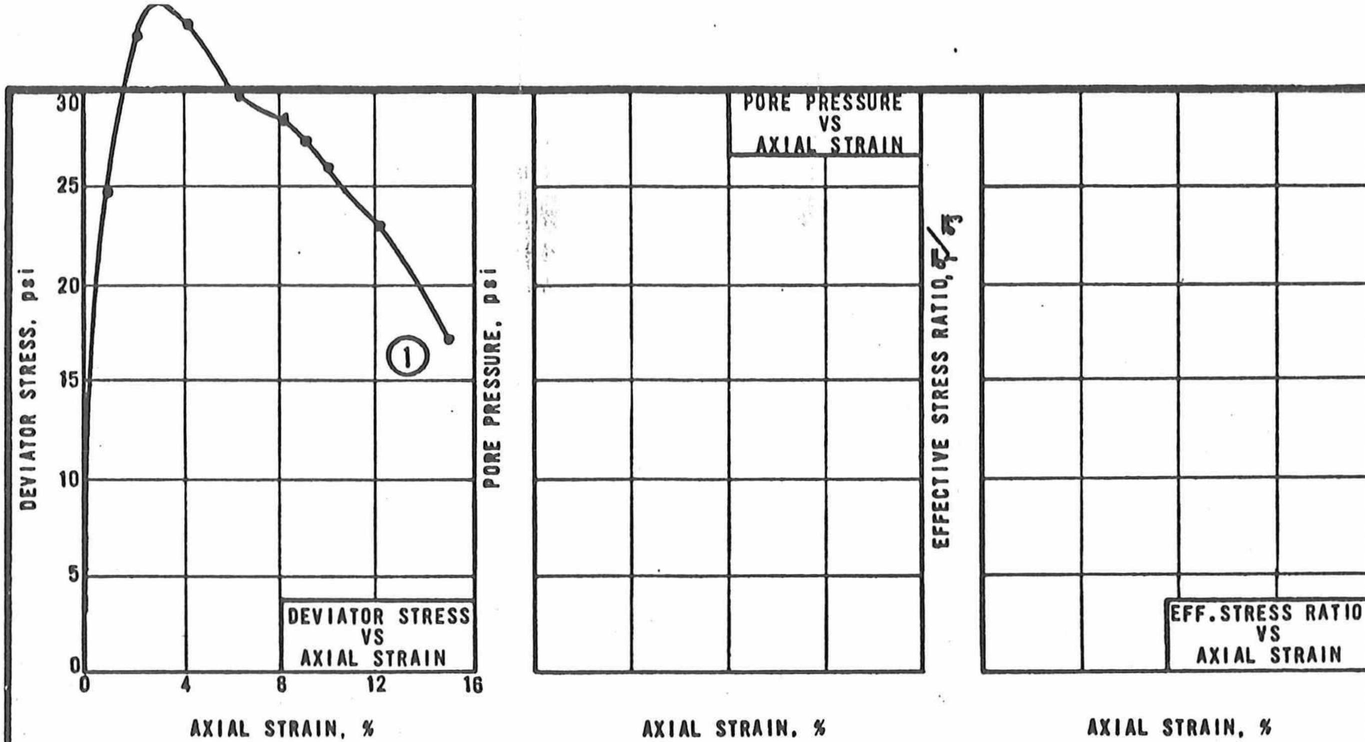
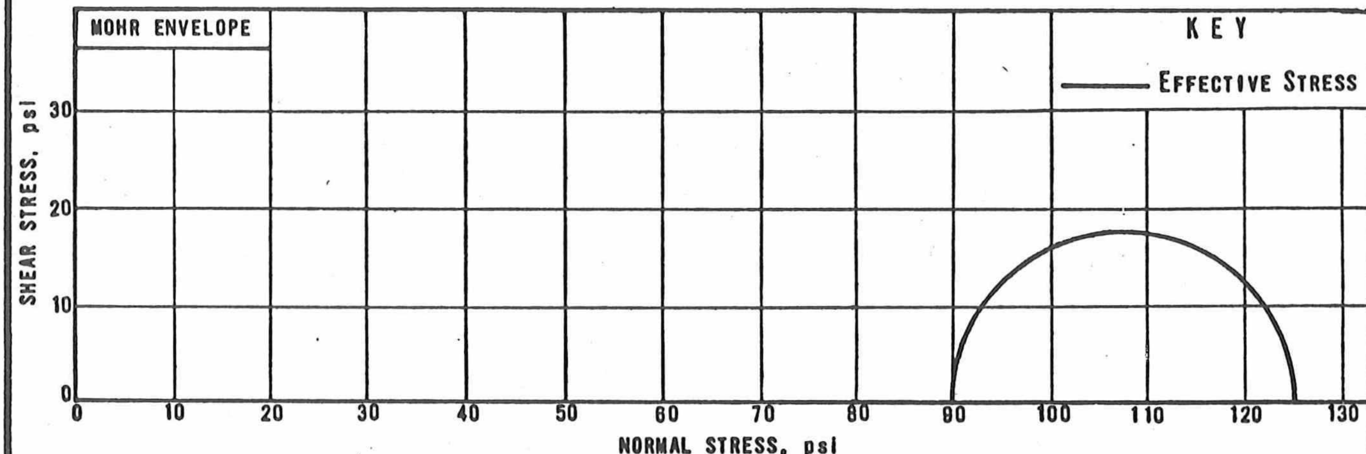
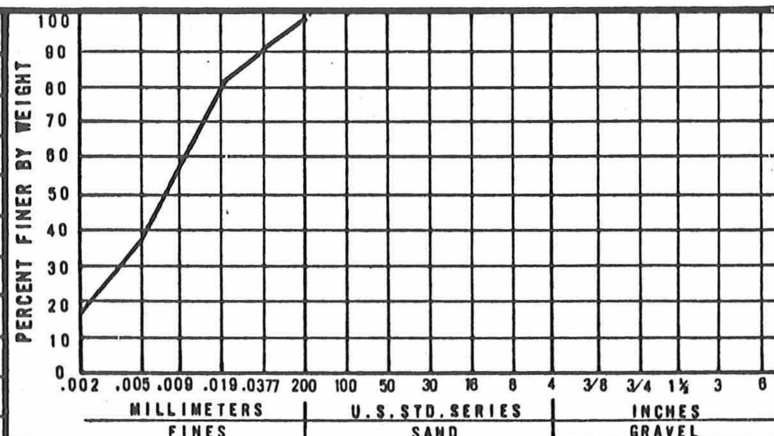
SAMPLE NO. 3020 PS-4

FIG. B-7





SPECIMEN NO.		1		
INITIAL CONDITION	Water Content, %	32.5		
	Opt. Water Content, %	---		
	Dry Density, pcf	89.6		
	Max. Dry Density, pcf	---		
	Void Ratio	0.917		
	Saturation, %	97.8		
FINAL CONDITION	Confin. Pressure, psi	90.0		
	Water Content, %	---		
	Dry Density, pcf	---		
	Void Ratio	---		
	Saturation, %	---		
GENERAL	Specimen Diameter, in.	2.875		
	Back Pressure, psi	0		
	Test Time to Failure, hrs.	1.93		
	Rate of Strain, %/hr.	7.76		



SYMB	CL	SOIL CLASSIFICATION: Red Brown, Silty Clay
LL	---	
PL	---	SAMPLE LOCATION: Hole 3020, PS-5, 11'-13'
PI	---	
SG	EST. 2.75	NOTE:

834(REV)

W. A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	UNCONSOLIDATED UNDRAINED TRIAXIAL TEST RESULTS			SAMPLE NO. 3020 PS-5
		PROJECT NO.	DATE	SHEET NO.	
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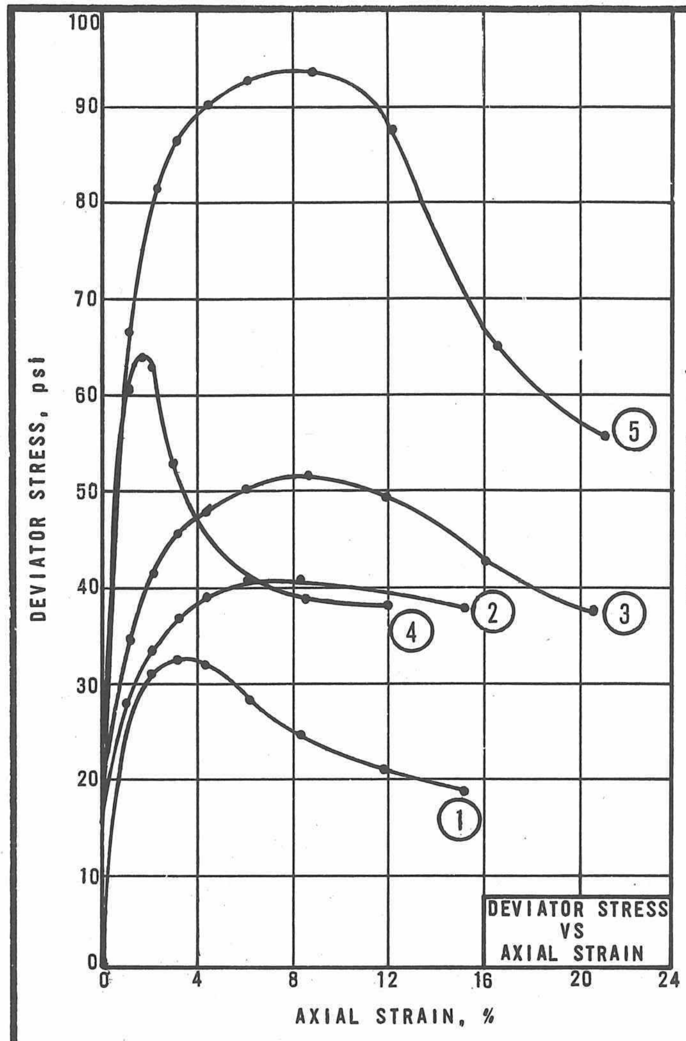
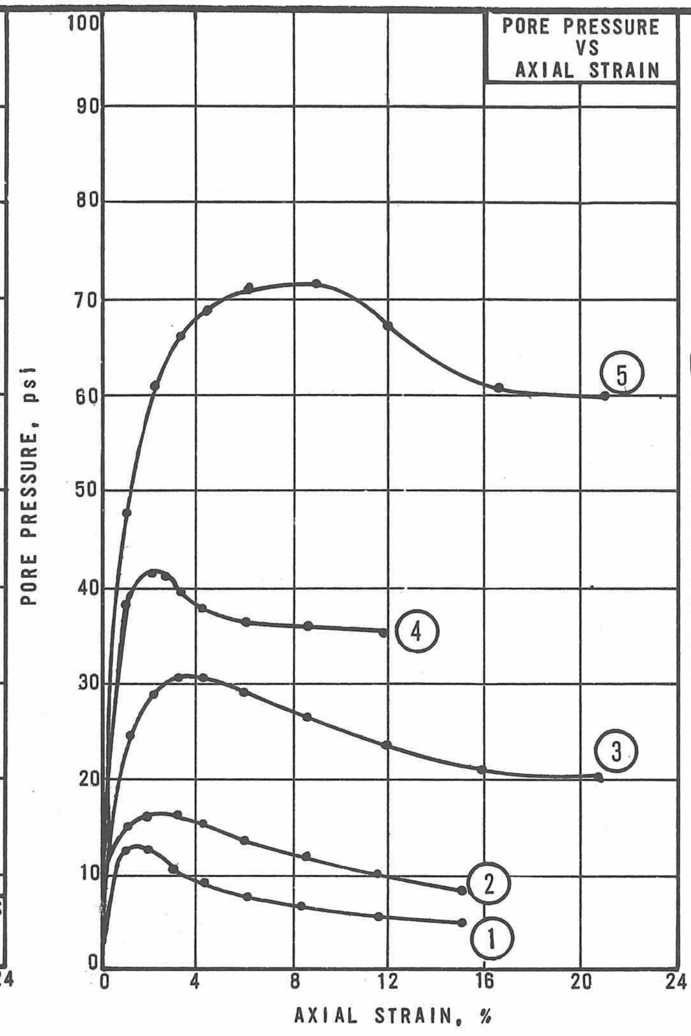
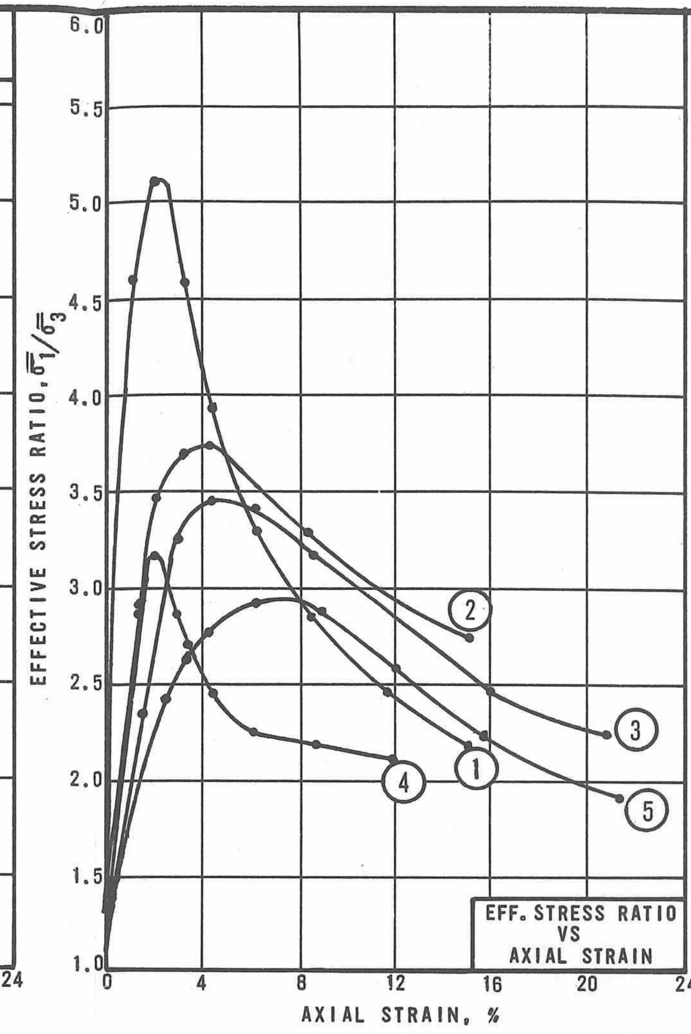
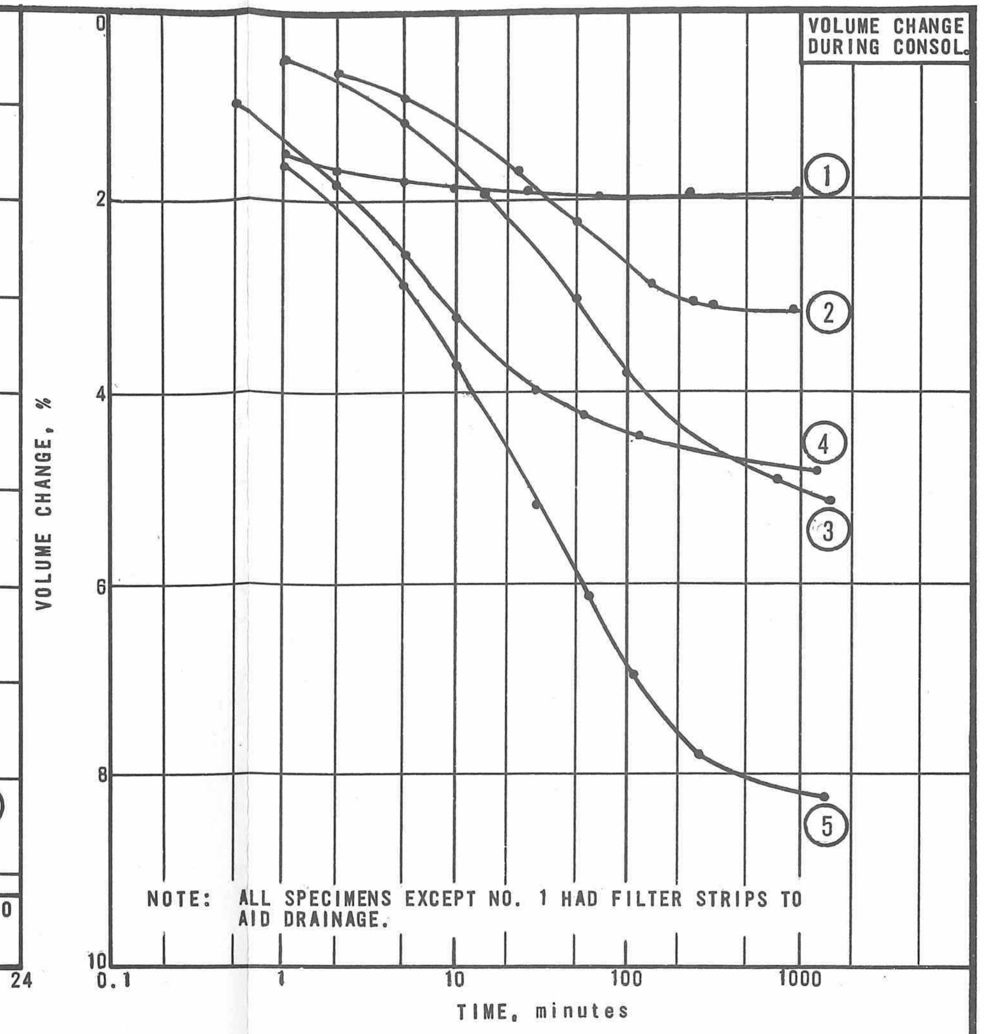
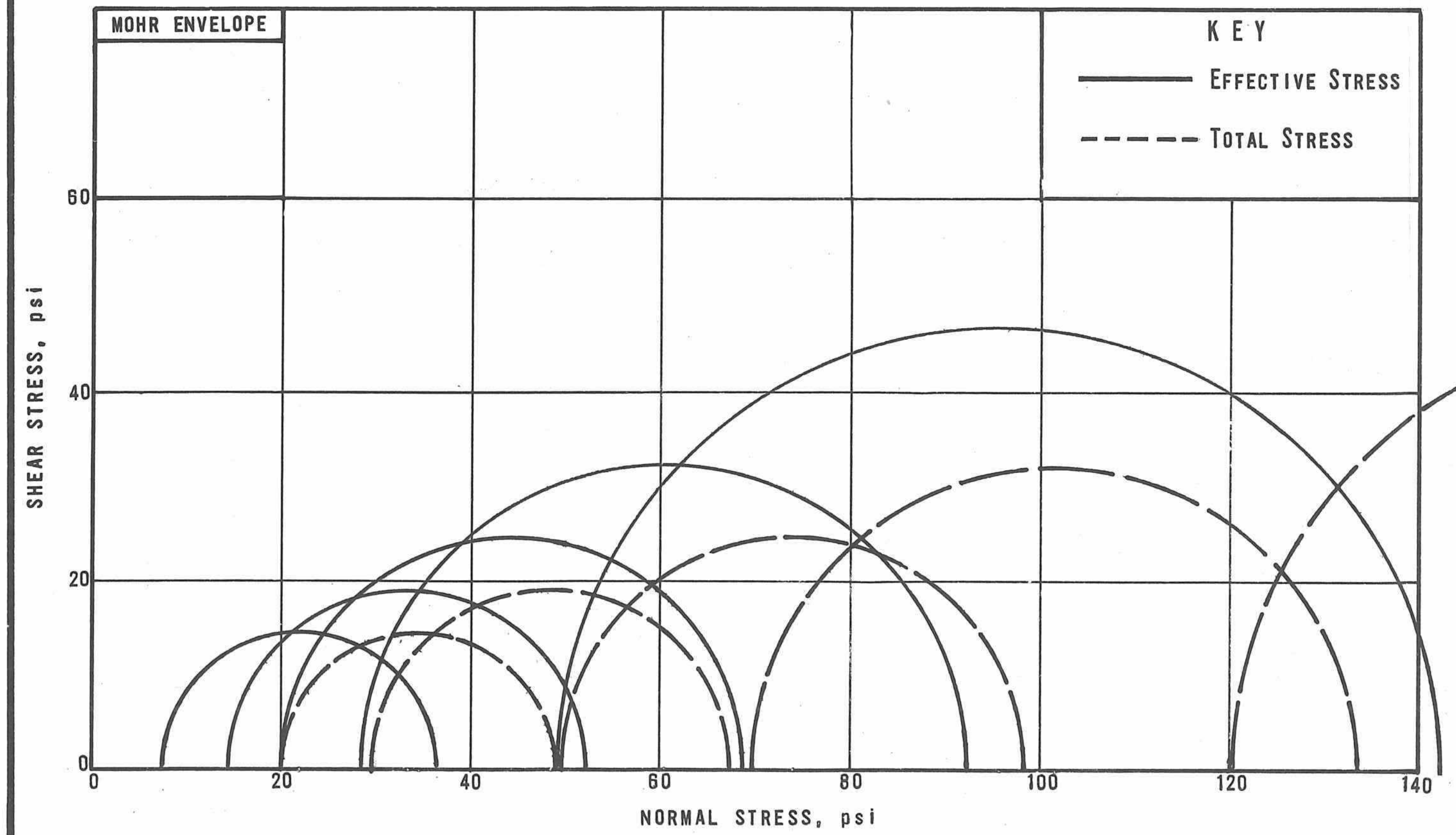
FIG. B-7











SPEC. NO.	HOLE NO.	DEPTH (ft.)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	FINER THAN #200 SIEVE (%)	SPECIMEN DIAMETER (in.)	STRAIN RATE (%/hr.)	SPECIFIC GRAVITY	UNIFIED SOIL CLASSIFICATION SYMBOL
1	1076	4-6.4	54	29	93.1	2.875	3.95	2.79	CH
2	3020	1-3	45	23	71.2	2.875	3.99	(EST.) 2.75	CL
3	3020	4-5.5	47	31	81.8	2.875	4.05	(EST.) 2.75	CL
4	3020	9.5-10.6	35	17	96.8	2.875	4.03	2.75	CL
5	1006	2-4	53	27	98.4	2.875	4.10	(EST.) 2.75	CH

SPEC. NO.	INITIAL SPECIMEN DATA				FINAL SPECIMEN DATA			BACK PRESSURE (psi)	EFFECTIVE CONSOL. PRESSURE (psi)
	DRY DENSITY (pcf)	WATER CONTENT (%)	VOID RATIO	DEGREE OF SATURATION (%)	DRY DENSITY (pcf)	WATER CONTENT (%)	VOID RATIO		
1	88.3	33.0	0.972	95.1	90.1	32.7	0.933	50.0	20.0
2	104.7	22.7	0.639	97.7	108.2	22.0	0.587	50.0	30.0
3	99.6	24.1	0.724	91.7	104.9	22.0	0.637	50.0	50.0
4	100.4	25.6	0.710	99.5	105.5	24.0	0.627	50.0	70.0
5	91.5	29.8	0.876	93.7	99.7	26.4	0.722	50.0	120.0

NOTE: SAMPLE DESCRIPTION: SPECIMEN 1 - RED BROWN, SILTY CLAY; SPECIMENS 2 & 3 - RED BROWN, SANDY CLAY; SPECIMENS 4 & 5 - RED BROWN CLAY.

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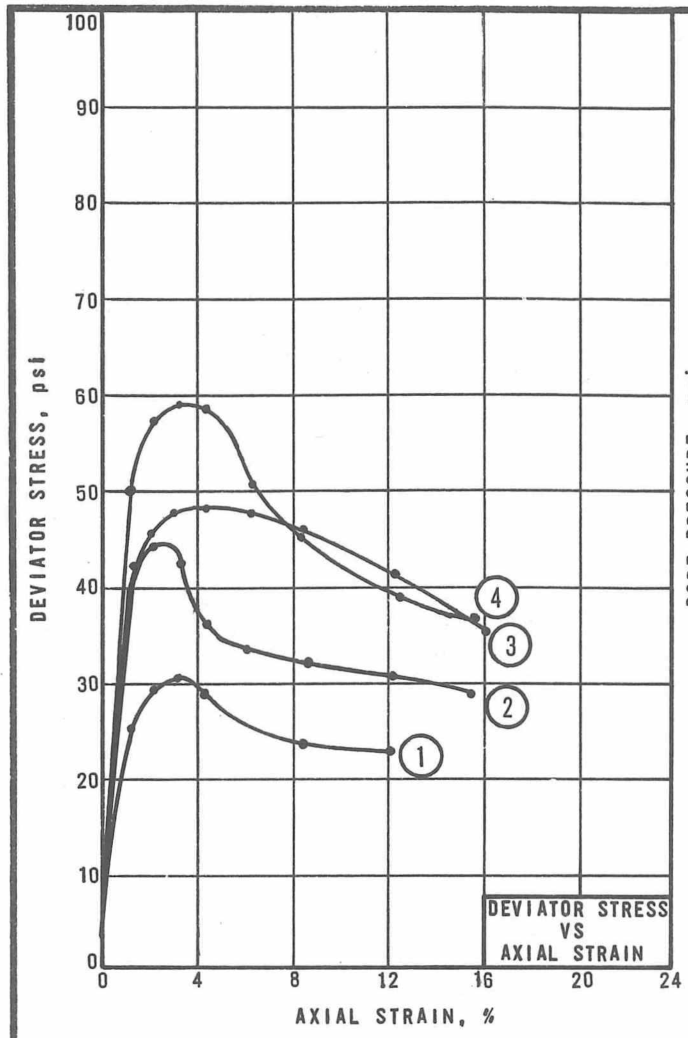

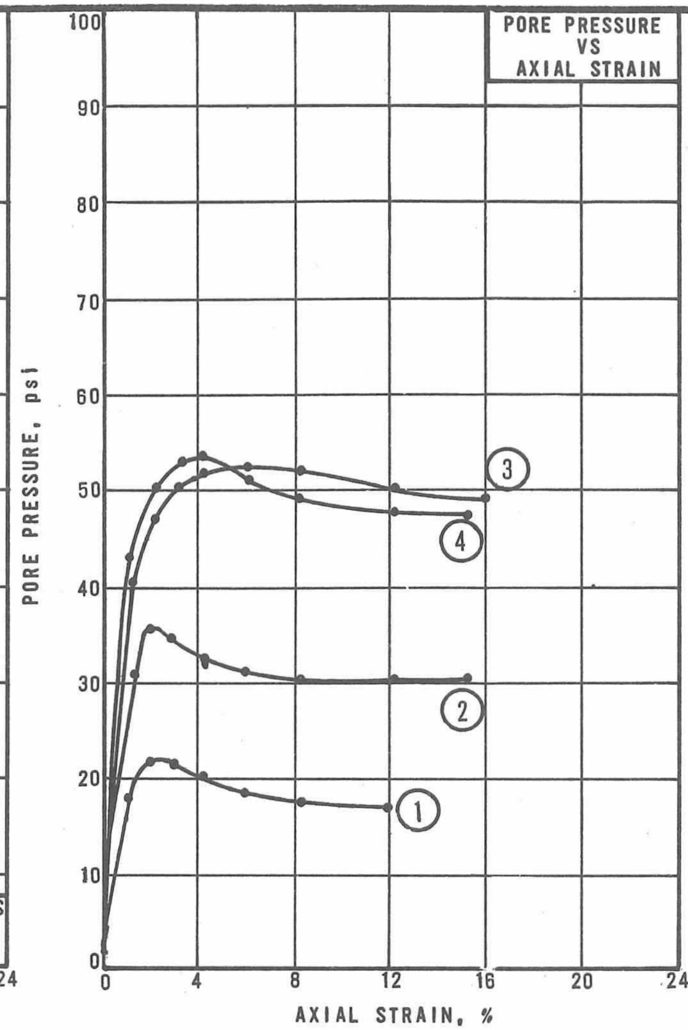

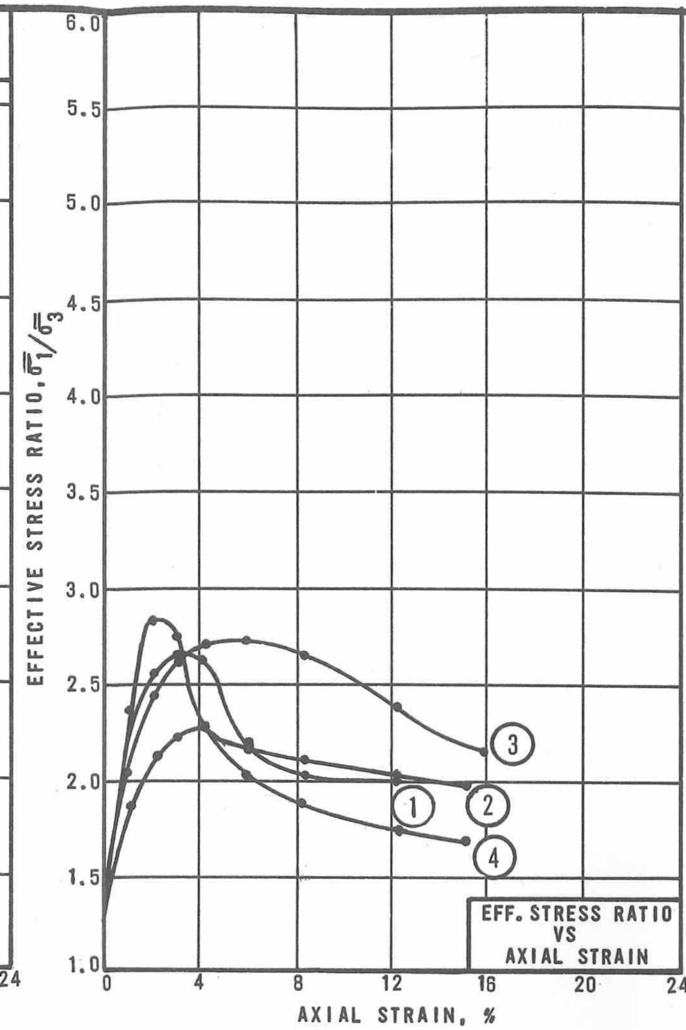

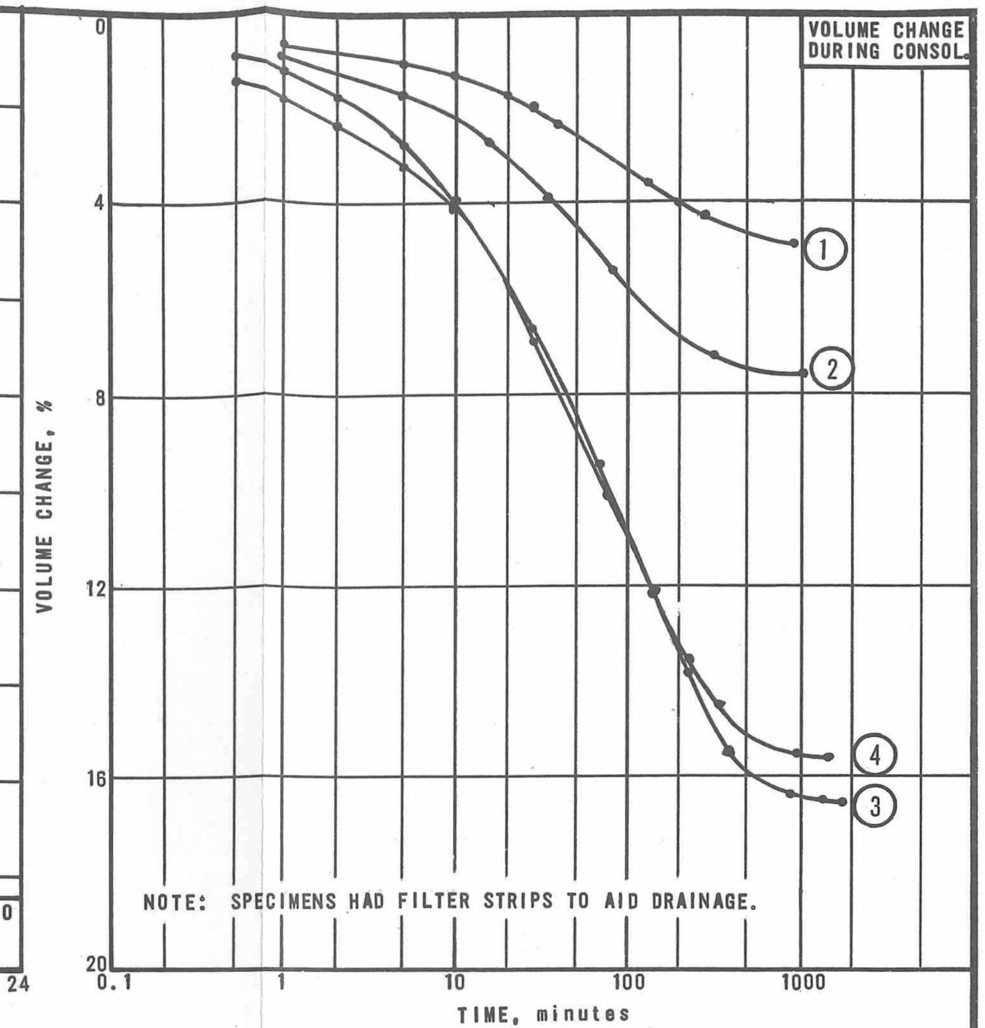

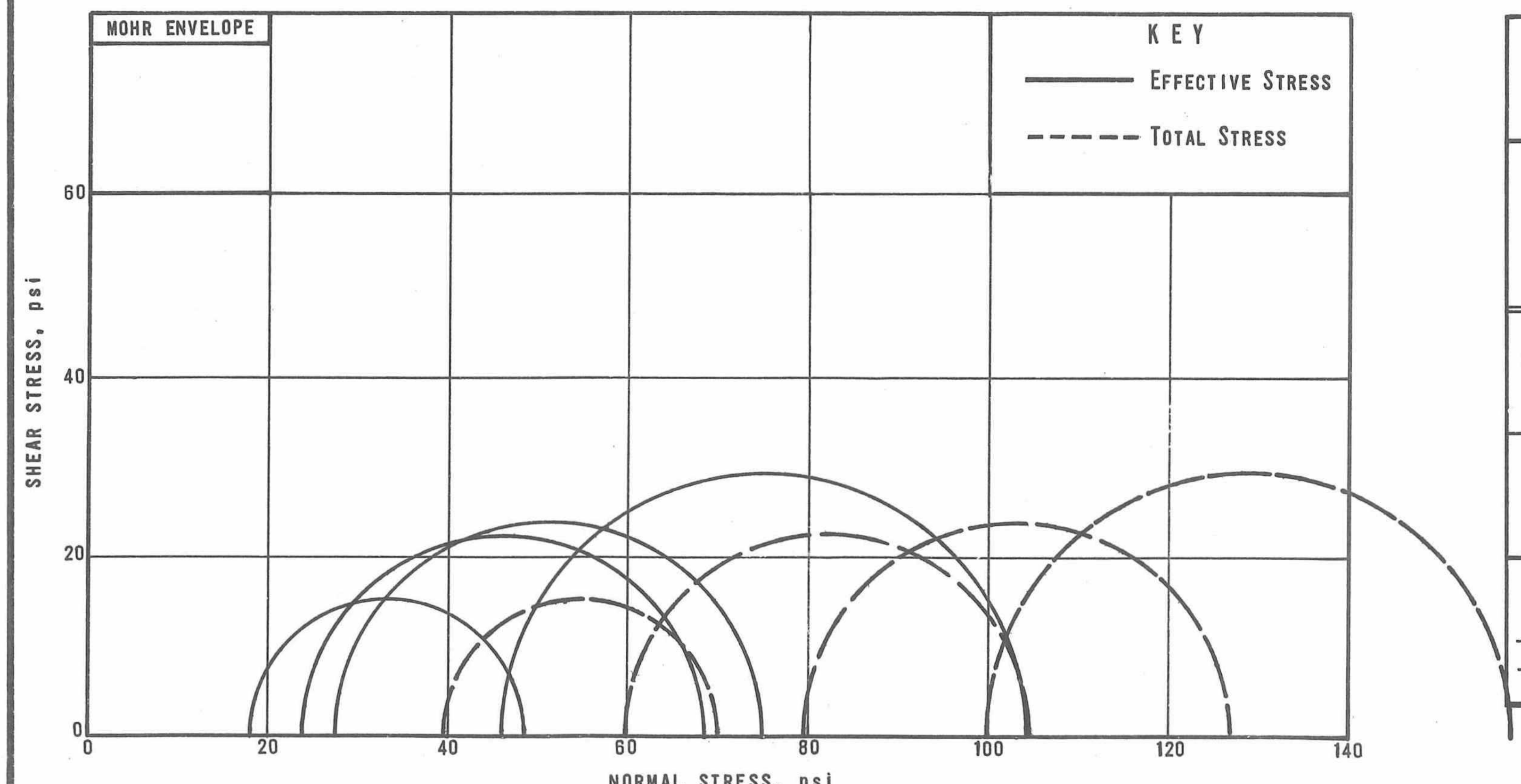

SPEC. NO.	HOLE NO.	DEPTH (ft.)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	FINER THAN #200 SIEVE (%)	SPECIMEN DIAMETER (in.)	STRAIN RATE (%/hr.)	SPECIFIC GRAVITY	UNIFIED SOIL CLASSIFICATION SYMBOL
1	1076	1.5-3.5	86	60	96.5	2.875	4.03	(EST.) 2.75	CH
2	1076	8.5-10.5	73	48	92.0	2.875	4.12	(EST.) 2.75	CH
3	1071	5-7	50	28	56.9	2.875	4.44	2.70	CL-CH
4	1071	10.5-12.5	68	50	83.7	2.875	4.27	(EST.) 2.75	CH

SPEC. NO.	INITIAL SPECIMEN DATA				FINAL SPECIMEN DATA			BACK PRESSURE (psi)	EFFECTIVE CONSOL. PRESSURE (psi)
	DRY DENSITY (pcf)	WATER CONTENT (%)	VOID RATIO	DEGREE OF SATURATION (%)	DRY DENSITY (pcf)	WATER CONTENT (%)	VOID RATIO		
1	76.7	44.4	1.239	98.8	80.7	42.5	1.128	50.0	40.0
2	83.6	37.7	1.053	98.7	90.4	33.6	0.899	50.0	60.0
3	76.8	42.8	1.195	96.9	92.0	29.3	0.833	50.0	80.0
4	78.1	42.5	1.197	97.9	92.5	30.9	0.855	50.0	100.0

NOTE: SAMPLE DESCRIPTION: SPECIMENS 1, 2 & 4 - RED BROWN CLAY; SPECIMEN 3 - RED BROWN, SANDY CLAY.

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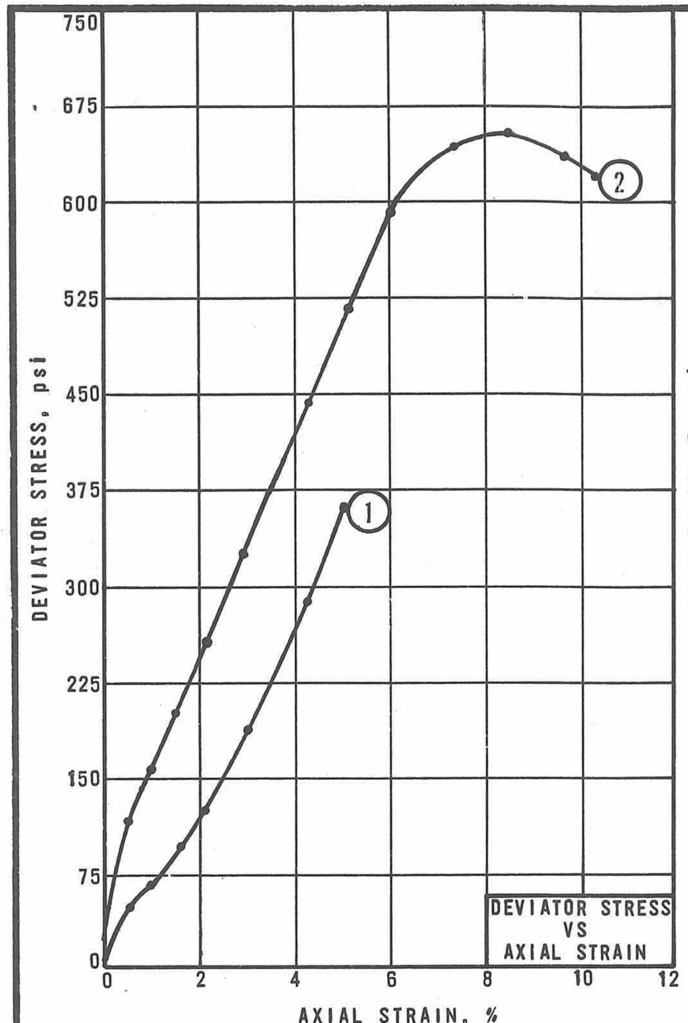
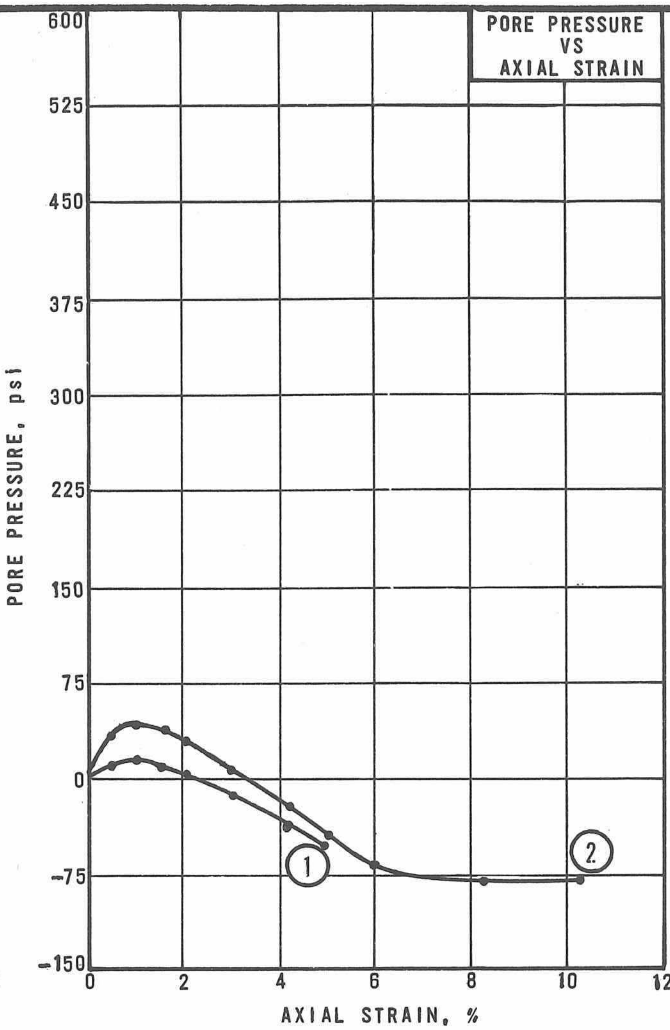
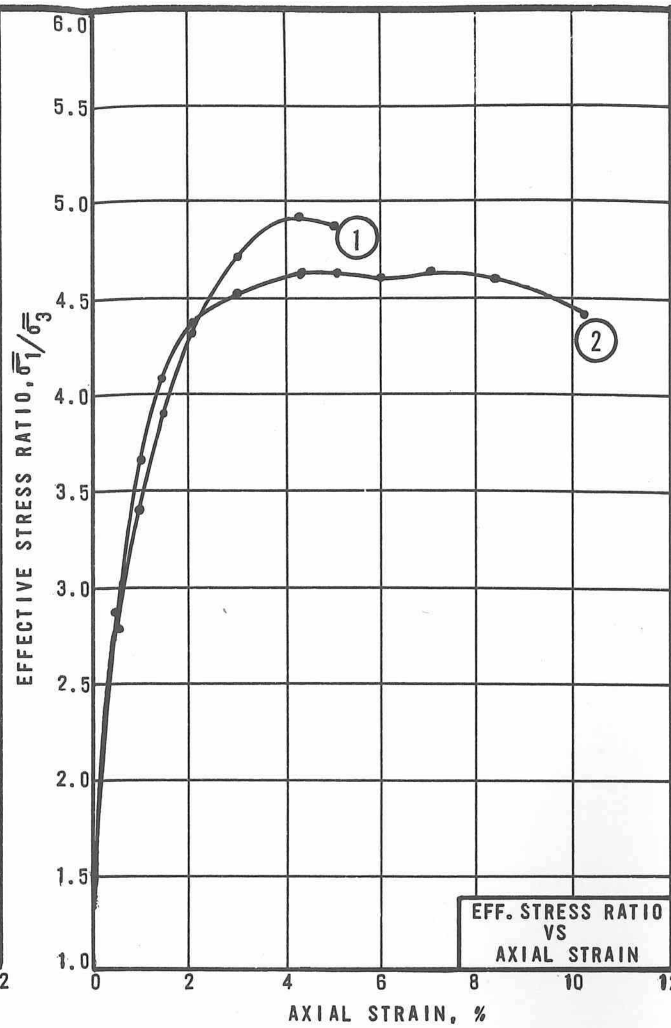
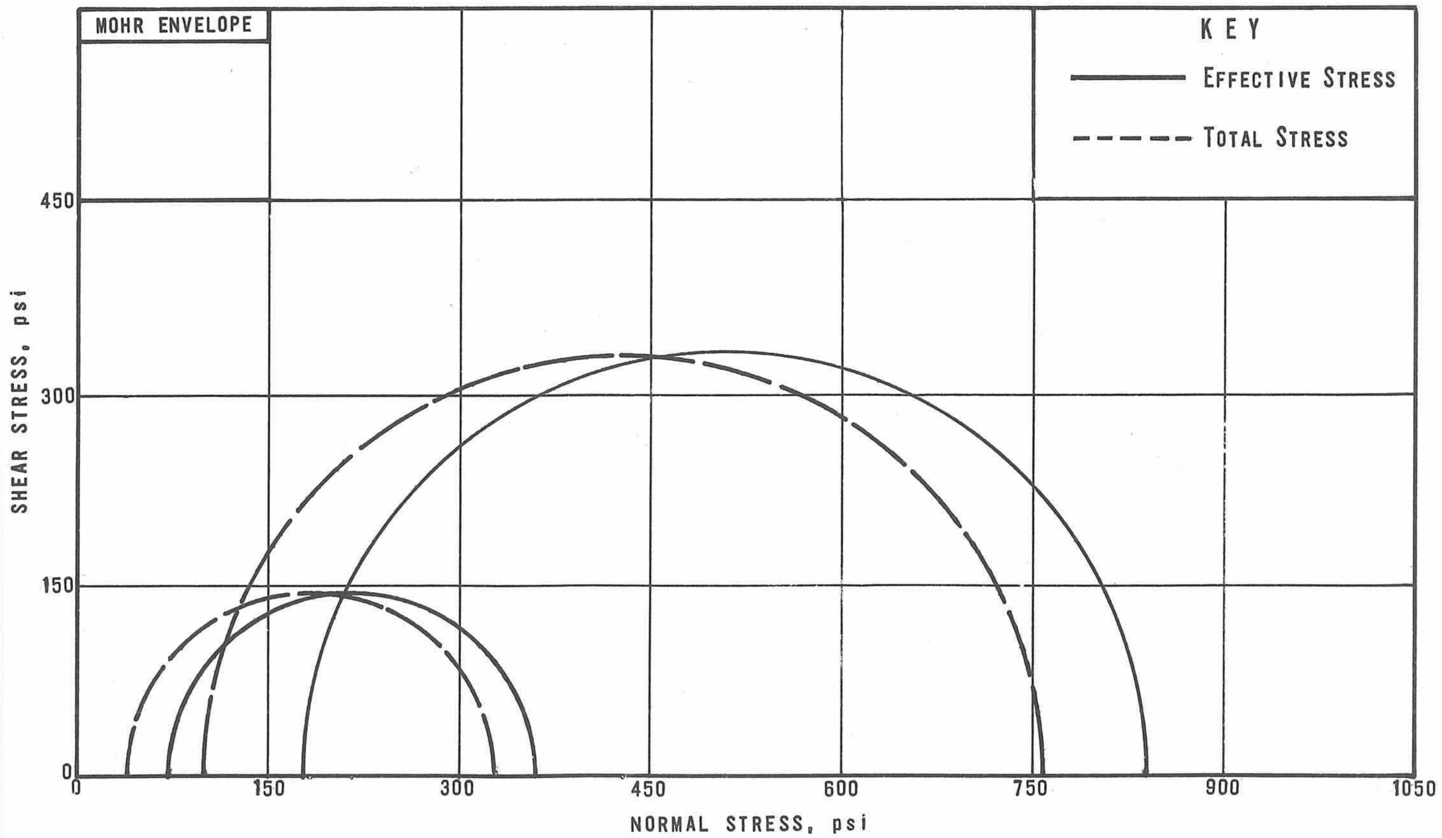






SPECIMEN NO.	VOLUME CHANGE PRIOR TO SHEAR, %
1	2.79
2	4.79



SPEC. NO.	HOLE NO.	DEPTH (ft.)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	FINER THAN #200 SIEVE (%)	SPECIMEN DIAMETER (in.)	STRAIN RATE (%/hr.)	SPECIFIC GRAVITY	UNIFIED SOIL CLASSIFICATION SYMBOL
1	3020	19-20	---	NP	44.0	2.875	4.17	2.79	SM
2	3020	21-22.2	---	NP	65.6	2.875	3.94	(EST.) 2.79	ML

SPEC. NO.	INITIAL SPECIMEN DATA				FINAL SPECIMEN DATA			BACK PRESSURE (psi)	EFFECTIVE CONSOL. PRESSURE (psi)
	DRY DENSITY (pcf)	WATER CONTENT (%)	VOID RATIO	DEGREE OF SATURATION (%)	DRY DENSITY (pcf)	WATER CONTENT (%)	VOID RATIO		
1	111.4	18.0	0.563	89.3	114.6	18.9	0.520	80.0	40.0
2	109.1	19.5	0.596	91.4	114.6	18.2	0.519	70.0	100.0

NOTE: SAMPLE DESCRIPTION: SPECIMEN 1 - BROWN, SILTY SAND; SPECIMEN 2 - BROWN, SANDY SILT.

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PALO ALTO • NEWPORT BEACH • CALIF.

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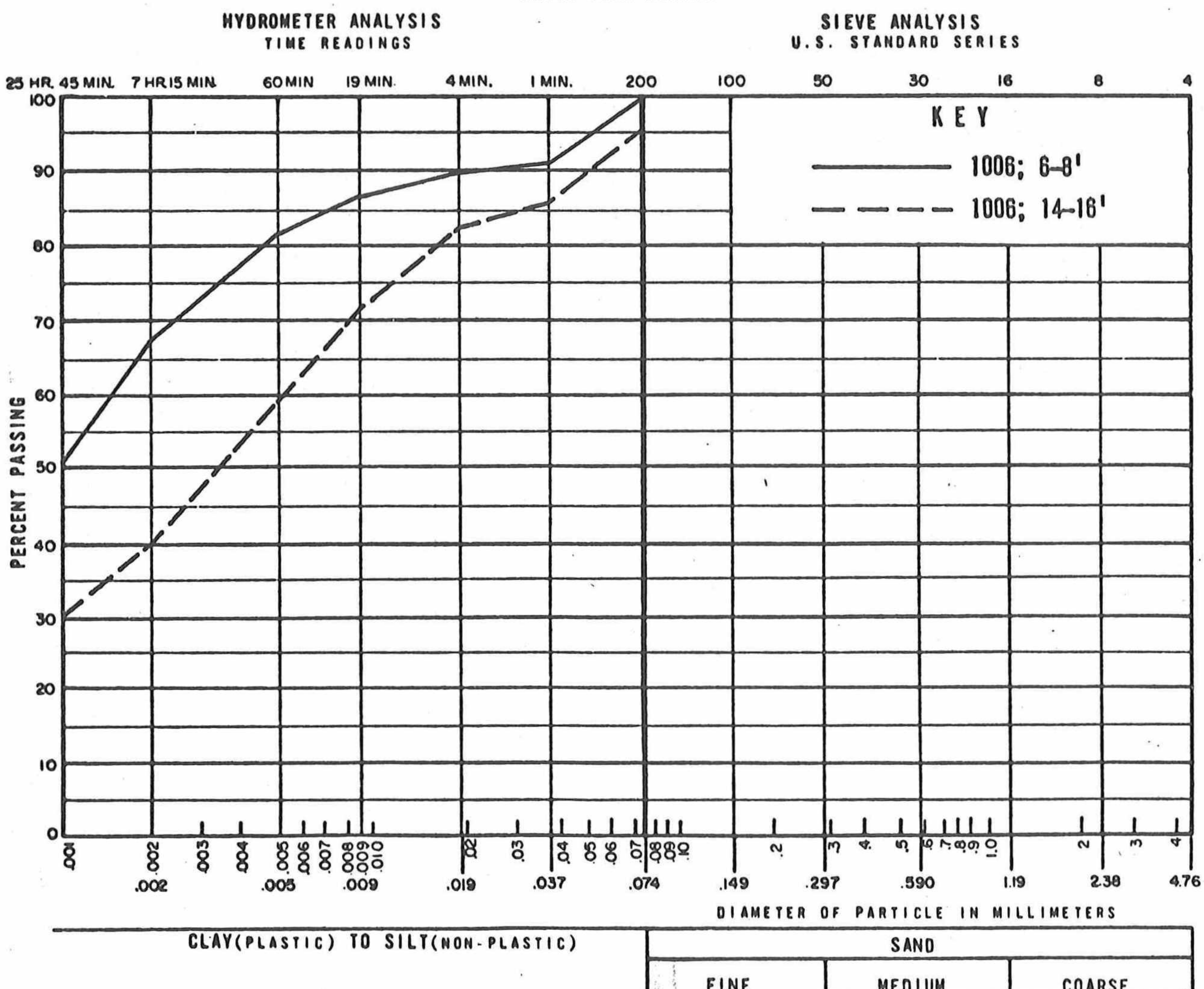
SUMMARY OF PERMEABILITY TEST DATA

SAMPLE NO.	DEPTH (ft)	SOIL* TYPE	AS TESTED			DEGREE OF SATURATION (%)		COEFFICIENT OF PERMEABILITY (cm/sec)
			DRY DENSITY (pcf)	VOID RATIO (%)	WATER CONTENT (%)	INITIAL	DURING TEST	
1006 PS-2	6-8 VERTICAL PERM	CH	83.1	1.065	36.5	94.2	100	1.8×10^{-8}
1006 PS-2	6-8 HORIZ. PERM	CH	85.7	1.002	36.3	99.6	100	1.85×10^{-8}
1006 PS-4	14-16 VERTICAL PERM	CH	73.0	1.351	45.7	93.0	100	1.7×10^{-8}
1006 PS-4	14-16 HORIZ. PERM	CH	85.7	1.002	34.8	95.5	100	5.15×10^{-8}

* Unified Soil Classification Symbol

GRAIN SIZE CURVES



W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	PERMEABILITY-GRAIN SIZE SUMMARY		
		PROJECT NO.	DATE	DRAWING NO.
	PALO ALTO • NEWPORT BEACH • CALIF.	0829	AUGUST 1975	FIG. B-9

Sheet 1 of 4

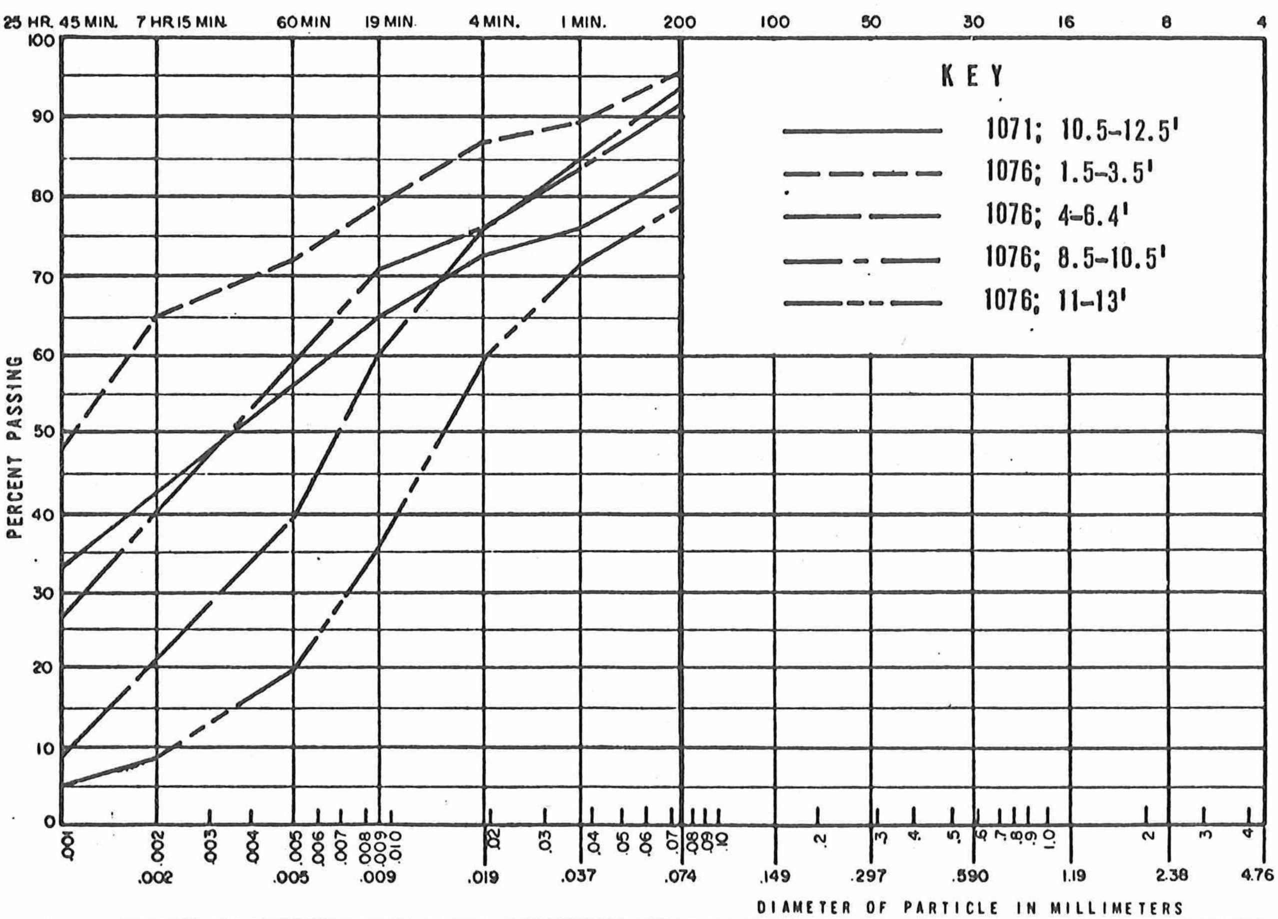
SUMMARY OF PERMEABILITY TEST DATA

SAMPLE NO.	DEPTH (ft)	SOIL TYPE *	AS TESTED: DRY DENSITY (pcf)	AS TESTED: VOID RATIO (%)	AS TESTED: WATER CONTENT (%)	DEGREE OF SATURATION (%): INITIAL	DEGREE OF SATURATION (%): DURING TEST	COEFFICIENT OF PERMEABILITY (cm/sec)
1071	10.5-12.5	CH	94.8	0.810	28.9	95.6	100	6.8 X 10^{-9}
1076	1.5-3.5	CH	84.7	1.026	36.5	95.6	100	4.1 X 10^{-9}
1076	4-6.4	CH	90.1	0.933	32.7	95.1	100	1.7 X 10^{-5}
1076	8.5-10.5	CH	85.4	1.009	37.9	98.7	100	7.4 X 10^{-9}
1076	11-13	ML	113.6	0.533	19.3	93.4	100	6.2 X 10^{-7}

* Unified Soil Classification Symbol

NOTE: SAMPLES BACKPRESSURED TO 100% SATURATION.

GRAIN SIZE CURVES



W. A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	PERMEABILITY-GRAIN SIZE SUMMARY		
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	DRAWING NO. FIG. B-9

Sheet 2 of 4

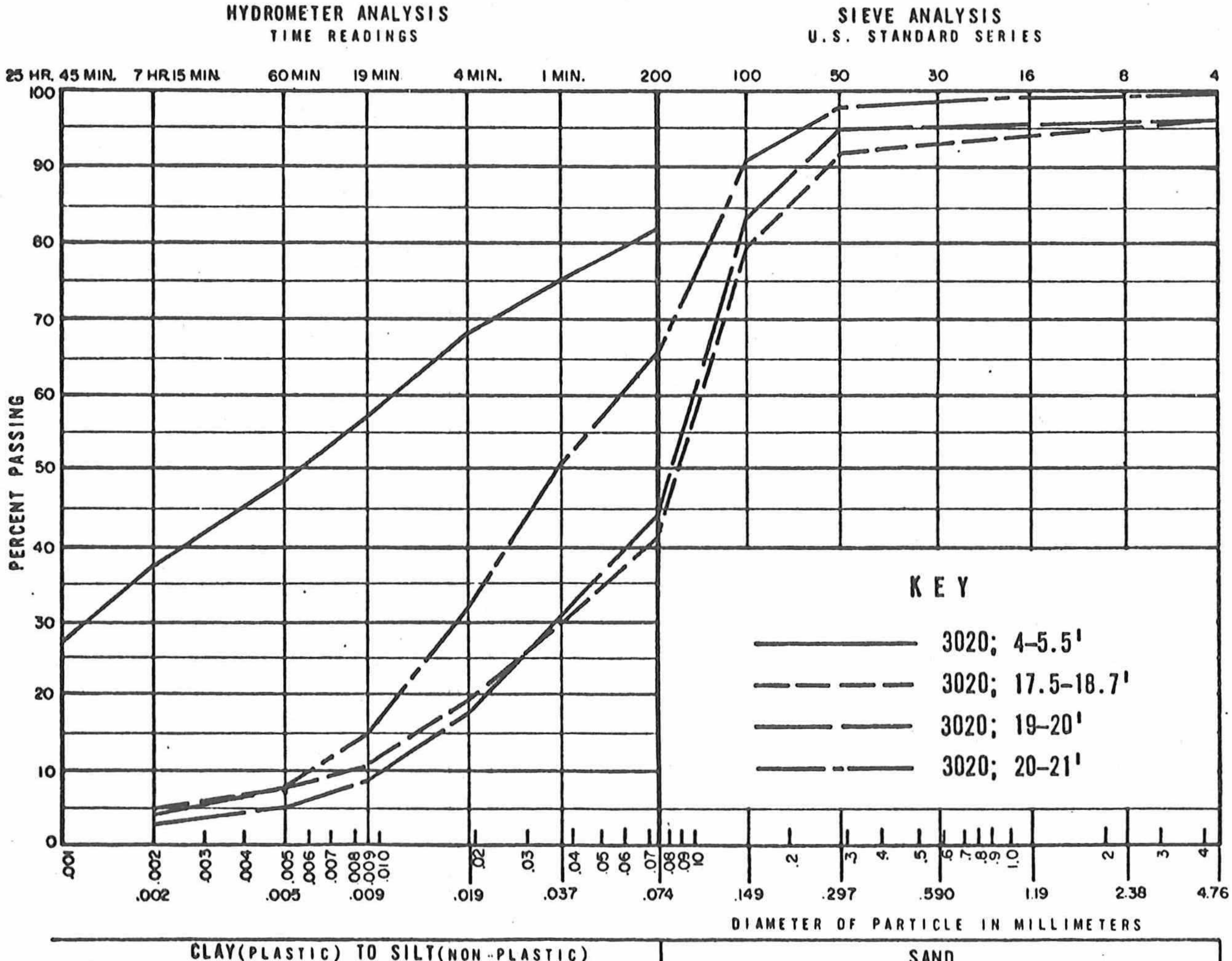
SUMMARY OF PERMEABILITY TEST DATA

SAMPLE NO.	DEPTH (ft)	SOIL TYPE *	AS TESTED DRY DENSITY (pcf)	AS TESTED VOID RATIO (%)	AS TESTED WATER CONTENT (%)	DEGREE OF SATURATION (%) INITIAL	DEGREE OF SATURATION (%) DURING TEST	COEFFICIENT OF PERMEABILITY (cm/sec)
3020	4-5.5	CL	105.8	0.625	21.0	89.3	100	3.4 X 10^{-9}
3020	17.5-18.7	SM	118.2	0.473	16.7	95.5	100	7.4 X 10^{-5}
3020	19-20	SM	114.8	0.520	18.9	89.3	100	3.1 X 10^{-4}
3020	21-22.2	ML	114.8	0.519	18.2	91.4	100	2.0 X 10^{-5}

* Unified Soil Classification Symbol

NOTE: SAMPLES BACKPRESSURED TO 100% SATURATION.

GRAIN SIZE CURVES



W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	PERMEABILITY-GRAIN SIZE SUMMARY		
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE AUGUST 1975	DRAWING NO. FIG. B-9

Sheet 3 of 4

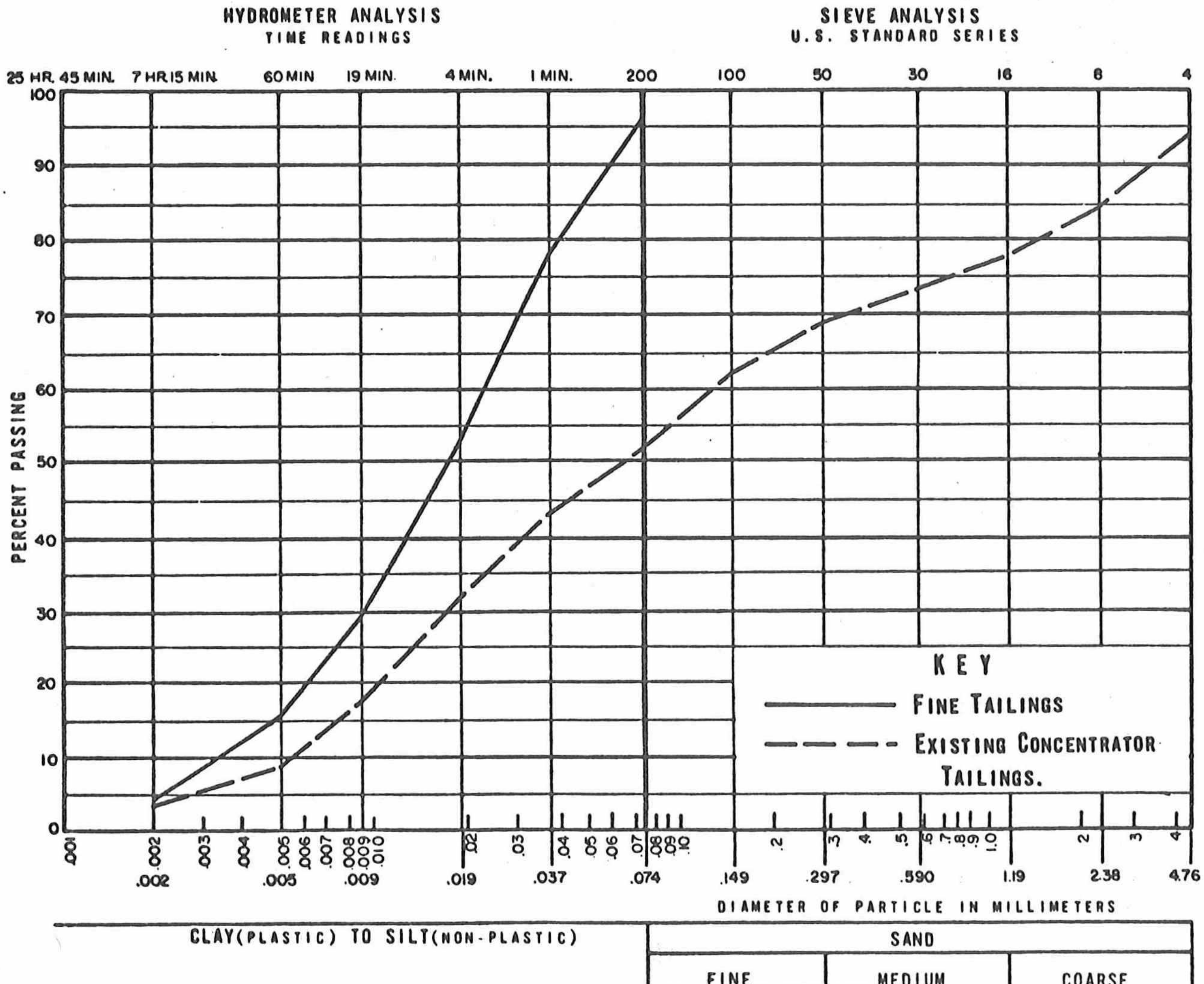
SUMMARY OF PERMEABILITY TEST DATA

SAMPLE NO.	SOIL* TYPE	AS TESTED: DRY DENSITY (pcf)	AS TESTED: VOID RATIO (%)	AS TESTED: WATER CONTENT (%)	DEGREE OF SATURATION (%): INITIAL	DEGREE OF SATURATION (%): DURING TEST	COEFFICIENT OF PERMEABILITY (cm/sec)
FINE TAILINGS	ML	92.2	1.024	29.3	58.5	100	4.5×10^{-5}
FINE TAILINGS	ML	97.5	0.914	28.6	84.9	100	4.2×10^{-5}
FINE TAILINGS	ML	102.7	0.817	28.5	71.3	100	3.2×10^{-5}
EXISTING CONCENTRATOR TAILINGS	ML	102.3	0.812	22.3	56.0	100	1.2×10^{-4}

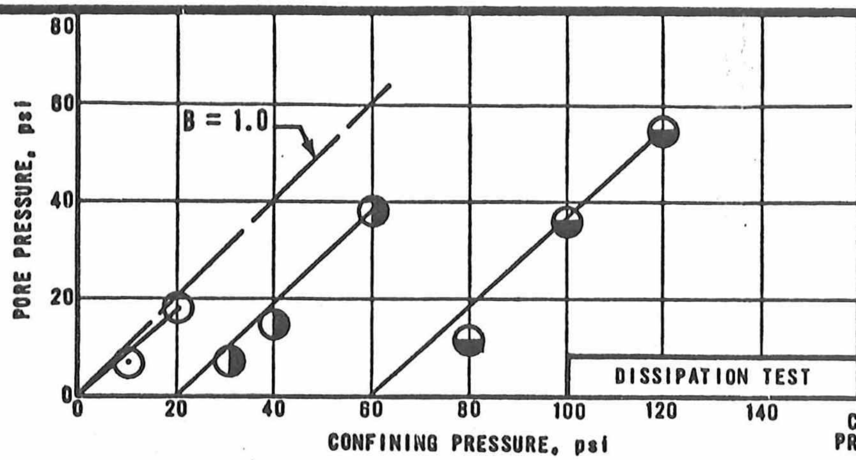
* Unified Soil Classification Symbol

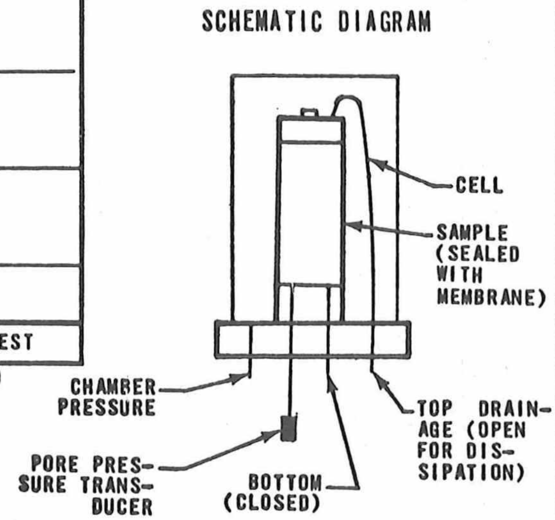
NOTE: SAMPLES BACKPRESSURED TO 100% SATURATION.

GRAIN SIZE CURVES

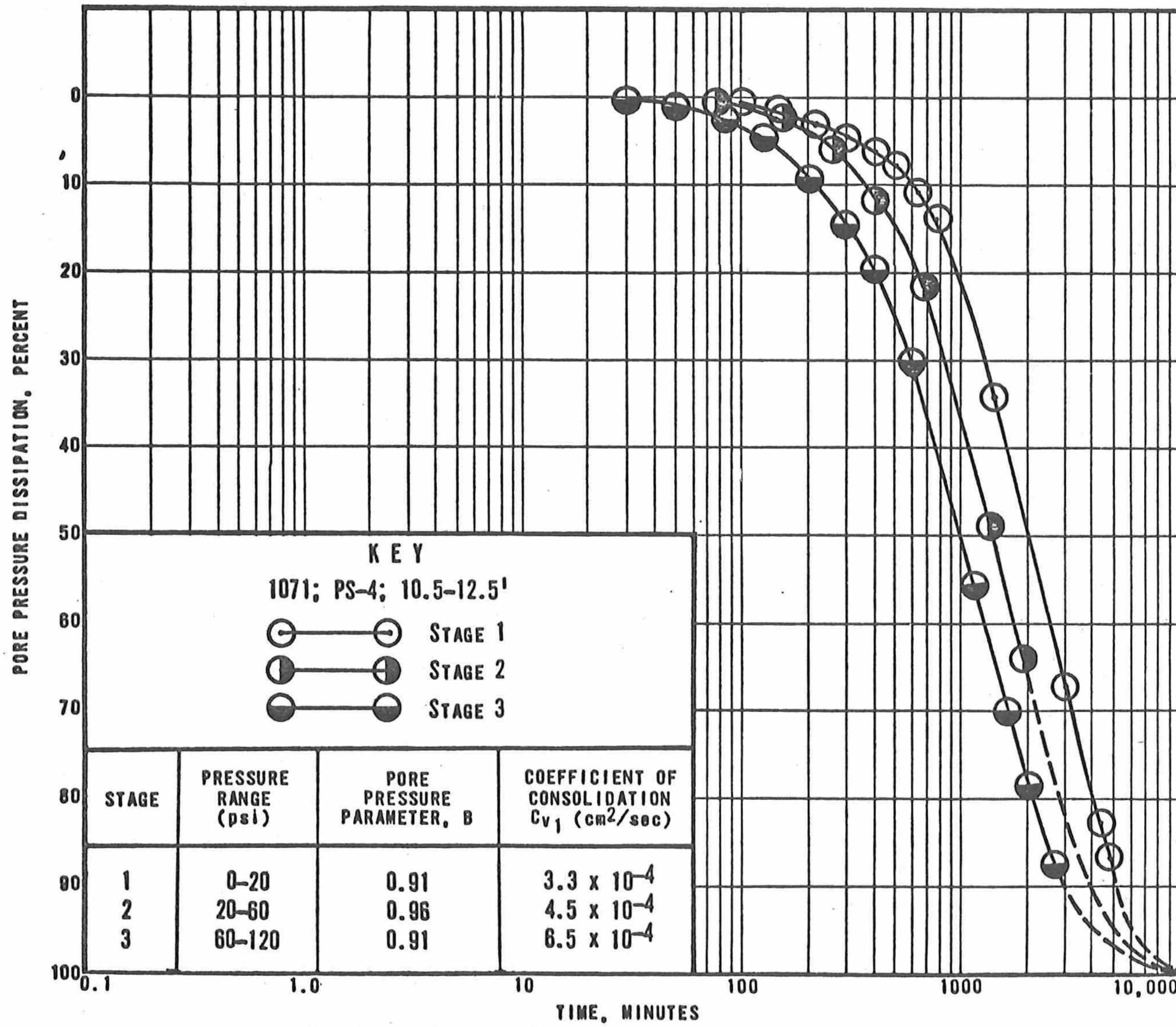


W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	PERMEABILITY-GRAIN SIZE SUMMARY		
		PROJECT NO.	DATE	DRAWING NO.
	PALO ALTO • NEWPORT BEACH • CALIF.	0829	AUGUST 1975	FIG. B-9





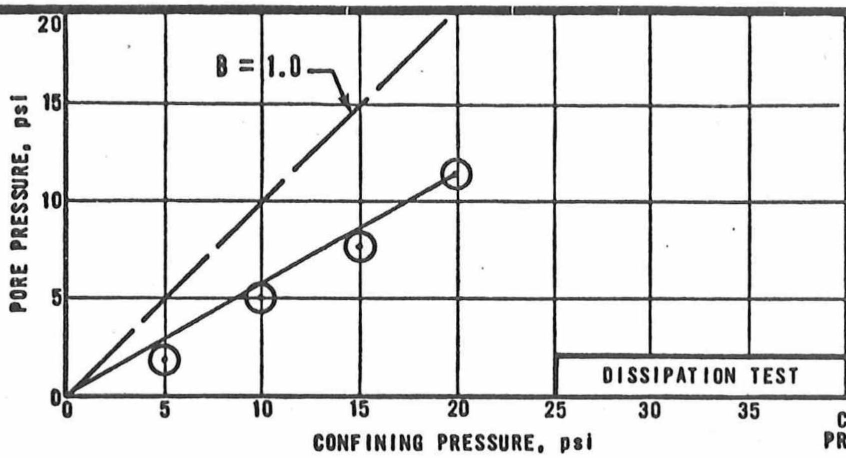
SAMPLE HEIGHT = 4.0"



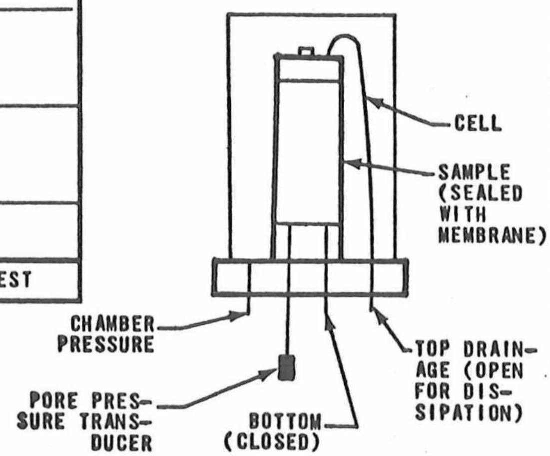
STAGE	PRESSURE RANGE (psi)	PORE PRESSURE PARAMETER, B	COEFFICIENT OF CONSOLIDATION C_{v_1} (cm^2/sec)
1	0–20	0.91	3.3×10^{-4}
2	20–60	0.96	4.5×10^{-4}
3	60–120	0.91	6.5×10^{-4}

SAMPLE INFORMATION: RED BROWN, SLIGHTLY SANDY CLAY
INITIAL WATER CONTENT = 44.9%
INITIAL DRY DENSITY = 74.9 pcf

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	PORE PRESSURE DISSIPATION TEST UNSATURATED SAMPLE		
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE JULY 1975	DRAWING NO. FIG. B-10



SCHEMATIC DIAGRAM

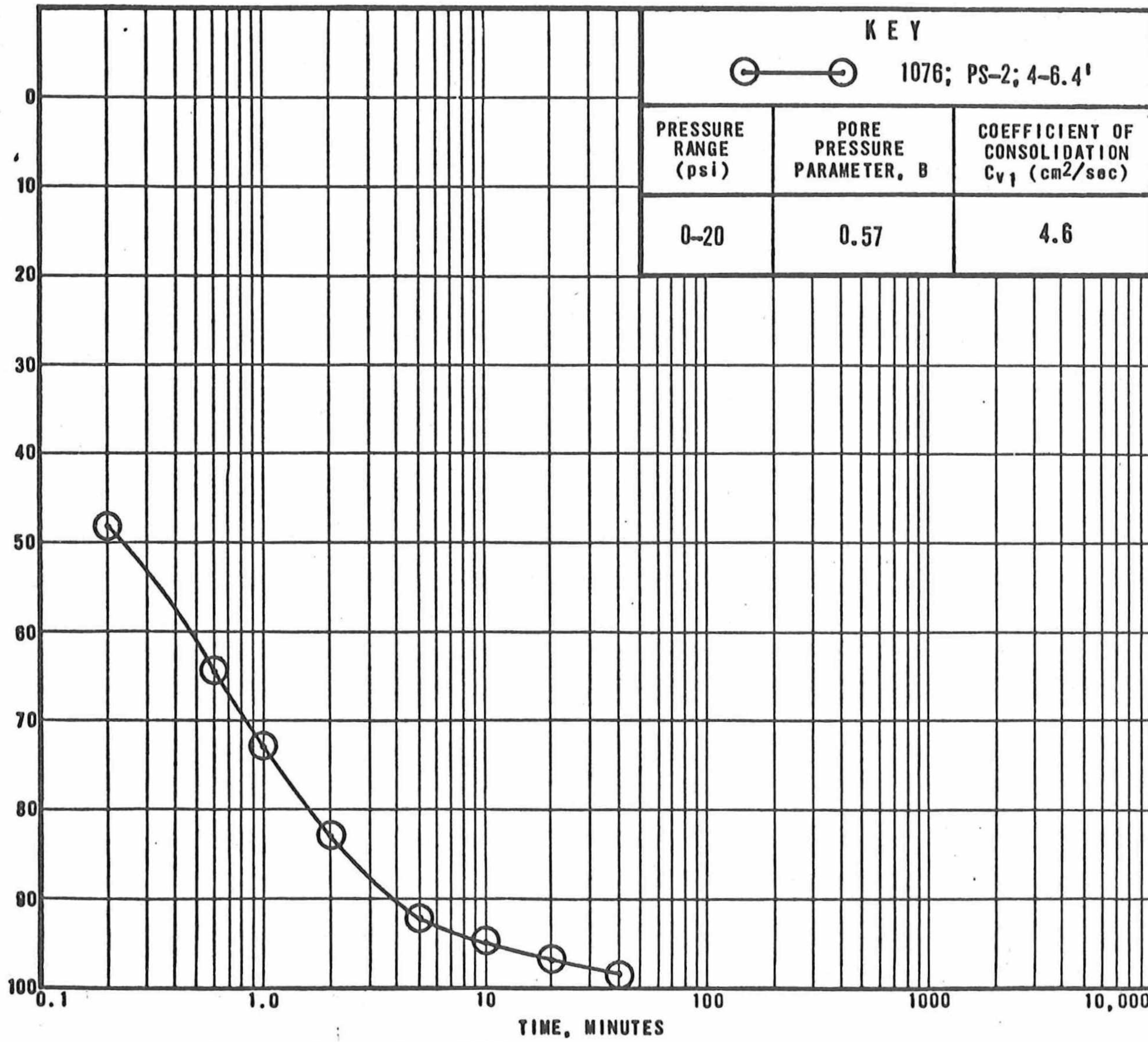


SAMPLE HEIGHT = 5.0"

KEY

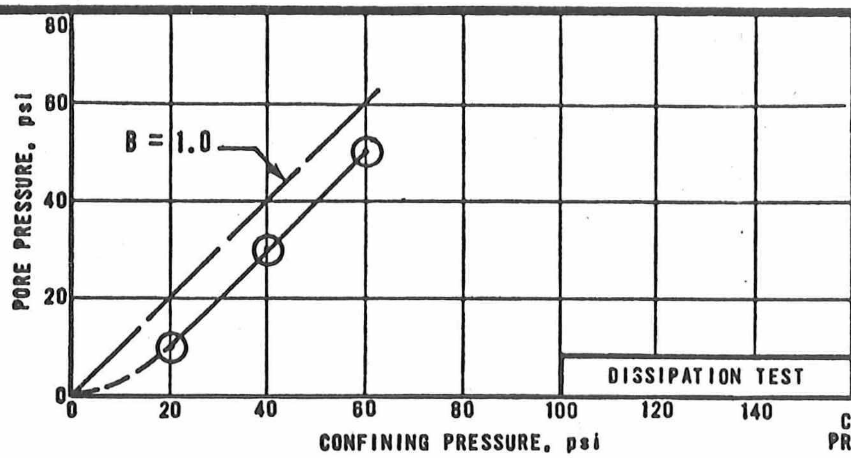
1076; PS-2; 4-6.4'

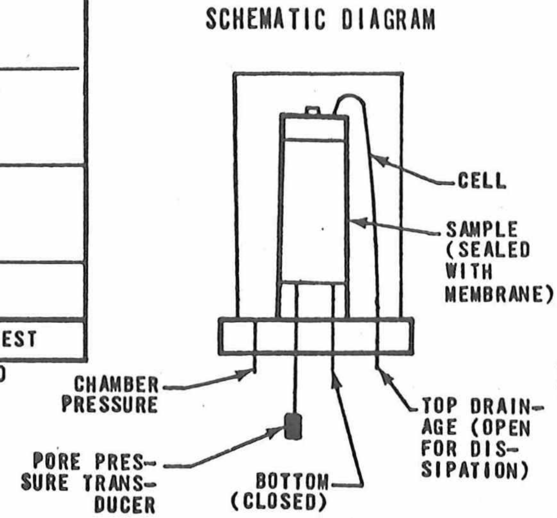
PRESSURE RANGE (psi)	PORE PRESSURE PARAMETER, B	COEFFICIENT OF CONSOLIDATION C_{v1} (cm^2/sec)
0-20	0.57	4.6



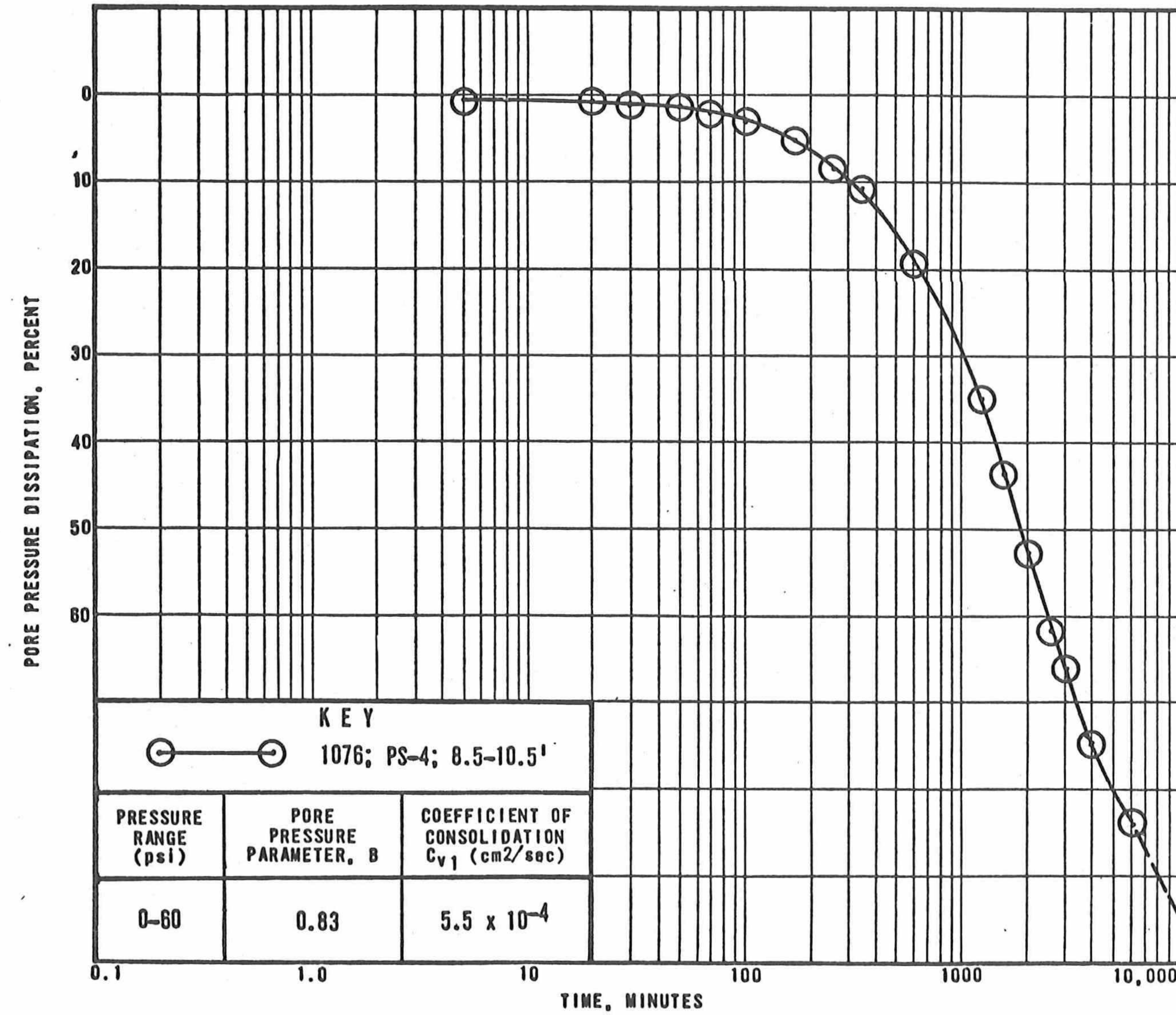
SAMPLE INFORMATION: RED BROWN, SILTY CLAY
INITIAL WATER CONTENT = 41.0%
INITIAL DRY DENSITY = 80.1 pcf

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	PORE PRESSURE DISSIPATION TEST UNSATURATED SAMPLE		
		PROJECT NO.	DATE	DRAWING NO.
	PALO ALTO • NEWPORT BEACH • CALIF.	0829	JULY 1975	FIG. B-10





SAMPLE HEIGHT = 5.0"
B = 0.83



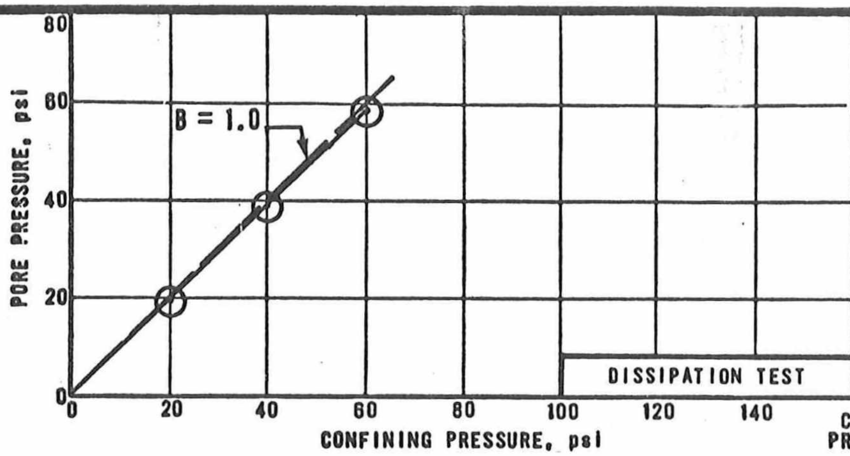
KEY

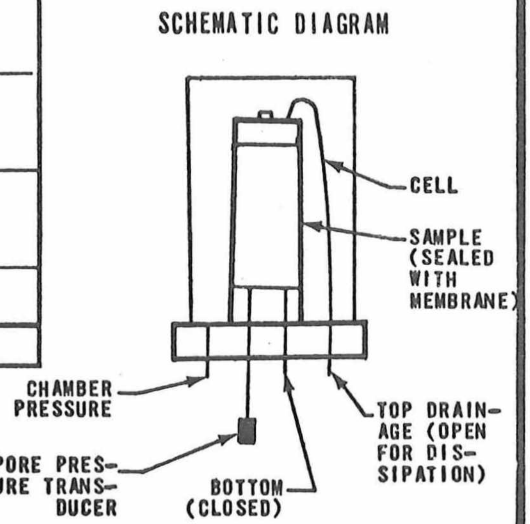
⊙——⊙ 1076; PS-4; 8.5-10.5'

PRESSURE RANGE (psi)	PORE PRESSURE PARAMETER, B	COEFFICIENT OF CONSOLIDATION C_{v1} (cm2/sec)
0-60	0.83	5.5×10^{-4}

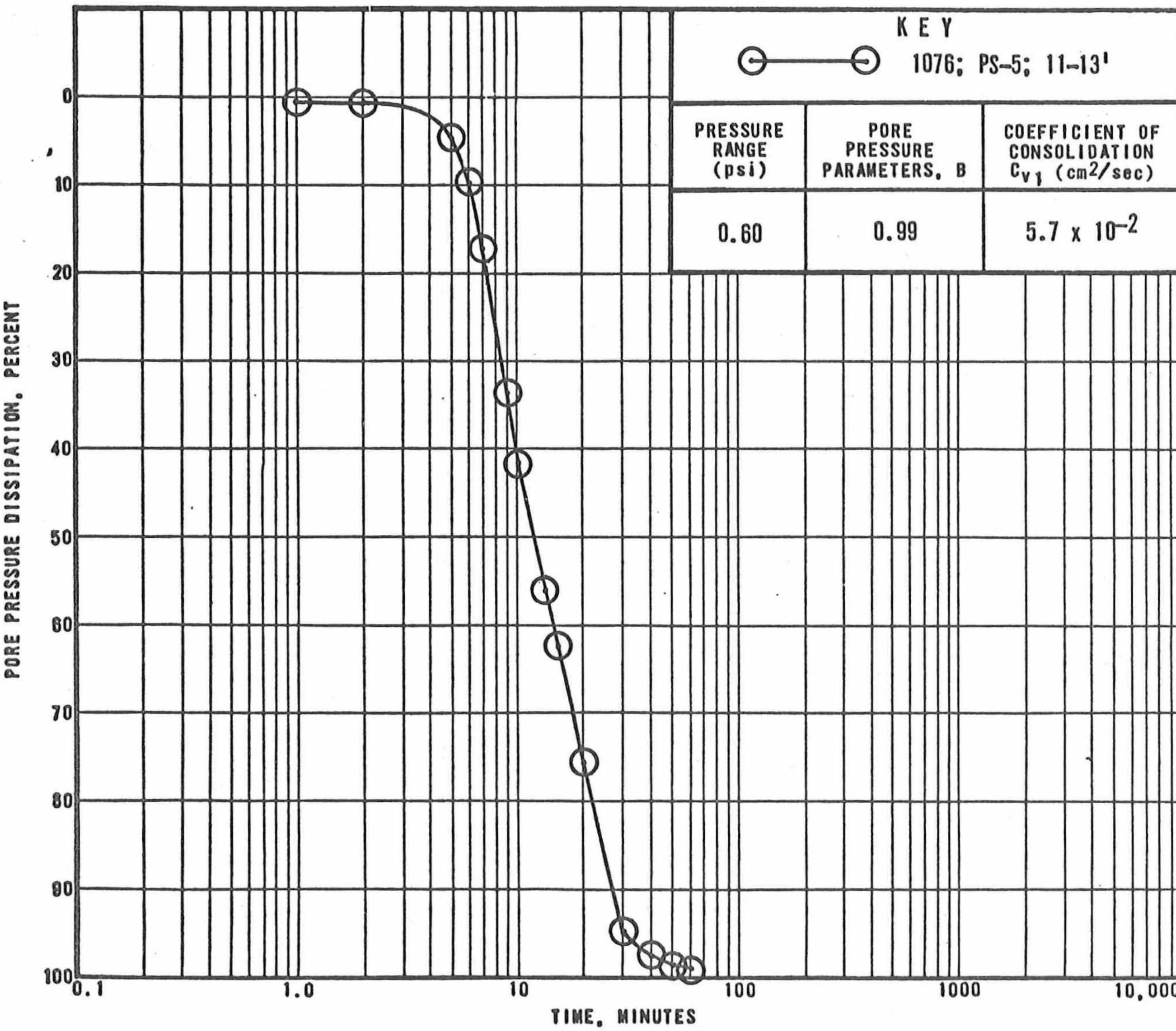
SAMPLE INFORMATION: RED BROWN, SANDY CLAY
INITIAL WATER CONTENT = 41.0%
INITIAL DRY DENSITY = 80.1 pcf

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	PORE PRESSURE DISSIPATION TEST UNSATURATED SAMPLE		
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE JULY 1975	DRAWING NO. FIG. B-10





SAMPLE HEIGHT = 4.0"



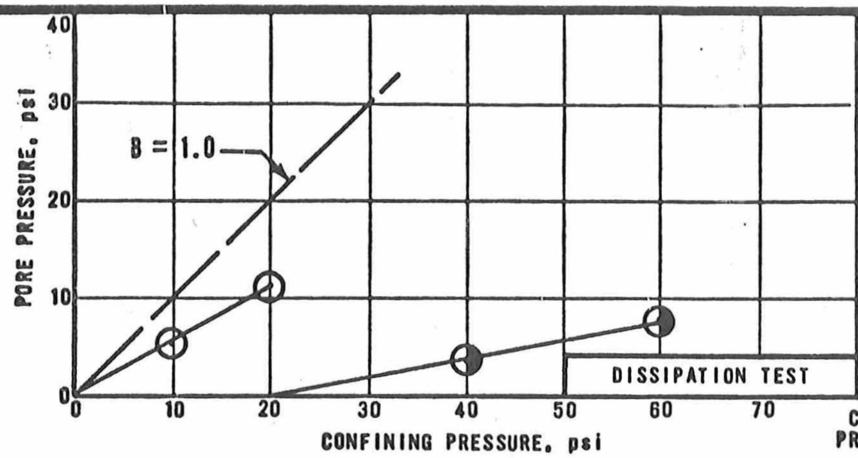
KEY

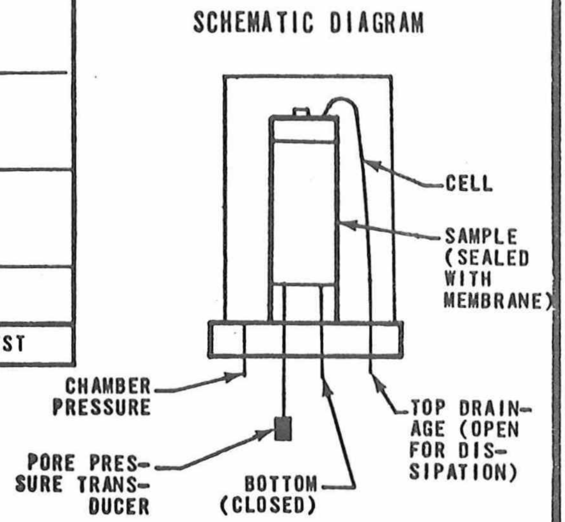
⊖——⊖ 1076; PS-5; 11-13'

PRESSURE RANGE (psi)	PORE PRESSURE PARAMETERS, B	COEFFICIENT OF CONSOLIDATION C_{v1} (cm^2/sec)
0.60	0.99	5.7 x 10^{-2}

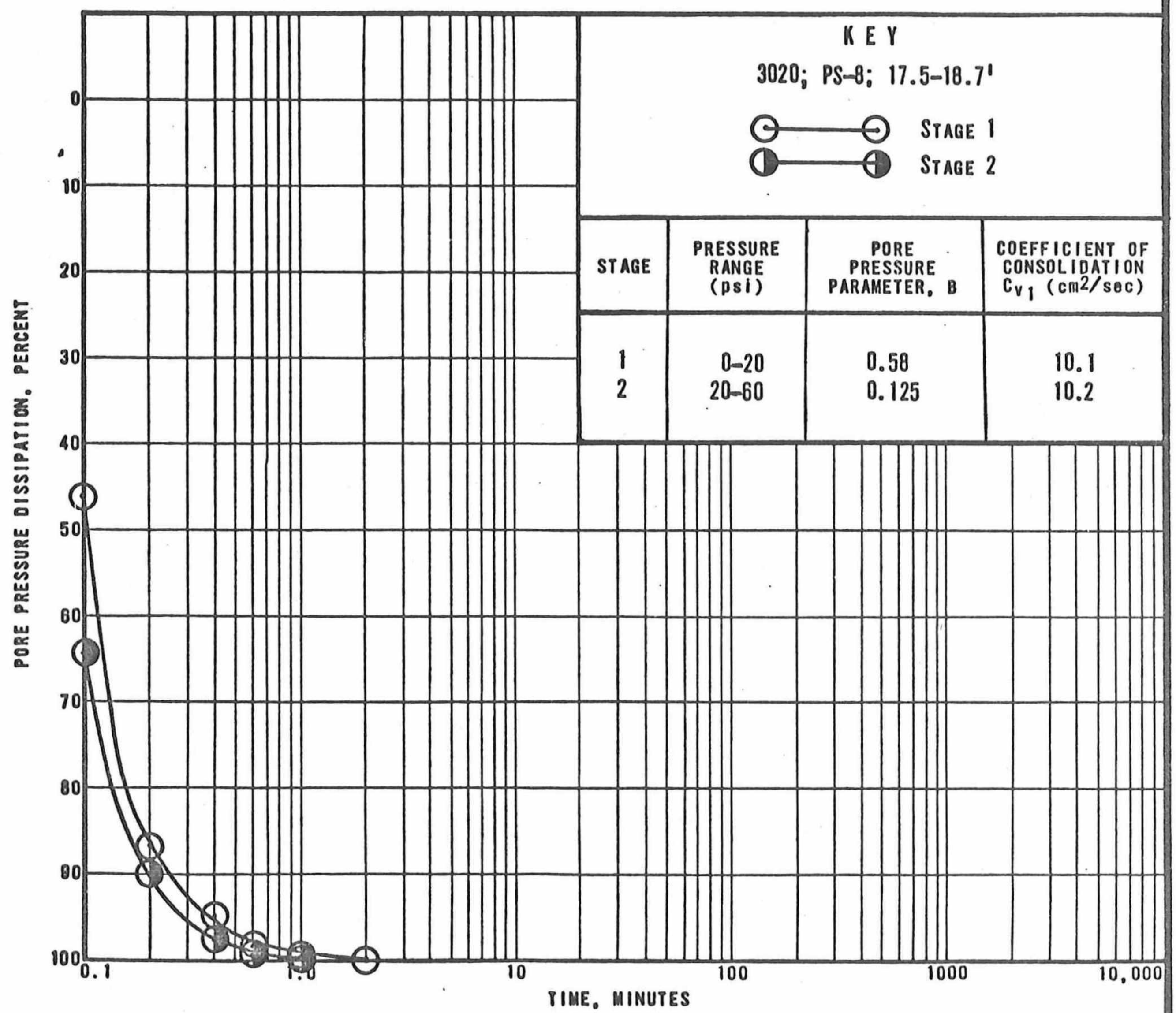
SAMPLE INFORMATION: BROWN, CLAYEY SILT
INITIAL WATER CONTENT = 22.2%
INITIAL DRY DENSITY = 104.7 pcf

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	PORE PRESSURE DISSIPATION TEST UNSATURATED SAMPLE		
		PROJECT NO.	DATE	DRAWING NO.
	PALO ALTO • NEWPORT BEACH • CALIF.	0829	JULY 1975	FIG. B-10





SAMPLE HEIGHT = 5.0"



KEY

3020; PS-8; 17.5-18.7'

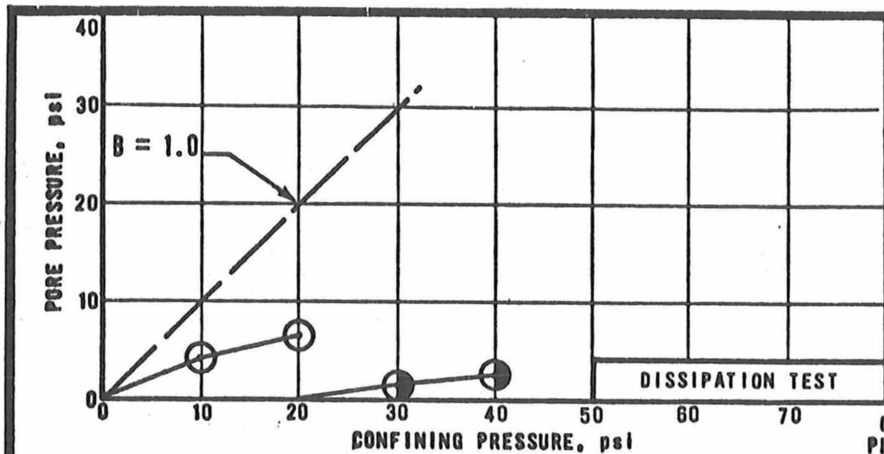
Stage 1

Stage 2

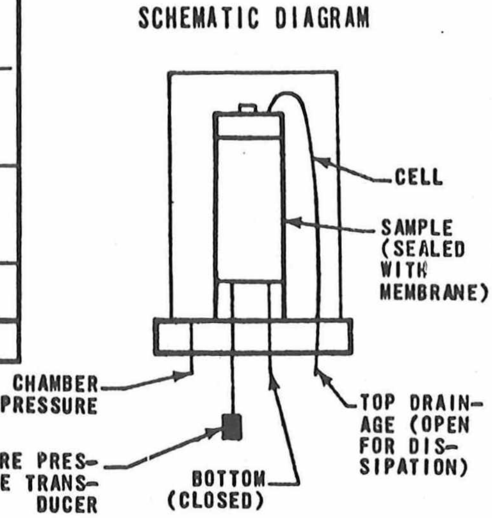
STAGE	PRESSURE RANGE (psi)	PORE PRESSURE PARAMETER, B	COEFFICIENT OF CONSOLIDATION C_{v_1} (cm^2/sec)
1	0-20	0.58	10.1
2	20-60	0.125	10.2

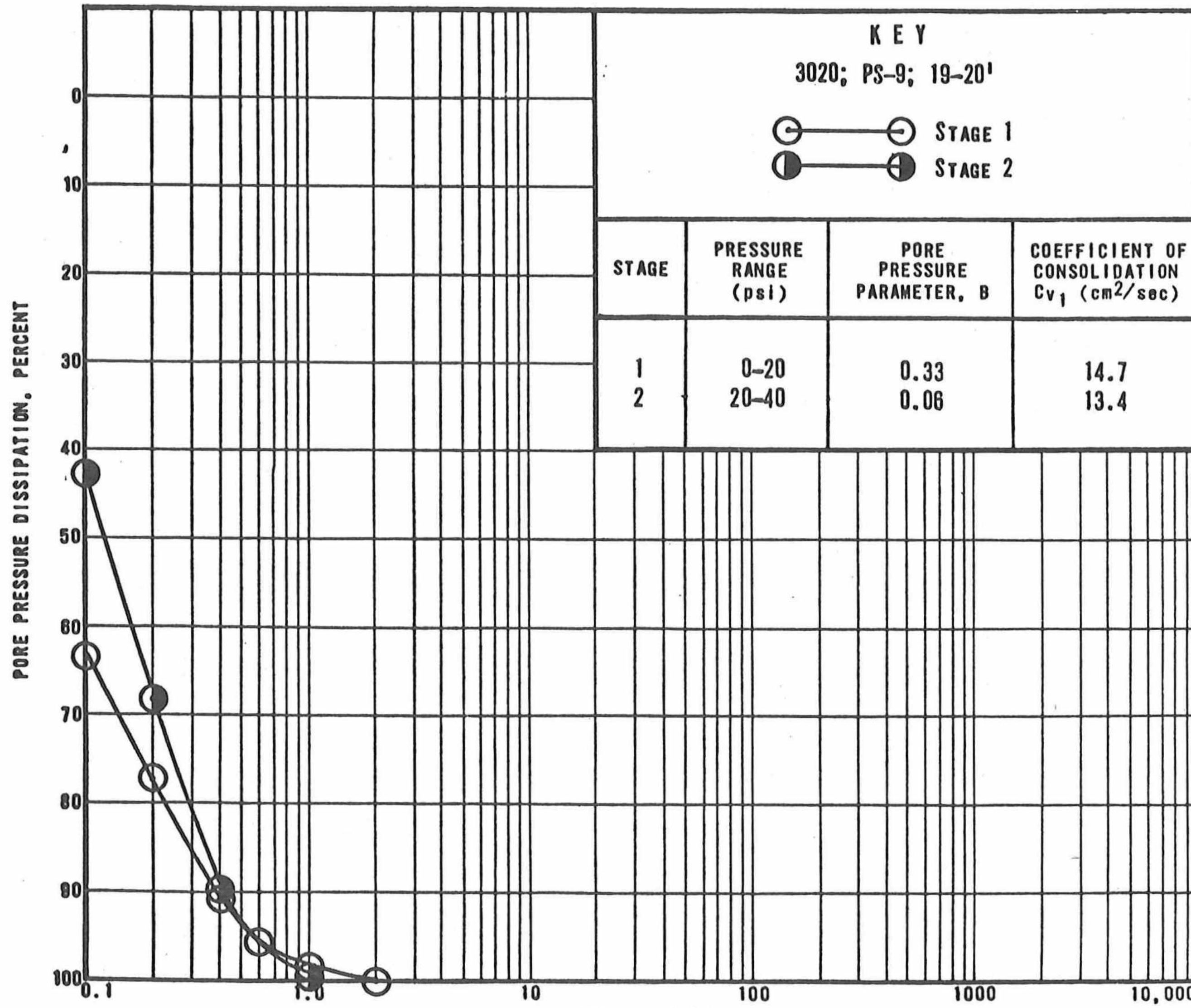
SAMPLE INFORMATION: Brown, Silty SAND
Initial Water Content = 18.5%
Initial Dry Density = 113.0 pcf

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	PORE PRESSURE DISSIPATION TEST UNSATURATED SAMPLE		
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE JULY 1975	DRAWING NO. FIG. B-10



SAMPLE HEIGHT = 6.0"





KEY

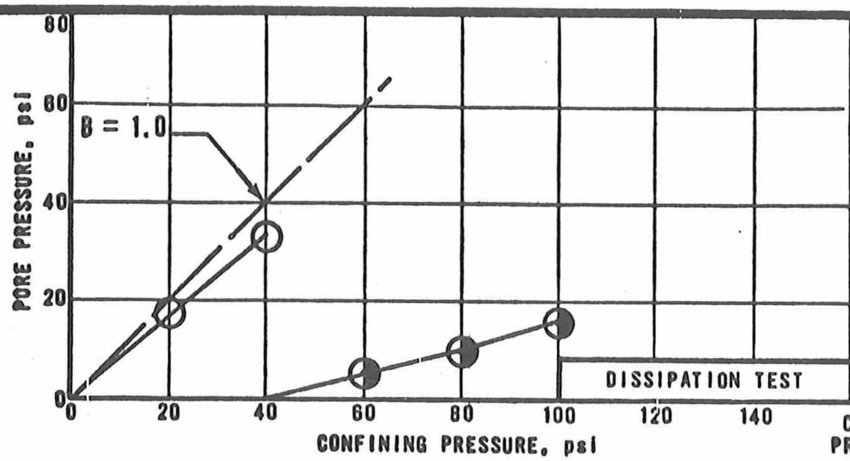
3020; PS-9; 19-20'

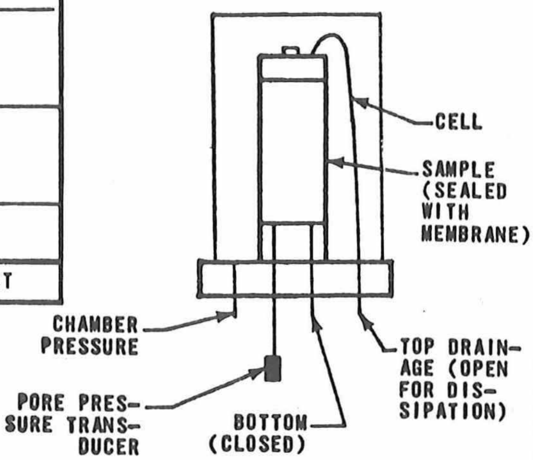
○—○ STAGE 1
◐—◐ STAGE 2

STAGE	PRESSURE RANGE (psi)	PORE PRESSURE PARAMETER, B	COEFFICIENT OF CONSOLIDATION C_{v_1} (cm^2/sec)
1	0-20	0.33	14.7
2	20-40	0.06	13.4

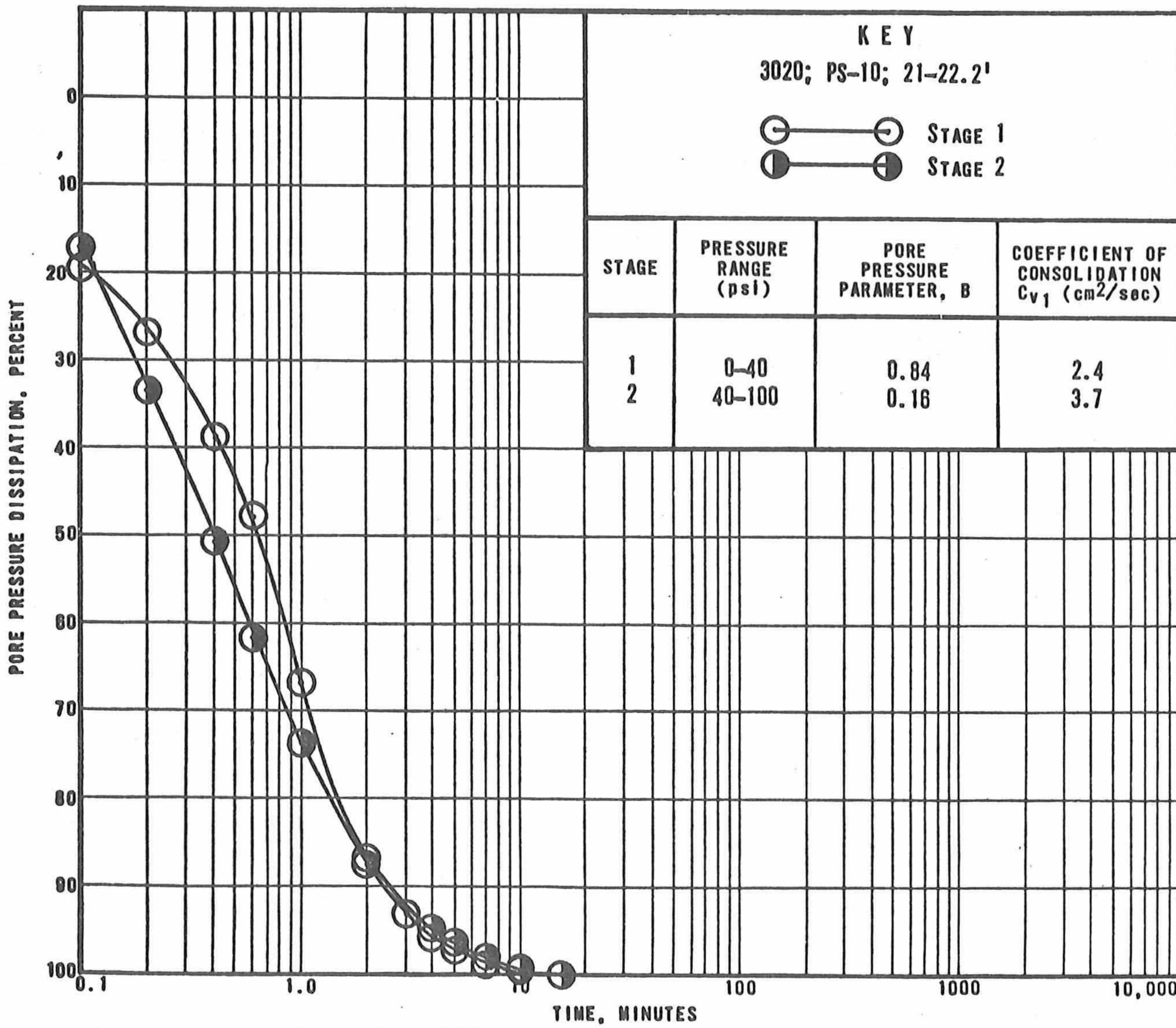
SAMPLE INFORMATION: BROWN, SILTY SAND
INITIAL WATER CONTENT = 18.0%
INITIAL DRY DENSITY = 111.4 pcf

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA	PORE PRESSURE DISSIPATION TEST UNSATURATED SAMPLE		
	PALO ALTO • NEWPORT BEACH • CALIF.	PROJECT NO. 0829	DATE JULY 1975	DRAWING NO. FIG. B-10





SAMPLE HEIGHT = 6.0"



KEY

3020; PS-10; 21-22.2'

Stage 1 (open circles)

Stage 2 (half-filled circles)

STAGE	PRESSURE RANGE (psi)	PORE PRESSURE PARAMETER, B	COEFFICIENT OF CONSOLIDATION C_{v1} (cm^2/sec)
1	0-40	0.84	2.4
2	40-100	0.16	3.7

SAMPLE INFORMATION: BROWN, SILTY SAND
INITIAL WATER CONTENT = 19.5%
INITIAL DRY DENSITY = 109.1 pcf

W.A. WAHLER & ASSOCIATES	REVIEW OF MILE POST 7 PLAN FOR STATE OF MINNESOTA PALO ALTO • NEWPORT BEACH • CALIF.	PORE PRESSURE DISSIPATION TEST UNSATURATED SAMPLE		
		PROJECT NO.	DATE	DRAWING NO.
		0829	JULY 1975	FIG. B-10

Sheet 7 of 7

APPENDIX C

MODIFIED MERCALLI INTENSITY SCALE

APPENDIX C

MODIFIED MERCALLI INTENSITY SCALE
1956 Version

INTENSITY	EFFECTS
I	Not felt. Marginal and long-period effects of large earthquakes.
II	Felt by persons at rest, on upper floors, or favorably placed.
III	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV	Hanging objects swing. Vibration like passing of heavy trucks, or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV, wooden walls and frame creak.
V	Felt outdoors; direction estimated. Sleepers awakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
VI	Felt by all. Many frightened and run outdoors. People walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and Masonry D cracked. Small bells ring (church, school). Trees, bushes shaken visibly, or heard to rustle.
VII	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to Masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices, unbraced parapets and architectural ornaments. Some cracks in Masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
VIII	Steering of motor cars affected. Damage to Masonry C; partial collapse. Some damage to Masonry B, none to Masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

INTENSITY	EFFECTS
IX	General panic. Masonry D destroyed; Masonry C heavily damaged, sometimes with complete collapse; Masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frame cracked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluvial areas, sand and mud ejected, earthquake fountains, sand craters.
X	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI	Rails bent greatly. Underground pipelines completely out of service.
XII	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

DEFINITIONS

Masonry A, B, C, D--To avoid ambiguity of language, the quality of masonry, brick or otherwise, is specified by the following lettering (which has no connection with the conventional Class A, B, C construction).

Masonry A--Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B--Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C--Ordinary workmanship and mortar; no extreme weakness like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.

Masonry D--Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

APPENDIX D

LISTING OF REPORTS AND MISCELLANEOUS PAPERS RECEIVED FROM STATE OF MINNESOTA

APPENDIX D

LISTING OF REPORTS AND MISCELLANEOUS PAPERS RECEIVED FROM STATE OF MINNESOTA

1. Appendix A, Volume 1 to Feasibility Report On-Land Tailings Disposal Study Mile Post No. 7 Site, by Earle Klohn, Klohn Leonoff Consultants, Ltd.

2. Appendix A, Volume 2 to Feasibility Report On-Land Tailings Disposal Study Mile Post No. 7 Site, by Earle Klohn, Klohn Leonoff Consultants, Ltd.

3. Appendix 3, Consultants Report on Mile Post 7 Site.

4. Reserve Mining Company Mile Post 7 On-Land Tailings Disposal and Air Quality Plan.

5. Feasibility Report - On-Land Tailings Disposal Study - Mile Post No. 7 Site, by Earle Klohn, Klohn Leonoff Consultants, Ltd.

6. Design Report - On-Land Tailings Disposal Study - Mile Post No. 7 Site, by Klohn Leonoff Consultants, Ltd.

7. General Geology, Mile Post 7 Site for the Reserve Mining Company, E. A. Hickok and Associates.

8. Hydrological Analysis, Beaver River Watershed for the Reserve Mining Company, E. A. Hickok and Associates.

9. Progress Report, Reserve Mining Company, Silver Bay, Minnesota, Period Ending March 21, 1975, Klohn Leonoff Consultants, Ltd.

10. Assortment of Principal Documents Contained Within One Binding. From: Reserve Mining Company. To: State of Minnesota. . . 1) Department of Natural Resources, 2) Pollution Control Agency, and 3) Environmental Quality Council, Transmitted February 1, 1975.

11. Additional Technical Information transmitted by: Reserve Mining Co. to State of Minnesota. . . 1) Department of Natural Resources, 2) Pollution Control Agency, 3) Environmental Quality Council. Date of Transmittal, March 7, 1975.

12. Tailings Disposal and Reserve Mining (History, Court Decisions of New Site Alternatives) prepared by State of Minnesota.

13. Environmental Report Concerning On-Land Tailings Disposal and Air Quality Plan for the E. W. Davis Works, Reserve Mining Company, Silver Bay, Minnesota, Volumes I, II, III, and Appendix, dated April 30, 1975, by Arthur D. Little, Inc.

14. Particle Size Analysis and Relative Density Tests on Taconite Tailings From Silver Bay, Minnesota, by Professor Donald H. Gray, dated May 9, 1973.

15. Transcripts of Proceedings, Court Hearings of the State of Minnesota Vs. Reserve Mining Company, Silver Bay, Minnesota, June 1975.

MISCELLANEOUS PAPERS

1. Clarification of Concepts of Mile Post 42 Estimate As Discussed With State of Minnesota, January 2, 1975.

2. Reclamation of Tailings Basin, January 21, 1975.

3. Letters dated January 17 and January 20, 1975, to Reserve Mining Company. Subjects: 1) Infiltration Tests Mile Post 7; and 2) Seepage Estimates Mile Post 7.

4. Letter dated January 21, 1975, to Reserve Mining Co., from Erie Mining Co., concerning monthly tailings composites for 1967 - Tyler Screen Analysis.

5. X-Ray Diffraction Analyses of Soil Core Samples from Reserve Mining Co., Mile Post 7 Proposed Dam Sites.

6. Final Deposition of Tailings in the Mile Post 7 Tailings Basin for Reserve Mining Co., Silver Bay, Minnesota.

7. Progress Report on Laboratory Tests - Mile Post #7 Site - Dam Site #1, VA 1965, PO#RF 75-32424 - Sec. #20869, dated November 12, 1974.

8. Transmittal Letter to Mr. M. Sherman from Reserve Mining Company dated May 21, 1975, Regarding the Delta Exploration and Testing Results. Enclosures Included Drill Logs, Gradation Sheets and Other Miscellaneous Test Data.

9. Note on Reserve Delta and Tailings Composition by Dr. James R. Kramer, dated July 17, 1975.

DRAWINGS

(Reserve Mining Company):

Drawing No.	Title
292-0003	Mile Post No. 7 Site Tailings Disposal Area: General Plan.
292-0016	Mile Post No. 7 Site Access Roads
292-0022	Mile Post No. 7 Site Tailing Disposal Area: Damsite No. 1 Test Hole Location Plan

Drawing No.	Title
292-0023	Mile Post No. 7 Site Tailing Disposal Area: Damsite No. 2-3 Test Hole Location Plan
292-0030	Mile Post No. 7 Site Tailing Disposal Area: Summary of Test Data
292-0035	Mile Post No. 7 Site Tailing Disposal Area: Damsite No. 1 Subsoil Profile, Section A-A
292-0036	Mile Post No. 7 Site Tailing Disposal Area: Damsite No. 1 Subsoil Profile, Section B-B, C-C, D-D
292-0037	Mile Post No. 7 Site Tailing Disposal Area: Damsite No. 2-3 Subsoil Profile, Section A-A, B-B
292-0038	Mile Post No. 7 Site Tailing Disposal Area: Damsite No. 2-3 Subsoil Profile, Section C-C
292-0039	Mile Post No. 7 Site Tailing Disposal Area: Borrow Pits, Locations and Estimated Volumes
292-0041	Mile Post No. 7 Site Tailing Disposal Area: Damsite No. 1 - General Arrangement
292-0042	Mile Post No. 7 Site Tailing Disposal Area: Damsite No. 1 - Starter Dam
292-0044	Mile Post No. 7 Site Tailing Disposal Area: Starter Dam - Damsite No. 1, Sand Drain Details
292-0048	Mile Post No. 7 Site Tailing Disposal Area: Typical Seepage Recovery Pump Station
292-0050	Mile Post No. 7 Site Tailing Disposal Area: Damsite No. 2-3, General Arrangement
292-0060	Mile Post No. 7 Site Tailing Disposal Area: Damsite No. 4 - General Arrangement
292-0070	Mile Post No. 7 Site Tailing Disposal Area: Damsite No. 5 - General Arrangement
292-0081	Mile Post No. 7 Site Tailing Disposal Area: Diversion Structure No. 1
292-0083	Mile Post No. 7 Site Tailing Disposal Area: Diversion Structure No. 2
292-0090	Mile Post No. 7 Site Tailing Disposal Area: Tailing Storage, Fine and Coarse Tailings

Drawing No.	Title
292-0092	Mile Post No. 7 Site Tailing Disposal Area: Tailing Storage, Detail East Side
294-0005	Mile Post No. 7 Delta Stabilization: Section For Model Studies
A-118	Lake Contours Delta Area
WA-73	Silver Bay Area Bathymetry
(no number)	Composite Drawing - Profile-Lake Bottom & Tailings Fill Area Sept. 5, 6, and 18, 1956
294-0001	Delta Stabilization: Test Hole No's. Location & Elevations
(no number)	Sheet 27 - Topographic Map of Existing Delta
22-0010-1	Delta Area Launder System, General Arrangement
292-0003	Map of Preliminary Geologic Reconnaissance, prepared by Michael Baker, Jr., Inc., and W. A. Wahler & Associates, dated June 1975, with use of Reserve Mining Company drawing.

(U.S. Army Corps of Engineers)

File No.	Title
DUL.D. 754 D/S	Soundings North Shore, Lake Superior, Vicinity of Beaver Bay, Minnesota

APPENDIX E

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