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Annual Technical Report No. 1

INTERRELATIONSHIP OF IN SITU ROCK PROPERTIES, EXCAVATION METHOD, AND MUCK CHARACTERISTICS

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
ARPA Order 1579, Amendment 2
Program Code No. 1F10

Report Period
January 12, 1971 - January 11, 1972

HOLMES & NARVER, INC.

A Resources Sciences Company

Advanced Technology / Engineered Construction / Management Services

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By

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FOREWORD

This report presents the technical findings and accomplishments of research into the interrelationship of in-situ rock properties and the characteristics of muck produced by various excavation methods. The period covered is from January 12, 1971 through January 11, 1972.

TABLE OF CONTENTS

INTRODUCTION AND SUMMARY

Sections

TABLE OF CONTENTS (Cont)

LIST OF ILLUSTRATIONS

INTRODUCTION AND SUMMARY

PURPOSE

The purpose of the program is to develop a method for predicting the materials handling properties of muck from the engineering properties of rock, and a means of selecting the most suitable transportation equipment for muck produced by various excavation systems, through the concept of Muck Designation Numbers (MDN's).

CONCLUSIONS

Program activities have been confined to data collection, processing, development of tentative MDN's, and preliminary correlation with rock properties and muck handling systems. Although final conclusions cannot be stated, it is apparent that the size distribution of the sampled muck from high strength rocks differs distinctly from that of muck from most of the low strength rocks. Exceptions may be associated with the excavation method and/or the rock structure. Refinement of MDN's and detailed correlation analysis is within the scope of the 1972 program.

REFERENCE TO DETAILS

Details of the topics summarized below are arranged under the same headings in the report.

SUMMARY

1. Technical Problems

The importance of increasing the speed of underground excavation while decreasing the cost is emphasized by recent surveys which indicate that a great volume of this work will be required in the near future. Considerable research has been conducted to determine relationships between rock properties and rock drillability, excavation, and support requirements. However, data concerning the characteristics of muck produced by various excavation methods in various rocks are not available for general use in selection or design of muck transport systems. Correlations have not been established between muck characteristics, the properties of the in-situ rock and the components of rapid excavation systems. In the absence of these data, an adequate basis does not exist for optimum selection from the transportation systems in current use, or for development of the high speed systems required in the future.

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13. ABSTRACT Reports results of research to correlate the properties of in-situ rocks with materials handling properties of muck from excavation. Goals are to develop methods for predicting muck properties from rock properties and for selection of transport equipment through the Muck Designation Number concept. Muck sample, rock, and operating data collection, testing methods, data processing, development of MDN's, and equipment selection are described.

Results include sample and data collection from fifteen sites, sample testing by commercial testing laboratories and the PMSRC, and development of raw data-printouts, narrative-graphic summaries, tentative MDN's and transport equipment summaries. Samples are classified by operating method, rock strength, and lithology. Program phasing precludes detailed data analysis and final conclusions at the present stage. Curves showing muck size distribution vary distinctly with operating methods, rock type, and rock strength.

DOD implications include more rational transport equipment selection and design, with resultant speed and cost benefits. Recommended additional research includes Hardness, Abrasiveness, stress-strain testing, sampling operations and formations not previously available, and resampling to improve the confidence level of the data.

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Materials Handling in Tunnels						
Muck Transportation						

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2. General Methodology

The r search plan is to collect muck samples, lithologic and operating data, and rock specimens where necessary, from operating tunnels; determine muck characteristics and rock properties by physical testing; correlate and analyze rock and muck properties, and quantify relationships through Muck Designation Numbers (MDN's); and to correlate rock and muck characteristics, MDN's, and the components of rapid excavation systems with muck transport system capabilities.

Lithologic data consists of descriptions of rocks, their classifications by probable origin and subsequent alteration, and Rock Quality Designations (RQD's) which indicate the frequency of discontinuities. Operating data includes descriptions of the equipment and methods used in the total excavation system. Rock test data includes unconfined uniaxial compressive strength, dry unit weight, and hardness where available. Commercial muck test data includes size distribution and shape, moisture content, and dry loose unit weight.

3. Technical Results

3.1 Site Selection

A list of current and scheduled tunnels was compiled to assure that program objectives could be met. Sites for data and sample collection were selected with emphasis on mechanical operations in hard rock. Some soft rock and conventional tunnels were included as examples of unusual advance rates and systems. The current list is enclosed as Appendix A.

3.2 Sample and Data Collection

Operating data and thirty four muck samples were collected from fifteen sites. Resampling was done at four sites to confirm the reliability of initial results. All other samples reflect differing lithologies, operating methods, or equipment.

Rock specimens for engineering property tests were collected from twenty formations at twelve sites.

Shield operations in two formations, conventional tunneling in eleven formations, tunnel boring machine (TBM) operations in fifteen formations, and raise boring machine (RBM) vertical reaming in two formations were sampled during the year.

Rock types sampled include four classified as very High Strength, ten as High Strength, ten in the Medium - Medium to High range, three Low, and six Very Low Strength. A basis for these classifications follows in the body of the report.

3.3 Physical Testing

Test procedures were reviewed in detail. Standard tests, approved by the American Society for Testing and Materials, were selected for use by commercial laboratories to insure consistency of results.

Contracts to perform muck tests were negotiated with thirteen commercial laboratories. Samples were delivered for testing and shipment of fractions to the U. S. Bureau of Mines, Pittsburgh Mining and Safety Research Center (PMSRC), for additional tests. At the end of the contract year, muck tests by commercial laboratories had been reported on thirty three sets of samples, and on twenty three sets by the PMSRC.

Contracts to perform rock tests were negotiated with five commercial laboratories. Nineteen sets of specimens were delivered for testing, of which two were destroyed in preparation, and the remainder were tested and reported.

Other tests reviewed and recommended for inclusion in the second year of the program will provide data on Schmidt hardness, abrasiveness, and stress-strain relationships.

3.4 Data Processing

A format was developed for printout of lithologic, muck, and rock test data; test results have been stored on punch cards, and printouts of these data are included as Appendix B. A form was developed for narrative and graphic presentation of lithologic, operating, rock and muck test data. These "System Data Sheets" are included as Appendix C.

Summaries of rock and muck properties which affect materials handling, and of muck handling system parameters were prepared as guidelines in the development of correlation analysis programs.

3.5 Development of MDN's

The size distribution curves from initial sampling varied distinctly, generally as had been expected, and development of an algorithm to correlate MDN's, in-situ rock properties, and excavation methods was initiated.

Continued sampling produced some curves which fit well with the initial curves, and others which suggested establishing additional categories. Curves of similar form were plotted together, and preliminary MDN's were assigned. The resulting composite curves are shown as Figures 1 through 8.

MDN assignments are tentative, and will undoubtedly be changed to reflect solutions in problem areas, which may involve use of raw data derivatives, additional rock property data, varying the predictor equation, or separate MDN series for special types of boring machines.

3.6 Transport System Selection

A listing of equipment capabilities, system constraints, and MDN applications was prepared for the unitized and semi-continuous systems in common use. The listing also is tentative, and will be refined and quantified in the 1972 program.

4. DoD Implications

The data accumulated under the program are non-existant elsewhere in rapid excavation technology and should provide a more rational basis for selection of materials handling systems for excavation methods in current use. These data will also be invaluable to the design of the equipment required to match the improved advance rates resulting from current excavation research.

5. Implications for Further Research

Collection is recommended of data and samples from stratified volcanic and fine grained igneous rocks, and from excavation methods not previously sampled in the metamorphic rocks, to provide information on formations and methods which were not encountered in the first year.

Field work at new sites in formations similar to those previously sampled is also recommended, either to provide data on different methods, or to determine what similarities and differences in muck characteristics may exist.

Continuation of the sampling program in conventional and shield operations is suggested to provide operating data on transport systems in high advance rate tunnels.

Resampling at selected sites to improve the confidence level of collected data is considered advisable.

Collection of hardness, abrasiveness, and stress-strain data previously recommended has been included in the program plan for 1972.

Sampling muck produced by unusual rock breaking methods under current development, such as the electron beam and the water cannon, is recommended to provide data for design of compatible transport systems.

6. Special Comments

No equipment has been purchased or developed, nor has any invention been made in the course of the work performed under this contract.

1. TECHNICAL PROBLEMS

The effectiveness of planning for new tunnels has been limited by the quantity and quality of information concerning subsurface conditions which has been available. For many reasons, owners and owner-agencies often have been reluctant to collect data on the properties of materials to be excavated, or to publish information which has been collected. Interested contractors have been forced to base proposals on their own assessments of conditions to be encountered, and to base cost estimates on methods and equipment which may not be well suited for conditions as they exist. Generally, significant allowances are made, both for contingencies which can be anticipated and for those which cannot be foreseen.

The importance of a more logical approach to selection of methods and equipment for tunneling has been emphasized by recent estimates of the great volume of this work probable in the near future, and by the wider application of tunnel boring machines which require rock property data as a basis for design. A trend towards collection and dissemination of more adequate exploratory information for tunnel sites is apparent in the reports of subsurface investigations published by some owner agencies.

Progress has been made and is continuing in research to determine relationships between rock properties, drillability, excavation, and support requirements. Recent investigations have shown, however, that very little information has been collected on the characteristics of the muck produced by the various excavation methods, and that correlations between the engineering properties of rock, muck characteristics, and the components of excavation systems have not been established.

In the absence of muck characteristic data, an adequate basis for selection of optimum transportation methods and equipment does not exist, and tunneling progress and cost have been affected adversely. Muck data are also a basic requirement for engineering the improvements to existing transport systems, and the development of the new systems which will be necessary to keep pace with the higher rates of excavation predicted for the future.

2. GENERAL METHODOLOGY

The objectives of the program are to develop a method for predicting materials handling properties of muck from the in-situ properties of rock, and a means of selecting the most suitable transportation equipment for muck produced by various excavation systems. The major emphasis is on mechanical excavation of hard rock. However, some soft rock and some conventional operations are included as examples of unusual advance rates, equipment, and operating methods.

The program plan is to collect muck samples and operating data from tunnels in rock of known properties; collect specimens from sites where the in-situ properties are unknown; determine muck characteristics and rock properties by physical testing; correlate and analyze rock and muck properties and quantify relationships through the concept of Muck Designation Numbers (MDN's); and to establish correlations between rock and muck characteristics, MDN's, the components of rapid excavation systems, and selection of muck transport equipment.

3. TECHNICAL RESULTS

3.1 SITE SELECTION

A list of operating and scheduled tunnels was prepared originally to assure that program objectives could be met. This list has been revised to incorporate changes, and is included as Appendix A. All but one of the tunnels listed are expected to be in operation during the coming year. Letter inquiries inviting program participation by off-continent tunnel operators have met with no response. These tunnels have been deleted from the list.

An original reluctance of tunnel contractors to approve site access has been overcome at all but one site. Operators, although under no obligation to participate in the program, have become cooperative when convinced that sampling and data collection are scheduled on a noninterference basis, with full observance of tunnel safety requirements.

Access to operating mine tunnels usually requires more operator participation than access to a contract tunnel. The impact of economic conditions has reduced emphasis on and interest in research. While mine operators were most cooperative in the 1971 program, less data is expected from such sources in 1972.

Early planning assumed that one basis for site selection would be the availability of rock property data at specific sites. Experience has shown that collection of these data is necessary from the majority of locations, and the program has been modified to reflect this requirement.

3.2 SAMPLE AND DATA COLLECTION

Muck samples and operating data have been collected from fifteen tunnel sites. Of thirty four samples, six were collected from sites visited only once. Resampling was done in similar formations at four sites to confirm the reliability of initial results. All other samples reflect differing lithologies, operating methods, or equipment.

The scope of collecting in-situ rock data has been greater than was anticipated, because of the nondisclosure policies of some owners and agencies and because formations encountered in some locations could not be correlated with the existing rock data. Rock specimens were collected for engineering property tests from twenty formations at twelve sites, under a modification of the contract.

Shield operations in two lithologic formations, conventional tunneling in eleven formations, TBM operations in fifteen formations, and RBM raise boring in two formations have been sampled to date. Rock types represented include four classified as Very High Strength, ten classified as High Strength, two in the Medium to High Strength range, eight in the Medium range, three Low, and six Very Low Strength. One rock sampled remains to be classified.

Seven of the sampled sites are no longer available for field work. One tunnel has been closed indefinitely following a disastrous explosion and fire, and excavation of interest to the program has been completed at the others.

3.3 PHYSICAL TESTING

Test methods were studied in detail to ensure that tests performed by commercial laboratories would yield consistent results. The following American Society for Testing and Materials (ASTM) standard methods were selected as specifications:

C566-67: Total Moisture Content by Drying

C136-67: Sieve or Screen Analysis of Fine and Coarse Aggregates

C117-69: Materials Finer than No. 200 Sieve in Mineral Aggregates by Washing

C29-69: Unit Weight of Aggregate, Loose Weight Determination

C170-50: Compressive Strength of Natural Building Stone

Specifications for the last test procedure have been modified to provide for greater accuracy in specimen preparation so that results will be comparable to those reported by other rock property research programs.

Contracts to perform muck tests have been negotiated with thirteen commercial testing laboratories. Collected samples were delivered for testing and shipment of minus two inch fractions to the U. S. Bureau of Mines, Pittsburgh Mining and Safety Research Center (PMSRC) for additional tests to be performed at this facility. At the end of the contract year, muck tests by commercial laboratories had been reported on thirty three sets of samples, and on twenty three by the PMRSC. One sample, tested commercially, was lost in transit to the PMRSC, and the remainder of these reports are expected during 1972, the samples having been collected too late for processing during the contract year.

Contracts to perform tests on rock specimens were negotiated with five commercial laboratories. Nineteen sets of specimens were delivered for testing of which two sets were destroyed in preparation. Reports on seventeen sets of specimens were received, and one set collected is being held for possible future testing.

Standard methods of testing abrasiveness were reviewed to determine the feasibility of collecting these data from tests on muck samples. The standard ASTM tests were found to measure the resistance of the sample to abrasion, rather than the abrasive effect on other materials. The latter is the property of greater interest in materials handling. Fractions of all muck samples are being retained for possible tests for this property, pending selection of an appropriate test procedure.

Results of hardness tests by the Shore scleroscope, a laboratory instrument which tests hardness by rebound of a hammer, are available for only three of the rock formations sampled. Additional tests by this method were found to be beyond the scope of this study. Hardness testing by the Schmidt hammer, a portable device which also tests rebound hardness, is described as nondestructive and relatively inexpensive. Rock specimens are also being retained for future tests by this method which are currently scheduled for 1972. Schmidt hardness values shown have been inferred as described in the footnote to the illustrations.

Modification of the standard test procedure was found necessary in testing muck from some low strength rocks. Screen testing the samples in the natural state was performed prior to the standard tests to avoid distortion of the curves caused by the disintegration of material during the wash screening which normally preceeds dry seive analysis. Natural screen test results are identified and shown as dotted lines on the size distribution curves.

3.4 DATA PROCESSING

A summary of rock and muck properties which affect materials handling, the range of the values of muck and rock properties which will be available, and the parameters of muck handling systems was prepared as a guideline in the development of correlation and analysis programs.

A format was developed for computer printout of lithologic, rock and muck data. Test results received to date have been stored on punch cards. Printouts of these raw data are included as Appendix B. Blank spaces on the printout indicate that data is not available on the date of the report.

Narrative and graphic summaries were prepared to combine these data with descriptions of the excavation systems from which rock and muck samples were taken, and are included as Appendix C. Rock strength classifications are based on uniaxial compressive strength, and conform with those proposed by D. U. Deere, et al, in the "Engineering Classification and Index Properties for Intact Rock", referenced above. These classifications are:

Very High Strength	-	Greater than 32,000 psi
High Strength	-	16,000 - 32,000 psi
Medium Strength	-	8,000 - 16,000 psi
Low Strength	-	4,000 - 8,000 psi
Very Low Strength	-	Less than 4,000 psi

Grain size classifications of igneous rocks, from A. Johannsen's "A Descriptive Petrology of Igneous Rocks", 1931, are used as follows:

Very Coarse	-	above 3 cm
Coarse	-	1 to 3 cm
Medium	-	1 to 10 mm
Fine	-	below 1 mm

From J. F. Kemp's "A Handbook of Rocks", 1950, sedimentary rocks of fragmental grains above 2 mm, are classified as conglomerates, while those below 2 mm in size are classified as sandstones or siltstones.

Symbols used to describe the shape of particles in the sample fractions between screen sizes are the following:

A - Angular	S - Sub-Angular
P - Platy	R - Rounded
E - Elongated	C - Cubic
I - Irregular	Sp - Spheroid

The curves show the percentage of the total sample weight passing one screen size and retained on the next. Screen sizes below 1/2" were selected to provide openings which become progressively smaller by approximately fifty percent, as shown below:

Screen Size	#4	#8	#16	#30	#50	#100	#200
Nominal Square Openings, Inches	0.187	0.094	0.047	0.023	0.012	0.006	0.003

The abbreviation NA is used to indicate that an item of data is not available.

3.5 DEVELOPMENT OF MDN'S

In accordance with the program plan, which provides for placing major emphasis on data collection during the first year, analysis of data and development of MDN's has been preliminary. As data first became available, test results were reviewed to confirm the validity of the conceptual classification criteria. Based on a plan of classification by materials handling characteristics, the proposed designation system employed seven numbered categories in which to group excavation products by size and size distribution. Numbers were assigned in a progression from No. 1 for muck with a relatively large maximum piece size and a predominant distribution in the 1" to 200 mesh range to No. 7, in which the maximum size is relatively small and the predominant distribution is in the minus 50 mesh sizes. The concept also recognized that muck characteristics would vary with the excavation method, and contemplated modifying the MDN's to distinguish between excavation techniques.

Initial field work was scheduled at sites where rock strengths varied over a wide range, and which would provide examples of shield, machine, and conventional operations. The size distribution curves of the muck from these sites, (Identification Numbers H-1, 5-1, CL-1, NAST-1, and SF-1, Appendix C), varied distinctly, in general accordance with the criteria, except that the size range of the predominant distribution was somewhat higher than had been inferred.

Using the initial data as a guide, a preliminary algorithm was developed for data analysis to correlate MDN's, in-situ rock properties, and excavation methods. The quantitative relationship sought was a predictor equation, obtained by multiple regression of the physical property data obtained from the rock sample tests and a predictor equation for the MDN. A discussion of this technique follows.

In simple regression, it is supposed that with each observation value, there is another quantity which can be observed or somehow related to the observation. After n observations, there exists a series of pairs, (x_1, y_1), (x_2, y_2), $\cdots$, (x_n, y_n). The question we wish to answer is to determine if there is a relationship between y and x and how this relationship can be obtained.

One may assume that there is such a relationship, and that this relationship is linear. With this assumption, one may write

$$y = \alpha x + \beta \qquad (1)$$

The x_i, $i = 1, \cdots, n$, are the values of the independent variable x, and the y_i, $i = 1, \cdots, n$, are the values of the dependent variable y. α and β are the coefficients which will have to be determined from the observation points.

It is possible that a relationship exists between x and y, but the relationship is not linear. A possible alternate in this case is to find another variable, x^1, related to x, such that y can then be linearly related to x^1. The new variable x^1 will then be used in place of x in the discussions that follow.

Assuming that the linear relationship is valid, we can create an error term which is the sum of the squares of all deviations of observed values from the linear Equation (1). Thus the error ϵ is

$$\epsilon = \sum_{i=1}^{n} (y_i - (\alpha x_i + \beta))^2 \qquad (2)$$

and determine α and β so ϵ is minimum. This simple regression is known as the method of "least squares". The solution can be shown to be:

$$\alpha = v_{xy}/s_x^2 \qquad (3)$$

$$\beta = \bar{y} - \alpha\bar{x} \qquad (4)$$

where

$$s_x^2 = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2 \qquad (5)$$

$$v_{xy} = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y}) \qquad (6)$$

$\bar{x}$ and $\bar{y}$ are the arithmetic averages of the x_i and y_i respectively.

Equations (3) and (4) give the necessary coefficients in terms of observed values for the predictor Equation (1). If y had been the MDN, and x an in-situ rock property (or some transformation of it), then this simple regression would have resulted in a predictor equation for the MDN.

A procedure similar to the simple regression technique will be applicable if we want to relate a dependent variable y to several independent variables $x_1, x_2, x_3, \cdots, x_{m-1}$. (Note the $x_1, x_2, \cdots, x_{m-1}$ are independent variable and not the observation points themselves). If n observations are taken, then one has the following sets of points: $(y_1, x_{1,1}, x_{2,1}, x_{3,1}, \cdots, x_{m-1,1}), (y_2, x_{1,2}, x_{2,2}, x_{3,2}, \cdots, x_{m-1,2}), \cdots, (y_n, x_{1n}, x_{2n}, x_{3n}, \cdots, x_{m-1,n})$.

A linear relationship is assumed to exist between y and $x_1, x_2, \cdots, x_{m-1,n}$. Thus, one has

$$y = \alpha_o + \alpha_1 x_1 + x_2 y_2 + \cdots + \alpha_{m-1} x_{m-1} \tag{7}$$

The coefficients $\alpha_o, \alpha_1, \cdots, \alpha_{m-1}$ will have to be determined from the n observations of the variables.

To solve for the coefficients requires the manipulation of certain arrays. Defining the following one dimensional arrays:

$$\alpha = \begin{pmatrix} \alpha_o \\ \alpha_1 \\ \cdot \\ \cdot \\ \cdot \\ m-1 \end{pmatrix} \quad ; \quad w = \begin{pmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ \cdot \\ y_n \end{pmatrix} \tag{8}$$

Let A be the two-dimensional array.

$$A = \begin{pmatrix} 1 & x_{1,2} & x_{2,1} & \cdots & x_{m-1,1} \\ 1 & x_{1,2} & x_{2,2} & \cdots & x_{m-1,2} \\ \cdot & & & & \cdot \\ \cdot & & & & \cdot \\ \cdot & & & & \cdot \\ 1 & x_{1,n} & x_{2,n} & \cdots & x_{m-1,n} \end{pmatrix} \tag{9}$$

Setting up an error term is no longer as easy. One possibility is

$$z_i = y_i - \alpha_o - \sum_{j=1}^{m-1} \alpha_j x_{j,i} \quad ; \quad i = 1, 2, \cdots, n \tag{10}$$

Two other one dimensional arrays are needed:

$$z = \begin{pmatrix} z_1 \\ z_2 \\ \cdot \\ \cdot \\ \cdot \\ z_n \end{pmatrix} \quad ; \quad z^T = (z_1, z_2, \cdots, z_n) \tag{11}$$

z and z^T are both functions of the observation points and the coefficients, which are still unknown. One can set up a covariance matrix

$$V = zz^T = \begin{pmatrix} z_1^2 & z_1z_2 & \cdots & z_1z_n \\ z_2z_1 & z_2^2 & \cdots & z_2z_n \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ z_nz_1 & z_nz_2 & \cdots & z_n^2 \end{pmatrix} \tag{12}$$

The coefficients $\alpha_0, \alpha_1, \cdots, \alpha_{m-1}$ which minimize the error term can be shown to be obtained from

$$\alpha = J^{-1}A^TV^{-1}w \tag{13}$$

where

$$J = A^TV^{-1}A \tag{14}$$

However, V is a function of z which contains the unknown coefficients themselves. By assuming that the random errors in Equation (10) have zero mean and a constant variance σ^2 regardless of z, V can be shown to be equal to $\sigma^2 I$, where I is the unit matrix. If this is so, then the coefficients for the predictor equation will be given by

$$\alpha = (A^TA)^{-1}A^Tw \tag{15}$$

A^T is the transpose of the matrix A given by Equation (9).

The general computational procedure is as follows:

(1) Form the array A as given by Equation (9).

(2) Obtain the transpose, A^T, from A. This is just a matter of interchanging rows and columns.

(3) Compute A^TA, then $(A^TA)^{-1}$, then $(A^TA)^{-1}A^T$. This involves a series of matrix multiplications and matrix inversion. These techniques are readily available from a computer.

(4) Form the array w from Equation (8).

(5) Multiply the result of Step (3) by the result of Step (4). This yields a set of coefficients $\alpha_o, \alpha_1, \cdots, \alpha_{m-1}$.

(6) Test for goodness of fit or the quality of the predictor equation.

A basic assumption is that the predictor equation is linear, and that the independent variables to use are the observation variables themselves. It may be necessary to define another set of variables $x_1^1, x_2^1, \cdots, x_{m-1}^1$ to use in order to obtain a linear relationship.

It often happens that the independent variables are themselves related. If a linear relationship exists between any two of the independent variables, $(A^TA)^{-1}$ will be singular, i.e., A^TA will have zero determinant, and hence $(A^TA)^{-1}$ cannot be computed. If this is so, α is difficult to compute, and the standard errors of the calculated coefficients are huge, giving an inaccurate predictor equation. This problem can be circumvented by performing the regression analysis with one variable, then with two variables, etc. while being careful when this problem arises. One may combine linearly any two variables that are highly correlated and use the combined variable as in the dependent variable.

To obtain Equation (15) from Equation (13), it was necessary to assume that the off-diagonal terms in Equation (12) are zero. If this is not so, the observations are known to be auto-correlated, and will result in an inefficient predictor equation. The marked presence of auto-correlation implies that alternate modes of estimation should be used.

Good computer routines exist which are available on most computers, including routines for matrix transpose, matrix multiplication and matrix inversion, together with standard routines to compute means and standard deviations of a set of observations.

In multiple regression to predict an MDN, the MDN is treated as the dependent variable. The set of independent variables may include the following:

(a) Dry Unit Weight, DUW

(b) Compressive strength, Fc

(c) Rock quality designation, RQD

(d) Hardness, H

(e) Abrasiveness, Ab

Some of these variables may be excluded from the analysis; others still undefined may be included. The regression analysis may be performed using one or more of these variables.

A set of observations is obtained, and with each set of observations, an MDN is indicated. A table with the following entries will be created:

MDN	DUW	Fc	RQD	H	Ab

It is seen that y corresponds to MDN, and DUW, Fc, RQD, H, and Ab, correspond to x_1, x_2, x_3, x_4, and x_5, respectively. The matrix in Equation (9) corresponds to the observation points. The array in Equation (8) corresponds to the MDN indicated in column 1. The predictor equation may be obtained from Equation (15).

Several iterations of this analysis should be performed on the computer in order to determine which variable or combinations of variables are appropriate to include in the predictor equation. Certain tests can be performed to determine the quality and accuracy of this predictor equation. With computer routines readily available, several iterations may be performed with reasonable cost and in a very short time.

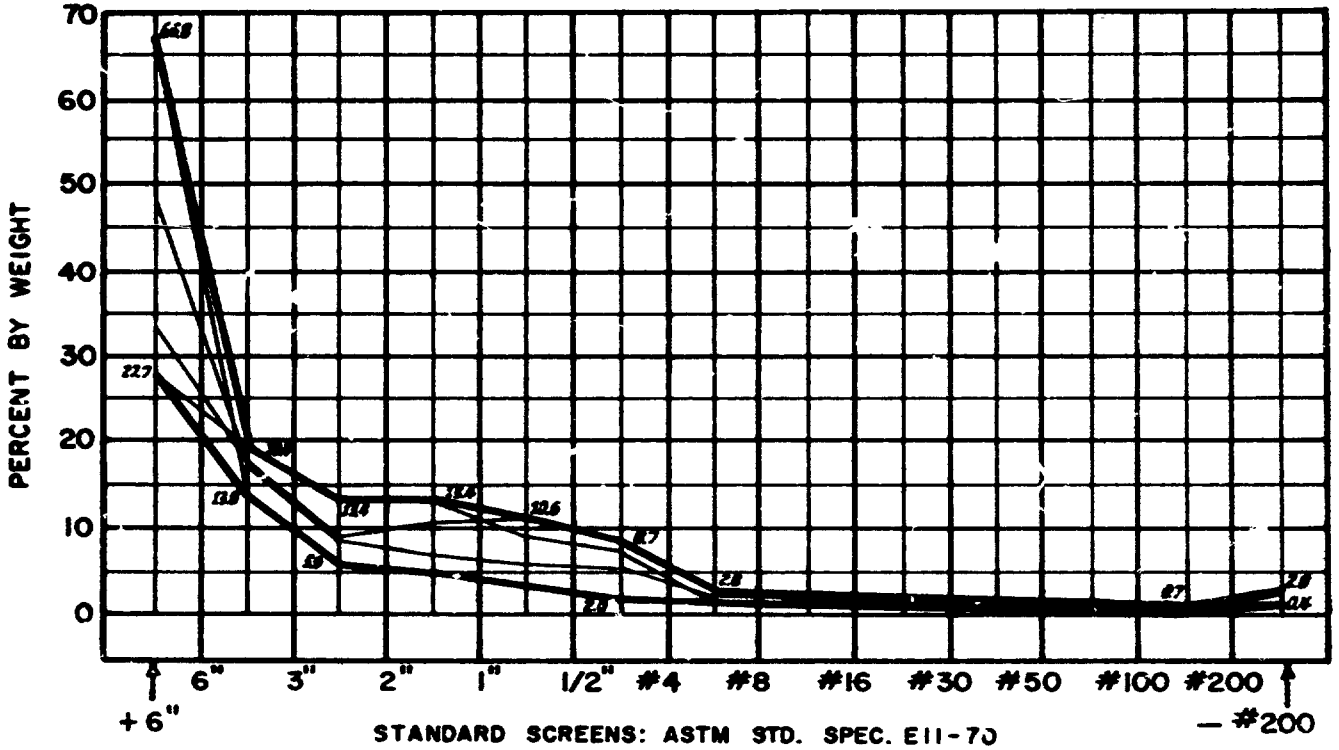
During algorithm development, re-sampling at three of the original sites confirmed the distinctive shape of the size distribution curves, but was impossible at the other two sites because one tunnel had progressed

into a different formation, and the TBM had been removed from the other. Sampling at other sites produced some curves which fit well into the original categories, and others which were distinctive enough to suggest establishing additional categories. When most of the data had been collected, curves of similar form were plotted together, and tentative designation numbers were assigned. The resultant composites are shown as Figures 1 through 8 on the following pages. The prefix "C" was added to MDN's for muck produced by conventional operations, and "M" and "S" were used to indicate boring machine and shield systems. To avoid reducing data derivatives to extremely small values, rocks with compressive strengths of 1KPSI or less have been assigned arbitrary strengths of 1. In the few cases where Shore hardness was available, values have been converted to the Schmidt scale; other Schmidt hardness values have been inferred from data published by D. U. Deere, et al, in the "Engineering Classification and Index Properties for Intact Rock," referenced above. The "T" prefix was added to all MDN's to indicate the preliminary nature of the assignments.

The tentative nature of the MDN assignments must be stressed, since changes will undoubtely result from analysis and from resolution in problem areas which became apparent in the course of the program. These include the apparent lack of direct correlation between middle range MDN's and some rock properties, the characteristics of the muck from tunnel boring machines using drag cutters, and the performance of the raise boring machine which was sampled late in the program. A solution to the first problem may be found in the use of raw data derivatives, and of additional rock property data such as Schmidt hardness, stress-strain curves, Young's modulus, and Poisson's ratio, which will be collected during the second year of the program. Varying the predictor equation or setting up separate MDN series for drag cutter TBM's and for RBM's may be necessary to solve the others. Because the effectiveness of the proposed solutions remains to be confirmed, use of computer techniques has been confined to data storage and retrieval and to development of the algorithm described above.

3.6 TRANSPORT SYSTEM SELECTION

The following listing of equipment capabilities, system constraints, and MDN applications is taken in part from Report No. FRA-RT-71-57 "Materials Handling for Tunnels", HN 8080, Holmes & Narver, Inc. and Resource Management Corp., Sept. 1970, prepared for the U. S. Department of Transportation, Washington, D. C., with additional details provided by the authors. The list, consistent with the goals of the program in the first year, is preliminary, and will be refined and quantified in scheduled future work.



MUCK: PCT. BY WT. BETWEEN SCREENS

ABBREVIATIONS

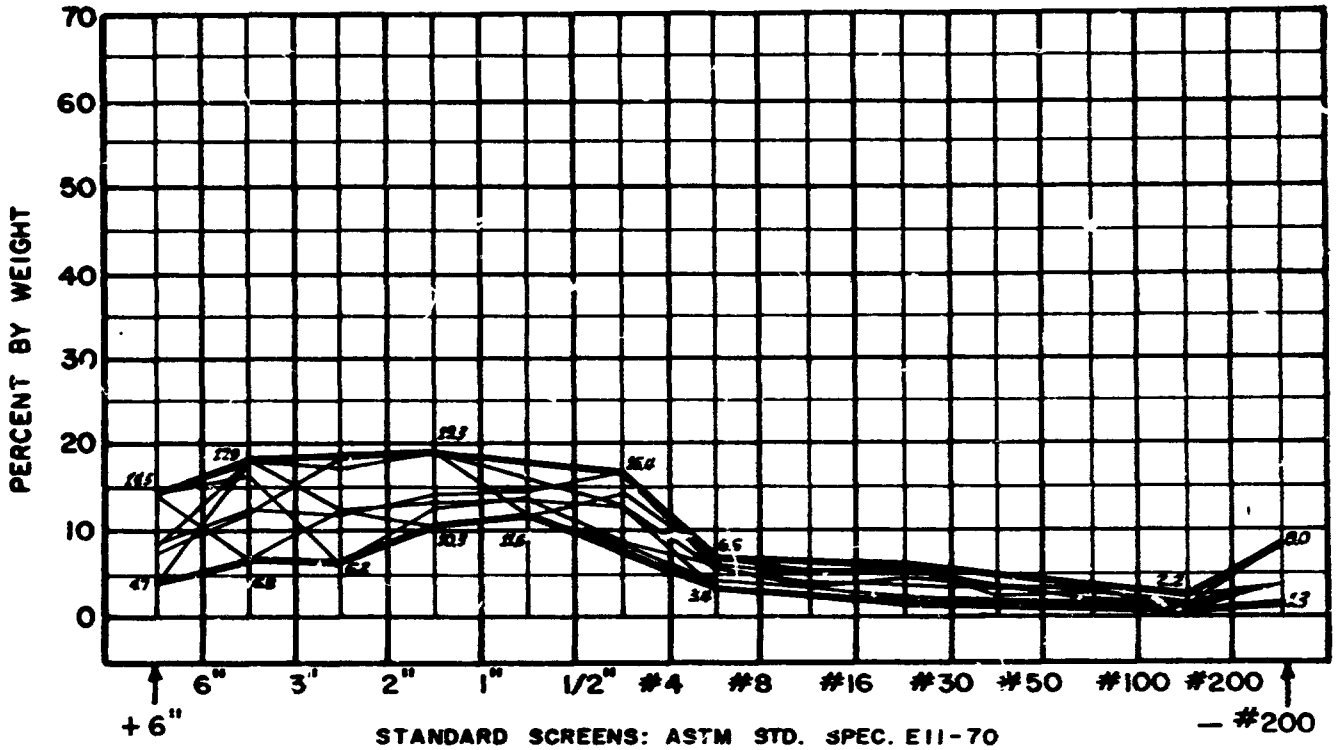
f_c	=	Uniaxial Compressive Strength
Ig	=	Igneous
Sed	=	Sedimentary
Met	=	Metamorphic
Gr	=	Granite
Gn	=	Gneiss
Ss	=	Sandstone
Sch	=	Schist.
Sh	=	Shale
Ls	=	Limestone
Qz	=	Quartz
M	=	Monzonite
Sts	=	Siltstone
Qe	=	Quartzite
Te	=	Tactite
He	=	Hematite
Me	=	Martite
Md	=	Mudstone
L	=	Laminated
Ma	=	Massive
J	=	Jointed
Hy	=	Highly
My	=	Moderately
Mr	=	Minor
PC	=	Poorly Cemented
O		Oscillator
Shld	=	Shield
Conv	=	Conventional
TC		Tungsten Carbide
Tri		Tricone
GW	=	Ground Water

IDENT NO	ROCK CLASS	ROCK TYPE	ROCK STRUCT.	f_c in K LBS	RQD %	ROCK DUW PCF	HARDNESS SHORE	HARDNESS SCHMIDT	G. W.	EXCAV METHOD	MACHINE CUTTERS DISC	MACHINE CUTTERS ROL'R	MACHINE CUTTERS DRAG	MACHINE CUTTERS CONE	MAX. SIZE OBSERVED
LK1	Ig	Qz M	Mr J	25	83	162		55	Dry	Conv					4' x 3' x 2'
LK2	Ig	Qz M	Mr J	28	83	165		55	Dry	Conv					3-1/2' x 2' x 2'
LK3	Met	Qe-Te	LMy J	26	80	178		50	Dry	Conv					2-1/2' x 1' x 1/2'
LK4	Met	Te	My J	15 (Est)	70	181		47	Dry	Conv					27" x 18" x 12"

Inferred from D. I. Deere AD 64t 610-1966

ROCK, OPERATING DATA, & MUCK SIZE RANGE, MDN T-C1, C2

FIGURE 3-1



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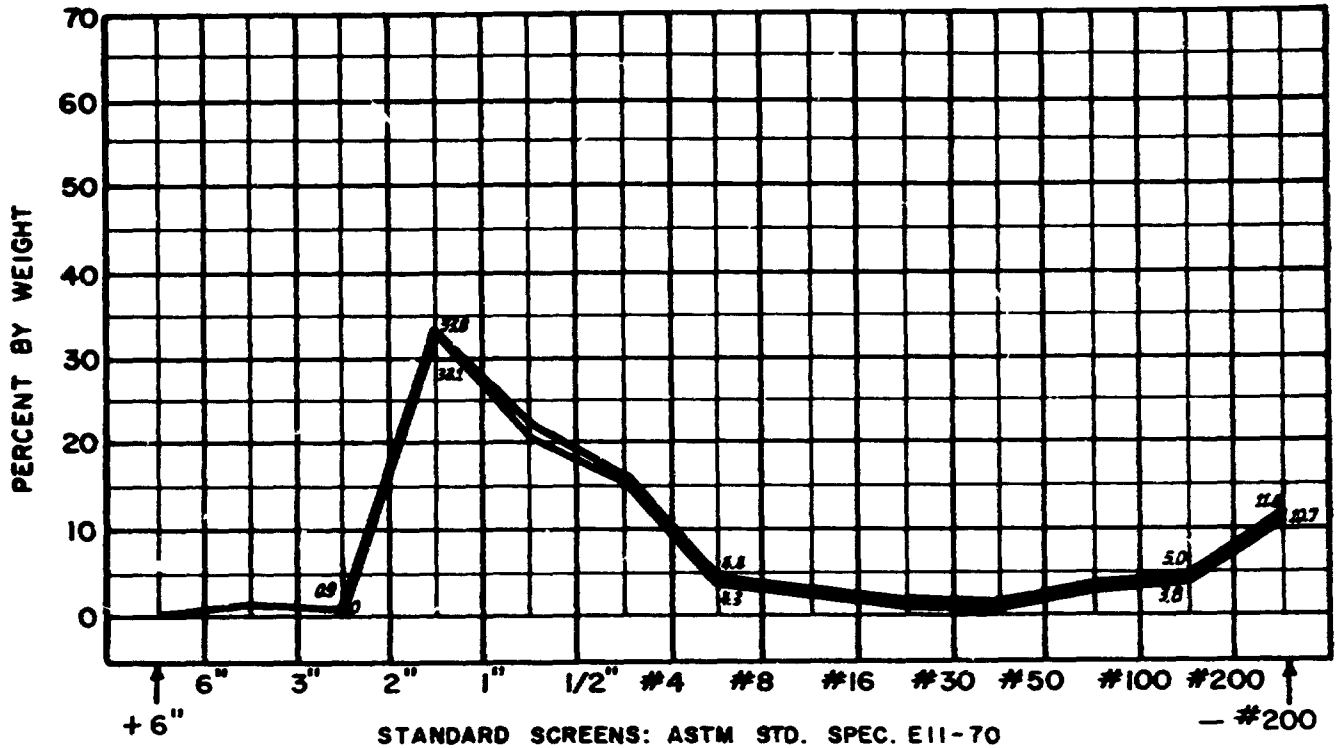
Sch	:	Schist.
Sh	:	Shale
Ls	:	Limestone
Qz	:	Quartz
M	:	Monzonite
Sts	:	Siltstone
Qe	:	Quartzite
Te	:	Tactite
He	:	Hematite
Me	:	Martite
Md	:	Mudstone
L	:	Laminated
Ma	:	Massive
J		Jointed
Hy	:	Highly
My	:	Moderately
Mr	:	Minor
PC	:	Poorly Cemented
O		Oscillator
Shld	:	Shield
Conv	:	Conventional
TC	:	Tungsten Carbide
Tri	:	Tricone
GW	:	Ground Water

IDENT NO.	ROCK			f_c in K LBs	RQD %	ROCK DUW PCF	HARDNESS		C W.	EXCAV METHOD	MACHINE CUTTERS				MAX. SIZE OBSERVED
	CLASS	TYPE	STRUCT				SHORE	SCHMIDT			DISC	ROLLR	DRAG	CONE	
GA1	Ig	Gr	Mr J	35	90	161		55	Dry	Conv					2-1/2" x 2" x 1"
11-3	Sed	StsSh	MMrL	22	90	152	48	43	Dry	Conv					18" x 18" x 4"
H1	Ig	Gr	Mr J	32	80	162		52	Mr	Conv					3" x 2" x 1"
NAS13	Ig	Gr	Mr J	13	90	152		42	M	Conv					2-1/2" x 1-1/2" x 1"
H2	Ig	GrGn	Mr J	39	80	164		55	Mr	Conv					2" x 1-1/2" x 1"
11-4	Sed	StsSh	MMrL	22	90	160	48	43	Dry	TBM			48TC		8" x 8" x 4"

Interred from J. C. Deere AD 64c 10-19c6

ROCK, OPERATING DATA & MUCK SIZE RANGE, MDN T-C3, M1

FIGURE 3-2



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Ls	=	Limestone
Qz	=	Quartz
M	=	Monzonite
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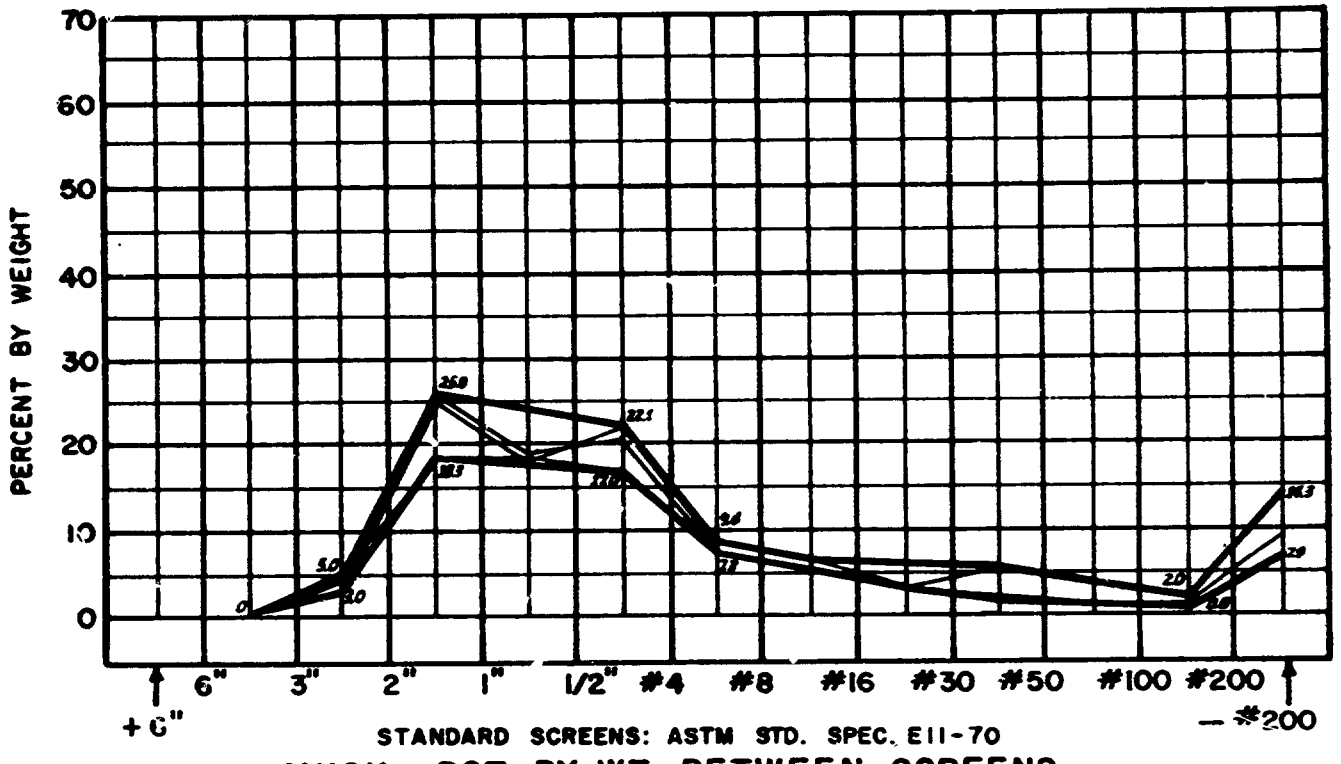
Te		Tactite
He	=	Hematite
Me	=	Martite
Md	=	Mudstone
L	=	Laminated
Ma	=	Massive
J	=	Jointed
Hy	=	Highly
My	=	Moderately
Mr	=	Minor
PC		Poorly Cemented
O		Oscillator
Shld	=	Shield
Conv	=	Conventional
TC		Tungsten Carbide
Tri		Tricone
GW		Ground Water

DEPTH FT.	ROCK CLASS	ROCK TYPE	ROCK STRUCT.	f_c in K LBS	RQD %	ROCK DUW PCF	HARDNESS SHORE	HARDNESS SCHMIDT	G. W.	EXCAV METHOD	MACHINE CUTTERS DISC	MACHINE CUTTERS ROL'R	MACHINE CUTTERS DRAG	MACHINE CUTTERS CONE	MAX. SIZE OBSERVED
B-1	Sed	Ss	Ma	1t	92	171	61	49	Dry	TBM	47 (Center triple - 1)				2-1/2" x 8" x 3/4"
B-2	Sed	Ss	Ma	1t	92	171	61	49	Dry	TBM	47 (Center triple - 1)				3" x 9" x 1"

Adapted from D. L. Deere AD-746 610-1966

ROCK, OPERATING DATA, & MUCK SIZE RANGE, MDN T-M2

FIGURE 3-3



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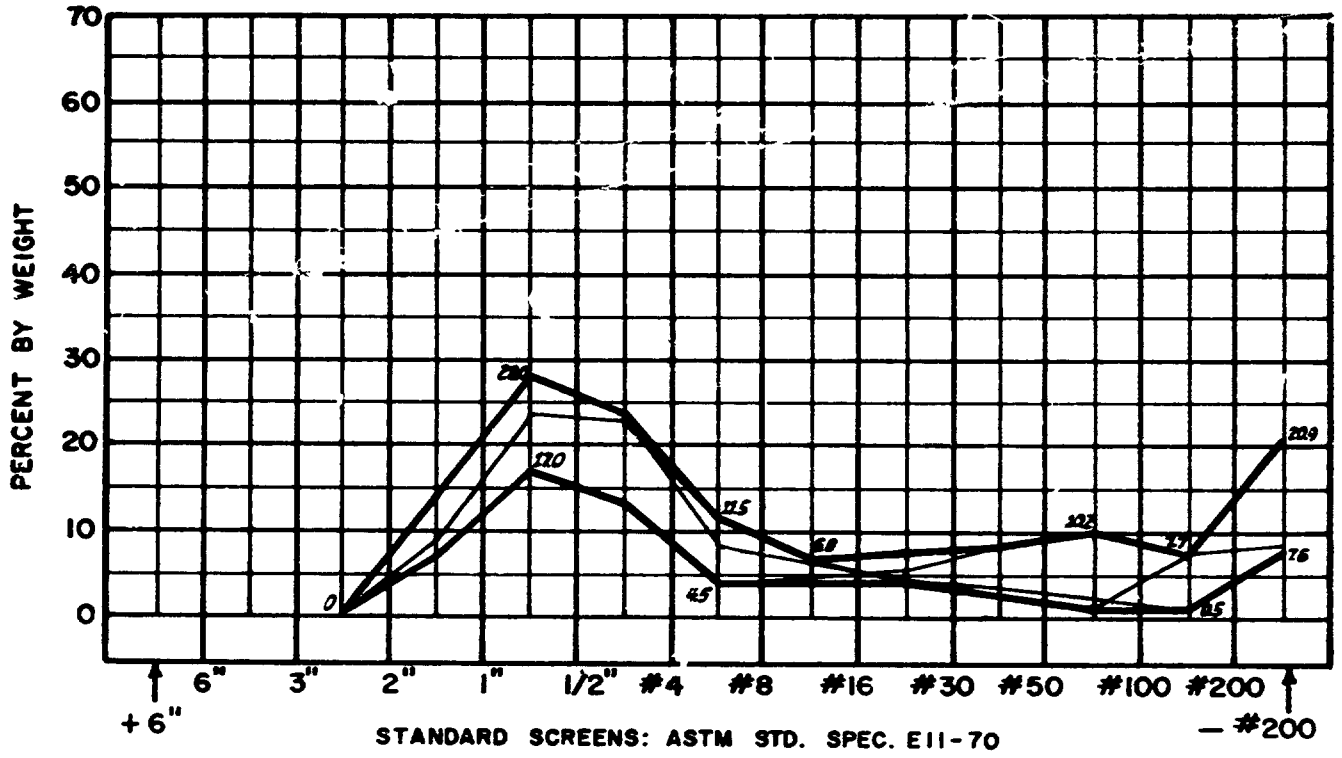
Sh	:	Shale
Ls	:	Limestone
Qz	:	Quartz
M	:	Monzonite
Sts	:	Siltstone
Qe	:	Quartzite
Te	:	Tactite
He	:	Hematite
Me	:	Martite
Md	:	Mudstone
L	:	Laminated
Ma	:	Massive
J	:	Jointed
Hy	:	Highly
My	:	Moderately
Mr	:	Minor
PC	:	Poorly Cemented
O	:	Oscillator
Shld	:	Shield
Conv	:	Conventional
TC	:	Tungsten Carbide
Tri		Tricone
GW		Ground Water

IDENT NO	ROCK			f_c in K LBS	RQD %	ROCK DUW PCF	HARDNESS		G. W.	EXCAV METHOD	MACHINE CUTTERS				MAX SIZE OBSERVED
	CLASS	TYPE	STRUCT.				SHORE	SCHMIDT			DISC	ROL R	DRAG	CONE	
LAW3	Sed	Ls	Ma	8	100	17c	4c	42	Dry	TBM	11TC	16TC		TCTri	3" x 2-1/2" x 1/2"
LAW2	Sed	Ls	Ma	8	100	17c	4c	42	Dry	TBM	11TC	16TC		TCTri	3" x 2" x 1/2"
LAW4	Sed	Ls	Ma	10	100	17c	4c	42	Dry	TBM	11TC	16TC		TCTri	3-1/2" x 2-1/2" x 3/4"

Interred from: D U Deere AD 646 (10-196)

ROCK, OPERATING DATA, & MUCK SIZE RANGE, MDN T-M3

FIGURE 3-4



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Ls	:	Limestone
Qz	:	Quartz
M	:	Monzonite
Sts	:	Siltstone
Qe	:	Quartzite
Te	:	Tactite
He	:	Hematite
Me	:	Martite
Md	:	Mudstone
L	:	Laminated
Ma	:	Massive
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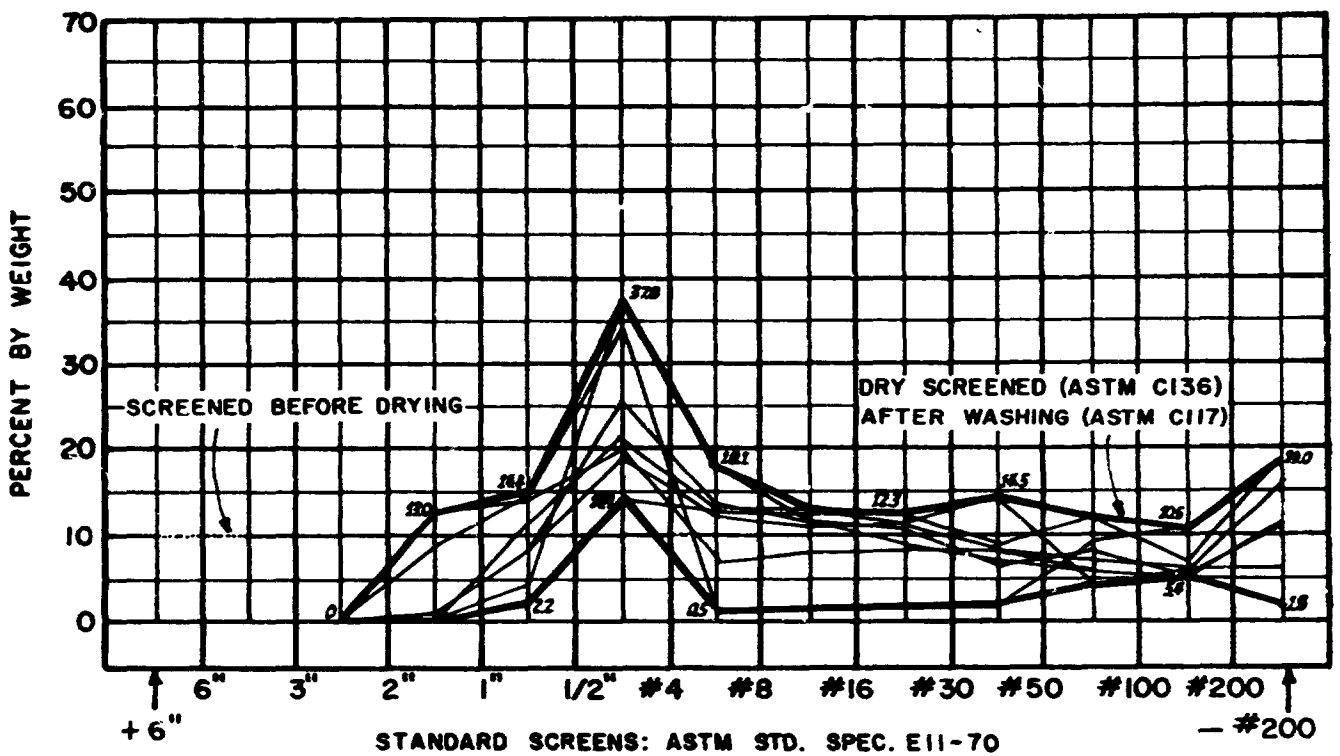
Hy	:	Highly
My	:	Moderately
Mr	:	Minor
PC	:	Poorly Cemented
O	:	Oscillator
Shld	:	Shield
Conv	:	Conventional
TC	:	Tungsten Carbide
Tri	:	Tricone
GW	:	Ground Water

IDENT NO	ROCK			f_c in K LBS	RQD %	ROCK DUW PCF	HARDNESS		G. W.	EXCAV METHOD	MACHINE CUTTERS				MAX. SIZE OBSERVED
	CLASS	TYPE	STRUCT.				SHORE	SCHMIDT			DISC	ROL'R	DRAG	CONE	
MIL1	Sed	Ls	My J	36	85	166		50	Mr	TBM	26"*			1"*	2" x 1" x 1/2"
MIL2	Sed	Ls	My J	36	85	166		50	Mr	TBM	26"*			1"*	3" x 2" x 1/2"
QL 1	Met	Sch	L	11	30	165		37	Mr	TBM	36"**				2" x 1" x 1/2"

Inferred from D U Deere AD 646 610-1966
Triple Disc

ROCK, OPERATING DATA, & MUCK SIZE RANGE, MDN T-M4

FIGURE 3-5



MUCK: PCT. BY WT. BETWEEN SCREENS

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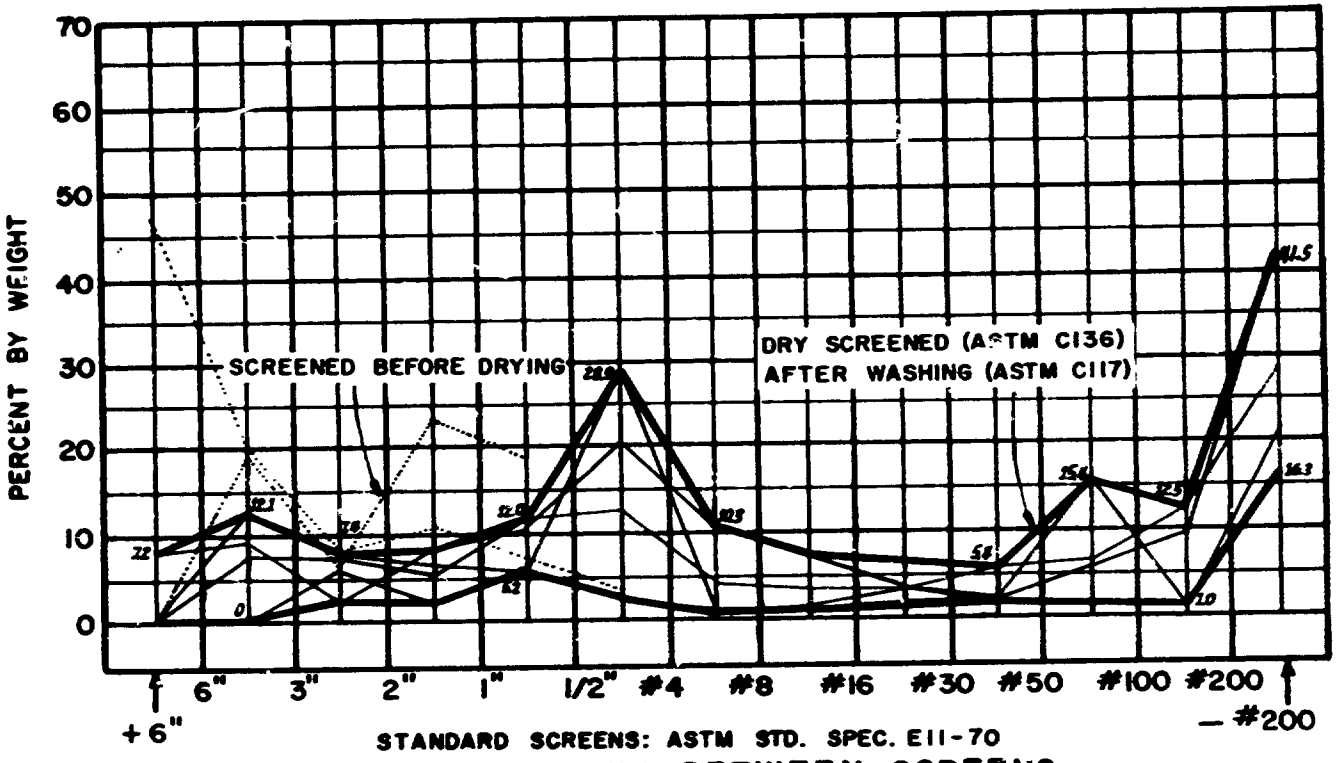
Ls	:	Limestone
Qz	:	Quartz
M	:	Monzonite
Sts	:	Siltstone
Qe	:	Quartzite
Te	:	Tactite
He	:	Hematite
Me	:	Martite
Md	:	Mudstone
L	:	Laminated
Ma	:	Massive
J	:	Jointed
Hy	:	Highly
My	:	Moderately
Mr	:	Minor
PC	:	Poorly Cemented
O	:	Oscillator
Shld	:	Shield
Conv	:	Conventional
TC	:	Tungsten Carbide
Tri	:	Tricone
GW	:	Ground Water

IDENT NO.	ROCK CLASS	ROCK TYPE	ROCK STRUCT	f_c in K LBS	RQD %	ROCK DUW PCF	HARDNESS SHORE	HARDNESS *SCHMIDT	G. W.	EXCAV METHOD	MACHINE CUTTERS DISC	MACHINE CUTTERS ROL'R	MACHINE CUTTERS DRAG	MACHINE CUTTERS CONE	MAX. SIZE OBSERVED
CL1	Met	GrGh	Hy J	9	10	174		45	Mr	TBM		18TC		1-TCTri	1-1/2" x 2-1/2" x 3/4"
SF2	Sed	Ss	PC	2	50	142		30	Wet	Shld.	Single Ripper Tooth				3' x 2' x 8"
NAST2	Ig	Gr	My J	18	90	167		55	Mr	TBM		23TC		2TC	1" x 1" x 1/2"
NAST4	Ig	Gr	My J	24	90	160		55	Mr	TBM		27TC		2TC	1-1/2" x 1" x 1/2"
LK5	Ig	QzM	My J	32	92	165		55	Dry	RBM	27				2-1/2" x 4" x 3/4"
LK6	Ig	QzM	Hy J	15 (E)	86	137		50	Dry	RBM	11				2" x 3-1/2" x 1-1/4"
NAST1	Ig	Gr	My J	18	90	167		55	Mr	TBM		23TC		2TC	1 x 3/4" x 1/2

Inferred from D. U. Deere AD 646 619-1966

ROCK, OPERATING DATA, & MUCK SIZE RANGE, MDN T-M5, S5

FIGURE 3-6



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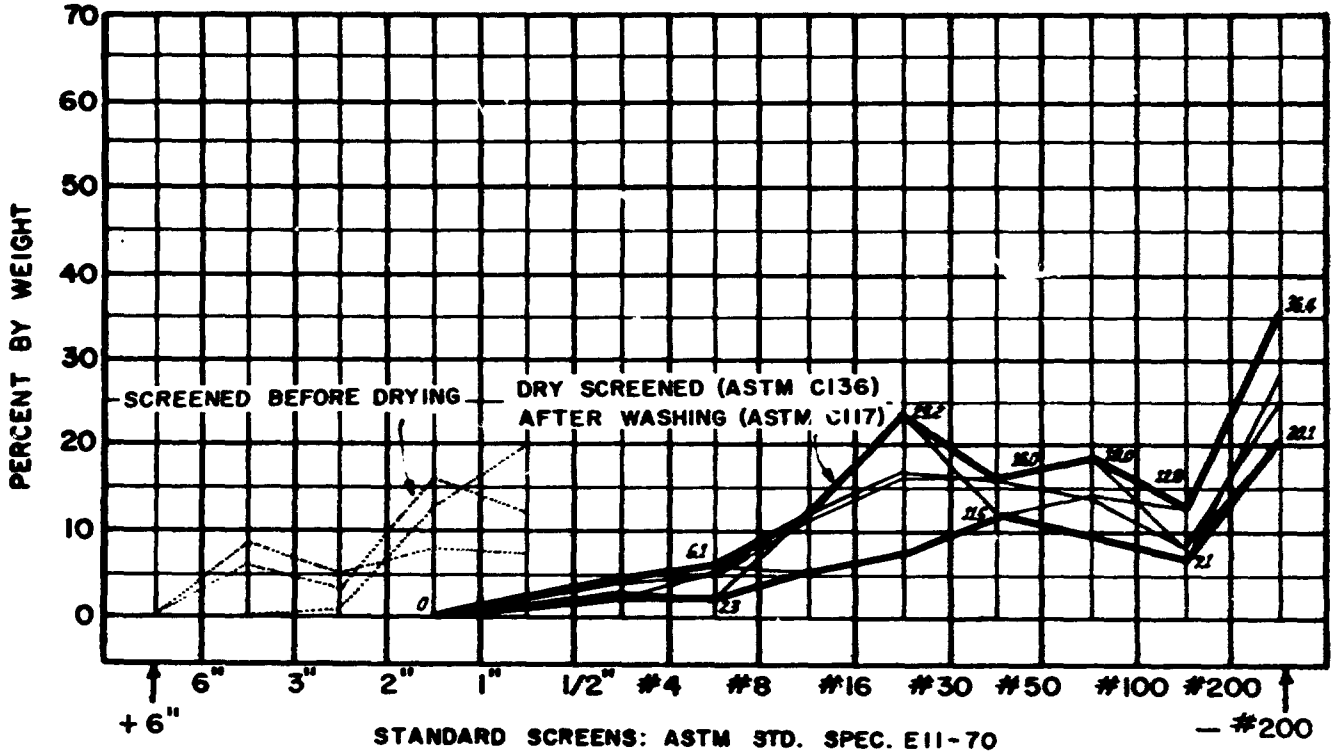
Sch	:	Schist.
Sh	:	Shale
Ls	:	Limestone
Qz	:	Quartz
M	:	Monzonite
Sts	:	Siltstone
Qe	:	Quartzite
Te	:	Tactite
He	:	Hematite
Me	:	Martite
Md	:	Mudstone
L	:	Laminated
Ma	:	Massive
J	:	Jointed
Hy	:	Highly
My	:	Moderately
Mr	:	Minor
PC	:	Poorly Cemented
O		Oscillator
Shld	:	Shield
Conv	:	Conventional
TC	:	Tungsten Carbide
Tri	:	Tricone
GW	:	Ground Water

IDENT NO	ROCK			f_c in K LBS	RQD %	ROCK DUW PCF	HARDNESS		G. W.	EXCAV METHOD	MACHINE CUTTERS				MAX. SIZE OBSERVED
	CLASS	TYPE	STRUCT.				SHORE	*SCHMIDT			DISC	ROL'R	DRAG	CONE	
KM1	Sed	Md	Ma	11	90	144		40	Dry	TBM			40TC		36" x 14" x 8"
MB1	Met	HeMe	LHy J	7	10	207		28	Dry	TBMO			278TC		24" x 18" x 8"
LAY1	Sed	Ss	Ma	19	84	150		47	Dry	TBM	30 including 1 triple disc				4" x 4" x 1/2"
NAV1	Sed	Sts	Ma	2	70	142		25	Dry	TBM	6TC+30		32TC		6" x 5" x 2"

*Inferred from D. U. Deere AD 646 610-1966

ROCK, OPERATING DATA, & MUCK SIZE RANGE, MDN T-M6

FIGURE 3-7



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He	:	Hematite
Me	:	Martite
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L	:	Laminated
Ma		Massive
J	:	Jointed
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My	:	Moderately
Mr	:	Minor
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O	:	Oscillator
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GW	:	Ground Water

IDENT NO.	ROCK			f_c in K LBS	RQD %	ROCK DUW PCF	HARDNESS		G. W.	EXCAV METHOD	MACHINE CUTTERS				MAX. SIZE OBSERVED
	CLASS	TYPE	STRUCT.				SHORE	*SCHMIDT			DISC	ROL'R	DRAG	CONE	
NAV2	Sed	Ss	PC	1	60	117		25	Dry	TBM	6TC+30		32TC		5" x 2" x 1"
WNG1	Sed	Ss	PC	1	30	125		20	Wet	TBM			72TC		14" x 4" x 4"
WNG2	Sed	Ss	PC	1	30	125		20	Wet	Conv					18" x 10" x 4"
SF1	Sed	Ss	PC	1	0-35	113		20	Wet	Shld.	Single Ripper Tooth				5" x 4" x 3"

*Inferred from D. U. Deere AD 646 610-1966

ROCK, OPERATING DATA, & MUCK SIZE RANGE, MDN T-C7, M7, S7

FIGURE 3-8

MDN applicability to equipment selection is rated only on muck characteristics, and would be subject to constraints imposed by such factors as tunnel size, grade and length, equipment and power cost and availability, and environmental considerations in any final analysis.

Unitized systems in common use include Conventional Rail, Side Rail, and Free Vehicles.

Conventional rail systems capabilities and advantages include:

Hauling capacities can be varied by the addition or removal of cars or trains.

Materials, supplies and personnel can be transported by the system.

Easily adaptable to automatically controlled operation.

Loading and dumping can be done rapidly.

Track extension is relatively simple.

System constraints include:

The large percentage of tunnel cross section which is occupied by equipment.

High speeds needed for short cycle time.

Ideal road bed and track conditions are necessary if delays cannot be tolerated.

Passing tracks are required in long tunnels.

A secondary system or assisted haulage needed if vertical grade is over 4%.

Supply of materials required for system extension is a major operation at high advance rates.

Small clearances, high speeds, and massive moving equipment combine to produce long delays and serious injuries in event of accidents.

Combustion products complicate ventilation unless vehicles are powered electrically.

Conventional rail systems are applicable to any of the MDN's so far developed. Special cars would be required for high speed operations with very wet muck, and special dumping facilities with MDN's 6 and 7.

Siderail systems capabilities and advantages include:

Hauling capacities can be varied by the addition or removal of units.

Materials, supplies and personnel can be transported by the system.

Automatically controlled operation.

Loading and dumping can be done rapidly.

Can be used on much steeper grades than conventional rail systems.

Vertical and horizontal guidance tends to reduce frequency of derails and other accidents.

System constraints include:

Power units for side rail systems require electrical bus bars to be extended with the track.

The small size of units in current use limits haulage capacity, and the number of power units can result in maintenance problems and delays.

Continuous bus bars may be a personnel hazard.

MDN's 1 through 7 could be transported by this system. Problems in unloading cars can be expected from MDN's 6 and 7 if wet, due to the high percentage of fines.

Free vehicle capabilities and advantages include:

System capacity can be varied by the number of vehicles, or by change in speed.

Materials can be transported inbound and outbound.

Guideway for operation is not required.

System constraints are:

Tunnel size limits use of free vehicles in long tunnels unless turnouts are provided.

Roadway must be well graded and maintained to support weight and speed of vehicles.

Present design of vehicles uses excessive amounts of tunnel volume per ton of capacity, and does not provide the ability to operate in both directions equally well.

Inability to climb grades of 8 - 12% at adequate speeds.

Operator required for each vehicle.

Small clearances, high speeds, and massive equipment combine to produce long delays in case of malfunction, and serious injuries in event of accident.

Combustion products complicate ventilation unless vehicles are powered electrically.

MDN's 1 through 5 can be transported by free vehicles. Excessive tire wear could be expected in the MDN 1 and 2 range, due to angularity and abrasiveness of these materials. This system may not be practical for sites producing muck in the MDN 6 and 7 range because of traction and roadbed maintenance problems.

Semi-continuous systems in common use are belt conveyors, hydraulic, and pneumatic pipeline systems.

Belt conveyor capabilities and advantages include:

Possible installation overhead or at sides of tunnel leaves floor space for other uses.

Capacities can be increased by changing belt speed.

Conveyors can go up or down slopes to 22°.

Constraints on the system include:

Supplementary transportation which must be provided for incoming materials, and personnel.

Delays inherent as the conveyor is extended from a temporary to a semi-permanent installation.

All MDN's can be transported by conveyors. Excessive belt damage and wear can be expected in the 1 and 2 MDN range, because of piece size and shape, unless the material is crushed prior to being placed in the system. In the MDN 6 to 7 range, through a wide range of water occurrence, considerable material will stick to the belt causing excessive cleaning problems. In the entire MDN range it is mandatory that the water content be below the point where the muck will slip or flow on the belt, or overflow the sides.

Hydraulic pipeline capabilities and advantages include:

Capacities adequate for the tonnage from any tunnel in the foreseeable future.

Pipelines use very little space in the tunnel.

Especially adaptable to very wet sites and to hydraulic excavation systems.

Adaptable to any grade, including vertical.

System contraints are:

Capacity to handle plus 1" to plus 2" material through centrifugal pumps has not been demonstrated in field usage.

Crushing or scalping equipment for through-centrifugal pump systems, or lock-feed equipment for alternate designs may cause congestion in the near face area.

Large amounts of water are required.

Required electrical power may be difficult to provide for long tunnels in remote areas.

Dewatering, recirculation, and muck disposal systems may be elaborate.

For high advance rates, methods of advancing pumping units and pipelines must be developed.

The heat load from large electrical installations may be difficult to dissipate.

System malfunctions may be hazardous to personnel.

MDN 7 is best suited for pumping because of the low percentage of plus #4 material, and a high fines content. Preliminary screening and/or crushing would be needed for transporting all MDN's by a through-centrifugal pump system.

Pneumatic pipeline capabilities and advantages include:

Pipelines use very little space in the tunnel.

Adaptable to any grade, including vertical.

System constraints are:

Power requirements appear excessive.

Muck must be relatively dry.

Crushing or scalping equipment must be used if pieces are too large for system.

Pipe wear and maintenance may be excessive.

Secondary transportation must be provided for materials and personnel.

Methods of advancing blower units and pipe must be developed.

Dust at the discharge or from malfunctions may be hazardous to personnel.

MDN 7 is best suited for pneumatic systems because of the low percentage of plus #4 material and the high fines content. Preliminary screening and/or crushing would be needed for transporting all MDN's.

4. DOD IMPLICATIONS

Other investigations have shown that the data accumulated under the program are nonexistant in usable form elsewhere. While some tunnel boring machine (TBM) manufacturers and operators consider muck size an indicator of cutter efficiency, changes are noted during informal inspections at the machine, and are seldom recorded except as showing a need for cutter replacement. A few screen analyses have been run, but results normally are not made available outside of the manufacturer's organization.

The choice of transportation systems usually is based on availability and contractor familiarity with the equipment used at other sites. In some cases, the choice has been completely unsuitable for the muck produced. This has resulted in delays and additional expense which may be avoided by using the information collected under this program.

Previous investigations also have indicated that major modifications of conventional equipment, or design of completely new systems, will be necessary to dispose of the muck from the high speed excavation systems predicted for the future. Muck characteristic data is a requisite as a basis for the engineering design of system improvements, and should be used to indicate the areas in which research and development of new methods will be most productive.

5. IMPLICATIONS FOR FURTHER RESEARCH

The planned program for the first year's work provided for a third of the samples to be taken in each of the "High" and "Medium" strength rock classifications, and for the remainder to come from "Low" and "Very Low" classifications. This ratio was maintained, and four additional samples were taken from operations in rock classified "Very High" in strength. Lithologic classifications sampled to date include examples of relatively coarse grained igneous rocks, four types of metamorphic rocks, and three types of sedimentary rocks. Both conventional and machine operations were sampled in all categories except the metamorphic rocks. Rock types not yet sampled, including the stratified volcanic and the finer grained igneous rocks, should be sampled to provide data on these formations, and data on excavation by different methods in rocks previously sampled should be collected to provide comparative data.

The engineering and muck properties of rocks of the same lithologic type may vary over a wide range. To make the MDN concept a useful tool in the rapid excavation program, every opportunity should be taken to obtain data from as many new sites as possible in order to confirm a previous assignment of an MDN to a rock type, or to obtain data indicating that another category is justified.

Nearly one-third of the operations sampled were conventionally driven tunnels. While the major interest is in mechanical excavation, the most rapid progress is being made by conventional and shield methods. Therefore, it is believed that this ratio should be maintained to provide data from high speed materials handling systems.

Statistically, the reliability of data and conclusions is a function of the sampling frequency. For this reason, at least three specimens of the same rock have been tested whenever possible to provide engineering property information. Less than fifteen percent of the operations sampled have been resampled to improve the confidence level of the muck characteristic data. Subject to site availability, resampling is recommended.

Reference to other rock property research programs indicates that Young's modulus and Poisson's ratio may be important engineering properties to correlate with muck characteristics. Both can be determined from stress-strain data taken during compressive testing. Provision for collection of these data in the 1972 program has been recommended.

To provide other data which may be highly significant, provision for Schmidt hardness tests on rocks and abrasiveness tests on muck has been recommended as part of the continuing research.

Unusual rock breaking techniques now under development, such as the electron beam and the water cannon, may become standard practice in the future. Sampling muck from tests of these methods whenever possible is recommended.

6. SPECIAL COMMENTS

No equipment has been purchased or developed, nor has any invention been made in the course of the work performed under this contract.

GLOSSARY

ASTM	American Society for Testing and Materials	PMSRC	Pittsburgh Mining and Safety Research Center
BM	Beam	POT.	Potential
CFM	Cubic feet per minute	PCF	Pounds per cubic foot
COMPR.	Compressed	PSI	Pounds per square inch
CONTIN.	Continuous		
CY	Cubic Yard	Rect.	Rectangle
DEG.	Degrees	REG.	Regular
DIA.	Diameter	RBM	Raise Boring Machine
DUW	Dry Unit Weight	RPM	Revolutions per Minute
Est, (E)	Estimated	RQD	Rock Quality Designation
FWD	Four Wheel Drive		
GPM	Gallons per Minute	ST	Scoop Tram
HP	Horse Power	SPECIF.	Specific
HRS.	Hours	STRNTH.	Strength
IN.	Inch	TBM	Tunnel Boring Machine
Inter.	Internal	TC	Tungsten Carbide
K	Thousand	TCB	Tungsten Carbide Button
LBS	Pounds		
LT	Long Ton	T	Tentative
MDN	Muck Designation Number	T.	Ton
		V	Volt
MAX	Maximum	VOL	Volume
Moist.	Moisture	W/	With
MM	Millimeter	WT.	Weight
NA.	Not Available	'	Foot
NO.	Number	''	Inch
PCF	Pounds per Cubic Foot	#	Number
		%	Percent
PCT	Percent	(+)	Plus
PF	Powder Factor	(-)	Minus

APPENDIX A

TUNNEL LIST

TUNNEL PROJECTS

Compiled by Holmes & Narver, Inc., Anahiem, California, under U. S. Bureau of Mines, Contract HO210013. Revised 1 January 1972

NORTH AMERICAN CONTINENT

PROJECT & LOCATION	OWNER OR AGENCY	SIZE	LENGTH	CONTRACTOR
MINERAL CREEK DIVERSION TUNNEL Ray, Arizona	Kennecott Copper Corporation Ray Mines Div. Hayden, Arizona	16'x16' Excav. 15'x15' Lined	3.6 Miles	Fluor-Utah Engrg & Const Company

Excavation by conventional methods. Formations include 14 rock classifications, predominantly quartzite, shale, diabase, schist, altered granite, porphyry and dacite. Core specimens exist. Owner management has not approved core testing or muck sampling.

LAKESHORE MINE Casa Grande, Arizona	Hecla Mining Company - El Paso Natural Gas	14'x14' 14'x18' plus level development	7500' 7500'	Hecla Mining Co. -own force

The two 7500' headings are declines at a minus 15°, currently at about 6200' slope distance from the portal. Levels are being developed at 900' and 1400' vertically below the portal. Formations include mylonite, quartzite, tactite, and quartz monzonite. A raise boring machine has started a series of holes to the development levels.

NAST TUNNEL Fryingpan Project Merideth, Colorado	U.S. Bureau of Reclamation Denver, Colorado	10' Dia.	3 Miles	Peter Kiewit Sons Company

A Wirth boring machine, modified by installation of shields and a new cutter head, has completed about 1 mile of tunnel from the outlet portal. Formations penetrated are predominantly granite, granite gneiss, granite porphyry, and granodiorite with compressive strengths from 18,000 psi to 24,300 psi. Rock is highly sheared in zones from a few feet to 400' thick.

TUNNEL PROJECTS (continued)

PROJECT & LOCATION	OWNER OR AGENCY	SIZE	LENGTH	CONTRACTOR
TONNER #1 and #2 Brea, Cal.	The Metropolitan Water District of Southern Calif.	8' Dia. Lined	#1-4589' #2-19,360'	Up for bids Feb. 1972

Expected to be a shield operation in low strength sandstone and siltstone. Geologic data and cores are available from the owner agency.

HUNTER TUNNEL Fryingpan Project Merideth, Colorado	U.S. Bureau of Reclamation Denver, Colorado	10'x10'	4.4 Miles	Granite Construction Company

A conventional operation in formations similar to the Nast tunnel. Lithologic and Engineering property data has been collected from the U.S. Bureau of Reclamation.

FOGGY BOTTOM- ROSSLYN TUNNEL Section C-4 Washington, D.C.	W.M.A.T.A. Washington, D.C.	16'-8" Dia. Finished	4,000' each of two bores	S & M Constructors (E.W. Murphy)

Excavation by conventional methods in gneiss under the Potomac River. The schistose rock structure is reported to result in high shear strength and low compressive strength. Lithologic and Engineering property data has been collected from the W.M.A.T.A.

MT. GREENWOOD TUNNEL Chicago, Illinois	Dept. of Public Works, City of Chicago, Illinois	10'-4" Diameter	1.8 Miles	S. A. Healy

A new Robbins machine is being assembled for operation in limestone, reported similar to that in the Lawrence Avenue tunnel.

TUNNEL PROJECTS (continued)

PROJECT & LOCATION	OWNER OR AGENCY	SIZE	LENGTH	CONTRACTOR
WHITE PINE COPPER CO. White Pine, Michigan	Copper Range Company, New York, New York	18'-1" Diameter 18'x8½' Rect.	Various	Tunneling by White Pine with own force

A Robbins machine has been operating in sandstone since 1969, is now passing through a conglomerate horizon to reach the overlying shale. An Atlas-Copco machine is operating in the shale. Normal drifting is conventional. Existing rock property data includes compression, Brazilian tensile, and Shore hardness test results.

NEVADA TEST SITE Mercury, Nevada	U.S.A.E.C. and Defense Atomic Support Agency (DASA) Mercury, Nevada	Various.		Reynolds Electrical & Engineering Co.

Two conventional tunnels are operating. An Alpine Miner has been used on an experimental basis, and may provide an opportunity for comparison of the muck produced by the two systems. Formations are volcanic tuffs which vary from 600 to 4,500 psi in unconfined compressive strength. Engineering property data has been collected by the U.S. Geological Survey and by DASA.

NAVAJO IRRIGATION PROJECT Farmington, New Mexico	U.S. Bureau of Reclamation Denver, Colo.	20.5' Dia.	3 Miles	Fluor-Utah Engrg & Const Company

A Dresser boring machine is operating in sandstone with an unconfined compressive strength of less than 1000 psi, is expected to reach an 8000 psi sandstone as the tunnel advances.

SECTION 35 URANIUM MINE Grants (Ambrosia Lake)New Mexico	Kerr-McGee Corporation	10'x10' and 8'x8'	Various	Kerr-McGee own force

An Alpine Miner is operating in siltstone development headings, is expected to reach an underlying sandstone in which normal operations are conventional.

TUNNEL PROJECTS (continued)

PROJECT & LOCATION	OWNER OR AGENCY	SIZE	LENGTH	CONTRACTOR
CURRANT & LAYOUT TUNNELS Strawberry Aqueduct, Heber City, Utah	U.S. Bureau of Reclamation Denver, Colorado	10'-4" Dia.	Combined Length 4.9 miles	S. A. Healy

A Robbins boring machine has been operating in sandstone. Existing logs of 13 drill holes show lithology. Compressive strength test results, varying from 5,000 psi for a shale to over 38,000 psi in the conglomerate, have been provided by the Bureau of Reclamation. This tunnel has been stopped indefinitely pending provision of additional funds.

CONTR. 843 SEWER TUNNEL Milwaukee, Wisc.	City of Milwaukee	11'-2" Dia.	5000'	W.J. Lazynski Company

A Jarva boring machine is being rebuilt before starting a new contract on a lateral to the present tunnel in 1972.

GOLDEN GOOSE II URANIUM MINE Jeffrey City, Wyoming	Western Nuclear Inc.	8'x10'	Development Drifts	Owner Operated

An Alpine Miner equipped with a Serpentix conveyor is driving mining headings in soft sandstone. Conventional drifts are also being driven in similar formations.

NEW YORK CITY, N.Y., Contract #13	Dept/Public Works, NYC	11' Dia.	9200'	Perini-B & R-G.H. Ball-S & M Constructors, JV

Scheduled to start in January 1972 using a new Jarva boring machine. Formation is mica schist; compressive strength 15,000 to 30,000 psi. Cores and rock test data are reported to be available from the owner.

APPENDIX B

RAW DATA SHEETS

Identification	Page
MAST-1	B-1
MAST-2	B-2
MAST-3	B-3
MAST-4	B-4
CA-1	B-5
H-1	B-6
H-2	B-7
LK-1	B-8
LK-2	B-9
LK-5	B-10
LK-6	B-11
CL-1	B-12
LK-3	B-13
LK-4	B-14
MB-1	B-15
QL-1	B-16
5-1	B-17
7-2	B-18
11-3	B-19
11-4	B-20
LAW-2	B-21
LAW-3	B-22
LAW-4	B-23
MIL-1	B-24
MIL-2	B-25
LAY-1	B-26
NAV-1	B-27
NAV-2	B-28
WNG-1	B-29
WNG-2	B-30
SF-1	B-31
SF-2	B-32
KM-1	B-33

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST.	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
1	NAST SAMPLE NO NAST-1	IGNEOUS: GRANITE, GRAY, MEDIUM TO FINE GRAINED, MODERATELY TO SLIGHTLY FRACTURED AND JOINTED 10 TO 20 PCT QUARTZ, 50 TO 60 PCT FELDSPAR, BALANCE DARK MINERALS.	167	18	90	NA	NA	NA

ROCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
83	9.4	0.0	0.0	0.0	0.0	2.2	14.9	12.5	12.4	12.3	8.6	11.8	6.8		18.5

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

		PI	AI	AI	AI	AI	SI	S

POT VOL CHANGE (-)0.065 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.185IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	14.50	14.00	13.50	0.50	3.0	0.16

(-) 0.50IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-) 0.50 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 9.0 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 9.0 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 9.0 PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-)0.185 IN. ANGLE INTER FRICTION DEGREES AT 8.5 PCT MOIST
2.69	37	36	41	NA	NA	42

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
2	NAST SAMPLE NO NAST-2	IGNEOUS: GRANITE, GRAY, MEDIUM TO FINE GRAINED, MODERATELY TO SLIGHTLY FRACTURED AND JOINTED 10 TO 20 PCT QUARTZ 50 TO 60 PCT FELDSPAR BALANCE DARK MINERALS.	167	18	90	NA	NA	NA

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
76	10.8	0.0	0.0	0.0	0.8	8.0	25.0	13.8	11.5	10.3	6.6	7.7	5.5		10.8

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PI PI PI AI AI SI SI S

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	19.5	18.2	17.9	1.3	4.6	0.28

(-) 0.50IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-) 1.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 8.7 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 8.7 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 8.7 PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-)1.0 IN. ANGLE INTER FRICTION DEGREES AT 8.5 PCT MOIST
2.66	38	38	49	NA	NA	31

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
3	NAST SAMPLE NO NAST-3	IGNEOUS: BIOTITIC GRANITE FINE GRAINED. MAJOR QUARTZ. MINOR FELDSPAR AND DARK MINERAL CONTENT.	152	13	90	NA	NA	NA

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
117	3.4	14.5	16.2	6.2	12.6	10.7	8.9	5.8	5.3	6.1	2.6	2.8	1.5		3.8

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

AI	AI	AI	AI	AI	AI	AI	AI	AI	AI	AI	

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	19.50	17.41	17.13	2.09	4.10	0.51

(-) 0.75IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 2.8 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 2.8 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 2.8 PCT MOIST	APPARENT COHESION PSF AT 3.0 PCT MOIST	BULK DENSITY PCF AT 0.0 PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 3.0 PCT MOIST
2.65	39	36	31	80	91.2	38

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	ROD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
4	NAST SAMPLE NO NAST-4	IGNEOUS, GRANITE, FINE GRAINED MODERATELY FRACTURED, MAJOR QUARTZ AND MINOR FELDSPAR CONTENTS.	160	24	90	NA	NA	NA

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
83	17.2	0.0	0.0	0.0	0.0	11.5	20.6	13.6	12.7	11.0	14.5	4.4	5.8		5.9

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PI PI PI AI AI A A

POT VOL CHANGE (-)	IN.SIZE	ATTERBERG LIMITS..SIZE(-) IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX

(-) SPECIF GRAVITY	IN.SIZE	MATERIAL SIZE(-) IN. ANGLE/REPOSE 1 IN DROP DEGREES AT PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-) IN. ANGLE INTER FRICTION DEGREES AT PCT MOIST

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	ROD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
5	GRANITE ADIT	IGNEOUS: GRANITE, MASSIVE, MAJOR QUARTZ AND FELDSPAR, MINOR DARK MINERAL CONTENT.	161	35	96	NA	NA	NA
	SAMPLE NO GA-1							

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
114	1.9	4.7	17.9	12.2	10.3	11.7	14.4	6.6	5.6	5.6	3.7	3.6	0.2		3.5

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

AI AI AI AI AI AI AI AI AI AI AI

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	16.2	15.78	13.67	0.42	3.00	0.14

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 0.9 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 0.9 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 0.9 PCT MOIST	APPARENT COHESION PSF AT 0.9 PCT MOIST	BULK DENSITY PCF AT 0.0 PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 0.9 PCT MOIST
2.59	39	36	34	215	106	46

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	ROD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
6	HUNTER SAMPLE NO M-1	IGNEOUS: GRANITE, GRAY, FINE GRAINED, MODERATELY JOINTED, WITH 1.5 TO 2 FT BANDS OF LIGHT TAN PEGMATITE AND LAMINATED GRANITIC GNEISS.	163	32	80	NA	NA	NA

MUCK DATA DRY WT	UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
107		3.4	14.3	6.8	12.7	13.2	13.6	12.9	5.7	4.3	4.1	3.0	3.8	2.2		3.4

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

AI AI AI AI AI AI AI AI AI AI AI

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	18.0	17.0	13.4	1.0	4.4	0.23

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 1.3 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 1.3 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 1.3 PCT MOIST	APPARENT COMESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 2.2 PCT MOIST
2.70	40	37	32	NA	NA	44

M-1 CURRENT: 11 JAN. 1972

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
7	HUNTER SAMPLE NO H-2	IGNEOUS: GRANITE GRAY, GNEISSIC, MODERATELY JOINTED.	164	39	88	NA	NA	NA

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
109	3.4	7.3	11.7	18.2	19.3	11.6	9.3	4.8	4.2	4.5	3.4	1.3	1.1		3.3

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

AI	AI	AI	AI	AI	AI	AI	AI	AI	AI	AI	

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	18.10	17.95	11.00	0.15	3.20	0.04

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 3.8 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 3.8 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 3.8 PCT MOIST	APPARENT COHESION PSF AT 2.6 PCT MOIST	BULK DENSITY PCF AT 0.0 PCT MOIST	SIZE(-)2.00 IN. ANGLE INTER FRICTION DEGREES AT 2.6 PCT MOIST
2.60	38	35	38	30	105	44

H-2 CURRENT: 11 JAN. 1972

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	ROD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
8	LK SAMPLE NO LK-1	IGNEOUS. BIOTITIC QUARTZ MONZONITE. FINE TO MEDIUM GRAINED PORPHYRY.	162	25	83	NA	NA	NA

MUCK DATA DRY WT	UNIT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
102		0.4	66.8	13.8	5.9	5.0	3.8	2.0	0.7	0.5	0.4	0.3	0.3	0.1		0.4

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

AI	AI	AI	AI	AI	AI	AI	AI	AI	AI	AI

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	18.10	17.98	17.69	0.12	3.90	0.30

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 0.8 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 0.8 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 0.8 PCT MOIST	APPARENT COHESION PSF AT 0.4 PCT MOIST	BULK DENSITY PCF AT 0.0 PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 0.4 PCT MOIST
2.85	33	30	29	435	97.3	43

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
9	LK SAMPLE NO LK-2	IGNEOUS: BIOTITIC QUARTZ MONZONITE, FINE TO MEDIUM GRAINED PORPHYRY, WITH MINOR STEEPLY INCLINED JOINTS.	165	28	83	NA	NA	NA

MUCK DATA DRY WT	UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
103		1.6	49.1	16.9	8.7	5.8	5.5	5.3	2.0	1.8	1.3	1.0	0.8	0.5		1.3

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

AI	AI	AI	AI	AI	AI	AI	AI	AI	AI	AI

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	20.50	19.14	17.29	0.36	6.2	0.058

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 4.7 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 4.7 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 4.7 PCT MOIST	APPARENT COHESION PSF AT 4.9 PCT MOIST	BULK DENSITY PCF AT 0.0 PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 4.9 PCT MOIST
2.73	43	42	33	210	97.6	39

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
10	LK SAMPLE NO LK-5	IGNEOUS: BIOTITIC QUARTZ MONZONITE, FINE TO MEDIUM GRAINED PORPHYRY	165	32	92	NA	NA	NA

MUCK DATA DRY WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
94	16.8	0.0	0.0	0.0	13.0	14.0	20.0	7.0	8.0	8.0	8.0	6.0	5.0		11.0

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PE	PI	PI	A	A	A	A	A

POT VOL CHANGE (-)	IN.SIZE	ATTERBERG LIMITS..SIZE(-) IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX

(-) SPECIF GRAVITY	IN.SIZE	MATERIAL SIZE(-) IN. ANGLE/REPOSE 1 IN DROP DEGREES AT PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-) IN. ANGLE INTER FRICTION DEGREES AT PCT MOIST

LK-5 CURRENT: 11 JAN. 1972

KEY	IDENTIFICATION	ROCK PROPERTIES
11	LK	IGNFOUS: BIOTITIC QUARTZ MONZONITE, FINE TO MEDIUM GRAINED PORPHYRY, FREQUENT FLAT ANGLED JOINTS.
	SAMPLE NO LK-6	

DRY WT PCF	COMPR STRNTH KPSI EST	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
137	15	86	NA	NA	NA

TEST SPECIMENS BROKE ALONG JOINTS DURING PREPARATION.

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
90	16.8	9.0	0.0	0.0	1.0	9.0	19.0	12.0	11.0	11.0	8.0	7.0	6.0		16.0

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

NA

POT VOL CHANGE (-)	IN.SIZE	ATTERBERG LIMITS..SIZE(-) IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX

(-) SPECIF GRAVITY	IN.SIZE	MATERIAL SIZE(-) IN. ANGLE/REPOSE 1 IN DROP DEGREES AT PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-) IN. ANGLE INTER FRICTION DEGREES AT PCT MOIST

LK-6 CURRENT: 11 JAN. 1972

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
12	CLIMAX	METAMORPHIC: GRANITIC GNEISS. HIGHLY METAMORPHOSED.						
	SAMPLE NO CL-1	MODERATELY TO HIGHLY FRACTURED. HIGHLY SILICIFIED.	174	9	10	NA	NA	NA

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
87	8.8	0.0	0.0	0.0	0.0	4.8	37.8	18.1	11.2	8.5	6.8	5.6	5.4		1.8

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

AI AI AI AI AI AI AI

POT VOL CHANGE (-)	IN.SIZE	ATTERBERG LIMITS..SIZE(-) IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
NA		NA	NA	NA	NA	NA	NA

(-) SPECIF GRAVITY	IN.SIZE	MATERIAL SIZE(-) IN. ANGLE/REPOSE 1 IN DROP DEGREES AT PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-) IN. ANGLE INTER FRICTION DEGREES AT PCT MOIST
NA		NA	NA	NA	NA	NA	NA

CL-1 CURRENT: 11 JAN. 1972

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
13	LK SAMPLE NO LK-3	METAMORPHIC: INTERLAYERED TRANSITION BETWEEN QUARTZITE AND TACTITE. MODERATELY TO STRONGLY ALTERED METASEDIMENTS WITH REPLACEMENT PYRITE. CHALCOPYRITE AND MAGNETITE AND A HIGH PERCENTAGE OF SILICATES VERY FINE TO MEDIUM GRAINED.	178	26	80	NA	NA	NA

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
105	0.1	34.1	17.4	9.1	10.2	10.6	8.7	2.8	1.6	1.2	0.8	0.8	0.4		2.3

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

AI	AI	AI	AI	AI	AI	AI	AI	AI	AI	AI	

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LINIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	18.25	17.92	17.80	0.33	5.50	0.06

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 1.5 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 1.5 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 1.5 PCT MOIST	APPARENT COHESION PSF AT 0.4 PCT MOIST	BULK DENSITY PCF AT 0.0 PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 0.4 PCT MOIST
3.21	30	29	29	175	117.8	41

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI EST	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
14	LK SAMPLE NO LK-4	METAMORPHIC: TACTITE STRONGLY ALTERED CALCAREOUS METASEDIMENTS, WITH REPLACEMENT PYRITE, CHALCOPYRITE AND MAGNETITE AND A HIGH PERCENTAGE OF SILICATES, FINE TO VERY FINE GRAINED.	181	15 TEST SPECIMENS BROKE ALONG STEEP INCLINED JOINTS DURING PREPARATION.	78	NA	NA	NA

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
124	1.3	27.7	19.4	13.4	13.4	9.5	7.2	1.6	1.6	1.2	0.7	0.8	0.7		2.8

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

	AI	AI	AI	AI	AI	AI	AI	AI	AI	AI	AI

POT VOL CHANGE (-)	IN.SIZE	ATTERBERG LIMITS..SIZE(-) IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX

(-) SPECIF GRAVITY	IN.SIZE	MATERIAL SIZE(-) IN. ANGLE/REPOSE 1 IN DROP DEGREES AT PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-) IN. ANGLE INTER FRICTION DEGREES AT PCT MOIST

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	ROD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
15	MATHER B	METAMORPHIC: INTER LAYERED BANDS HEMATITE AND MARTITE						
	SAMPLE NO MB-1	HIGHLY JOINTED NORMALLY FLAT LYING. OFTEN HIGHLY FOLDED.						
		NATURAL IRON OVER 60 PCT	207	7	10	NA	NA	NA
		MOISTURE 9 PCT. SILICA 5 PCT.						

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
128	7.2	7.2	9.7	1.4	8.7	11.4	20.1	10.3	7.4	3.3	1.8	1.3	1.1		16.3

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

AI	AI	AI	AI	AI	AI	AI	AI	AI	AI	AI	

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	17.8	15.1	13.9	2.7	4.1	0.66

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 6.2 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 6.2 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 6.2 PCT MOIST	APPARENT COHESION PSF AT 6.9 PCT MOIST	BULK DENSITY PCF AT 0.0 PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 6.9 PCT MOIST
4.34	37	35	31	235	141	35

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
16	QUEEN LANE	METAMORPHIC: GRAY MICA SCHIST OCCASIONAL QUARTZ SEAMS. MICA VARIES FROM DENSE. FINE GRAINED TO EXTREMELY COARSE.	165	11	30	NA	NA	NA
	SAMPLE NO QL-1							

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
108	9.0	0.0	0.0	0.0	7.6	17.0	13.4	4.5	4.9	5.4	8.4	10.2	7.7		20.9

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PE PE PI PI PI PI PI PI

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	24.0	23.3	22.7	0.7	4.0	0.17

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 9.8 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 9.8 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 8.4 PCT MOIST	APPARENT COHESION PSF AT 9.3 PCT MOIST	BULK DENSITY PCF AT 8.0 PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 9.3 PCT MOIST
2.57	39	37	40	125	75	30

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
17	S-1	SEDIMENTARY: SANDSTONE FINE GRAINED, WELL COMPACTED, LIGHT BROWN OVER 50 PCT QUARTZ.	171	16	92	61	NA	NA
	SAMPLE NO S-1							

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
83	5.4	0.0	0.0	0.0	33.8	20.9	15.5	4.4	2.7	1.3	1.1	3.5	5.0		11.8

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PI	PI	PI	PI	PI	A	A	A

POT VOL CHANGE (-)0.065 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.185IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	16.90	15.50	15.18	1.40	5.0	0.28

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 6.3 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 6.3 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 6.3 PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 4.8 PCT MOIST
2.73	35	29	28	NA	NA	29

S-1 CURRENT: 11 JAN. 1972

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
18	7-2 SAMPLE NO 7-2	SEDIMENTARY: SANDSTONE FINE GRAINED. WELL COMPACTED. LIGHT BROWN. OVER 50 PCT QUARTZ.	171	16	92	61	NA	NA

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
90	4.0	0.0	1.5	0.9	33.1	22.6	15.4	4.3	2.6	1.4	1.2	2.5	3.8		10.7

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SF=SPHEROID

PI	PI	PI	PI	PI	PI	PI	A	A	A

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	23.0	17.63	17.58	5.37	6.90	0.78

(-)3" IS IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 2.6 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 2.6 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 2.6 PCT MOIST	APPARENT COHESION PSF AT 2.8 PCT MOIST	BULK DENSITY PCF AT 0.0 PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 2.8 PCT MOIST
2.63	32	31	29	0	92.8	44

7-2 CURRENT: 11 JAN. 1972

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
19	11-3	SEDIMENTARY: SHALE. MASSIVE TO THINLY LAMINATED. INTERBEDDED SILTSTONE AND SHALE. WITH MINOR SANDSTONE AND LIMESTONE LAYERS. GRAIN SIZE FINE TO COARSE. QUARTZ 24 TO 33 PCT.	152	4 MAJOR BEDS 22 TO 29. 2 MINOR BEDS 15 TO 17.	90	PARALLEL 41-55. NORMAL 41-54.	NA	NA

SAMPLE NO
11-3

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
99	1.1	7.8	12.6	11.3	14.4	14.9	16.4	5.7	3.5	2.0	1.4	1.1	0.9		8.0

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PA PA PA PA PA A A A A A

POT VOL CHANGE (-)	IN.SIZE	ATTERBERG LIMITS..SIZE(-) IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX

(-) SPECIF GRAVITY	IN.SIZE	MATERIAL SIZE(-) IN. ANGLE/REPOSE 1 IN DROP DEGREES AT PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-) IN. ANGLE INTER FRICTION DEGREES AT PCT MOIST

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	MOH	SCHMIDT
20	11-4	SEDIMENTARY: SHALE. MASSIVE TO THINLY LAMINATED. INTERBEDDED SILTSTONE AND SHALE WITH MINOR SANDSTONE AND LIMESTONE LAYERS GRAIN SIZE FINE TO COARSE. QUARTZ 24 TO 33 PCT.	166	4 MAJOR BEDS 22 TO 29. 2 MINOR BEDS 15 TO 17.	90	PARALLEL 41-55. NORMAL 41-54.	NA	NA

SAMPLE NO
11-4

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
96	1.1	8.2	17.7	17.0	19.3	15.7	12.7	3.4	2.5	1.2	0.6	0.2	0.2		1.3

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PA PA PA PA PA PA PA PA A A A

POT VOL CHANGE (-)	IN.SIZE	ATTERBERG LIMITS..SIZE(-) IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX

(-) SPECIF GRAVITY	IN.SIZE	MATERIAL SIZE(-) IN. ANGLE/REPOSE 1 IN DROP DEGREES AT PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-) IN. ANGLE INTER FRICTION DEGREES AT PCT MOIST

11-4

CURRENT: 11 JAN. 1972

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	ROD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
21	LAWRENCE SAMPLE NO LAW-2	SEDIMENTARY: LIMESTONE LIGHT TO MEDIUM GRAY FINE GRAINED, SOME CHERT NODULES, TRACES TO OCCASIONAL CLAY PARTINGS	176	8	100	46	NA	NA

MUCK DATA DRY WT	UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
92		7.2	0.0	0.0	3.0	25.0	18.0	22.1	9.4	6.5	3.5	2.0	1.8	0.8		7.9

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

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POT VOL CHANGE (-)0.065 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.185IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	12.5	12.3	9.6	0.2	4.0	0.05

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 5.4 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 5.4 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 5.4 PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 7 PCT MOIST
2.83	39	38	31	NA	NA	30

LAW-2 CURRENT: 11 JAN. 1972

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
22	LAWRENCE SAMPLE NO LAW-3	SEDIMENTARY: LIMESTONE LIGHT TO MEDIUM GRAY, FINE GRAINED, SOME CHERT NODULES, TRACES TO OCCASIONAL CLAY PARTINGS.	176	8	100	46	NA	NA

MUCK DATA DRY WT	UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
93		5.5	0.0	0.0	4.3	25.9	19.6	20.2	7.4	5.0	3.5	1.8	1.3	1.1		9.9

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PAI	PAI	PI	PAI	I	I	I	I	I	

PO. VOL CHANGE (-)0.065 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.185IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0.	11.8	10.6	10.0	1.2	2.9	0.41

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 6.1 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 6.1 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 8.4 PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 7 PCT MOIST
2.80	41	40	38	NA	NA	32

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
23	LAWRENCE SAMPLE NO LAW-4	SEDIMENTARY: LIMESTONE LIGHT TO MEDIUM GRAY FINE GRAINED. SOME CHERT NODULES. TRACES TO OCCASIONAL CLAY PARTINGS.	176	13	100	46	NA	NA

MUCK DATA DRY WT	UNIT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
80	7.9	0.0	0.0	5.0	18.3	18.3	17.0	7.3	5.1	3.4	5.5	3.8	2.0	14.3		

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PI	PI	PI	PI	PI	PI	PA	PA	A

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	20.2	20.0	13.5	0.2	4.7	0.05

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 8.9 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 8.9 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 8.9 PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 8.8 PCT MOIST
2.73	42	34	37	NA	NA	28

LAW-4 CURRENT: 11 JAN. 1972

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
24	MILWAUKEE SAMPLE NO MIL-1	SEDIMENTARY: LIMESTONE. GRAY FINE GRAINED. HORIZONTAL JOINT SPACING 6 IN. TO 1 FOOT.	166	36	85	NA	NA	NA

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
89	5.5	0.0	0.0	0.0	14.5	28.0	24.0	8.2	6.2	4.8	4.2	2.0	0.5		7.6

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PE PI PI PI PA S S S

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC. LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	16.90	15.69	15.46	1.21	5.00	0.24

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 2.5 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 2.5 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 2.5 PCT MOIST	APPARENT COHESION PSF AT 4.1 PCT MOIST	BULK DENSITY PCF AT 0.0 PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 3.5 PCT MOIST
2.89	36	35	30	95	86	35

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
25	MILWAUKEE	SEDIMENTARY: LIMESTONE, GRAY, FINE GRAINED, HORIZONTAL JOINT SPACING 6 IN. TO 1 FOOT.	166	36	85	NA	NA	NA
	SAMPLE NO MIL-2							

MUCK DATA DRY WT	UNIT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
89		6.1	0.0	0.0	0.0	9.2	24.7	22.8	11.5	6.8	4.9	2.7	1.2	7.6		8.6

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

		PE	PI	PI	PI	PR	S	S	S

POT VOL CHANGE (-)	IN.SIZE	ATTERBERG LIMITS..SIZE(-) IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX

(-) SPECIF GRAVITY	IN.SIZE	MATERIAL SIZE(-) IN. ANGLE/REPOSE 1 IN DROP DEGREES AT PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-) IN. ANGLE INTER FRICTION DEGREES AT PCT MOIST

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
26	LAYOUT SAMPLE NO LAY-1	SEDIMENTARY: SANDSTONE MEDIUM GRAINED. LIGHT BROWN TO RED. MASSIVE. POROUS. POORLY CEMENTED.	150	10	84	NA	NA	NA

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
105	4.1	0.0	7.6	7.5	5.7	12.0	12.6	4.6	3.4	2.7	1.8	15.4	1.0		25.7

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

	PI	PI	PI	PI	A	A	A	A	A	A

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	21.20	17.06	15.17	3.14	6.00	0.52

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 3.6 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 3.6 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 3.6 PCT MOIST	APPARENT COHESION PSF AT 3.6 PCT MOIST	BULK DENSITY PCF AT 0.0 PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 3.6 PCT MOIST
2.66	37	35	27	210	97.4	38

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
27	NAVAJO	SEDIMENTARY= SILTSTONE, FINE GRAINED, GRAY, MORE THAN 33 PCT QUARTZ, 30 PCT CLAY, 10 PCT FELDSPAR, 15 PCT MICA, CHLORITE AND GYPSUM.	142	2	70	NA	NA	NA
	SAMPLE NO NAV-1							

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
86	8.1	0.0	12.1	7.4	6.9	5.9	2.2	0.6	1.3	1.8	2.1	5.9	9.3		44.5
		0.0	19.1	6.8	23.0	19.0									

SCREEN ANALYSIS: UPPER LINE, DRY SCREENED (ASTM C136), AFTER WASHING (ASTM C117), LOWER LINE, SCREENED BEFORE DRYING

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PI	PI	PI	PI	AI	SI	S	S	A	A	A

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
1.3	36.80	23.61	21.04	13.19	7.00	1.88

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 7.7 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 7.7 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 7.7 PCT MOIST	APPARENT COHESION PSF AT 7.5 PCT MOIST	BULK DENSITY PCF AT 0.0 PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 7.5 PCT MOIST
3.13	30	30	30	340	98	36

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
28	NAVAJO SAMPLE NO NAV-2	SEDIMENTARY: SANDSTONE GRAY MEDIUM GRAINED. MASSIVE. FRIABLE AND POROUS. GRAINS ANGULAR TO SUBROUNDED. PRIMARILY QUARTZ. POORLY CEMENTED.	117	LESS THAN 1.	60	NA	NA	NA

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
87	8.2	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.4	1.3 12.6	2.5 19.6	2.3	11.8	23.2	12.7	10.0	7.1		29.1

SCREEN ANALYSIS: UPPER LINE. DRY SCREENED (ASTM C136). AFTER WASHING (ASTM C117). LOWER LINE. SCREENED BEFORE DRYING

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

AI AI A AI AI RE AI A A A

POT VOL CHANGE (-)	IN.SIZE	ATTERBERG LIMITS..SIZE(-) IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX

(-) SPECIF GRAVITY	IN.SIZE	MATERIAL SIZE(-) IN. ANGLE/REPOSE 1 IN DROP DEGREES AT PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-) IN. ANGLE INTER FRICTION DEGREES AT PCT MOIST

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
29	WESTERN NUCLEAR SAMPLE NO WNG-1	SEDIMENTARY: SANDSTONE COARSE GRAINED, POORLY CONSOLIDATED, ARKOSIC, WITH MINOR LAYERS OF THIN SEAMED SILTSTONE.	125	LESS THAN 1.	30	NA	NA	NA

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
82	10.5	0.0	0.0	6.0	0.0	1.0	2.0	5.0	12.0	17.0	16.0	14.0	8.1		24.9
		0.0	6.9	3.3	15.7	11.7									

SCREEN ANALYSIS: UPPER LINE, DRY SCREENED (ASTM C136), AFTER WASHING (ASTM C117), LOWER LINE, SCREENED BEFORE DRYING

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

AE	AE	AE	S	A	A	A	A	A	A	

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	24.90	19.97	19.94	4.93	7.40	0.66

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 10.1 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 10.1 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 10.0 PCT MOIST	APPARENT COHESION PSF AT 10.6 PCT MOIST	BULK DENSITY PCF AT 8.0 PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 10.6 PCT MOIST
2.71	34	31	32	0	85	27

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
30	WESTERN NUCLEAR SAMPLE NO WNG-2	SEDIMENTARY: SANDSTONE COARSE GRAINED. POORLY CONSOLIDATED. ARKOSIC. WITH MINOR LAYERS OF THIN SEAMED SILTSTONE. VARYING CONCENTRATIONS OF CARBONIFEROUS MATERIAL REPLACED BY SILICA.	125	LESS THAN 1.	30	NA	NA	NA

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
83	8.3	0.0	0.0	0.0	0.0	2.0	4.0	5.0	11.0	16.0	16.0	18.0	7.9		20.1
		0.0	8.7	5.4	7.9	7.3									

SCREEN ANALYSIS: UPPER LINE. DRY SCREENED (ASTM C136). AFTER WASHING (ASTM C117). LOWER LINE. SCREENED BEFORE DRYING

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

AE	AE	AE	S	A	A	A	A	A	A

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	25.25	24.74	23.37	0.51	4.00	0.13

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)2.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 9.0 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 9.0 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 9.0 PCT MOIST	APPARENT COHESION PSF AT 9.0 PCT MOIST	BULK DENSITY PCF AT 0.0 PCT MOIST	SIZE(-)2.0 IN. ANGLE INTER FRICTION DEGREES AT 9.0 PCT MOIST
2.72	32	31	40	0	86	28

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
31	SAN FERNANDO SAMPLE NO SF-1	SEDIMENTARY: SANDSTONE ARKOSIC IRREGULARLY BEDDED. LOOSELY CONSOLIDATED WITH LAYERS AND LENSES OF SILTY MUDSTONE.	113	LESS THAN 1.	0-35	NA	NA	NA

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
91	18.5	0.0	0.0	0.0	0.0	2.2	4.5	6.1	5.1	7.0	11.5	14.4	12.8		36.4

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

RE SE AI AI AI AI A

POT VOL CHANGE (-)0.065 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.185IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	17.75	16.19	13.94	1.56	5.8	0.27

(-)0.185IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)0.185 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 14.3 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 14.3 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 12.5 PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-)0.185 IN. ANGLE INTER FRICTION DEGREES AT 13.0 PCT MOIST
2.86	38	33	36	NA	NA	42

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRGTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
32	SAN FERNANDO SAMPLE NO SF-2	SEDIMENTARY: SANDSTONE AND BIOTITE RICH SILTSTONE. POORLY TO WELL CONSOLIDATED. POORLY TO WELL SORTED.	142	2	50	NA	NA	NA

MUCK DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
80	17.5	0.0 10	0.0 10	0.0	8.6	14.4	34.6	0.5	0.6	0.8	1.5	9.5	10.5	19.0	

SCREEN ANALYSIS: UPPER LINE. DRY SCREENED (ASTM C136). AFTER WASHING (ASTM C117). LOWER LINE. SCREENED BEFORE DRYING

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PE	PE	NA	R	RS	SI	SI	SI	SI	SI	SI

POT VOL CHANGE (-)0.056 IN.SIZE	ATTERBERG LIMITS..SIZE(-) 0.056IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX
0	31.5	26.8	21.5	4.7	7.6	0.61

(-)0.75 IN.SIZE SPECIF GRAVITY	MATERIAL SIZE(-)1.0 IN. ANGLE/REPOSE 1 IN DROP DEGREES AT 15.1 PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT 15.1 PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT 15.1 PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-)1.0 IN. ANGLE INTER FRICTION DEGREES AT 15 PCT MOIST
3.02	38	36	30	NA	NA	27

SF-2 CURRENT: 11 JAN. 1972

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT EST	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
33	KERR-MCGEE SAMPLE NO KM-1	SEDIMENTARY: MUDSTONE, DARK GRAY, FINE GRAINED, MASSIVE.	144	11	90	NA	NA	NA

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN.SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN.	3IN.	2IN.	1IN.	1/2IN.	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
81	9.4	0.0 46.7	0.0 20.1	5.9 8.4	1.9 11.0	5.2 6.4	28.9 3.3	0.3	1.3	2.7	5.4	6.3	12.5		29.6

SCREEN ANALYSIS: UPPER LINE, DRY SCREENED (ASTM C136), AFTER WASHING (ASTM C117), LOWER LINE, SCREENED BEFORE DRYING

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PE	PE	PI	PI	PI	A	A	A	A	A	A

POT VOL CHANGE (-)	IN.SIZE	ATTERBERG LIMITS..SIZE(-) IN. LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY INDEX PCT	FLOW INDEX	TOUGHNESS INDEX

(-) SPECIF GRAVITY	IN.SIZE	MATERIAL SIZE(-) IN. ANGLE/REPOSE 1 IN DROP DEGREES AT PCT MOIST	ANGLE/REPOSE 10 IN DROP DEGREES AT PCT MOIST	ANGLE/SLIDE STEEL PLATE DEGREES AT PCT MOIST	APPARENT COHESION PSF AT PCT MOIST	BULK DENSITY PCF AT PCT MOIST	SIZE(-) IN. ANGLE INTER FRICTION DEGREES AT PCT MOIST

APPENDIX C

[illegible] DATA SHEETS

ROCK DATA:

Lithology: Igneous, granite, gray, medium to fine grained, moderately to slightly fractured and jointed, 10 to 20% quartz, 50 to 60% feldspar, balance dark minerals.
Uniaxial Compressive Strength: 18 KPSI.
RQD: (Estimated) 90%.
Dry Unit Weight: 167 PCF.
Ground Water: Minor, primarily from fault zones.
Hardness: NA 1-11-72.

TUNNEL DATA:

Size: 9' 9" diameter. Grade: (+) 0.22%.
Ventilation System: 10 KCFM, exhaust, 22" pipe to rear of conveyor, 16" to face.
Utility System: 6" air line, 2" water line, 6" pump line.
Water Inflow: 5 to 20 gpm.
Power System: 4160/480V.
Haulage System: Muck, personnel, supplies by rail cars, 36" gage, 70# rail.
Support System: 4" ring and half sets, at 4', 3' and 2' centers in bad ground, 13" wide x 10' - 16 gage plates secured by 4-1" x 7' grouted bolts as required.

EXCAVATION DATA:

Machine: Wirth Erkelenz, Hardrock Model. Weight: 67 tons.
Cutters: 25 Hughes Tool/Wirth Tungsten Carbide Button. Gage: 6-11 1/2" TCB roller. Interior: 15-11 1/2" TCB roller. Center: 2-11 1/2" roller and 2-11 1/2" TCB Cone.
Rotation: Head, 8 to 11 RPM.
Torque: 600 HP.
Thrust: 500 K lbs.
Muck System: Bucket from face, 22" belt conveyor to rear.
Power System: 3-200 HP electric motor driven hydraulic pumps driving hydraulic motors.
Guidance System: Laser.

MDN STUDY SYSTEM DATA SHEET T-M5 Ident. No. NAST-1 Sheet 1

MUCK DATA

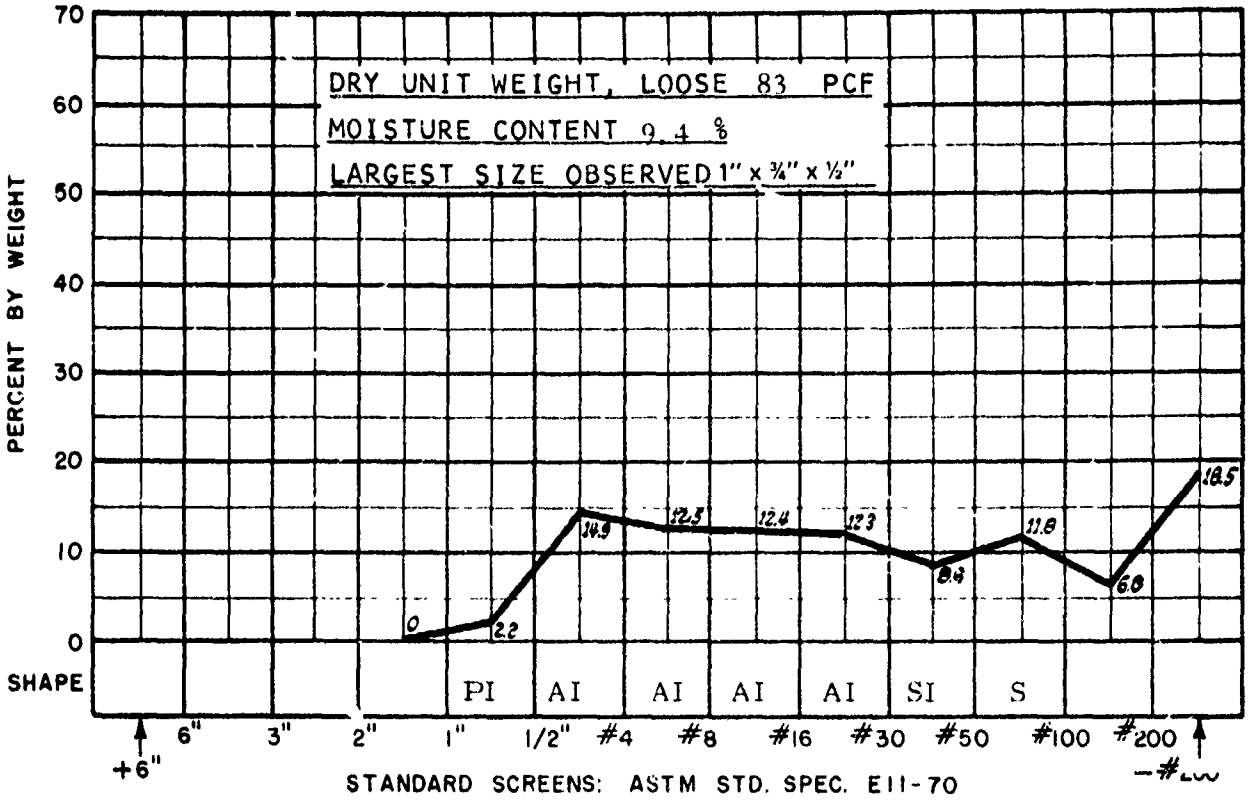
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size-0.065" : 0	Size - 0.50" : 2.69

ATTERBERG LIMITS, MATERIAL SIZE (-)0.185 IN.

Liquid Limit 14.50%	Plastic Limit 14.00%	Shrinkage Limit 13.50%
Plasticity Index 0.50 %	Toughness Index 0.16	Flow Index 3.0

MATERIAL SIZE (-)0.50 IN.

Angle/Repose 1 In. Drop @ 9.0% Moisture, 37°	Apparent Cohesion PSF @ % Moisture, NA	Angle/Repose 10 In. Drop @ 9.0% Moisture, 36°
Angle Slide Steel Plate @ 9.0% Moisture, 41°	Bulk Density PCF @ % Moisture, NA	Angle Internal Friction @ 8.5% Moisture, 42°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Igneous: Granite, moderately to slightly fractured and jointed. Medium to fine grained. High strength. RQD (Est.) 90%. DUW: 167 PCF. Ground water: Minor. Hardness: NA.

System Class: TBM, Wirth Erkelenz, Hardrock, 9'9" diam. 25 Hughes Tool/ Wirth TCBI roller and cone cutters. RPM: 8-11, 600 HP Torque, 500 K# Thrust. Mucking: Buckets to belt. Haulage: Rail. Support: Steel ring and half sets, roofplates and rock bolts.

MDN STUDY SYSTEM DATA SHEET MDN T-M5 Ident. No. NAST-1 Sheet 2

ROCK DATA:

Lithology: Igneous, granite, gray, medium to fine grained, moderately to slightly fractured and jointed, 10% to 20% quartz, 50% to 60% feldspar, balance dark minerals.
Uniaxial Compressive Strength: 18 KPSI.
RQD: (Estimated) 90%.
Dry Unit Weight: 167 PCF.
Ground Water: Minor, primarily from fault zones.
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 9'9" diameter. Grade: (+) 0.22%.
Ventilation System: 10 KCFM, exhaust, 22" pipe to rear of conveyor, 16" to face.
Utility System: 6" air line, 2" water line, 6" pump line.
Water Inflow: 5 to 20 gpm.
Power System: 4160/480V.
Haulage System: Muck, personnel, supplies by rail cars, 36" gage 70# rail.
Support System: 4" ring and half sets, at 4', 3' and -' centers in bad ground (approximately 650'), 13" wide x 10' - 16 gage plates secured by 4-1" x 7' grouted bolts as required, (approximately 1200').

EXCAVATION DATA:

Machine: Wirth Erkelenz, Hardrock Model. Weight 67 tons.
Cutters: 25 Hughes Tool/Wirth Tungsten Carbide Button. Gage: 6-11 1/2" TCB roller. Interior: 15-11 1/2" TCB roller. Center: 2-11 1/2" roller and 2-11 1/2" TCB cone.
Rotation: 8 to 11 RPM.
Torque: 600 HP
Thrust: 500 K lbs
Muck System: Bucket from face, 22" belt conveyor to rear.
Power System: 3-200 HP electric motor driven hydraulic pumps driving hydraulic motors and cylinders.
Guidance System: Laser.

MDN STUDY SYSTEM DATA SHEET T-M5 Ident. No. NAST-2 Sheet 1

MUCK DATA

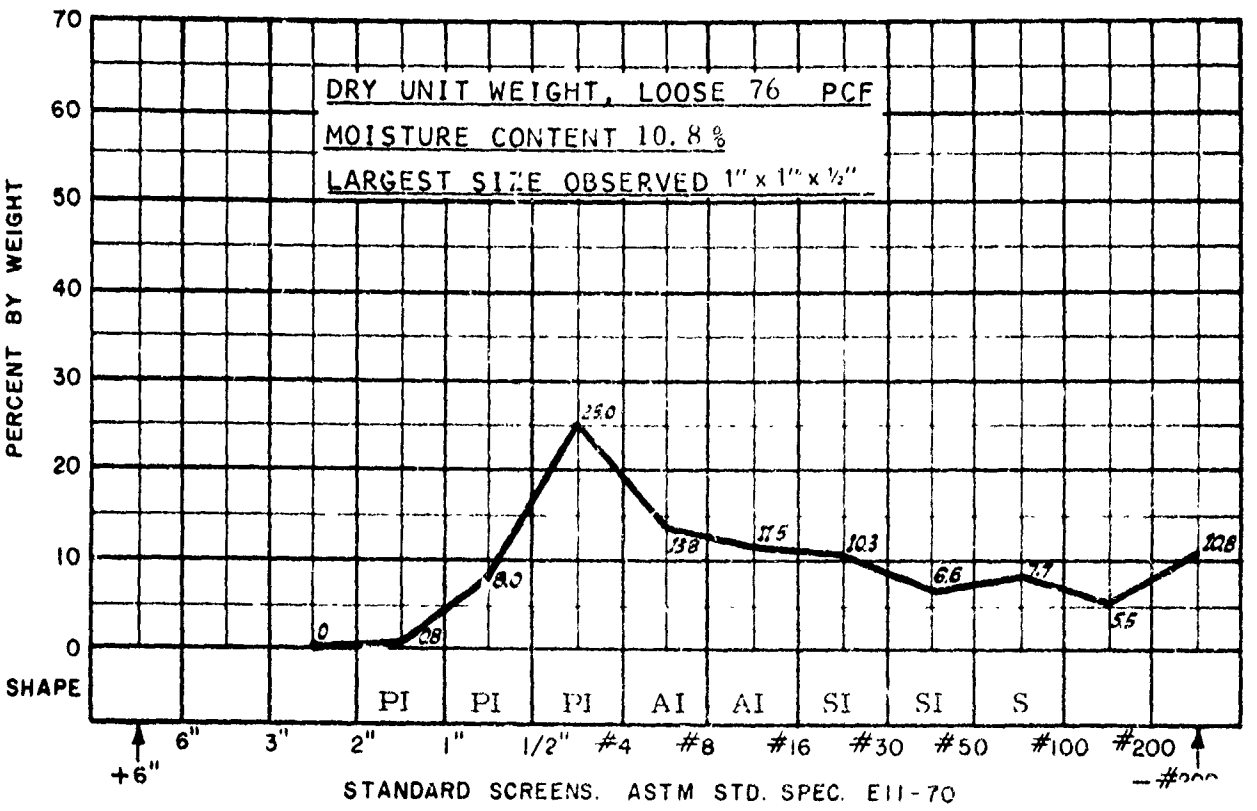
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size- 0.056" : 0	Size - 0.50" : 2.66

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 19.5 %	Plastic Limit 18.2 %	Shrinkage Limit 17.9 %
Plasticity Index 1.3 %	Toughness Index 0.28	Flow Index 4.6

MATERIAL SIZE (-)1.0 IN.

Angle/Repose 1 In. Drop @ 8.7 % Moisture, 38°	Apparent Cohesion PSF @ % Moisture, NA	Angle/Repose 10 In. Drop @ 8.7% Moisture, 38°
Angle Slide Steel Plate @ 8.7 % Moisture, 49°	Bulk Density PCF @ % Moisture, NA	Angle Internal Friction @ 8.5% Moisture, 31°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Igneous: Granite, medium to fine grained, moderately to slightly fractured and jointed. High strength. RQD: (Est.) 90%. DUW: 167 PCF. Ground water: Minor. Hardness: NA.

System Class: TBM, Wirth Erkelenz, Hardrock, 9' 9" dia. 25 Hughes Tool/Wirth TCBI roller and tricone cutters. RPM: 8-11, 600 HP Torque, 500 K# thrust. Mucking: Buckets to belt. Haulage: Rail. Support: 4" ring and half sets, roof plates and rock bolts.

ROCK DATA:

Lithology: Igneous, biotitic granite, fine grained, with major quartz and minor feldspar and dark mineral contents.
Uniaxial Compressive Strength: 13 KPSI.
RQD: (Estimated) 90%.
Dry Unit Weight: 152 PCF.
Ground Water: Minor, from fault zones.
Hardness: NA 1-11-72.

TUNNEL DATA:

Size: 10' high x 16' wide x 8', alcove from 9'-9" diameter tunnel.
Ventilation System: 10 KCFM, exhaust, 22" pipe.
Utility System: 6" air line, 2" water line, 6" pump line.
Water Inflow: 5-10 GPM.
Power System: Not applicable.
Haulage System: Muck, personnel, supplies by rail cars, 36" Gage, 70# rail.
Support System: 1" x 7' grouted rock bolts and 13" x 10'-16 gage roof plates.

EXCAVATION DATA:

Conventional Rail Haulage System.
Drilling: 2-S53F, 4' feed, jack legs.
Drill Round: 72 holes, 1 3/4" diameter, 9' av. depth, double V-cut.
Explosives: 300# Gelex #2-60%. Powder Factor, 6.3#/CY.
Blasting: Electrical, zero and 7 regular delays.
Mucking: Diesel front end loader, 1/2 CY.
Guidance: Not applicable.

MDN STUDY SYSTEM DATA SHEET T-C3 Ident. No. NAST-3 Sheet 1

MUCK DATA

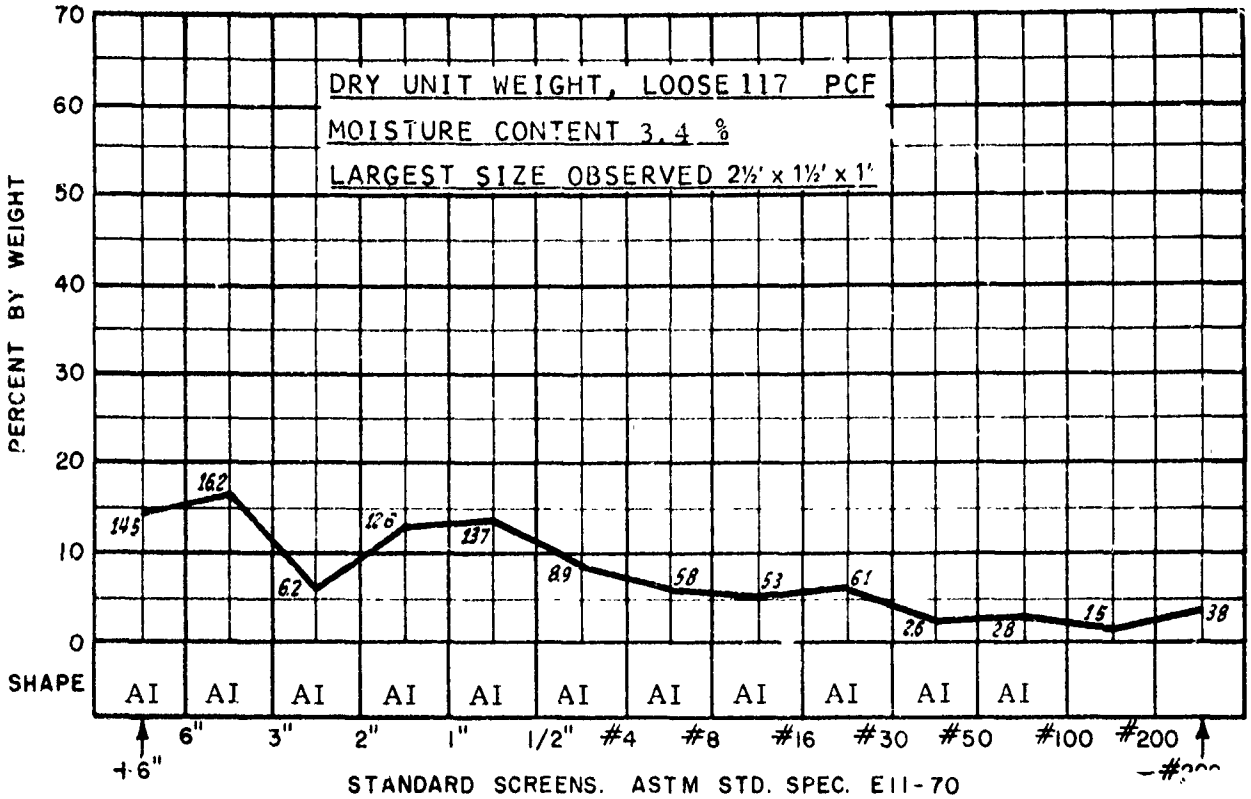
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size - 0.056" : 0	Size - 0.75" : 2.65

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 19.50%	Plastic Limit 17.41%	Shrinkage Limit 17.13 %
Plasticity Index 2.09 %	Toughness Index 0.51	Flow Index 4.10

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @ 2.8% Moisture, 39°	Apparent Cohesion PSF @ 3.0% Moisture, 80	Angle/Repose 10 In. Drop @ 2.8% Moisture, 36°
Angle Slide Steel Plate @ 2.8% Moisture, 31°	Bulk Density PCF @ 0.0 % Moisture, 91.2	Angle Internal Friction @ 3.0% Moisture, 38°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Igneous: Granite, biotitic, fine grained. Medium strength. RQD: (Est.) 90%. DUW: 152 PCF. Ground water: Minor. Hardness: NA.

System Class: Conventional Rail. 10' high x 16' wide x 8'alcove. Two jack leg drills, 72-9' holes, double V-cut. PF 6.3#/CY. Mucking: Diesel front end loader, 1/2 CY. Haulage: Rail. Support: Grouted rock bolts and roof plates.

MDN STUDY SYSTEM DATA SHEET MDN T-C3 Ident. No. NAST-3 Sheet 2

ROCK DATA:

Lithology: Igneous, granite, fine grained, moderately fractured, major quartz and minor feldspar and dark mineral contents.
Uniaxial Compressive Strength: 24 KPSI.
RQD: (Estimated) 90%.
Dry Unit Weight: 160 PCF.
Ground Water: Minor, primarily from fault zones.
Hardness: NA 1-11-72.

TUNNEL DATA:

Size: 9'-10" diameter. Grade: (+) 0.22%.
Ventilation System: 10 KCFM, exhaust, 22" pipe to rear of conveyor, 16" to face.
Utility System: 6" air line, 2" water line, 6" pump line.
Water Inflow: 5 to 20 gpm.
Power System: 4160/480V.
Muckage System: Muck, personnel, supplies by rail cars, 36" gage 70# rail.
Support System: 4" ring and half sets, at 4', 3' and 2' centers in bad ground (approximately 650'), 13" wide x 10' - 16 gage plates secured by 4-1" x 7' grouted bolts as required, (approximately 1200').

EXCAVATION DATA:

Machine: Wirth Erkelenz, Hardrock Model (Modified)*. Weight 67 tons.
Cutters: 29 Hughes Tool Tungsten Carbide Button. Gage: 6-11 1/2" TCB roller. Interior: 19-11 1/2" TCB roller. Center: 2-11 1/2" roller and 2-11 1/2" TCB cone.
Rotation: 8 1/2 RPM.
Torque: 600 HP.
Thrust: 660 K lbs.
Muck System: Bucket from face, 22" belt conveyor to rear.
Power System: 3-200 HP electric motor driven hydraulic pumps driving hydraulic motors and cylinders.
Guidance System: Laser.

*Modified by replacement of original by a Hughes Tool Co. cutting head and cutters.

MDN STUDY SYSTEM DATA SHEET T-M5 Ident. No. NAST-4 Sheet 1

MUCK DATA

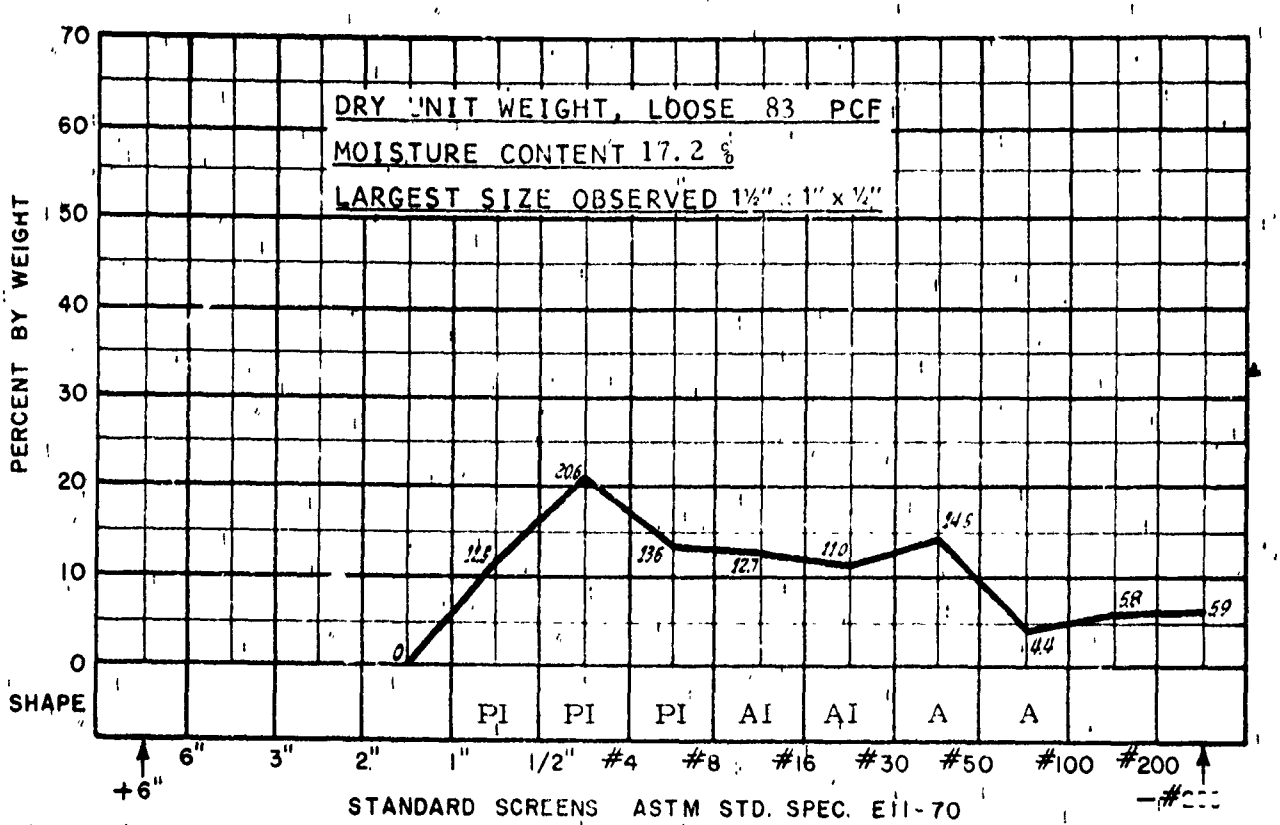
Abrasiveness N. A. 1/11/72	Pot. Vol. Change, Material Size : NA	Spec. Gravity, Material Size : NA

ATTERBERG LIMITS, MATERIAL SIZE IN.

Liquid Limit NA %	Plastic Limit NA %	Shrinkage Limit NA %
Plasticity Index NA %	Toughness Index NA	Flow Index NA

MATERIAL SIZE IN.

Angle/Repose 1 In. Drop @ % Moisture, NA	Apparent Cohesion PSF @ % Moisture, NA	Angle/Repose 10 In. Drop @ % Moisture, NA
Angle Slide Steel Plate @ % Moisture, NA	Bulk Density PCF @ % Moisture, NA	Angle Internal Friction @ % Moisture, NA



MUCK: PCT, BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Igneous: Granite, fine grained, moderately fractured. High strength. RQD (Est.) 90%. DUW: 160 PCF. Ground water: Minor. Hardness: NA

System Class: TBM, Wirth Erkelenz, Hardrock, with Hughes Tool head, 9' 10" dia. 29 Hughes Tool TCBI roller and cone cutters. RPM: 8 1/2. 600 HP torque, 660 K# thrust. Mucking: Buckets to belt. Haulage: Rail. Support: 4" ring and half sets, roof plates and rock bolts.

MDN STUDY SYSTEM DATA SHEET MDN T-M5 Ident. No. NAST-1 Sheet 2

ROCK DATA:

Lithology: Igneous, granite, massive, major feldspar and quartz, minor dark mineral content.
Uniaxial Compressive Strength: 35 KPSI
RQD: (Estimated) 96%
Dry Unit Weight: 161 PCF
Ground Water: Minor, through fractures.
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 10' x 10' Horse shoe. Grade 0.22%
Ventilation System: 8 KCFM, exhaust, 22" pipe.
Utility System: 6" air line, 2" water line
Water Inflow: 5-10 gpm.
Power System: 110V. lighting.
Haulage System: Muck and supplies: Eimco 912 diesel.
Support System: 4" WF steel sets @ 4' in 180' approx. at portal end; 1" x 7' grouted rock bolts for approx. 35'.

EXCAVATION DATA:

Conventional Trackless System.
Drilling: Crawler Jumbo, 2-D93 Drifters, 10' feeds.
Drill Round: 48-1 3/4" holes, double V cut, 8' depth.
Explosives: 175# Gelex #2-70%. Powder factor, 6.1#/CY.
Blasting: Electrical, regular delays, zero through #10.
Mucking System: Eimco 912 diesel, front end loader.
Guidance: Transit lines.

MDN STUDY SYSTEM DATA SHEET T-C3 Ident. No. GA-1 Sheet 1

MUCK DATA

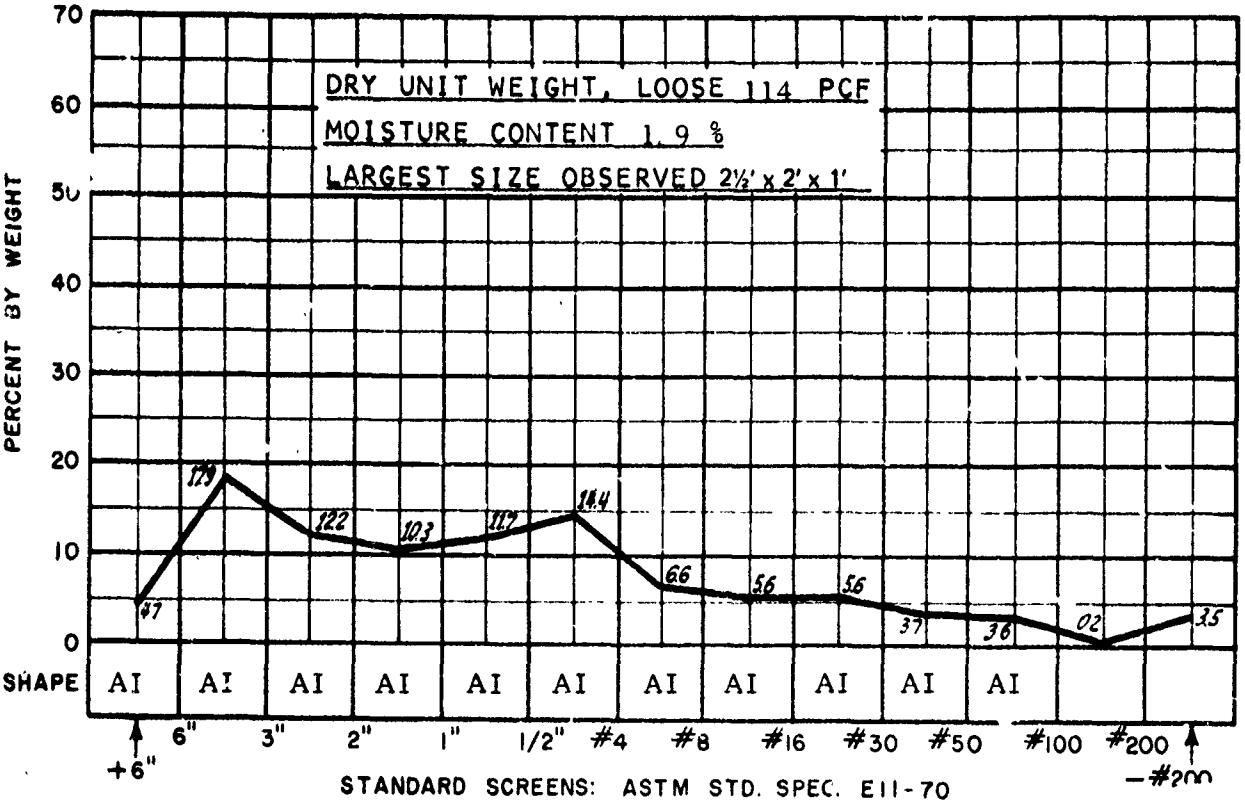
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size - 0.056" : 0	Size - 0.75" : 2.59

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 16.20%	Plastic Limit 15.78%	Shrinkage Limit 13.67%
Plasticity Index 0.42 %	Toughness Index 0.14	Flow Index 3.00

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @ 0.9% Moisture, 39°	Apparent Cohesion PSF @ 0.9% Moisture, 215	Angle/Repose 10 In. Drop @ 0.9% Moisture, 36°
Angle Slide Steel Plate @ 0.9% Moisture, 34°	Bulk Density PCF @ 0.0 % Moisture, 106	Angle Internal Friction @ 0.9% Moisture, 46°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Igneous: Granite, massive, minor dark minerals. Very high strength. RQD: (Est.) 96%. DUW: 161PCF. Ground water: Minor. Hardness: NA.

System Class: Conventional Trackless. 10' x 10' arch. Two machine jumbo, 48-8' holes, V-cut PF 6.1#/CY. Front end loader mucking and haulage. Support: Steel sets at 4', 25%, occasional rockbolts in 730'.

MDN STUDY SYSTEM DATA SHEET MDN T-C3 Ident. No. GA-1 Sheet 2

ROCK DATA:

Lithology: Igneous, granite, gray, fine grained, moderately jointed with 1.5' to 2' bands of light tan pegmatite and laminated granite gneiss.
Uniaxial Compressive Strength: 32 KPSI.
RQD: (Estimated) 80%.
Dry Unit Weight: 162 PCF.
Ground Water: Formations generally dry.
Hardness: NA 1/11/72

TUNNEL DATA:

Size: 10' x 10', Modified Horseshoe. Grade: (+) 1/2%.
Ventilation: 15 KCFM, exhaust, 26" dia. pipe, 125 HP at 7200' from portal.
Utility System: 8" air line, 4" water line, 10" pump line.
Water Inflow: 20 GPM. (As much as 400 GPM in occasional pockets)
Power System: 4160/440V.
Haulage System: Muck, personnel, supplies by rail cars, 36" gage, 75# rail. Three-15T. Goodman locomotives; 2 trains of 11 to 13 cars @ 4.8 CY. Canton car transfer at 50' to 250' from face, passing tracks @1500'.
Support System: 4" WF sets @ 4', 3' and 2' for 23%, 1" x 7' grouted bolts for 17%, Shotcrete: 500 psi @ 18 hrs., 3750 psi @ 28 days, for 16% of 7200'.

EXCAVATION DATA:

Conventional Rail System.
Drilling: Rail mounted hydrojib jumbo, 4-CF99, & 1-CF133 drifters, 12' feed.
Drill Round: 38 holes, 1-5" center hole and 37 at 1 3/4" dia. Spiral Burn Cut, 10 1/2' depth.
Explosives: 183 lbs. Gelex #2-75% x 1-1/2" dia., and 20 lbs. Smooth-tex 70% x 7/8" dia. in upper perimeter holes. Powder factor: 5 1/2#/CY.
Blasting: Electrical, regular delays zero through 10.
Mucking: EIMCO #25, rail, air operated.
Guidance: Laser

MDN STUDY SYSTEM DATA SHEET T-C3 Ident. No. H-1 Sheet 1

MUCK DATA

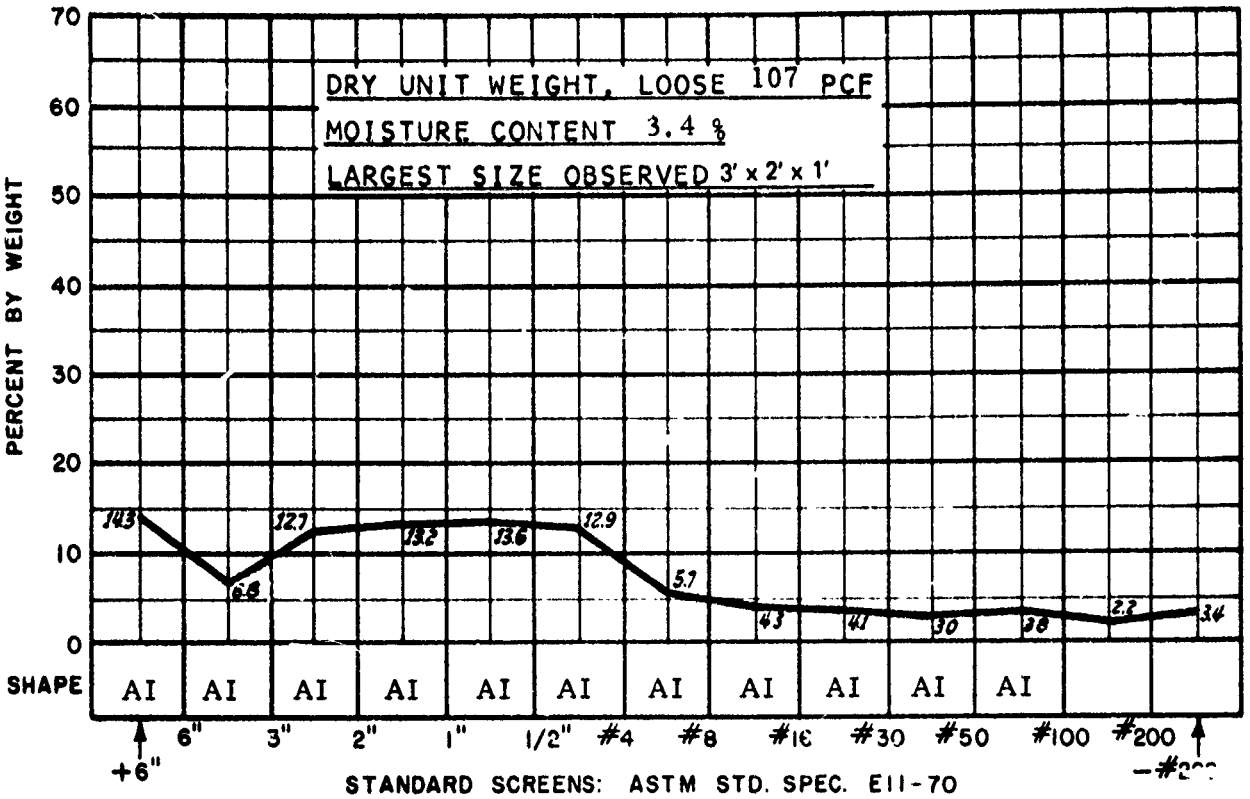
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size - 0.056" : 0	Size - 0.75" : 2.70

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 18.0 %	Plastic Limit 17.0 %	Shrinkage Limit 13.4 %
Plasticity Index 1.0 %	Toughness Index 0.23	Flow Index 4.4

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop	Apparent Cohesion PSF	Angle/Repose 10 In. Drop
@ 1.3 % Moisture, 40°	@ % Moisture, NA	@ 1.3 % Moisture, 37°
Angle Slide Steel Plate	Bulk Density PCF	Angle Internal Friction
@ 1.3 % Moisture, 32°	@ % Moisture, NA	@ 2.2 % Moisture, 44°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Igneous: Granite, fine grained, with 1.5' to 2' bands of pegmatite and laminated granite gneiss. High strength. RQD: (Est.) 80%. DUW: 162 PCF. Ground water: Minor. Hardness: NA.

System Class: Conventional Rail. 10' x 10' arch. Five machine jumbo, 38-10-1/2' holes, burn cut. PF 5.5#/CY. Overhead loader mucking, rail haulage. Support: Steel sets at 2' to 4', 23%, rockbolts 17%, shotcrete 16%, in 7200'.

MDN STUDY SYSTEM DATA SHEET MDN T-C3 Ident. No. H-1 Sheet 2

ROCK DATA:

Lithology: Igneous, granite, gray, gneissic, moderately jointed.
Uniaxial Compressive Strength: 39 KPSI
RQD: (Estimated) 80%
Dry Unit Weight: 164 PCF
Ground Water: Generally dry - occasional flows through fractures
Hardness: NA 1/11/72

TUNNEL DATA:

Size: 10' x 10' modified horseshoe. Grade: (+) 1/2%
Ventilation System: 8 KCFM exhaust, 26" pipe, 150 HP at 10,000 from portal.
Utility System: 8" air line, 4" water line, 10" pump line
Water Inflow: 20-400 GPM, normal 135 GPM
Power System: 4160/480/240V.
Haulage System: Muck, personnel, supplies by rail cars. 36" gage, 75# rail. Three-15T. Goodman locomotives, 3 trains of 5 to 7 cars @ 4.8 cy. Canton car transfers at 50' to 250' from face, passing tracks @ 1500' to 2500'.
Support System: Minor rock bolt support for last 2500'.

EXCAVATION DATA:

Conventional Rail System
Drilling: 4 boom Hydojib jumbo, 4-CF99 + 1-CF133 drifters, 12' contin. feed.
Drill Round: 36-40 holes, 1 3/4" diameter, 11' deep, spiral burn cut with 5" center hole.
Explosives: 200 lbs. 75% Gelex #2, 25 lbs. 30% Dupont 7/8" x 24" in back holes.
Blasting: Electrical, regular delays 0-10, Powder factor 5.6#/CY.
Mucking: EIMCO #25, rail, air operated
Guidance: Laser

MDN STUDY SYSTEM DATA SHEET T-C3 Ident. No. H-2 Sheet 1

MUCK DATA

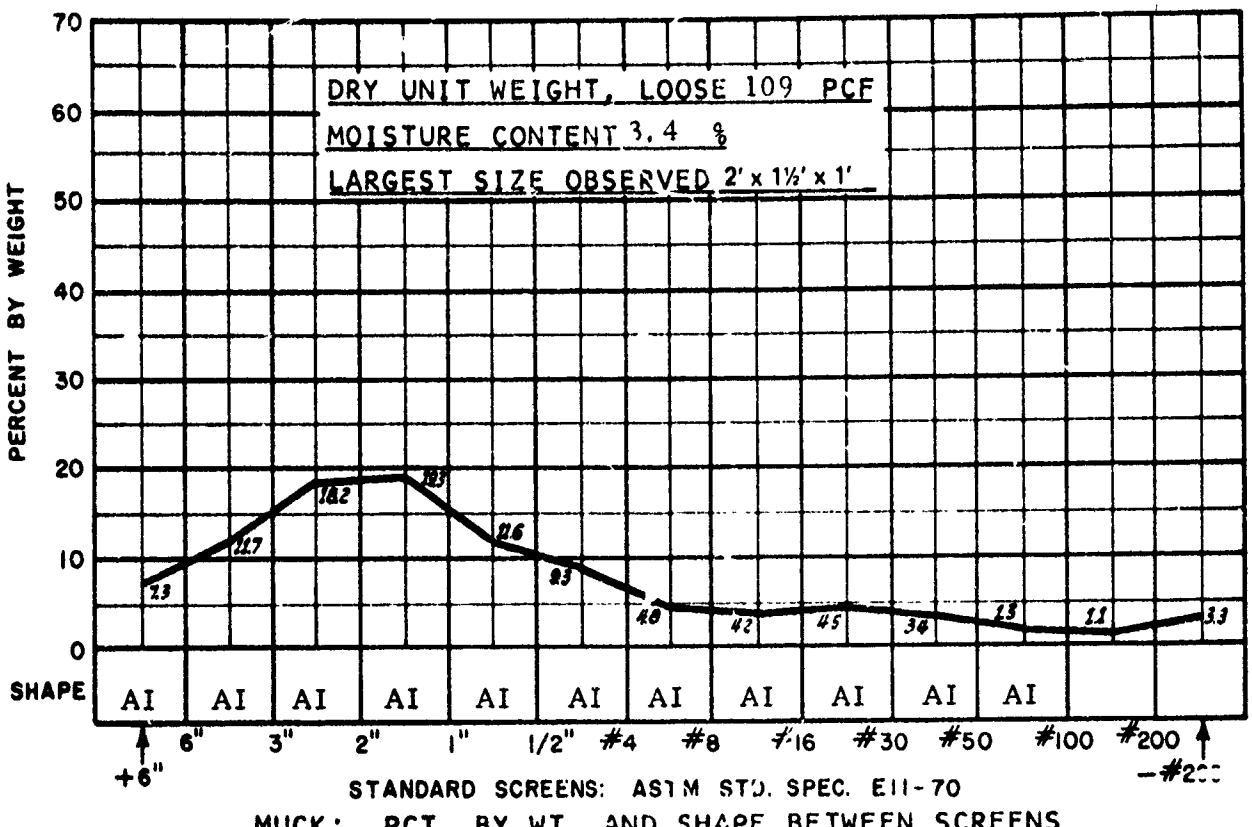
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size - 0.056" : 0	Size -0.75" : 2.60

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 18.10 %	Plastic Limit 17.95 %	Shrinkage Limit 11.00 %
Plasticity Index 0.15 %	Toughness Index 0.04	Flow Index 3.20

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @ 3.8 % Moisture, 38°	Apparent Cohesion PSF @ 2.6 % Moisture, 30	Angle/Repose 10 In. Drop @ 3.8% Moisture, 35°
Angle Slide Steel Plate @ 3.8 % Moisture, 38°	Bulk Density PCF @ 0.0 % Moisture, 105	Angle Internal Friction @ 2.6% Moisture, 44°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Igneous: Granite, gneissic, moderately jointed. Very high strength. RQD: (Est.) 80%. DUW: 164 PCF. Ground water: Minor. Hardness: NA.

System Class: Conventional Rail. 10' x 10' arch. Five machine jumbo, 36 to 40 - 11' holes, burn cut. PF 5.6#/CY. Overhead loader mucking - rail haulage. Support: occasional rockbolts 7200' to 10,000'.

MDN STUDY SYSTEM DATA SHEET MDN T-C3 Ident. No. H-2 Sheet 2

ROCK DATA:

Lithology: Igneous, biotitic quartz monzonite, fine to medium grained porphyry.
Uniaxial Compressive Strength: 25 KPSI
RQD: (Estimated) 83%
Dry Unit Weight: 162 PCF.
Ground Water: None apparent
Hardness: NA 1/11/72

TUNNEL DATA:

Size: 18' wide x 16' high, arched back. Grade: (+) 5 1/2%.
Ventilation System: 76 KCFM, pressure in heading, 48" pipe and tubing. Underground fans 48", 150 HP, 2 stage. Exhaust in return airway to 3-54", 150 HP, 2 stage, surface fans.
Utility System: 6" compressed air, 2" water.
Water Inflow: None apparent.
Power System: 4160/220V for fans, 110 volt lighting.
Haulage System: Wagner ST8 Scooptram to raise, chute loaded into rail mounted skip. Personnel and supplies by diesel truck.
Support System: 13 1/2" x 9' roof plates, 6' x 3/4" rock bolts @ 4'.

EXCAVATION DATA:

Conventional Trackless System
Drilling: Gardner-Denver 3 boom jumbo, 1 PR123 and 2 DH 123 drifters, 12' feeds.
Drill Round: 47 holes, 1 3/4" diameter, including 6 hole burn cut, and 1 center hole, 4" diameter, all 10 1/2' deep.
Explosives: 25# - 1 1/2 x 8", 60% or 75% primers, 25# - 7/8" x 16", 30% in trim holes, 40# - 1 1/2" x 16", 45% in 6 hole burn cut, and 275# AN/FO in remainder of round. Powder factor: 4#/cy.
Blasting: Electrical, regular delays, 0 through 15.
Mucking: Scooptram.
Guidance: Laser.

MDN STUDY SYSTEM DATA SHEET T-C1 Ident. No. LK-1 Sheet 1

MUCK DATA

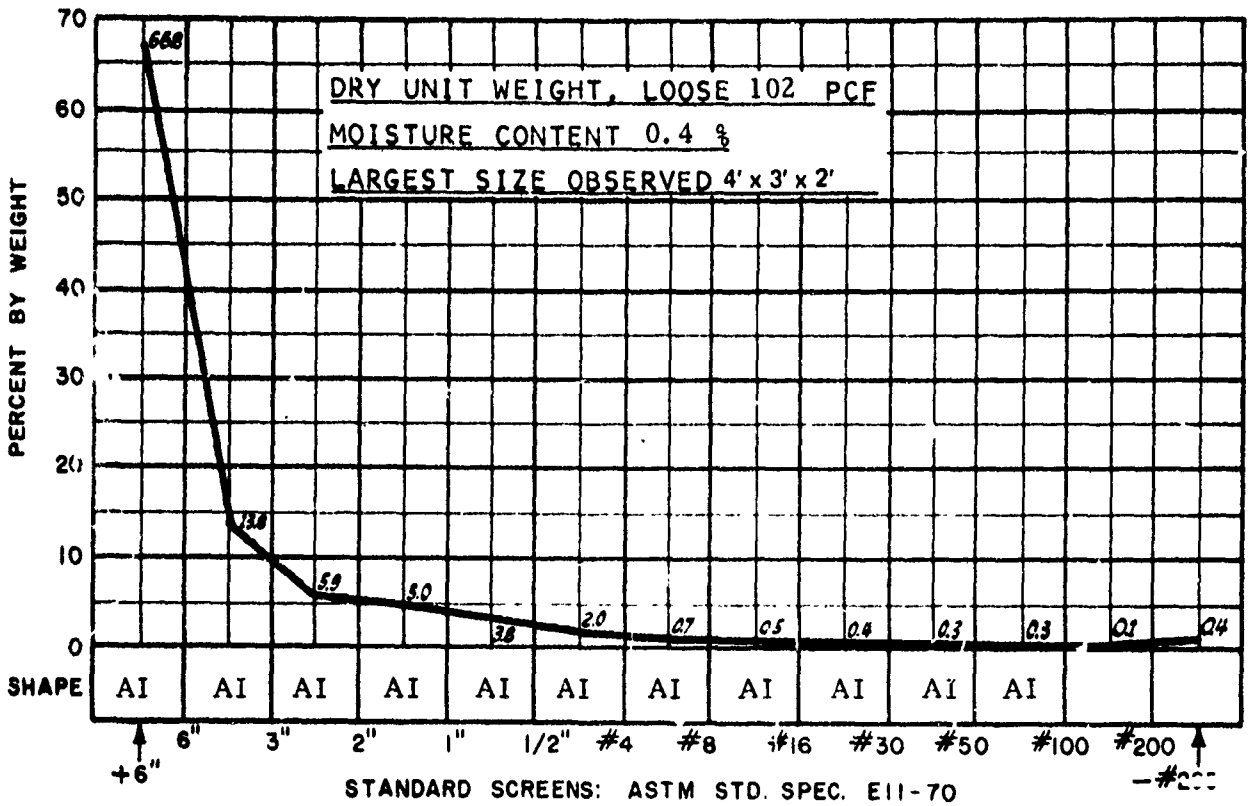
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size -0.056" : 0	Size -0.75" : 2.85

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 18.10%	Plastic Limit 17.98%	Shrinkage Limit 17.69%
Plasticity Index 0.12 %	Toughness Index 0.30	Flow Index 3.90

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @ 0.8% Moisture, 33°	Apparent Cohesion PSF @ 0.4% Moisture, 435	Angle/Repose 10 In. Drop @ 0.8% Moisture, 30°
Angle Slide Steel Plate @ 0.8% Moisture, 29°	Bulk Density PCF @ 0.0% Moisture, 97.3	Angle Internal Friction @ 0.4% Moisture, 43°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Igneous: Quartz monzonite, biotitic, fine to medium grained porphyry. High strength. RQD:(Est.) 83%. DUW: 162 PCF. Ground water: Dry. Hardness: NA.

System Class: Conventional Trackless. 18' wide x 16' arch. Three boom jumbo, 47-10 1/2' holes, burn cut. PF 4#/CY. Scooptram mucking and haulage to raise-rail skip to surface. Support: Roof plates and rock bolts at 4'.

MDN STUDY SYSTEM DATA SHEET MDN T-C1 Ident. No. LK-1 Sheet 2

ROCK DATA:

Lithology: Igneous, biotitic quartz monzonite, fine to medium grained porphyry, with minor steeply inclined joints.
Uniaxial Compressive Strength: 28 KPSI
RQD: (Estimated) 83%
Dry Unit Weight: 165 PCF
Ground Water: None apparent
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 18' wide x 16' high, arched back. Grade: (+) 2%.
Ventilation System: 22 KCFM, pressure in heading, 48" pipe and tubing. Underground fans 48", 150 HP, 2 stage. Exhaust in return airway to 3-54", 150 HP, 2 stage surface fans.
Utility System: 6" compressed air, 2" water.
Water Inflow: None apparent.
Power System: 4160/220 for pumps and fans, 110V lighting.
Haulage System: Wagner ST-8 Scooptram to surge pile at shaft station, rail mounted skip to surface. Personnel and supplies by diesel truck.
Support System: 13 1/2" x 9' roof plates, 6' x 3/4" rock bolts @ 4'.

EXCAVATION DATA:

Conventional Trackless system.
Drilling: Gardner-Denver 3 boom jumbo, 3 PR123 drifters, 12' feeds.
Drill Round: 47 holes, 1 3/4" diameter, including 6 hole burn cut, and 1 center hole, 4" diameter, all 10 1/2' deep.
Explosives: 25#-1 1/2" x 8", 60% or 75% primers, 25#-7/8" x 16", 30% in trim holes, 40#-1 1/2" x 16", 45% in 6 hole burn cut, and 275# AN/FO in remainder of round. Powder factor: 4#/CY.
Blasting: Electrical, regular delays, 0 through 15.
Mucking: Scooptram.
Guidance: Laser.

MDN STUDY SYSTEM DATA SHEET T-C1 Ident. No. LK-2 Sheet 1

MUCK DATA

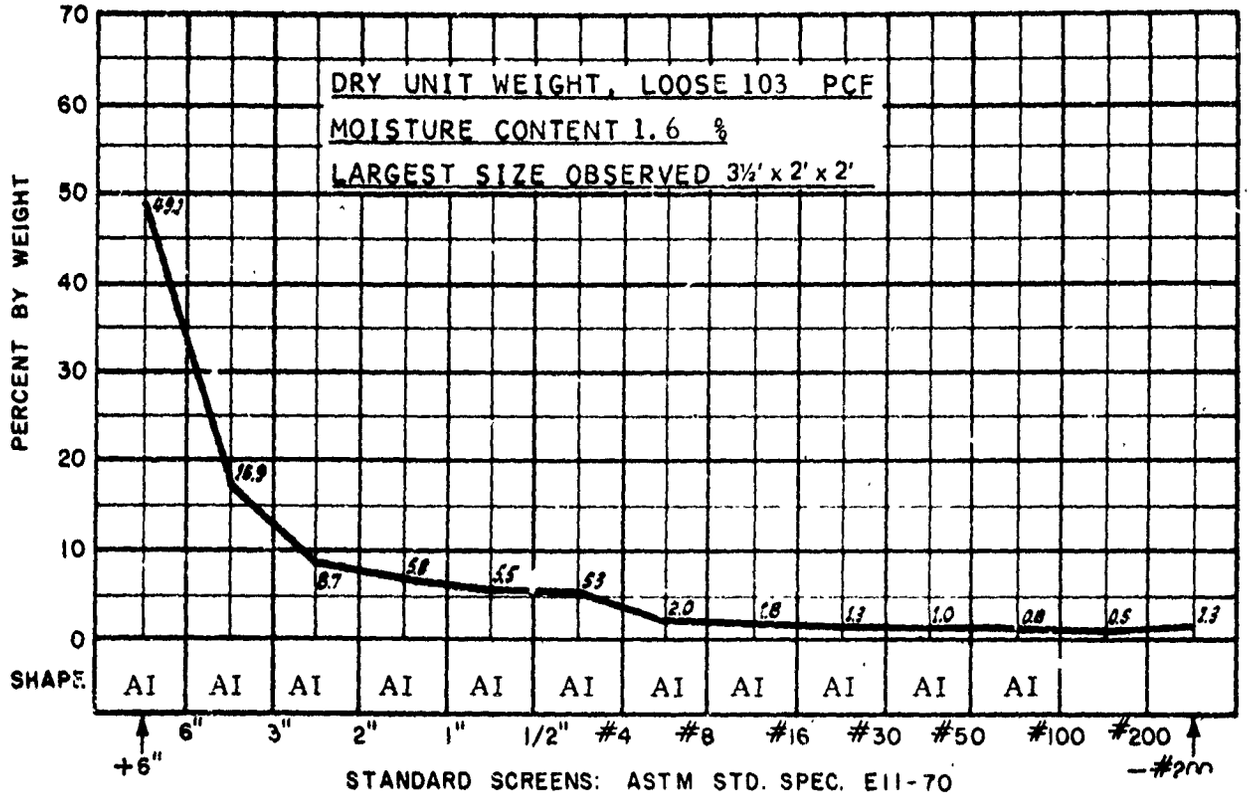
Abrasiveness	Pot. Vol. Change, Material	Sp. c. Gravity, Material
N. A. 1/11/72	Size -0. 056" : 0	Size -0. 75" : 2. 73

ATTERBFRG LIMITS, MATERIAL SIZE (-) 0. 056 IN.

Liquid Limit 20. 50 %	Plastic Limit 19. 14 %	Shrinkage Limit 17. 29 %
Plasticity Index 0. 36 %	Toughness Index 0. 058	Flow Index 6. 2

MATERIAL SIZE (-)2. 0 IN.

Angle/Repose 1 In. Drop @ 4. 7% Moisture, 43°	Apparent Cohesion PSF @ 4. 9 % Moisture, 210	Angle/Repose 10 In. Drop @ 4. 7 % Moisture, 42°
Angle Slide Steel Plate @ 4. 7% Moisture, 33°	Bulk Density PCF @ 0. 0 % Moisture, 97. 6	Angle Internal Friction @ 4. 9 % Moisture, 39°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Igneous: Quartz monzonite, biotitic, fine to medium grained porphyry minor steep angle joints. High strength. RQD:(Est.) 83%. DUW: 165 PCF. Grou water: Dry. Hardness: NA.

System Class: Conventional Trackless. 18' wide x 16' arch. Three boom jumbo, 47 - 10 1/2' holes, burn cut. PF 4#/CY. Scooptram mucking and haulage, rail skip to surface. Support: Roof plates and rock bolts at 4'.

MDN STUDY SYSTEM DATA SHEET MDN T-C1 Ident. No. LK-2 Sheet 2

ROCK DATA:

Lithology: Igneous, biotitic quartz monzonite, fine to medium grained porphyry.
Uniaxial Compressive Strength: 32 KPSI
RQD: (Estimated) 92%
Dry Unit Weight: 165 PCF
Ground Water: None apparent.
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 12' diameter vertical bore hole, reamed from 1312' to 1212' below collar, from a 13 7/8" diameter pilot hole.
Ventilation System: None in bore hole.
Utility System: 5 to 10 gpm. Water for dust suppression through pilot hole.
Water Inflow: None apparent
Power System: 440V to surface drive motors.
Haulage System: Wagner ST-8 Scooptram to surge pile at shaft station/ rail mounted skip to surface.
Support System: None in bore hole.

EXCAVATION DATA:

Machine: Robbins H81R Raise Drill. Weight 4[illegible] tons. Cutters: 27 Robbins, Steel Disc. Gage: 3-12", Center: 1-11", Interior: 19-12" single and 2-11" twin. Two sets of three 12" dia. TCB roller stabilizers are installed on third points below the cutter head.
Rotation, cutter head: 6 RPM.
Torque: 383.5 K Foot Lbs.
Reaming Pull: Total 814K Lbs @ 2400 PSI, net 490 K to 510 K#.
Muck Disposal: Scooptram, underground.
Power System: 3-440V, 100 HP constant torque motors, 1.667: 1 gathering box ratio.
Guidance System: Survey in pilot hole.

MDN STUDY SYSTEM DATA SHEET T-M5 Ident. No. LK-5 Sheet 1

MUCK DATA

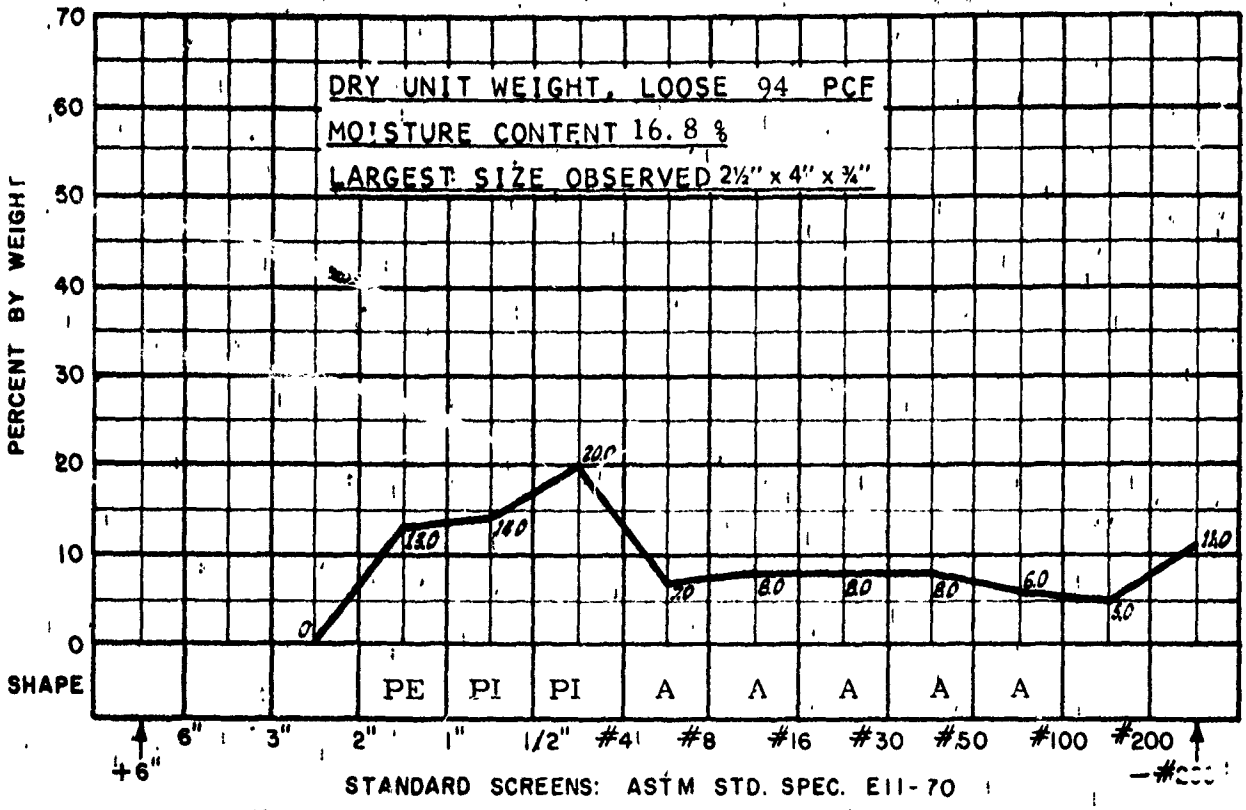
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size : NA	Size : NA

ATTERBERG LIMITS, MATERIAL SIZE IN.

Liquid Limit NA %	Plastic Limit NA %	Shrinkage Limit NA %
Plasticity Index NA %	Toughness Index NA	Flow Index NA

MATERIAL SIZE IN.

Angle/Repose 1 In. Drop @ % Moisture, NA	Apparent Cohesion PSF @ % Moisture, NA	Angle/Repose 10 In. Drop @ % Moisture, NA
Angle Slide Steel Plate @ % Moisture, NA	Bulk Density PCF @ % Moisture, NA	Angle Internal Friction @ % Moisture, NA



MUCK: POT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Igneous: Quartz monzonite, biotitic, fine to medium grained porphyry. High strength. RQD:(Est.) 92%, DUW: 165 PCF. Ground water: Dry. Hardness: NA.

System Class: RBM, Robbins H81R, 12' dia. 27 Robbins disc cutters, 6 RPM, 383.5 Kft. # torque, 500K # pull average. Mucking and haulage: Scooptram, underground, rail skip to surface Support: None.

ROCK DATA:

Lithology: Igneous, biotitic quartz monzonite, fine to medium grained porphyry, frequent flat angled joints,
Uniaxial Compressive Strength: (Estimated) 15 KPSI.
RQD: (Estimated) 86%.
Dry Unit Weight: 137 PCF.
Ground Water: None apparent.
Hardness: N.A. 1/11/72

TUNNEL DATA:

Size: 4' diameter vertical bore hole reamed from 298' to 286' below collar from a 13 7/8" diameter pilot hole.
Ventilation System: Not applicable.
Utility System: 5 to 10 gpm water for dust suppression through pilot hole.
Water Inflow: None apparent.
Power System: 440V to surface drive motors.
Haulage System: Wagner ST-8 Scooptram to surge pile at shaft station/ rail mounted skip to surface. Personnel and supplies by diesel truck.
Support System: None in bore hole.

EXCAVATION DATA:

Machine: Robbins H81R Raise Drill. Weight: 49 tons.
Cutters: 11-Robbins, Steel Disc. Gage: 1-12" twin. Center 1-12" single. Interior: 4-12" twin. Three 12" TCB roller stabilizers are installed at third points below the cutter head.
Rotation, Cutter head: 6 RPM
Torque: 383.5 K Foot/lbs.
Reaming Pull: Net 170 K to 205 K#.
Muck Disposal: Scooptram underground.
Power System: 3-440V, 100 HP constant torque motors, 1.667: 1 gathering box ratio.
Guidance System: Survey in pilot hole.

MDN STUDY SYSTEM DATA SHEET T-M5 Ident. No. LK-6 Sheet 1

MUCK DATA

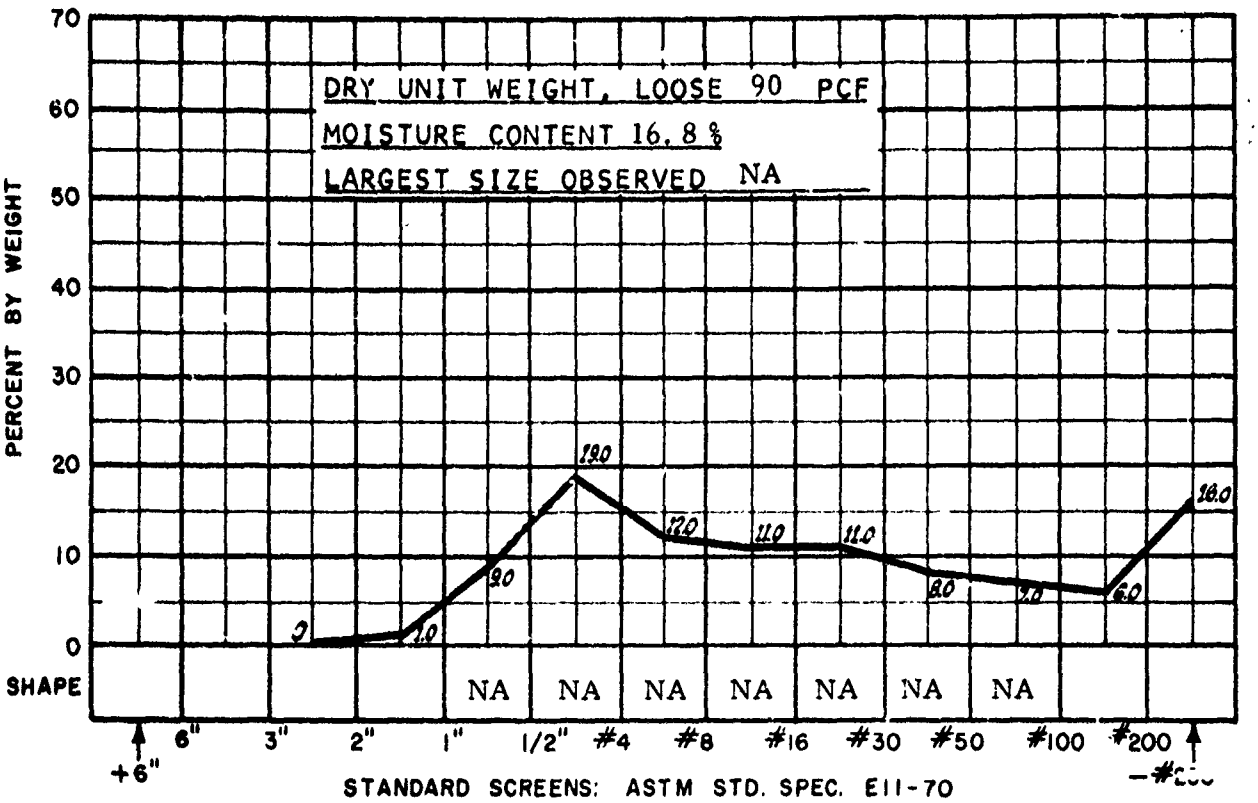
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size : NA	Size : NA

ATTERBERG LIMITS, MATERIAL SIZE IN

Liquid Limit NA %	Plastic Limit NA %	Shrinkage Limit NA %
Plasticity Index NA %	Toughness Index NA	Flow Index NA

MATERIAL SIZE IN.

Angle/Repose 1 In. Drop @ % Moisture, NA	Apparent Cohesion PSF @ % Moisture, NA	Angle/Repose 10 In. Drop @ % Moisture, NA
Angle Slide Steel Plate @ % Moisture, NA	Bulk Density PCF @ % Moisture, NA	Angle Internal Friction @ % Moisture, NA



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Igneous: Quartz monzonite, biotitic, fine to medium grained porphyry, frequent flat angled joints. Medium strength (Est.). RQD:(Est.) 86%. DUW: 137 PCF. Ground Water: Dry. Hardness: NA.

System Class: RBM, Robbins H81R, 4' dia. 11 Robbins disc cutters. 6 RPM, 385.5 K ft. # torque. 185K # pull (average). Mucking and Haulage: Scooptram underground, rail skip to surface. Support: None.

MDN STUDY SYSTEM DATA SHEET MDN T-M5 Ident. No. LK-6 Sheet 2

ROCK DATA:

Lithology: Metamorphic, granitic gneiss, highly metamorphosed, moderately to highly fractured, highly silicified.
Uniaxial Compressive Strength: 9 KPSI.
RQD: (Estimated) 10%.
Dry Unit Weight: 174 PCF.
Ground Water: Minimal-drains to other workings.
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 13', round, Grade (+) 1/4 percent.
Ventilation System: 10 K CFM. exhaust, 24" pipe
Utility System: 4" air line, 2" water line.
Water Inflow: 5-10 gpm.
Power System: 4160/480V.
Haulage System: Personnel, muck, supplies by rail cars.
Support System: None.

EXCAVATION DATA:

Machine: Calweld, Hardrock model, #40.
Weight: 200 tons.
Cutters: 19-Smith Tool Tungsten Carbide Button, Gage: 6-GT-SH 8 roller. Center: 1-TCB tricone, interior: 12-GT-MH8 roller.
Rotation: Center cutter-26 RPM, Head-12 RPM.
Torque: 347 K #.
Thrust: 1,128 K #.
Muck Collection: Buckets from face, 24" conveyor to rear.
Power System: 480V Electro-Hydraulic.
Guidance System: Laser.

MDN STUDY SYSTEM DATA SHEET T-M5 Ident. No. CL-1 Sheet 1

MUCK DATA

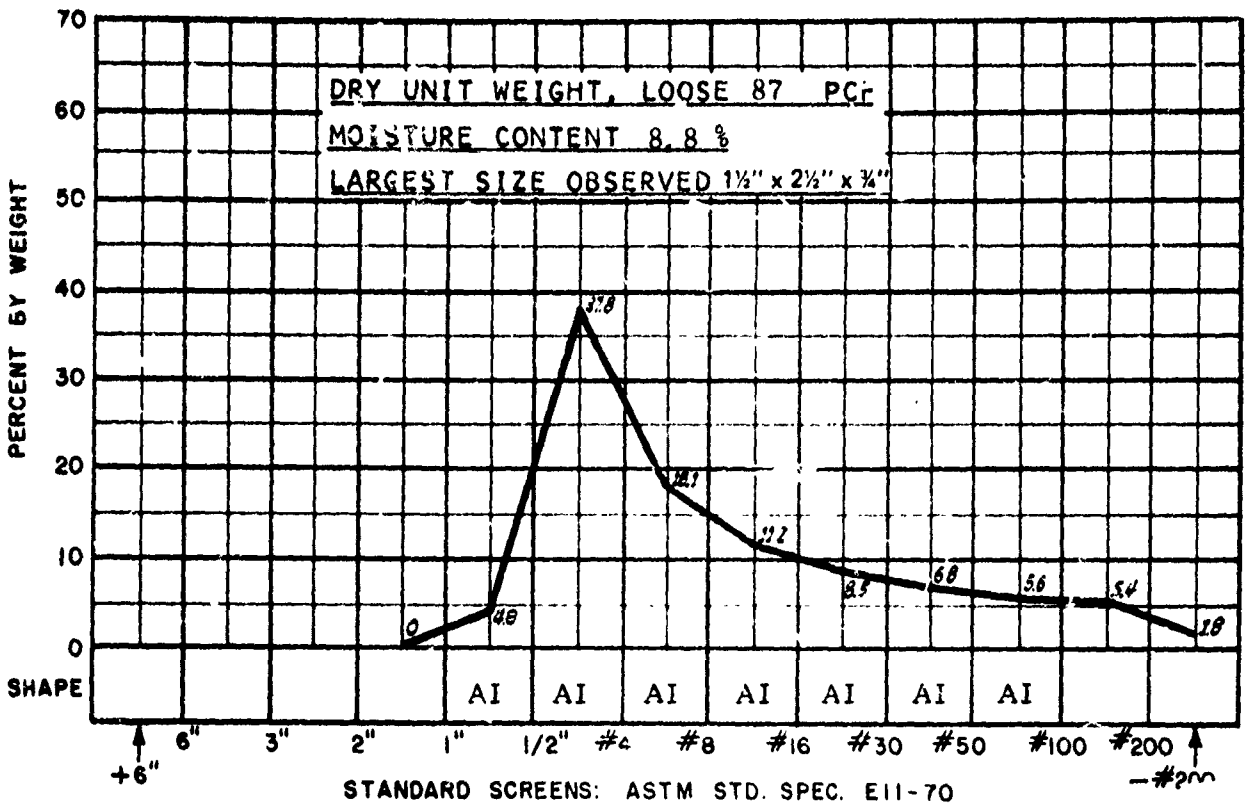
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size : NA	Size : NA

ATTERBERG LIMITS, MATERIAL SIZE IN.

Liquid Limit NA %	Plastic Limit NA %	Shrinkage Limit NA %
Plasticity Index NA %	Toughness Index NA	Flow Index NA

MATERIAL SIZE IN.

Angle/Repose 1 In. Drop	Apparent Cohesion PSF	Angle/Repose 10 In. Drop
@ % Moisture, NA	@ % Moisture, NA	@ % Moisture, NA
Angle Slide Steel Plate	Bulk Density PCF	Angle Internal Friction
@ % Moisture, NA	@ % Moisture, NA	@ % Moisture, NA



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Metamorphic: Granitic gneiss, highly metamorphosed and silicified, moderately to highly fractured. RQD: (Est.) 10%. DUW: 174 PCF. Medium strength. Ground water: Dry. Hardness: NA

System Class: TBM, Calweld #40, 13' dia. 19 Smith Tool TCBI roller and tricone cutters. RPM: Head 12, center 26. 347K ft # torque, 1 128K # thrust.

Mucking: Buckets to belt. Haulage: Rail. Support: None.

MDN STUDY SYSTEM DATA SHEET MDN T-M5 Ident. No. CL-1 Sheet 2

ROCK DATA:

Lithology: Metamorphic, interlayered transition between quartzite and tactite. Moderately to strongly altered metasediments, with replacement pyrite, chalcopyrite and magnetite, and a high percentage of silicates, very fine to medium grained.
Uniaxial Compressive Strength: 26 KPSI.
RQD: (Estimated) 80%
Dry Unit Weight: 178 PCF.
Ground Water: None apparent
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 16' wide x 14 1/2' high, arched back. Grade: (+) 2%.
Ventilation System: 52 KCFM, pressure in heading, 48" pipe and tubing. Underground fans 48", 150 HP, 2 stage. Exhaust in return airway to 3-54", 150 HP, 2 stage surface fans.
Utility System: 6" compressed air, 2" water.
Water Inflow: None apparent.
Power System: 4160/220V for pumps and fans, 110V lighting.
Haulage System: Wagner ST-8 Scooptram to surge pile at shaft station/rail mounted skip to surface. Personnel and supplies by diesel truck.
Support System: 13 1/2" x 9' roof plates, 6' x 3/4" rock bolts at 4'.

EXCAVATION DATA:

Conventional Trackless System.
Drilling: Gardner-Denver 3 boom jumbo, 3 PR123 drifters, 12' feeds.
Drill Round: 42 holes, 1 3/4" diameter, including 6 hole burn cut, and 1 center hole, 4" diameter, all 6' deep.
Explosives: 15# - 1 1/2" x 8", 60% or 75% as primers, 15# - 7/8" x 16", 30% in trim holes, 25# - 1 1/2" x 16", 45% in 6 hole burn cut, 150# AN/FO in remainder of round. Powder factor 5#/cy.
Blasting: Electrical, regular delays, 0 through 15.
Mucking: Scooptram.
Guidance: Laser.

MDN STUDY SYSTEM DATA SHEET T-C1 Ident. No. LK-3 Sheet 1

MUCK DATA

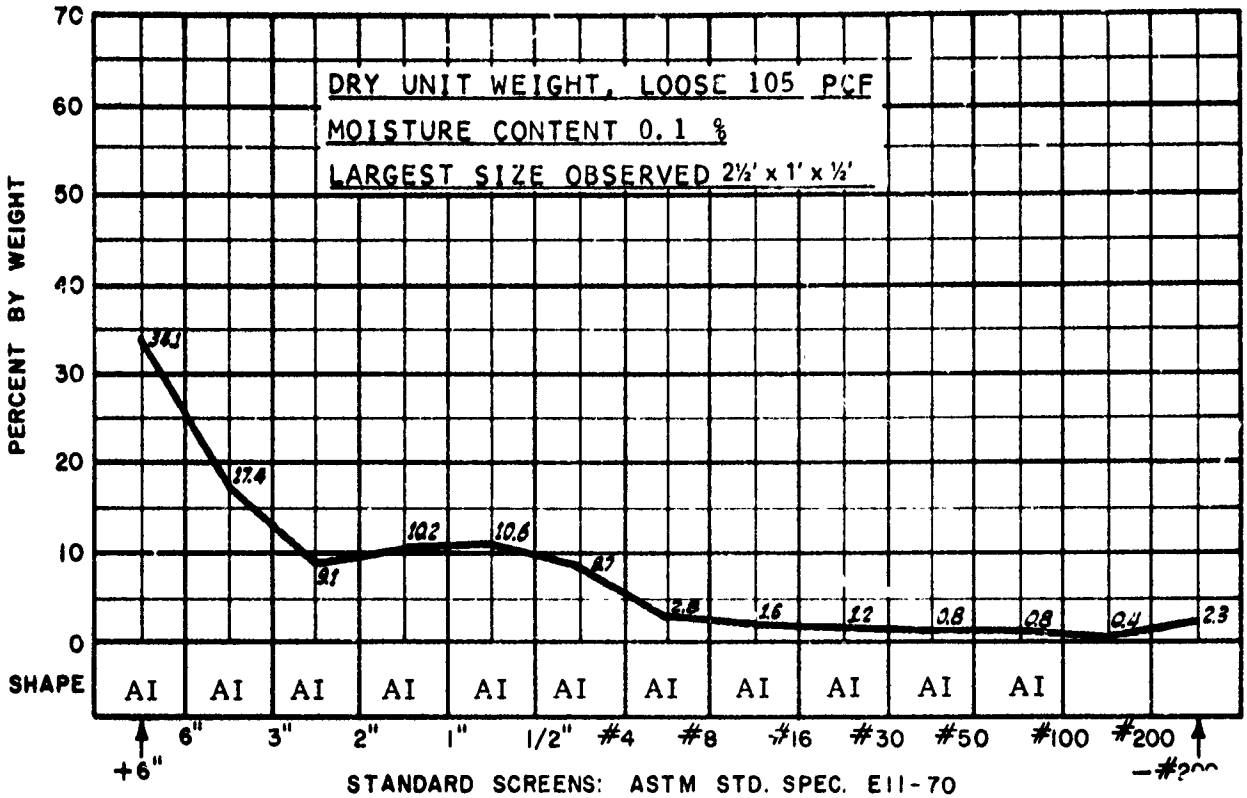
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size -0.056" : 0	Size -0.75" : 3.21

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 18.25 %	Plastic Limit 17.92 %	Shrinkage Limit 17.80 %
Plasticity Index 0.33 %	Toughness Index 0.06	Flow Index 5.50

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @ 1.5% Moisture, 30°	Apparent Cohesion PSF @ 0.4% Moisture, 175	Angle/Repose 10 In. Drop @ 1.5% Moisture, 29°
Angle Slide Steel Plate @ 1.5% Moisture, 29°	Bulk Density PCF @ 0.0 % Moisture, 117.8	Angle Internal Friction @ 0.4% Moisture, 41°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Metamorphic: Quartzite-tactite transition, very fine to medium grained, with replacement sulphides and magnetite, high in silicates. High strength. RQD:(Est.) 80%. DUW: 178 PCF. Ground water: Dry. Hardness: NA.

System Class: Conventional Trackless. 16' wide x 14-1/2' arch. Three boom jumbo, 42-6' holes, burn cut. PF 5#/CY. Scooptram mucking and haulage, rail skip to surface. Support: Roof plates and rock bolts at 4'.

MDN STUDY SYSTEM DATA SHEET MDN T-C1 Ident. No. LK-3 Sheet 2

ROCK DATA:

Lithology: Metamorphic, tactite, strongly altered calcareous metasediments, with replacement pyrite, chalcopyrite and magnetite, and a high percentage of silicates, fine to very fine grained.
Uniaxial Compressive Strength: (Estimated) [illegible]PSI.
RQD: (Estimated) 70%
Dry Unit Weight: 181 PCF
Ground Water: None apparent.
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 15' wide x 14' high, arched back. Grade: (+) 2%.
Ventilation System: 50 KCFM, pressure in heading, 48" pipe and tubing. Underground fans 48", 150 HP, 2 stage. Exhaust in return airway to 3-54", 150 HP, 2 stage surface fans.
Utility System: 6" compressed air, 2" water.
Water Inflow: None apparent.
Power System: 4160/220V for pumps and fans, 110V lighting.
Haulage System: Wagner ST-8 Scooptram to surge pile at shaft station/rail mounted skip to surface. Personnel and supplies by diesel truck.
Support System: 6" WF Steel Sets at 5'.

EXCAVATION DATA:

Conventional Trackless System.
Drilling: Gardner-Denver 3 boom jumbo, 3 PR123 drifters, 12' feeds.
Drill Round: 42 holes, 1 3/4" diameter, including 6 hole burn cut and 1 center hole, 4" diameter; all 6' deep.
Explosives: 15#-1 1/4" x 8", 60% or 75% as primers, 15#-7/8" x 16" 30% in trim holes, 25#-1 1/2" x 16", 45% in 6 hole burn cut, 150# AN/FO in remainder of round. Powder factor 5.5#/CY.
Blasting: Electrical, regular delays, 0 through 15
Mucking: Scooptram.
Guidance: Laser

MDN STUDY SYSTEM DATA SHEET T-C2 Ident. No. LK-4 Sheet 1

MUCK DATA

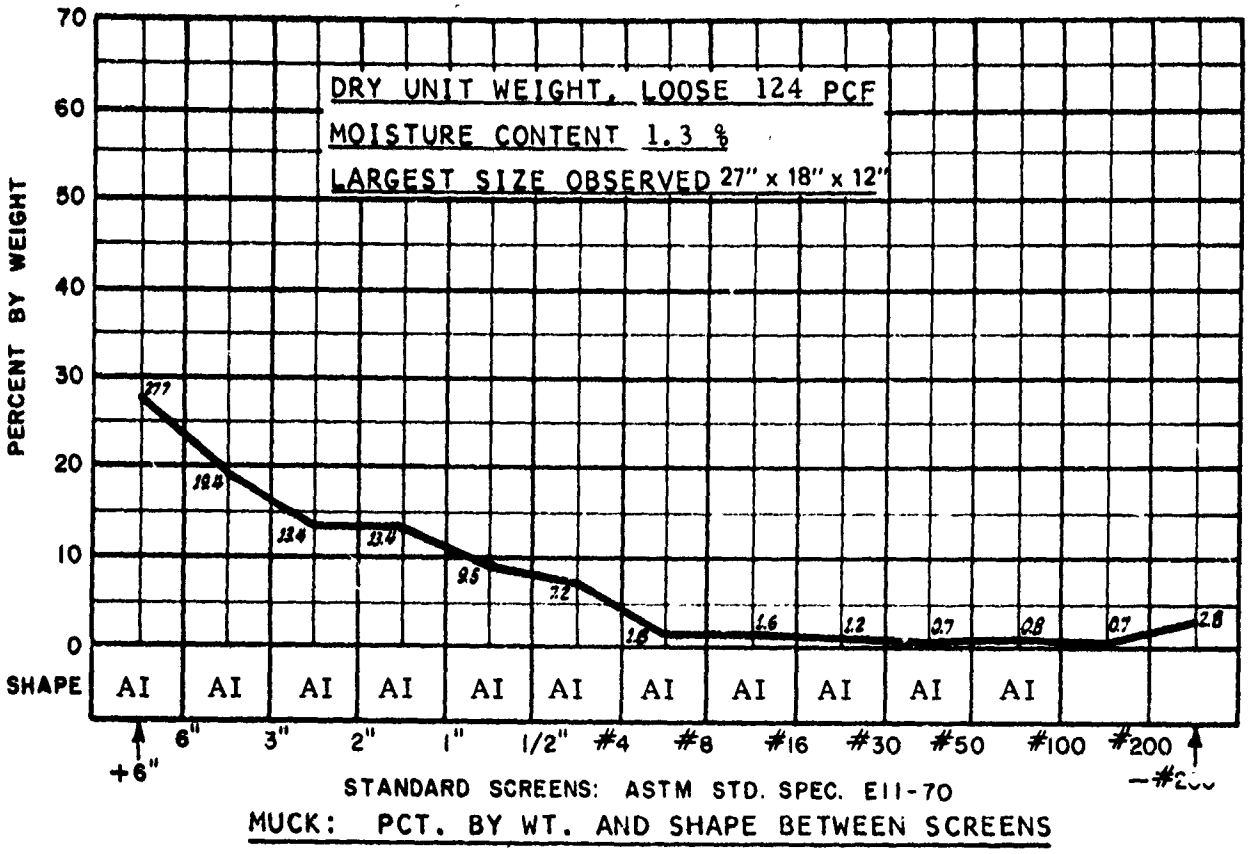
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size : NA	Size : NA

ATTERBERG LIMITS, MATERIAL SIZE IN.

Liquid Limit NA %	Plastic Limit NA %	Shrinkage Limit NA %
Plasticity Index NA %	Toughness Index NA	Flow Index NA

MATERIAL SIZE IN.

Angle/Repose 1 In. Drop	Apparent Cohesion PSF	Angle/Repose 10 In. Drop
@ % Moisture, NA	@ % Moisture, NA	@ % Moisture, NA
Angle Slide Steel Plate	Bulk Density PCF	Angle Internal Friction
@ % Moisture, NA	@ % Moisture, NA	@ % Moisture, NA



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Metamorphic: Tactite, fine to very fine grained, with replacement sulphides and magnetite, high in silicates. Medium strength (Est.).
RQD:(Est.) 70%. DUW: 181 PCF. Ground water: dry. Hardness: NA.
System Class: Conventional Trackless. 15' wide x 14', arch. Three boom jumbo, 42-6' holes, burn cut. PF 5.5#/CY. Scooptram mucking and haulage, rail skip to surface. Support: Steel sets at 5'.

MDN STUDY SYSTEM DATA SHEET MDN T-C2 Ident. No. LK-4 Sheet 2

ROCK DATA:

Lithology: Metamorphic, interlayered bands of hematite and martite, highly jointed, normally flat lying, but often highly folded. Natural iron over 60%, moisture 9%, silica 5%.
Uniaxial Compressive Strength: 7 KPSI.
RQD: (Estimated) 10%
Dry Unit Weight: 207 PCF
Ground Water: Formation generally dry.
Hardness: NA 1-11-72

TUNNEL DATA:

9'-11 1/2" diameter; normal grade: 0%.
Ventilation System: 3 KCFM, pressure, 8" dia. tube, 5 HP @ 250' from main level.
Utilities: 2" air line, 1" water line, 2-1 1/2" pressure and 1-3" return hydraulic lines.
Water Inflow: None
Power System: 110V lighting, 440V to scraper hoist.
Muck Haulage: 30 HP hoist, and 42" scraper to raise, all rail on main level. Personnel, rail and ladders; supplies by rail cars and hoist.
Support: Continuous; 9'-6" dia. x 4" WF sets at 45".

EXCAVATION DATA:

Machine: Calweld Oscillator. Wt: 69 K#.
Cutters: 278 Carboloy drag bits. Gage: 20 rippers (experimental). Interior: 258 "J" tools.
Rotation: 8 RPM
Torque: 1200 K ft.#.
Thrust: 300 K# max., 285 K# operating.
Anchorage: Thrust on installed sets, 285K# operating.
Muck Collection: Flight conveyor to rear of machine, removal by scraper
Power System: Remote power unit; 2-90 gpm, 2500 psi hydraulic pumps and 125 HP motors on main level; thrust and rotation through hydraulic cylinders.
Guidance System: Survey.

MDN STUDY SYSTEM DATA SHEET T-M6 Ident. No. MB-1 Sheet 1

MUCK DATA

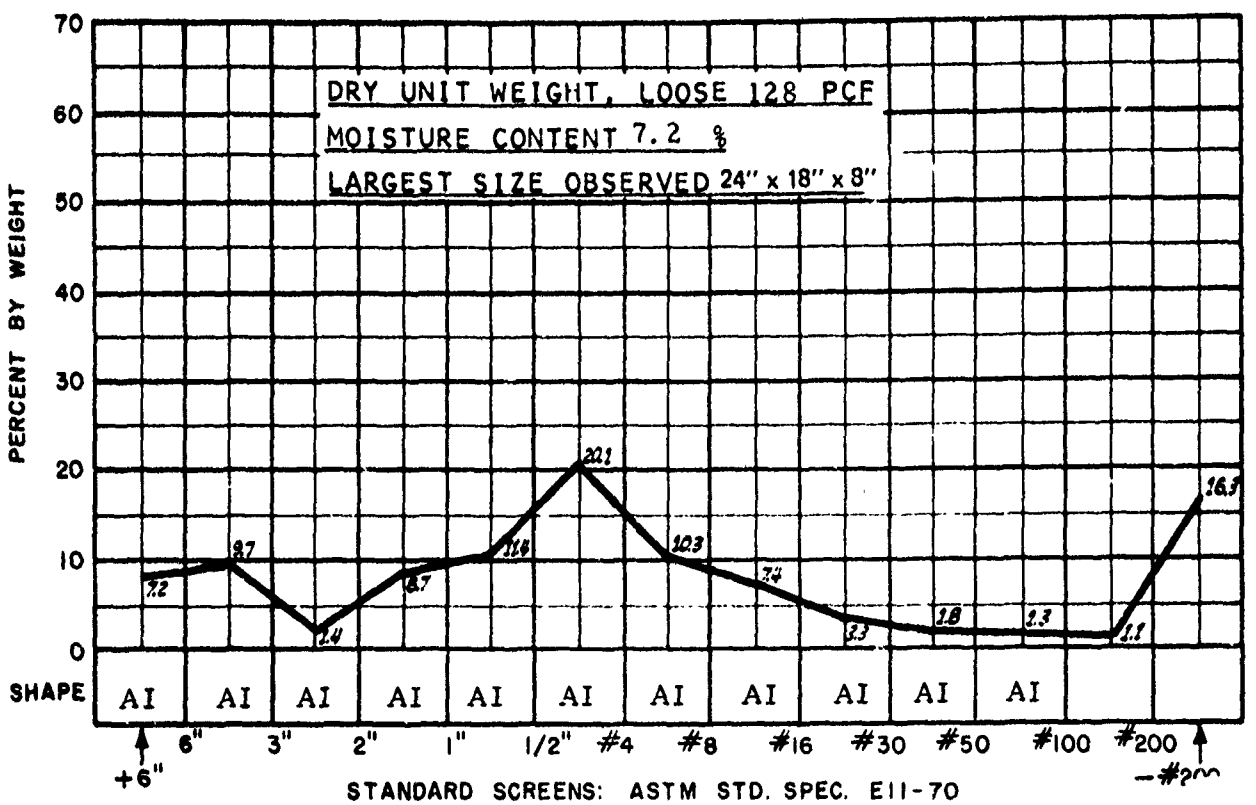
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size -0.056" : 0	Size -0.75" : 4.34

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 17.8 %	Plastic Limit 15.1 %	Shrinkage Limit 13.9 %
Plasticity Index 2.7 %	Toughness Index 0.66	Flow Index 4.1

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @ 6.2% Moisture, 37°	Apparent Cohesion PSF @6.9 % Moisture, 235	Angle/Repose 10 In. Drop @ 6.2 % Moisture, 35°
Angle Slide Steel Plate @ 6.2% Moisture, 31°	Bulk Density PCF @0.0 % Moisture, 141	Angle Internal Friction @ 6.9% Moisture, 35°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Metamorphic: Hematite and martite interlayered, highly jointed, bedding normally flat, often highly folded. Low strength. RQD (Est.) 10%. DUW: 207 PCF. Ground water: Dry. Hardness: NA.

System Class: TBM, oscillator, Calweld #53, 9'-11-1/2" diam. 278 Carboloy drag bits. 8 RPM, 1200 K, ft # torque, 285 K # thrust. Mucking: Flight conveyor and scraper to raise. Haulage: Rail. Support: Continuous, 9' 6" dia. x 4" H sets at 45".

MDN STUDY SYSTEM DATA SHEET MDN T-M6 Ident. No. MB-1 Sheet 2

ROCK DATA:

Lithology: Metamorphic, gray mica schist, occasional quartz seams, mica varies from dense fine grained to extremely coarse.
Uniaxial Compressive Strength: 11 KPSI.
RQD: (Estimated) 30%
Dry Unit Weight: 165 PCF
Ground Water: Major inflow occurs in faults and fault zones.
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 11', diameter. Grade: (+) 1 to 3%
Ventilation System: 4 KCFM exhaust 14" pipe.
Utility System: 4" waterpipe, no airline.
Water Inflow: 60 gpm, drains in ditch
Power System: 4160/480V
Haulage System: Muck, personnel, supplies by rail cars.
Support System: None, occasional semi-circular plates pinned at spring line in fault zones

EXCAVATION DATA:

Machine: Jarva, Mark 11-1100, Total Weight: 70 tons
Cutters: 36 Reed, type QK steel multiple disc. Gage: 8 triple disc. Center: 2-triple disc. Interior: 26 triple disc.
Rotation: Cutterhead, 10 RPM
Torque: 244 K ft. #
Anchor Pressure: Maximum 3, 402 K#.
Thrust: 1, 134 K#.
Muck System: Buckets from face, belt to rear
Power System: Four 100 HP, 480V motors drive head, 40 HP 480V motor driven hydraulic system.
Guidance System: Laser

MDN STUDY SYSTEM DATA SHEET T-M4 Ident. No. QL-1 Sheet 1

MUCK DATA

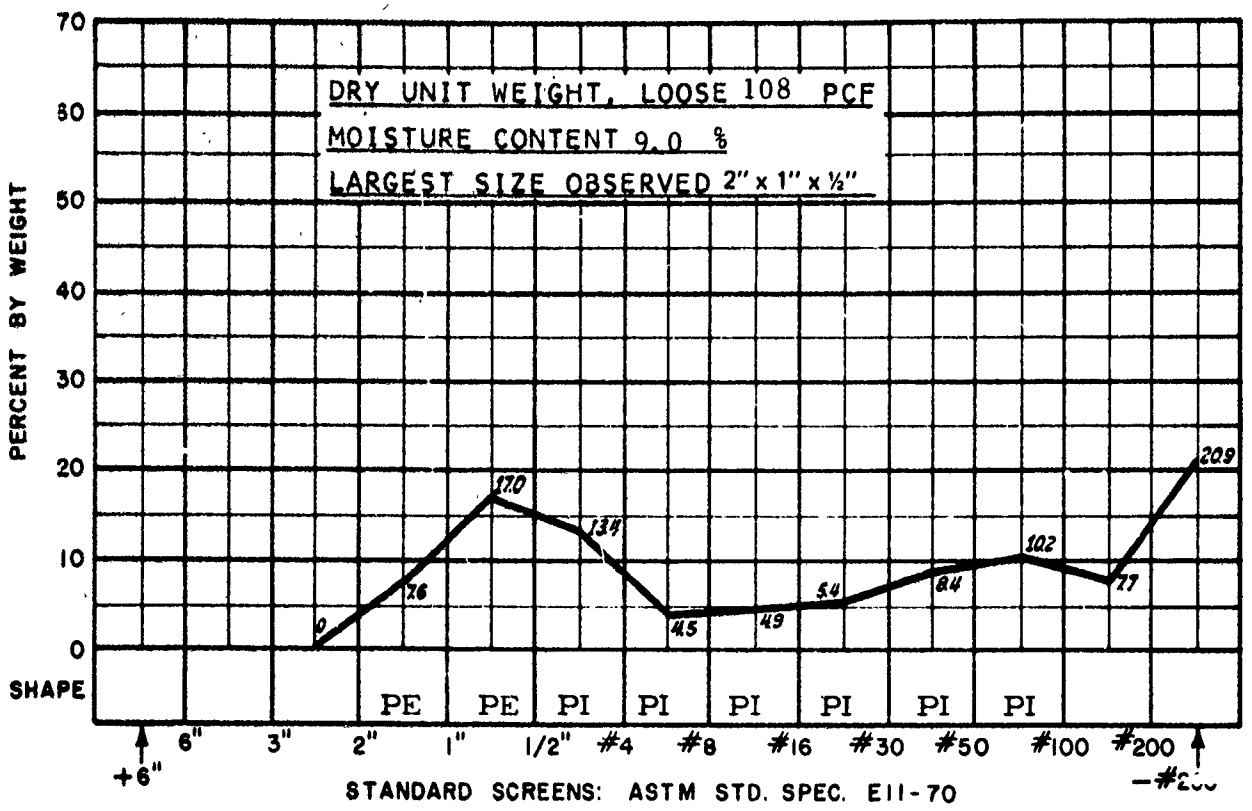
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size -0.056" : 0	Size -0.75" : 2.57

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 24.0 %	Plastic Limit 23.3 %	Shrinkage Limit 22.7 %
Plasticity Index 0.7 %	Toughness Index 0.17	Flow Index 4.0

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @9.8 % Moisture, 39°	Apparent Cohesion PSF @ 9.3 % Moisture, 125	Angle/Repose 10 In. Drop @ 9.8 % Moisture, 37°
Angle Slide Steel Plate @8.4 % Moisture, 40°	Bulk Density PCF @ 0.0 % Moisture, 75	Angle Internal Friction @ 9.3 % Moisture, 30°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Metamorphic: Mica schist, dense, fine grained to extremely coarse occasional quartz seams. Medium strength. RQD (Est.) 30%. DUW: 165 PCF. Ground water: Minor inflows at fault zones. Hardness: NA.
System Class: TBM, Jarva Mark 11-1100, 11' dia. 36 Reed triple discs. RPM: 10. Torque: 244 K ft #. Thrust: 1,134 K #. Mucking: Buckets to belt. Haulage: Rail. Support: Minor, semi-circular plates in fault zones.

MDN STUDY SYSTEM DATA SHEET MDN T-M4 Ident. No. QL-1 Sheet 2

ROCK DATA:

Lithology: Sedimentary, sandstone, fine grained, well compacted light brown, over 50 percent quartz.
Uniaxial Compressive Strength: 16 KPSI.
RQD: 92%.
Dry Unit Weight: 171 PCF
Ground Water: Dry.
Hardness: Shore 61.

TUNNEL DATA:

Size: 18'-1" dia. Grade (-) 7%
Ventilation System: 17 K CFM, exhaust, 36" dia. pipe, 75 HP @ 4100.
Utility System: 2" water line, 4" pump line. No air line - compressor on machine.
Water Inflow: 5-10 gpm
Power System: 4160/480V
Haulage System, Muck: 390' of 30" "piggy back" conveyor supported by a monorail advances with the TBM, discharges on a 36" conveyor suspended from the back of the tunnel. Supply and Personnel: Diesel jeeps and trucks.
Support System: 6" x 8.2# channels x 9.5' or 13.5' @ 4' or 2', secured by 4-5/8" x 4' rock bolts. Channels also support monorail.

EXCAVATION DATA:

Machine: Robbins 181-122 Weight: 260 tons.
Cutters: 47 Robbins, Steel Disc. Gage: 5-12". Center: 1-7 1/2" triple, Interior: 41-12".
Rotation: 4 1/2 RPM (Center integral with head)
Torque: 1200 HP input
Thrust: 1,580 K# max., 1,200K# operating.
Muck Collection: Buckets fixed to head, discharging on a 30" conveyor.
Power System: Six-480V., 200 HP motors drive head. Hydraulic pumps power thrust and anchor cylinders.
Guidance System: Laser.

MDN STUDY SYSTEM DATA SHEET T-M2 Ident. No. 5-1 Sheet 1

MUCK DATA

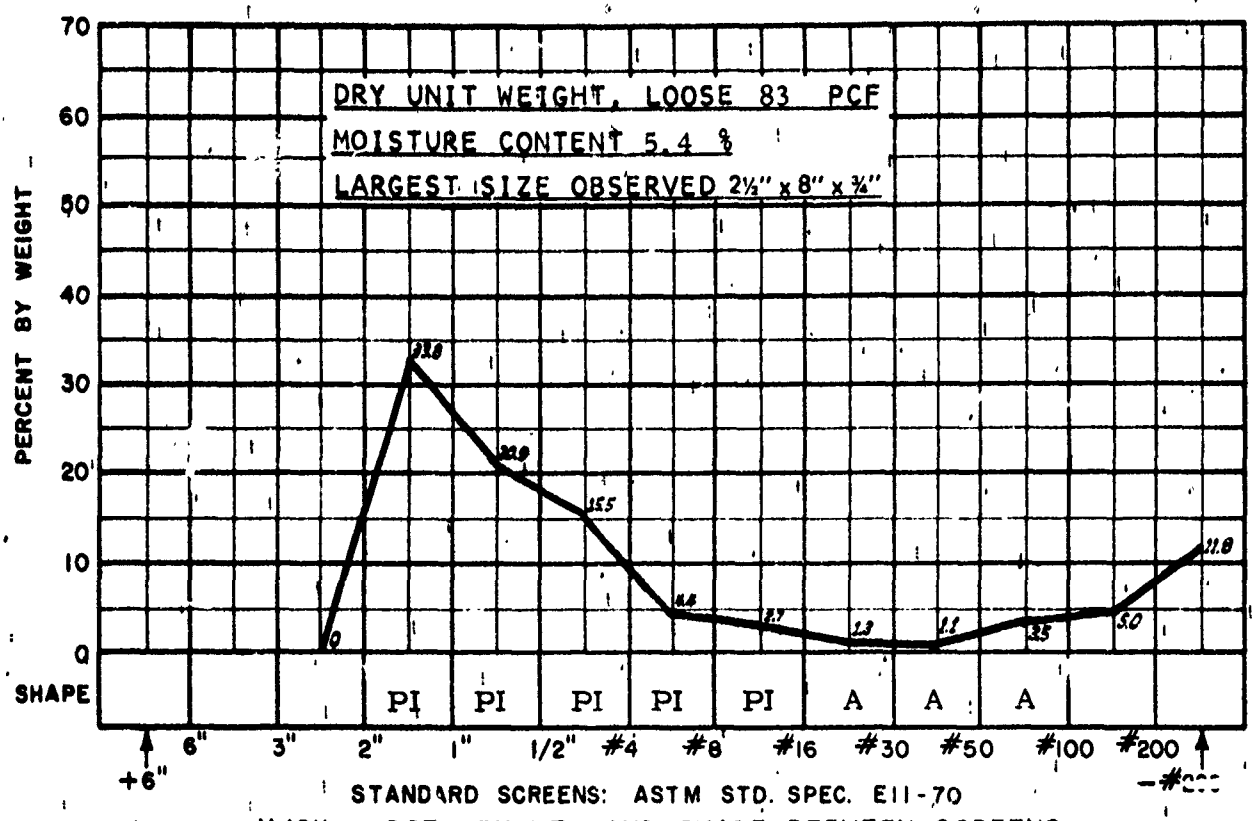
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size -0.065" : 0	Size -0.75" : 2.73

ATTERBERG LIMITS, MATERIAL SIZE (-)0.185 IN.

Liquid Limit 16.90 %	Plastic Limit 15.50 %	Shrinkage Limit 15.18 %
Plasticity Index 1.40 %	Toughness Index 0.28	Flow Index 5.0

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @ 6.3% Moisture, 35°	Apparent Cohesion PSF @ % Moisture, NA	Angle/Repose 10 In. Drop @ 6.3 % Moisture, 29°
Angle Slide Steel Plate @ 6.3% Moisture, 28°	Bulk Density PCF @ % Moisture, NA	Angle Internal Friction @ 4.8% Moisture, 29°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary: Sandstone, fine grained, well compacted, over 50% quartz. High strength. RQD: 92%. DUW: 171 PCF. Ground water: Dry. Hardness: Shore 61.

System Class: TBM, Robbins 181-122, 18'-1" dia. 47 Robbins disc cutters, 4-1/2 RPM, 1200 HP torque, 1,200 K # thrust. Mucking: Buckets to belt conveyor. Haulage: Traveling conveyor - suspended conveyor - skip to surface. Support: Channels and rock bolts at 4' or 2', continuous.

MDN STUDY SYSTEM DATA SHEET MDN T-M2 Ident. No. 5-1 Sheet 2

ROCK DATA:

Lithology: Sedimentary, sandstone, fine grained, well compacted light brown, over 50 percent quartz.
Uniaxial Compressive Strength: 16 KPSI.
RQD: 92%.
Dry Unit Weight: 171 PCF.
Ground Water: Dry.
Hardness: Shore 61.

TUNNEL DATA:

Size: 18'-1" dia. Grade (+) 2%.
Ventilation System: 17 K CFM, exhaust, 36" dia. pipe, 75 HP @ 4800'.
Utility System: 2" water line, 4" pump line. No air line - compressor on machine.
Water Inflow: 5-10 gpm.
Power System: 4160/480V.
Haulage System, Muck: 390' of 30" "piggy back" conveyor supported by a monorail advances with the TBM., discharges on a 36" conveyor suspended from the back of the tunnel. Supply and Personnel: Diesel jeeps and trucks.
Support System: 6" x 8.2# channels x 9.5' or 13.5', @ 4' or 2', secured by 4-5/8" x 4' rock bolts. Channels also support monorail.

EXCAVATION DATA:

Machine: Robbins 181-122 Weight: 260 tons.
Cutters: 47 Robbins, Steel Disc. Gage: 5-12". Center: 1-7 1/2" triple, Interior: 41-12".
Rotation: 4 1/2 RPM (Center integral with head)
Torque: 800 HP Input
Thrust 1,580 K# max., 1,200K# operating.
Muck Collection: Buckets fixed to head, discharging on a 30" conveyor.
Power System: Four-480V., 200 HP motors drive head. Hydraulic pumps power thrust and anchor cylinders.
Guidance System: Laser.

MDN STUDY SYSTEM DATA SHEET T-M2 Ident. No. 7-2 Sheet 1

MUCK DATA

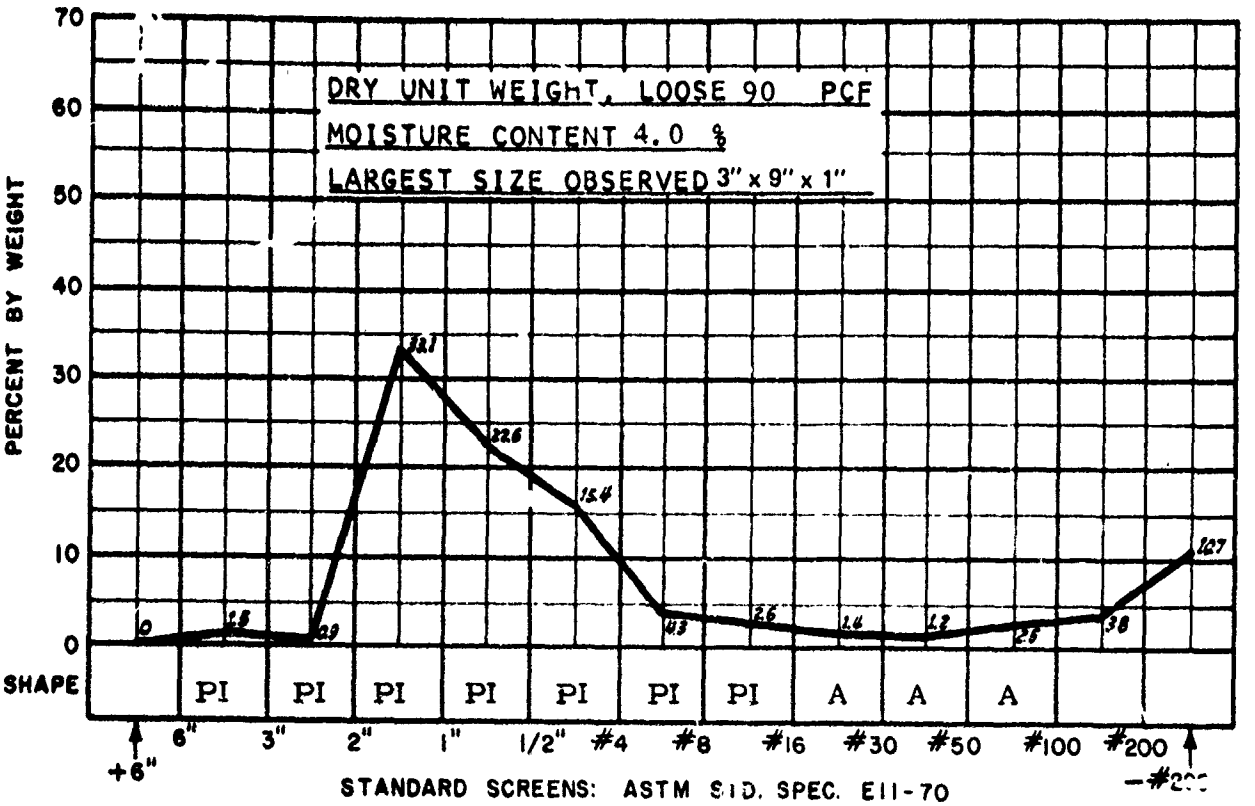
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size -0.056" : 0	Size -0.75" : 2.63

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 23.0 %	Plastic Limit 17.63 %	Shrinkage Limit 17.58%
Plasticity Index 5.37%	Toughness Index 0.78	Flow Index 6.90

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @ 2.6% Moisture, 32°	Apparent Cohesion PSF @ 2.8 % Moisture, 0	Angle/Repose 10 In. Drop @ 2.6 % Moisture, 31°
Angle Slide Steel Plate @ 2.6% Moisture, 29°	Bulk Density PCF @ 0.0 % Moisture, 92.8	Angle Internal Friction @ 2.8 % Moisture, 44°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary: Sandstone, fine grained, well compacted, over 50% quartz. High strength. RQD: 92%. DUW: 171 PCF. Ground water: Dry. Hardness: Shore 61.

System Class: TBM, Robbins 181-122, 18' -1" dia. 47 Robbins disc cutters. 4-1/2 RPM, 800 HP torque, 1,200 K# thrust. Mucking: Buckets to belt conveyor. Haulage: Traveling conveyor - suspended conveyor - skip to surface. Support: Channels and rock bolts at 4' or 2', continuous.

MDN STUDY SYSTEM DATA SHEET MDN T-M2 Ident. No. 7-2 Sheet 2

ROCK DATA:

Lithology: Sedimentary, "shale", massive to thinly-laminated, interbedded siltstone and shale, with minor sandstone and limestone layers. Grain size varies from fine to coarse, quartz content from 24 to 33%.
Uniaxial Compressive Strength: Four major beds: 27K to 29 KPSI, two minor beds: 15K to 17 KPSI.
RQD: (Estimated) 90%.
Dry Unit Weight: 152 PCF.
Ground Water: Dry
Hardness: Shore 41 to 55 parallel to bedding planes, 41 to 54 perpendicular.

TUNNEL DATA:

Size: 24' wide x 7 1/2' rectangular. Grade: Varies
Ventilation System: 80-100K CFM, pressure
Utility System: 4" air, 4" water, 4" pump, where required.
Water Inflow: Normally none.
Power System: 110V. lighting-all equipment diesel or air powered.
Haulage System: Wagner ST-5 Scooptrams, 16 ton shuttle cars to conveyors, 1 1/2 CY loaders for cleanup. Personnel and supplies, diesel jeeps and trucks.
Support System: 5/8" x 6' rock bolts on 4' x 4' pattern, 11" wide x 10' roof plates where required.

EXCAVATION DATA:

Conventional Trackless System.
Drilling: Two boom hydrojib jumbos, AR93 drifters, 14' feed.
Drill Round: 35 holes, 1 3/4" diameter, 10 1/2 to 11' deep, and 1-6' buster hole, V-cut.
Explosives: 16# -1 1/4" x 8", 75% primers, 32#-1 1/4" x 12" RXL, 60% in lifters, 11# coalite 5Y, 1 1/4' x 12" in back holes, 175# AN/FO in remainder of round. Powder factor: 3.5#/CY.
Blasting: Electrical, MS delays.
Mucking: Wagner ST-5 Scooptrams.
Guidance: Transit/Laser.

MDN STUDY SYSTEM DATA SHEET T-C3 Ident. No. 11-3 Sheet 1

MUCK DATA

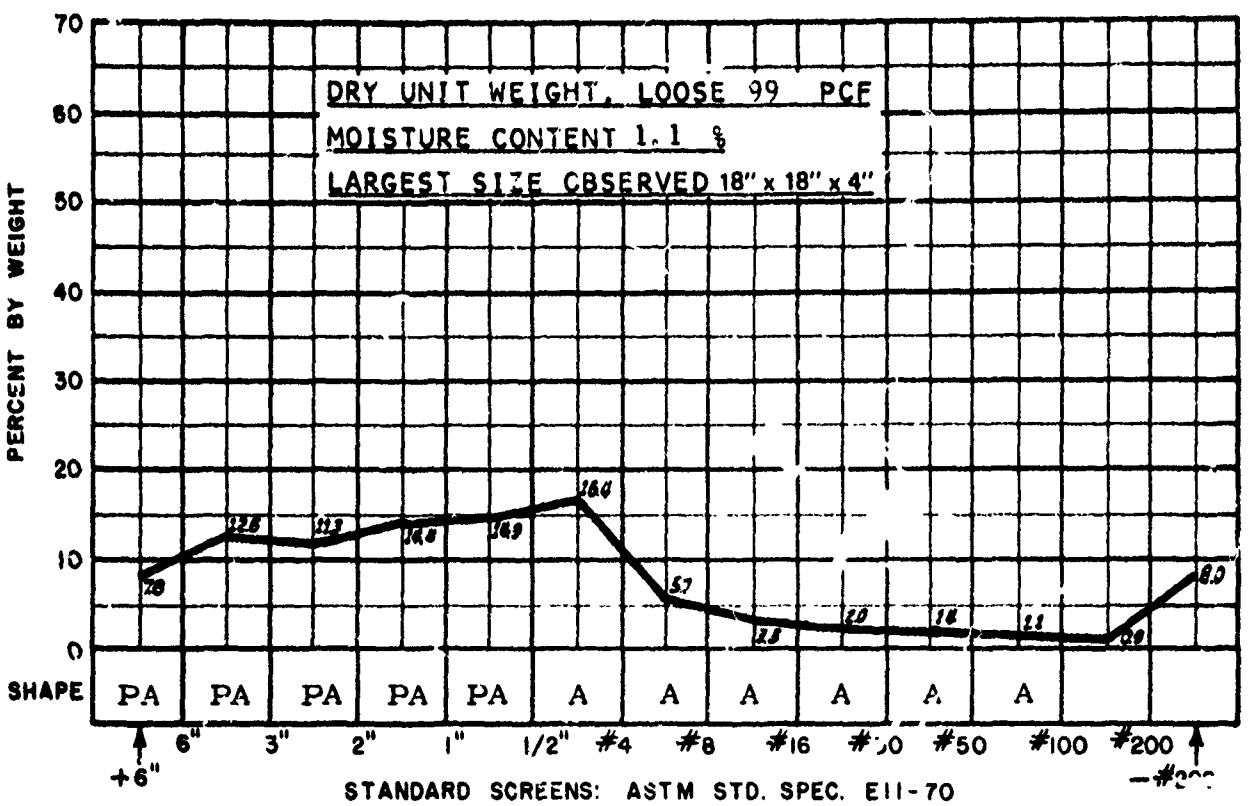
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size : NA	Size : NA

ATTERBERG LIMITS, MATERIAL SIZE IN.

Liquid Limit NA %	Plastic Limit NA %	Shrinkage Limit NA %
Plasticity Index NA %	Toughness Index NA	Flow Index NA

MATERIAL SIZE IN.

Angle/Repose 1 In. Drop	Apparent Cohesion PSF	Angle/Repose 10 In. Drop
@ % Moisture, NA	@ % Moisture, NA	@ % Moisture, NA
Angle Slide Steel Plate	Bulk Density PCF	Angle Internal Friction
@ % Moisture, NA	@ % Moisture, NA	@ % Moisture, NA



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary: Shale and siltstone, minor sandstone and limestone, thin to massive, fine to coarse grained. High to medium strength. RQD:(Est.) 90%. DUW: 152 PCF. Ground water: Dry. Hardness: Shore, 41-55.

System Class: Conventional trackless. 24' wide x 7-1/2', rectangular. Two boom jumbo, 35-11' holes, V cut. PF 3.5#/CY. Mucking: Scooptram. Haulage: Scooptram and/or shuttle cars to conveyor. Support: Rock bolts, 4' x 4' pattern.

MDN STUDY SYSTEM DATA SHEET MDN T-C3 Ident. No. 11-3 Sheet 2

ROCK DATA:

Lithology: Sedimentary, "shale", massive to thinly laminated, interbedded siltstone and shale, with minor sandstone and limestone layers. Grain size varies from fine to coarse, quartz content from 24 to 33%.
Uniaxial Compressive Strength: Four major beds: 27K to 29 KPSI, two minor beds: 15K to 17 KPSI.
RQD: (Estimated) 90%.
Dry Unit Weight: 166 PCF.
Ground Water: Dry.
Hardness: Shore 41.0 to 55 parallel to bedding planes, 41 to 54 perpendicular.

TUNNEL DATA:

Size: 18' wide x 8 1/2' high, rectangular. Grade: Level.
Ventilation System: 20 KCFM exhaust from face, pressure to entry, 40 HP.
Utility System: 2" water line (250 cfm compressor on machine trailer).
Water Inflow: None.
Power System: Cable to trailer mounted transformer.
Haulage: Muck by diesel shuttle car to conveyor, personnel and supplies by diesel truck.
Support System: 5/8" rock bolts, normally 6' long on 4' x 4' spacing, as required.

EXCAVATION DATA:

Machine: Atlas-Copco 4 head prototype. Weight: 180 LT. Two 4' dia. heads are mounted on each side of center on horizontal booms rotated about vertical pivots. Heads are rotated around boom centerlines by motors and reducers integral with the booms; booms and heads rotate from side to forward positions.
Cutters: 48 Sandvik T.C., drag type, mounted on head peripheries. Leading cutters, 40mm wide, 8 per head; Finish cutters, 120mm wide, 4 per head.
Rotation: Upper heads: 3 1/4 RPM. Lower: 1 3/8 RPM.
Torque: Head rotation: 80 KW. Boom rotation: 100 LT per boom.
Thrust: 488 LT produced by 4 hydraulic cylinders between advanced and front units.
Anchorage: Two top and two side cylinders, approximately 1,000 K#.
Muck Collection: Flight conveyors move muck from sides to a central 26" flight conveyor, discharging on a 9 1/2' dia. star wheel. The wheel feeds a 25" belt conveyor, transfering muck to a Joy loader and shuttle cars.
Power System: 4160/600/120V, 60 cy. Head rotation: 4-80 KW motors, hydraulics: 2-78 KW motors, 2300 psi.
Guidance: Transit/Laser.

MDN STUDY SYSTEM DATA SHEET T-M4 Ident. No. 11-4 Sheet 1

MUCK DATA

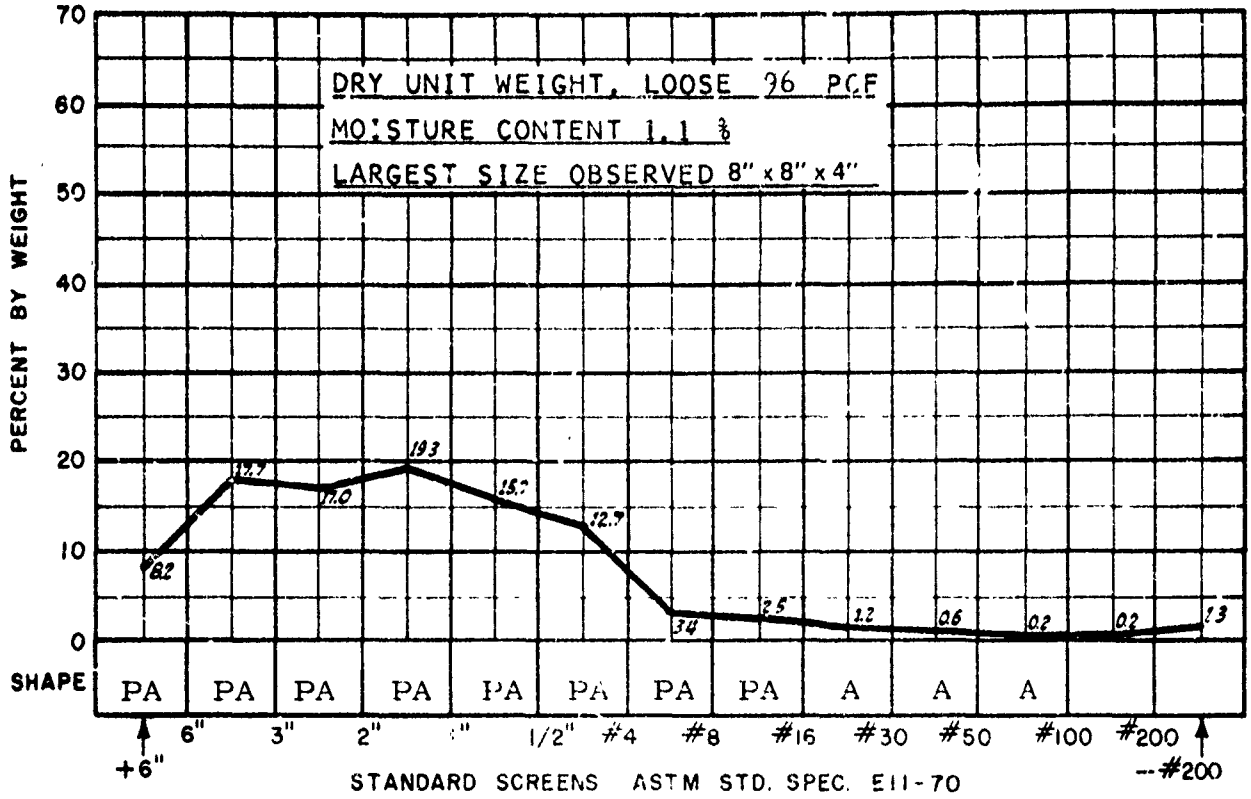
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size : NA	Size : NA

ATTERBERG LIMITS, MATERIAL SIZE IN.

Liquid Limit NA %	Plastic Limit NA %	Shrinkage Limit NA %
Plasticity Index NA %	Toughness Index NA	Flow Index NA

MATERIAL SIZE IN.

Angle/Repose 1 In. Drop @ % Moisture, NA	Apparent Cohesion PSF @ % Moisture, NA	Angle/Repose 10 In. Drop @ % Moisture, NA
Angle Slide Steel Plate @ % Moisture, NA	Bulk Density PCF @ % Moisture, NA	Angle Internal Friction @ % Moisture, NA



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary: Shale and siltstone, minor sandstone and limestone, thin to massive, fine to coarse grained. High to medium strength. RQD:(Est.) 90%. DUW: 166 PCF. Ground water: Dry. Hardness: Shore 41-55.

System Class: TBM, Atlas-Copco. 18' wide x 8-1/2' rect. heading. Sandvik TC "drag" bits, 12/head, 4 heads. RPM 3-1/4 normal. Torque 80KW/head, 100LT/boom. 480LT thrust. Mucking: Flight conveyor - starwheel-belt - loader. Haulage: Shuttle car to conveyor. Support: Rock bolts at 4'.

ROCK DATA:

Lithology: Sedimentary, limestone, light to medium gray, fine grained, some chert nodules, traces to occasional clay partings.
Uniaxial Compressive Strength: 8 KPSI.
RQD: (Estimated) 100 percent.
Dry Unit Weight: 176 PCF.
Ground Water: Table above tunnel, occasional seepage from minor fractures and faults.
Hardness: Shore, 46.

TUNNEL DATA:

Size: 13'-8" diameter. Grade (+) 1/4 percent.
Ventilation System: 21 K CFM exhaust, 28" pipe.
Utility System: 6" air line, 2" water line, 6" pump line.
Water Inflow: 40 to 120 gpm.
Power System: 4160/480V.
Haulage System: Muck, supplies, personnel, by rail cars.
Support System: None.

EXCAVATION DATA:

Machine: Alkirk Hardrock. Weight 400 tons. Cutters: 28-Lawrence Mfg. Company, Tungsten Carbide Button, roller, disc, and tricone. Gage: 5-15" TCB roller. Center: 1-24" TCB tricone. Interior: 11-15" TCB disc., 11-15" TCB roller.
Rotation: Center cutter-30 RPM, Head-9 RPM.
Torque: Center 150 HP. Head 600 HP.
Thrust: 853 K#
Muck Collection: Buckets from face discharging on 24" belt conveyor.
Power System: Electro-Hydraulic. Total HP: 910.
Guidance System: Laser.

MDN STUDY SYSTEM DATA SHEET T-M3 Ident. No. LAW-2 Sheet 1

MUCK DATA

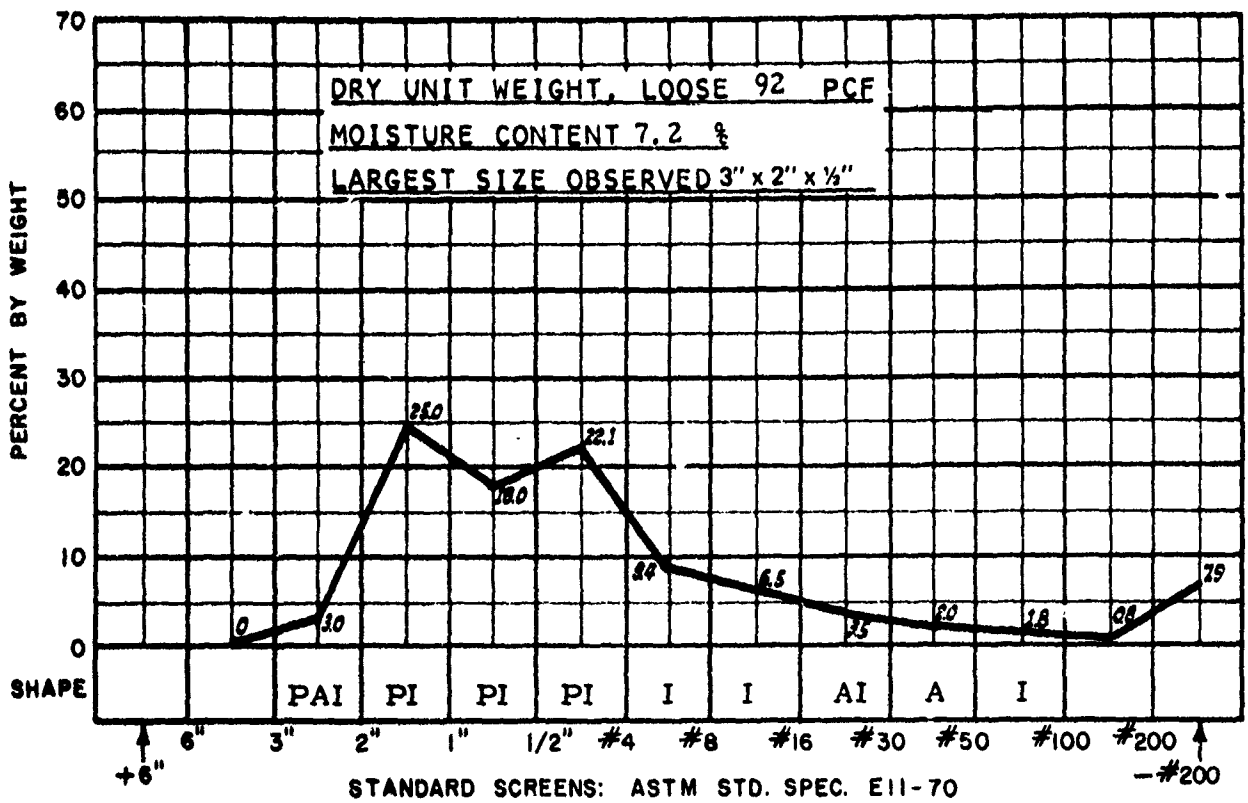
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size -0.065" : 0	Size -0.75" : 2.83

ATTERBERG LIMITS, MATERIAL SIZE (-)0.185 IN.

Liquid Limit 12.5 %	Plastic Limit 12.3 %	Shrinkage Limit 9.6 %
Plasticity Index 0.2 %	Toughness Index 0.05	Flow Index 4.0

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @ 5.4% Moisture, 39°	Apparent Cohesion PSF @ % Moisture, NA	Angle/Repose 10 In. Drop @ 5.4% Moisture, 38°
Angle Slide Steel Plate @ 5.4% Moisture, 31°	Bulk Density PCF @ % Moisture, NA	Angle Internal Friction @ 7 % Moisture, 30°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary: Limestone, fine grained, some chert nodules, occasional clay partings. Low strength. RQD: (Est.) 100%. DUW: 176 PCF. Ground water: Minor. Hardness: Shore 46.

System Class: TBM, Alkirk Hardrock, 13' 8" dia. 28 Lawrence TCBI roller, disc, tricone cutters. RPM: Center 30, head 9. Torque: Center 150 HP, head 600 HP. Thrust: 853 K #. Mucking: Buckets to belt. Haulage: Rail. Support: None.

MDN STUDY SYSTEM DATA SHEET MDN T-M3 Ident. No. LAW-2 Sheet 2

ROCK DATA:

Lithology: Sedimentary, limestone, light to medium gray, fine grained, some chert nodules, traces to occasional clay partings.
Uniaxial Compressive Strength: 8 KPSI.
RQD: (Estimated) 100 percent.
Dry Unit Weight: 176 PCF.
Ground Water: Table above tunnel, occasional seepage from minor fractures and faults.
Hardness: Shore, 46.

TUNNEL DATA:

Size: 13'-8" diameter. Grade (+) 1/4 percent.
Ventilation System: 20 K CFM exhaust, 28" pipe.
Utility System: 6" air line, 2" water line, 6" pump line.
Water Inflow: 40 to 120 gpm.
Power System: 4160/480V.
Haulage System: Muck, supplies, personnel, by rail cars.
Support System: None.

EXCAVATION DATA:

Machine: Akkirk Hardrock. Weight 400 tons. Cutters: 28-Lawrence Mfg. Company, Tungsten Carbide Button, roller, disc, and tricone. Gage: 5-15" TCB roller. Center: 1-24" TCB tricone. Interior: 11-15" TCB disc, 11-15 TCB roller.
Rotation: Center cutter-30 RPM, Head-9 RPM.
Torque: Center 150 HP. Head 600 HP.
Thrust: 855 Kp
Muck Collection: Buckets from face, discharging on 24" belt conveyor.
Power System: Electro-Hydraulic. Total HP: 910.
Guidance System: Laser.

MDN STUDY SYSTEM DATA SHEET T-M3 Ident. No. LAW-3 Sheet 1

MUCK DATA

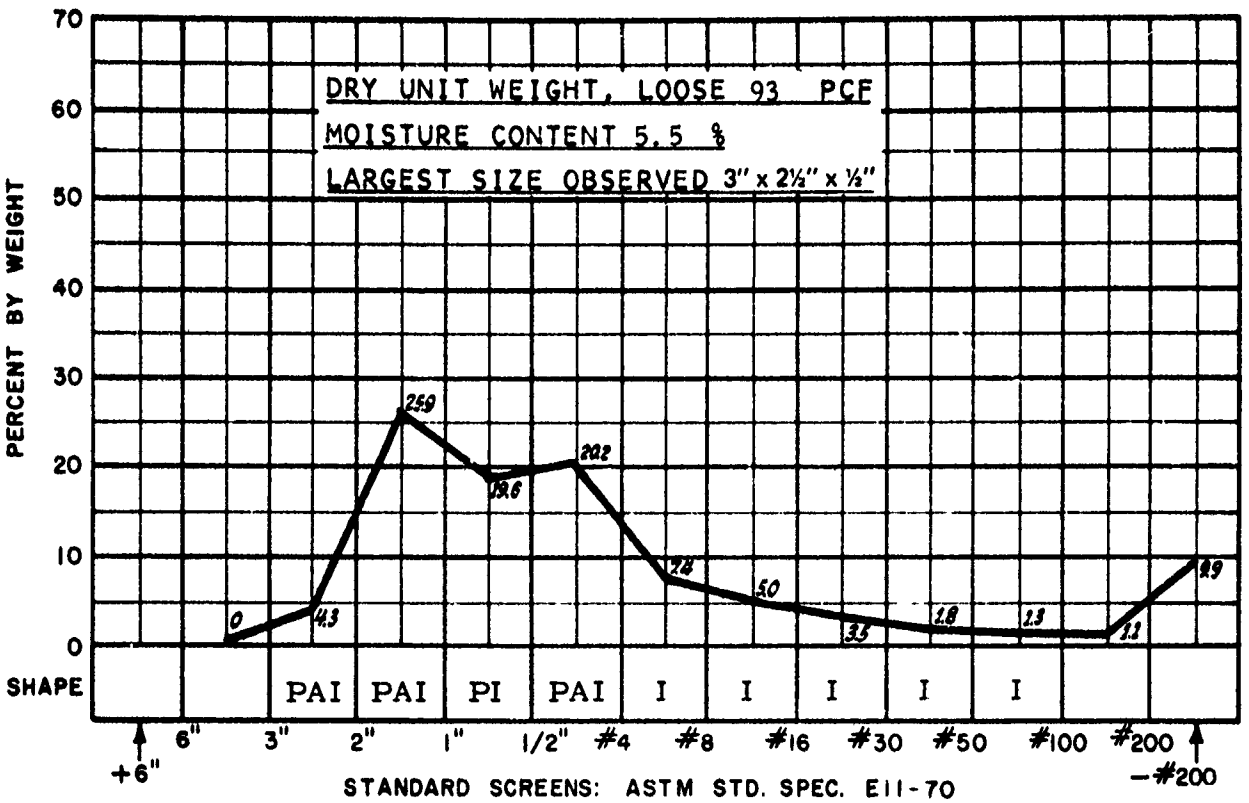
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size -0.065" : 0	Size -0.75" : 2.80

ATTERBERG LIMITS, MATERIAL SIZE (-)0.185 IN.

Liquid Limit 11.8 %	Plastic Limit 10.6 %	Shrinkage Limit 10.0 %
Plasticity Index 1.2 %	Toughness Index 0.41	Flow Index 2.9

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @ 6.1% Moisture, 41°	Apparent Cohesion PSF @ % Moisture, NA	Angle/Repose 10 In. Drop @ 6.1% Moisture, 40°
Angle Slide Steel Plate @ 8.4% Moisture, 38°	Bulk Density PCF @ % Moisture, NA	Angle Internal Friction @ 7 % Moisture, 32°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary: Limestone, fine grained, some chert nodules occasional clay partings, Low strength. RQD: (Est.) 100%. DUW: 176 PCF. Ground water: Minor. Hardness: Shore 46.

System Class: TBM, Alkirk Hardrock. 13' 8" dia. 28 Lawrence TCBI roller, disc, tricone cutters. RPM: Center 30, head 9. Torque: Center 150 HP, head 600 HP. Thrust: 853 K #. Mucking: Buckets to belt. Haulage: Rail. Support: None.

MDN STUDY SYSTEM DATA SHEET MDN T-M3 Ident. No. LAW-3 Sheet 2

ROCK DATA:

Lithology: Sedimentary, limestone, light to medium gray, fine grained, some chert nodules, traces to occasional clay partings.
Uniaxial Compressive Strength: 10 KPSI.
RQD: (Estimated) 100 percent.
Dry Unit Weight: 176 PCF.
Ground Water: Table above tunnel, occasional seepage from minor fractures and faults.
Hardness: Shore, 46.

TUNNEL DATA:

Size: 13'-8" diameter. Grade (+) 1/4 percent.
Ventilation System: 21 K CFM exhaust, 28" pipe.
Utility System: 6" air line, 2" water line, 6" pump line.
Water Inflow: 40 to 120 gpm.
Power System: 4160/480V.
Haulage System: Muck, supplies, personnel, by rail cars.
Support System: None.

EXCAVATION DATA:

Machine: Alkirk Hardrock. Weight 400 tons. Cutters: 28-Lawrence Mfg. Company, Tungsten Carbide Button, roller, disc, and tricone. Gage: 5-15" TCB roller. Center: 1-24" TCB tricone. Interior: 11-15" TCB disc., 11-15" TCB roller.
Rotation: Center cutter-30 RPM, Head-9 RPM.
Torque: Center 150 HP. Head 600 HP.
Thrust: 853 K#
Muck Collection: Buckets from face discharging on 24" belt conveyor.
Power System: Electro-Hydraulic. Total HP: 910.
Guidance System: Laser.

MDN STUDY SYSTEM DATA SHEET T-M3 Ident. No. LAW-4 Sheet 1

MUCK DATA

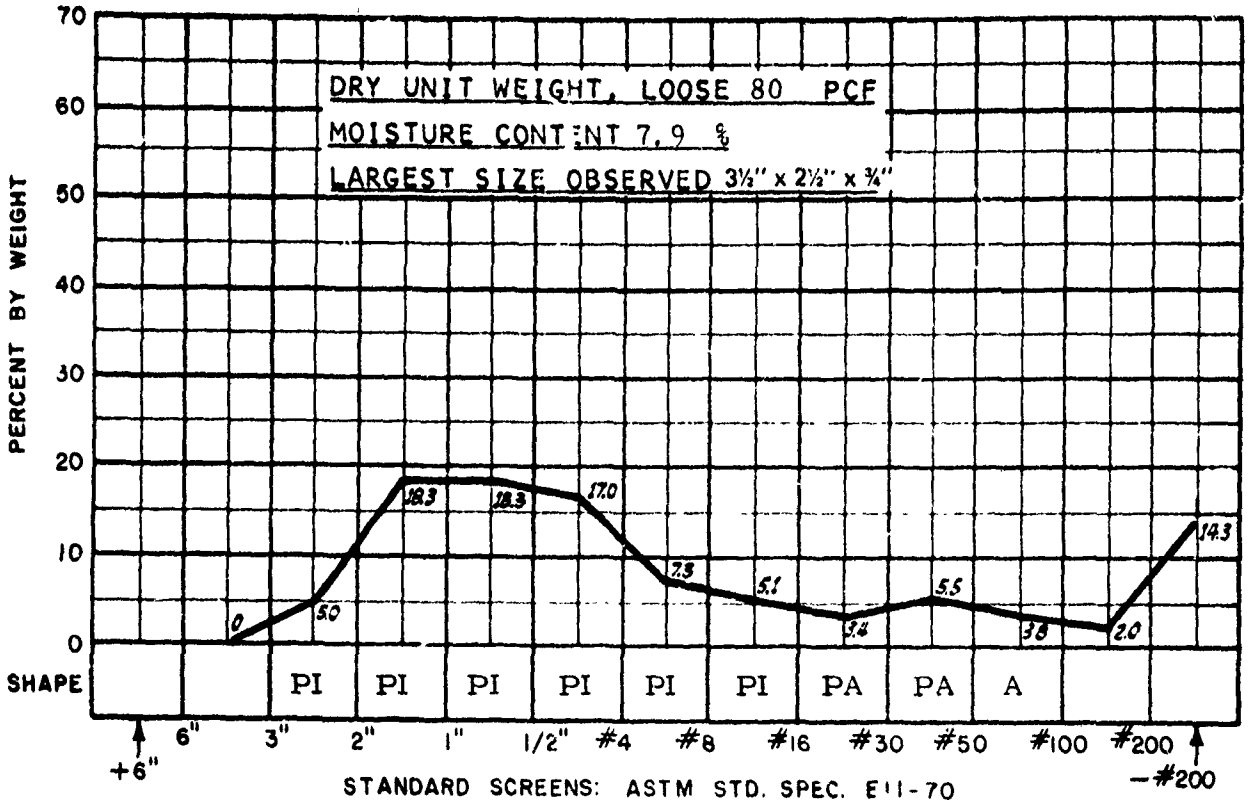
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size -0.056" : 0	Size -0.75" : 2.73

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 20.2 %	Plastic Limit 20.0 %	Shrinkage Limit 13.5 %
Plasticity Index 0.2 %	Toughness Index 0.05	Flow Index 4.7

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @ 8.9% Moisture, 42°	Apparent Cohesion PSF @ % Moisture, NA	Angle/Repose 10 In. Drop @ 8.9% Moisture, 34°
Angle Slide Steel Plate @ 8.9% Moisture, 37°	Bulk Density PCF @ % Moisture, NA	Angle Internal Friction @ 8.8% Moisture, 28°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary: Limestone, fine grained, some chert nodules, occasional clay partings. Medium strength. RQD: (Est.) 100%. DUW: 176 PCF. Ground water: Minor. Hardness: Shore 46.

System Class: TBM, Alkirk hardrock. 13' 8" dia. 28 Lawrence TCBI roller, disc, tricone cutters. RPM: Center 30, head 9. Torque: Center 150 HP, Head 600 HP. Thrust: 853 K #. Mucking: Buckets to belt. Haulage: Rail. Support: None.

MDN STUDY SYSTEM DATA SHEET MDN T-M3 Ident. No. LAW-4 Sheet 2

ROCK DATA:

Lithology: Sedimentary, limestone, gray, fine grained, horizontal joint spacing 6" to 1'.
Uniaxial Compressive Strength: 36 KPSI.
RQD: (Estimated) 85%
Dry Unit Weight: 166 PCF.
Ground Water: Minor, in fault zones.
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 11'3" round. Grade: (+) .2%.
Ventilation System: 4 KCFM, exhaust, 18" pipe, 25 HP.
Utility System: 6" air line, 1" water line, 6" pump line.
Water Inflow: 5-10 gpm.
Power System: 4680/440V.
Haulage System: Muck, supplies, personnel, rail cars, 5 ton motors, track gage 24".
Support System: 4" H rings sets in fault zones, occasional pinned steel lagging.

EXCAVATION DATA:

Machine: Jarva Mark 11. Total weight: 55 tons.
Cutters: 27 Reed steel triple disc and cone. Gage. 4-QK5 steel disc. Center: 1-QK1 steel cone. Interior: 22-QK3 steel disc.
Rotation: Cutterhead RPM 9.3.
Torque: Maximum 235 Kft#.
Thrust: 618 K# maximum, 596 K.#-operating. Anchor Pressure: 1,650 K#.
Muck Collection: Bucket from face to 18" belt to 24" belt on gantry.
Power System: 440 volt, 4-100 HP motors drive head and 1-40 HP motor for hydraulic system.
Guidance: Laser.

MDN STUDY SYSTEM DATA SHEET T-M4 Ident. No. MIL-1 Sheet 1

MUCK DATA

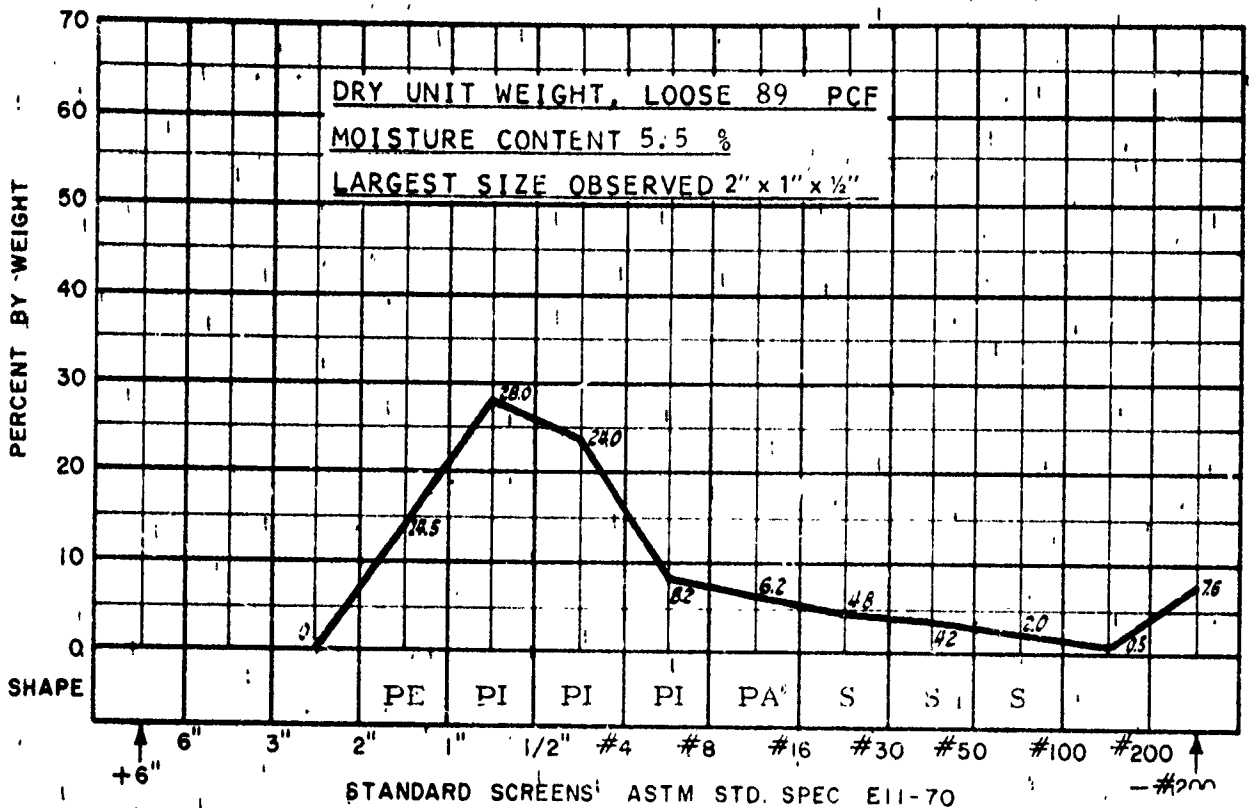
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size -0.056" : 0	Size -0.75" : 2.89

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 16.90%	Plastic Limit 15.69%	Shrinkage Limit 15.46%
Plasticity Index 1.21 %	Toughness Index 0.24	Flow Index 5.00

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @ 2.5% Moisture, 36°	Apparent Cohesion PSF @ 4.1% Moisture, 95	Angle/Repose 10 In. Drop @ 2.5 % Moisture, 35°
Angle Slide Steel Plate @ 2.5 % Moisture, 30°	Bulk Density PCF @ 0.0 % Moisture, 86	Angle Internal Friction @ 3.5 % Moisture, 35°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary, limestone, fine grained, horizontal joint spacing 6" to 1'. Very high strength. RQD:(Est.) 85%. DUW: 166 PCF.
Ground water: Minor. Hardness: NA.
System Class: TBM, Jarva Mark 11, 11' 3" dia. 27 Reed triple disc cutters. RPM: 9.3. Torque: 235.K ft #. Thrust: 596 K #. Mucking: Bucket to belt. Haulage: Rail. Support: H ring sets in fault zones.

MDN STUDY SYSTEM DATA SHEET MDN T-M4 Ident. No. MIL-1 Sheet 2

ROCK DATA:

Lithology: Sedimentary, limestone, gray, fine grained, horizontal joint spacing 6" to 1'.
Uniaxial Compressive Strength: 36 KPSI.
RQD: (Estimated) 85%
Dry Unit Weight: 166 PCF.
Ground Water: Minor, in fault zones.
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 11'3" round, Grade: (+) .2%.
Ventilation System: 4KCFM, exhaust, 18" pipe, 25 HP.
Utility System: 6" air line, 1" water line, 6" pump line.
Water Inflow: 5-10 gpm.
Power System: 4680/440V.
Haulage System: Muck, supplies, personnel, rail cars, 5 ton motors, track gage 24".
Support System: 4" H rings sets in fault zones, occasional pinned steel lagging.

EXCAVATION DATA:

Machine: Jarva Mark 11, Total weight: 55 tons.
Cutters: 27 Reed steel triple disc and cone. Gage: 4-QK5 steel disc. Center: 1-QK1 steel cone. Interior: 22-QK3 steel disc.
Rotation: Cutterhead RPM 9.3.
Torque: Maximum 235 Kft#.
Thrust: 618 K# maximum, 596 K.#-operating Anchor Pressure: 1,650 K#.
Muck Collection: Bucket from face to 18" belt to 24" belt on gantry.
Power System: 440 volt, 4-100 HP motors drive head and 1-40 HP motor for hydraulic system.
Guidance: Laser.

MUCK DATA

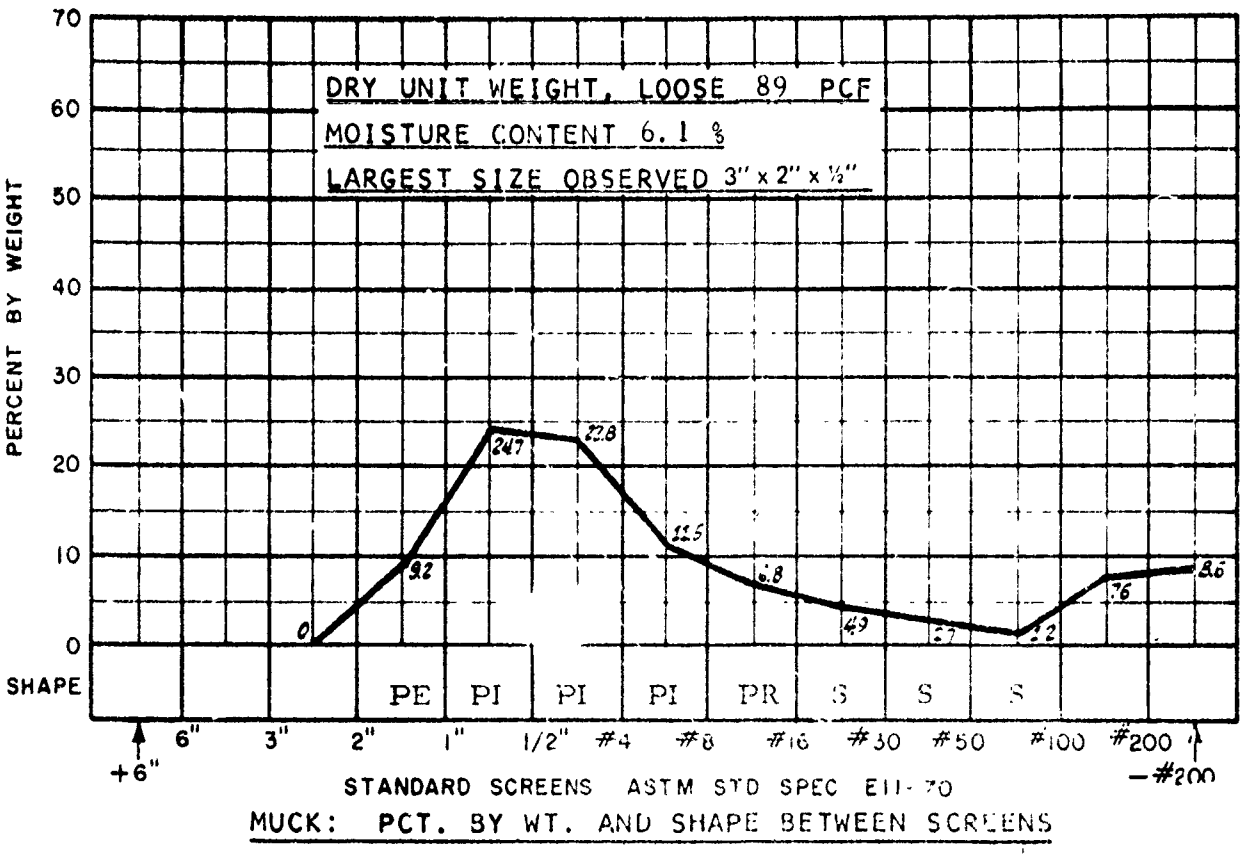
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size : NA	Size : NA

ATTERBERG LIMITS, MATERIAL SIZE IN.

Liquid Limit NA %	Plastic Limit NA %	Shrinkage Limit NA %
Plasticity Index NA %	Toughness Index NA	Flow Index NA

MATERIAL SIZE IN.

Angle/Repose 1 In. Drop @ % Moisture, NA	Apparent Cohesion PSF @ % Moisture, NA	Angle/Repose 10 In. Drop @ % Moisture, NA
Angle Slide Steel Plate @ % Moisture, NA	Bulk Density PCF @ % Moisture, NA	Angle Internal Friction @ % Moisture, NA



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary, limestone, fine grained, horizontal joint spacing 6" to 1'. Very high strength. RQD:(Est.) 85%. DUW: 166 PCF. Ground water: minor. Hardness: NA.

System Class: TBM, Jarva Mark II, 11' 3" dia. 27 Reed triple disc cutters. RPM: 9.3. Torque. 235 K ft #. Thrust: 596 K #. Mucking: Bucket to belt. Haulage: Rail. Support: H ring sets in fault zones.

MDN STUDY SYSTEM DATA SHEET MDN T-M4 Ident. No. MIL-2 Sheet 2

ROCK DATA:

Lithology: Sedimentary, sandstone, medium grained, light brown to red, massive, porous, poorly cemented.
Uniaxial Compressive Strength: 10 KPSI
RQD: (Estimated) 84%
Dry Unit Weight: 150 PCF
Ground Water: Generally dry.
Hardness: NA 1/11/72

TUNNEL DATA:

Size: 12'-11" diameter. Grade: (+) .125%
Ventilation System: 15-17 KCFM exhaust, 36" dia. pipe, 100 HP @ 4100'.
Utility System: 3 1/2" water line, 6" air line, 8" pump line.
Water Inflow: 20-100 gpm.
Power System: 7300/480V
Haulage System: Muck, supplies, personnel, 10 ton locomotives, 10 CY cars, 24" gage, 65 lb. rail.
Support System: 4" H full rings, 4' centers: 35%; 13" x 9' pans 3/4" x 7' rock bolts: 10%.

EXCAVATION DATA:

Machine: Robbins 141-127, total weight: 125 tons.
Cutters: 30 Robbins steel disc. Gage: 6-11". Center: 1-11" triple disc. Interior: 23-11".
Rotation: Center cutter integral with head, 6 or 3 RPM.
Torque: 600 HP
Thrust: 900 K# max., 685 K.# operating. Anchor pressure: 1,000 K #.
Muck Collection: Pickup by buckets fixed to head, discharging on 30" belt to a 24" x 204' belt on gantry.
Power System: 6-480/240V electric motors drive head. Hydraulic pumps power thrust and gripper cylinders.
Guidance System: Laser

MDN STUDY SYSTEM DATA SHEET T-M6 Ident. No. LAY-1 Sheet 1

MUCK DATA

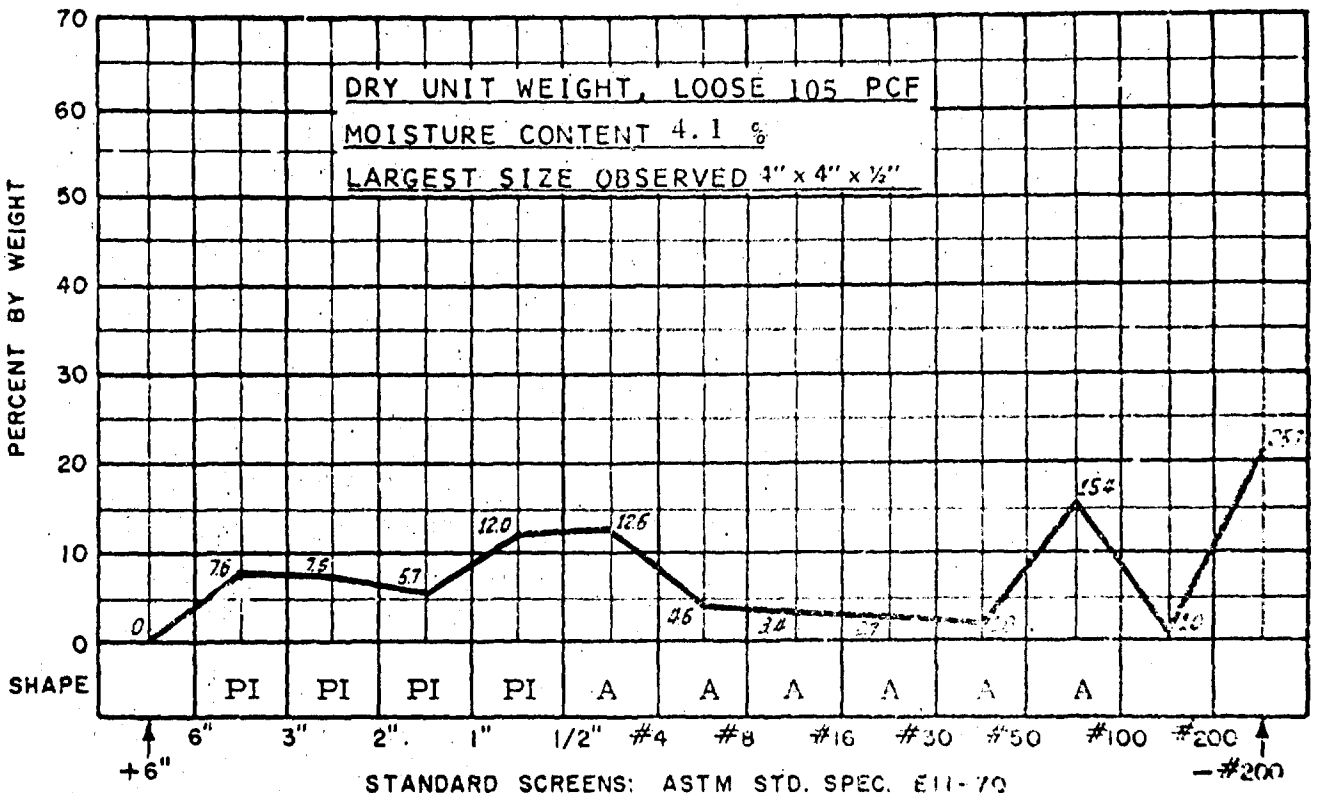
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size -0.056" : 0	Size -0.75" : 2.66

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 21.20%	Plastic Limit 17.06%	Shrinkage Limit 15.17%
Plasticity Index 3.14 %	Toughness Index 0.52	Flow Index 6.00

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @3.6% Moisture, 37°	Apparent Cohesion PSF @3.6 % Moisture, 210	Angle/Repose 10 In. Drop @3.6 % Moisture, 35°
Angle Slide Steel Plate @3.6 % Moisture, 27°	Bulk Density PCF @0.0 % Moisture, 97.4	Angle Internal Friction @3.6 % Moisture, 38°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary: Sandstone, medium grained, massive, porous, poorly cemented. Medium strength. RQD:(Est.) 84%. DUW: 150 PCF. Ground water: Dry. Hardness: NA.

System Class: TBM, Robbins 141-127, 12'-11" dia. 30 Robbins disc cutters. 3 or 6 RPM, 600 HP torque, 680 K# thrust. Mucking: Buckets to belt conveyor. Haulage: Gantry conveyor to rail cars. Support: Steel ring sets, 35%, roof pans and rock bolts, 10% of 4100'.

MDN STUDY SYSTEM DATA SHEET MDN T-M6 Ident. No. LAY-1 Sheet 2

ROCK DATA:

Lithology: Sedimentary, siltstone, fine grained, gray, more than 33% quartz, 30% clay, 10% feldspar, 15% mica, chlorite and gypsum.
Uniaxial Compressive Strength: 2 KPSI
RQD: (Estimated) 70%
Dry Unit Weight: 142 PCF
Ground Water: Table above tunnel but sealed off by overlying beds.
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 20.5' round, Grade: (+) .05%
Ventilation System: 18 KCFM exhaust 30" pipe, 60 HP.
Utility System: 6" air line, 4" pump line
Water Inflow: 50 GPH.
Power System: 4160/440V, rectified to 440 DC for head drive motors.
Haulage System: Muck, supplies, personnel, by 10 CY cars, 15 ton motor, 24" gage 70 lb rail.
Support System: Rock bolts, 8' and 10' x 3/4", set in epoxy with 5' and 13' x 16 gage pans, shotcrete placed to prevent air slacking.

EXCAVATION DATA:

Machine: Dresser TB-205, total weight: 200 tons
Cutters: 36 Dresser steel and TCB insert discs, 32 Kennametal U43 and U44 "pick" bits. Gage: 6-#9T5TD1 TCB insert discs. Center: 6-U43TC bits mounted on a 4" chisel. Interior: 30 Type STD steel discs and 26 U44 TC bits mounted on 4 bit blocks.
Rotation: 0-6 RPM range, 5 RPM normal operating.
Torque: Maximum 879 K ft. #., normal operating 586 K ft. #.
Thrust: Maximum 1,583 K # operating 750 K #.
Anchor Pressure: Maximum 6,616 K #.
Muck Collection: Buckets from face to 36" belt to 36" belt on 140' gantry.
Power System: Four 180 HP D.C. head motors, one 75 HP for hydraulic system.
Guidance System: Laser

MDN STUDY SYSTEM DATA SHEET T-M6 Ident. No. NAV-1 Sheet 1

MUCK DATA

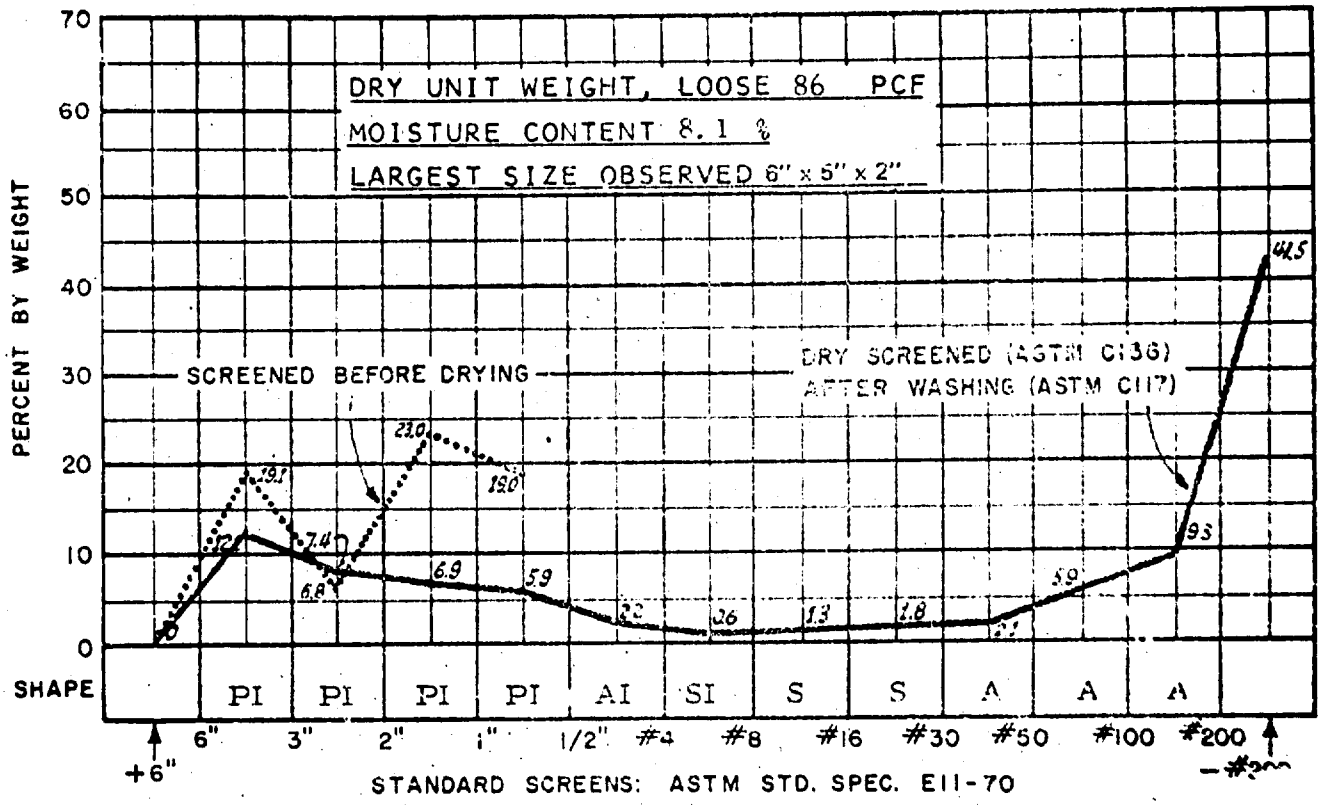
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size -0.056" : 1.3	Size -0.75" : 3.13

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 36.80%	Plastic Limit 23.61%	Shrinkage Limit 21.04 %
Plasticity Index 13.19%	Toughness Index 1.88	Flow Index 7.00

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @ 7.7 % Moisture, 30°	Apparent Cohesion PSF @ 7.5% Moisture, 340	Angle/Repose 10 In. Drop @ 7.7% Moisture, 30°
Angle Slide Steel Plate @ 7.7 % Moisture, 30°	Bulk Density PCF @ 0.0 % Moisture, 98	Angle Internal Friction @ 7.5% Moisture, 36°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary: Siltstone, fine grained. Very low strength. RQD: (Est.) 70%. DUW: 142 PCF. Ground water: Minor. Hardness: NA.

System Class: TBM, Dresser TB205, 20.5' dia., Dresser disc cutters: 6TCBI and 30 steel, 32 Kennametal, TCBI "pick" bits. RPM: 5, 586 K ft #. torque, 750 K # thrust. Mucking: Buckets to belt. Haulage: Rail. Support: Roof plates and rock bolts, at 3' or 4', continuous.

MDN STUDY SYSTEM DATA SHEET MDN T-M6 Ident. No. NAV-1 Sheet 2

ROCK DATA:

Lithology: Sedimentary, sandstone, gray, medium grained, massive, friable and porous. Grains angular to subrounded, primarily quartz, poorly cemented.
Uniaxial Compressive Strength: Less than 1 KPSI, disintegrates when wet.
RQD: (Estimated) 60%
Dry Unit Weight: 117 PCF
Ground Water: Table above tunnel but sealed off by overlying beds.
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 20.5' diameter. Grade: (+) .05%
Ventilation System: 18 KCFM exhaust, 30" pipe, 60 HP.
Utility System: 6" air line, 4" pump line
Water Inflow: 50 GPH.
Power System: 4160/440V, rectified to 440 DC for head drive motors.
Haulage System: Muck, supplies, personnel, by 16 CY cars, 15 ton motor, 24" gage 70 lb rail.
Support System: Rock bolts, 8' and 10' x 3/4", set in epoxy, with 5' and 13' x 16 gage pans, shotcrete placed to prevent air slacking.

EXCAVATION DATA:

Machine: Dresser TB-205, total weight: 200 tons
Cutters: 36 Dresser steel and TCB insert discs, 32 Kennametal U43 and U44 "pick" bits. Gage: 6-#9T5TD1 TCB insert discs. Center: 6-U43TC bits mounted on a 4" chisel. Interior: 30 Type STD steel discs and 26 U44TC bits mounted on 4 bit blocks.
Rotation: 0-6 RPM range, 5 RPM normal operating.
Torque: Maximum 879 K ft. #., normal operating 586 K ft. #.
Thrust: Maximum 1,583 K #. operating 750 K #.
Anchor Pressure: Maximum 6,616 K #.
Muck Collection: Buckets from face to 36" belt to 36" belt on 140' gantry.
Power System: Four 180 HP D.C. head motors, one 75 HP for hydraulic system.
Guidance System: Laser

MDN STUDY SYSTEM DATA SHEET T-M7 Ident. No. NAV-2 Sheet 1

MUCK DATA

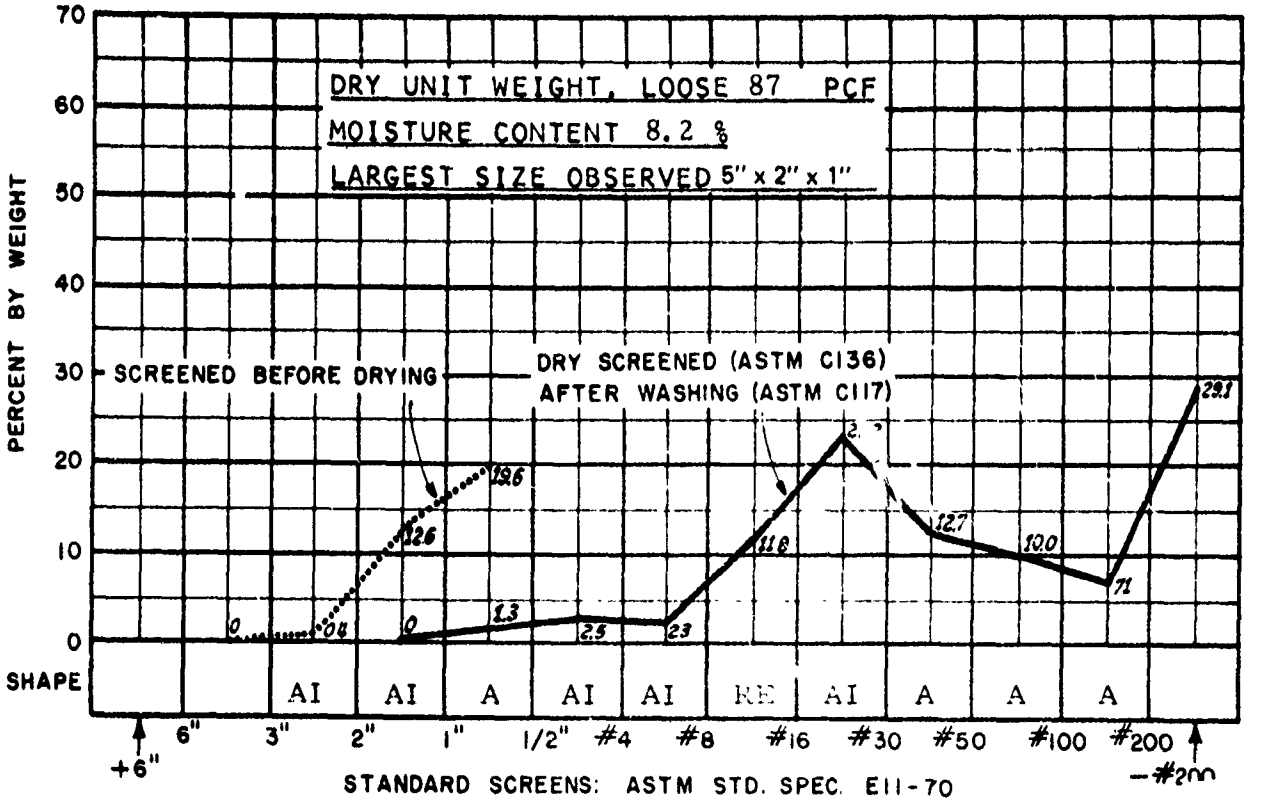
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size : NA	Size : NA

ATTERBERG LIMITS, MATERIAL SIZE IN.

Liquid Limit NA %	Plastic Limit NA %	Shrinkage Limit NA %
Plasticity Index NA %	Toughness Index NA	Flow Index NA

MATERIAL SIZE IN.

Angle/Repose 1 In. Drop @ % Moisture, NA	Apparent Cohesion PSF @ % Moisture, NA	Angle/Repose 10 In. Drop @ % Moisture, NA
Angle Slide Steel Plate @ % Moisture, NA	Bulk Density PCF @ % Moisture, NA	Angle Internal Friction @ % Moisture, NA



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary: Sandstone, massive, friable, porous, medium grained. Very low strength. RQD (Est.) 60%. DUW: 117 PCF. Ground water: Minor. Hardness: NA.

System Class: TBM, Dresser TB205, 20.5' dia. Dresser, disc cutters 6TCBI and 30 steel, 32 Kennametal, TCBI "pick" bits. RPM: 5, 586 K ft # torque, 750 K # thrust. Mucking: Buckets to belt. Haulage: Rail. Support: Roof plates and rock bolts, at 3' or 4', continuous.

MDN STUDY SYSTEM DATA SHEET MDN T-M7 Ident. No. NAV-2 Sheet 2

ROCK DATA:

Lithology: Sedimentary, sandstone, coarse grained, poorly consolidated, arkosic, with minor layers of thin seamed siltstone.
Uniaxial Compressive Strength: 50 to 150 PSI dry-disintegrates when wet.
RQD: (Estimated) 30%.
Dry Unit Weight: 125 PCF.
Ground Water: Saturated when first opened.
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 10' high by 8' wide, rectangular. Grade (+) 1/2%.
Ventilation System: 5 to 7 KCFM, pressure, 18" dia. vent tube.
Utility System: 4" airline.
Water Inflow: 20-25 gpm.
Power System: 440/110V, trailing cable.
Haulage System: Muck, personnel and supplies by rail cars, 24" gage, 40# rail.
Support System: None, rock bolts and/or shotcrete in bad ground.

EXCAVATION DATA:

Machine: Alpine Miner, Type F6-A. Total Weight: 11 tons.
Cutters: 72, Kennametal U43K, Carbide tipped, "pick" type. Cutters, mounted on twin ripper heads, rotating about a horizontal axis at 90° to a boom which moves the heads vertically and horizontally.
Rotation: 60 RPM, motor and gear box integral with boom.
Torque: 50.4 HP
Thrust: Sumping thrust from crawler motors, 2 @ 20.4 HP. Vertical and horizontal by hydraulic cylinders powered by a 10.4 HP electro-hydraulic system.
Anchor Pressure: Crawlers only.
Muck Collection: Central 14" chain conveyor, fed by gathering arms, discharges on an 18" x 30' belt feeding 116' of 20" Serpentix conveyor. Transverse folds are molded into 20" x 8" long rubber Serpentix sections, which are bolt connected at reinforced flanges connected to an endless chain driven by a sprocket. Folds allow inside edge to compress and outside to expand on curves. Vertebral side rail sections, alternating with straight sections, are supported by wheeled gantry legs riding a 60" gage track, under which cars are spotted.
Power System: 440V, trailing cable.
Guidance System: Transit/Laser.

MDN STUDY SYSTEM DATA SHEET T-M7 Ident. No. WNG-1 Sheet 1

MUCK DATA

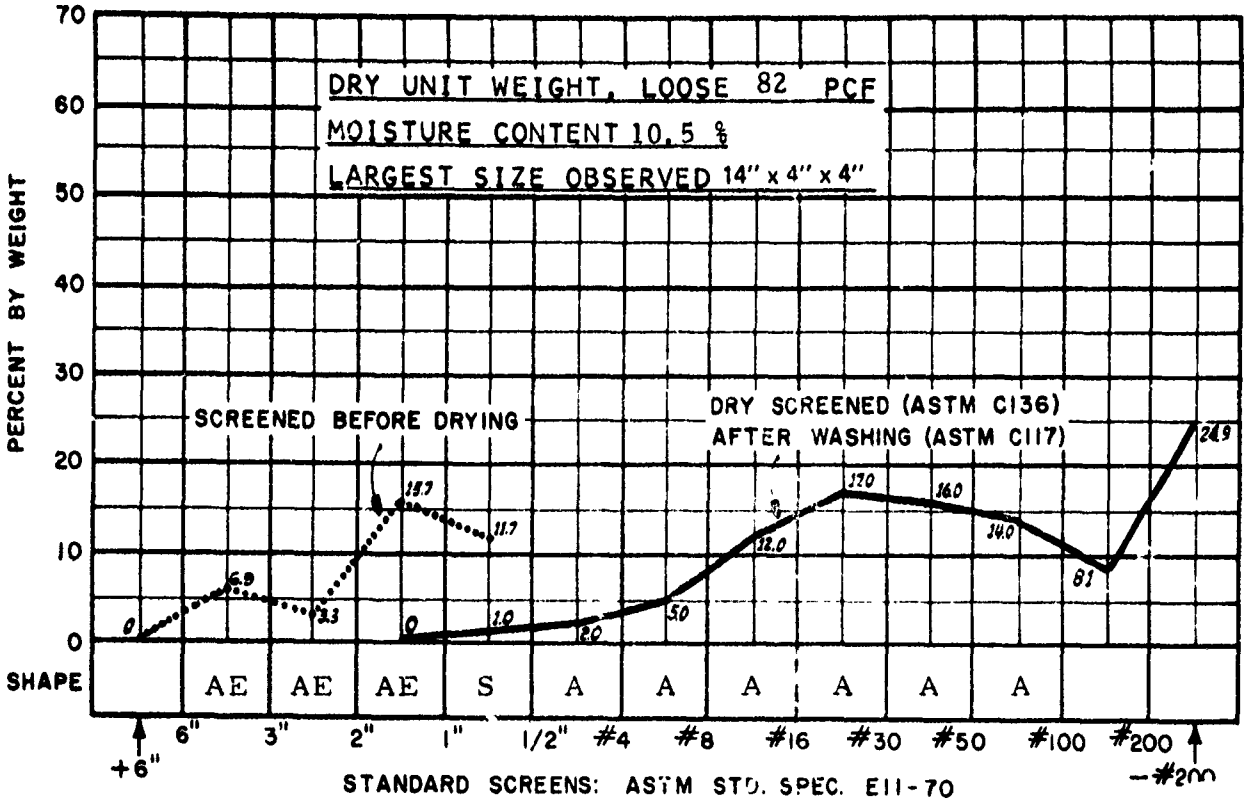
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size -0.056" : 0	Size -0.75" : 2.71

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 24.90 %	Plastic Limit 19.97 %	Shrinkage Limit 19.94 %
Plasticity Index 4.93 %	Toughness Index 0.66	Flow Index 7.40

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @10.1% Moisture, 34°	Apparent Cohesion PSF @10.6% Moisture, 0	Angle/Repose 10 In. Drop @10.1% Moisture, 31°
Angle Slide Steel Plate @10.0% Moisture, 32°	Bulk Density PCF @0.0 % Moisture, 85	Angle Internal Friction @10.6% Moisture, 27°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary: Sandstone, coarse grained, poorly consolidated, arkosic, minor thin seamed siltstone. Very low strength. RQD:(Est.) 30%. DUW: 125 PCF. Ground water: Saturated. Hardness: N.A.

System Class: TBM, Alpine F6A, twin head, 10' high x 8' heading. 72 Kennametal TCBI pick type bits. 60 RPM, 50.4 HP head torque, 10.4 HP boom power, 40.8 HP sumping thrust. Mucking: Gathering arms-flight conveyor. Haulage: Elevating conveyor - Serpentix conveyor on gantry - rail cars. Support: Normally none.

MDN STUDY SYSTEM DATA SHEET MDN T-M7 Ident. No. WNG-1 Sheet 2

ROCK DATA:

Lithology: Sedimentary, sandstone, coarse grained, poorly consolidated, arkosic, with minor layers of thin seamed siltstone, varying concentrations of replacement silica.
Uniaxial Compressive Strength: 50 to 150 PSI dry-disintegrates when wet.
RQD: (Estimated) 30%
Dry Unit Weight: 125 PCF
Ground Water: Saturated when first opened.
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 5' wide x 9' high, nominally rectangular. Grade: Varies.
Ventilation System: 5 to 7 KCFM, pressure, 18" vent tube.
Utility System: 2" air, 1" waterline.
Water Inflow: 20-25 gpm when levels are first opened; generally dry after drainage.
Power System: None in development headings, 440V to scraper hoists, 110V lighting.
Haulage System: Muck is scraped from the face of a cross cut to a slusher drift, cross scraped to a muck raise, and loaded into 4 cu. ft. rocker dump rail cars on main level about 80' below. Scrapers are 42", hoists 15 HP. Personnel access by ladder, supplies by rail cars and air-powered hoists through raises.
Support System: None. Rockbolts in bad ground.

EXCAVATION DATA:

Conventional Scraper-Rail Haulage System.
Drilling: LeRoi Model 35 jackhammers mounted on 6' airfeed legs.
Drill Round: Five hole box or vertical line burn cut, 6' depth, included in 18 hole round, all holes 1 1/2" diameter.
Explosives: 50# Dupont 40% Gelex #2, Powder factor: 5#/cu. yd.
Blasting: Safety fuse and caps.
Mucking System: 42" Scrapers, 15 HP hoists.

MDN STUDY SYSTEM DATA SHEET T-C7 Ident. No. WNG-2 Sheet 1

MUCK DATA

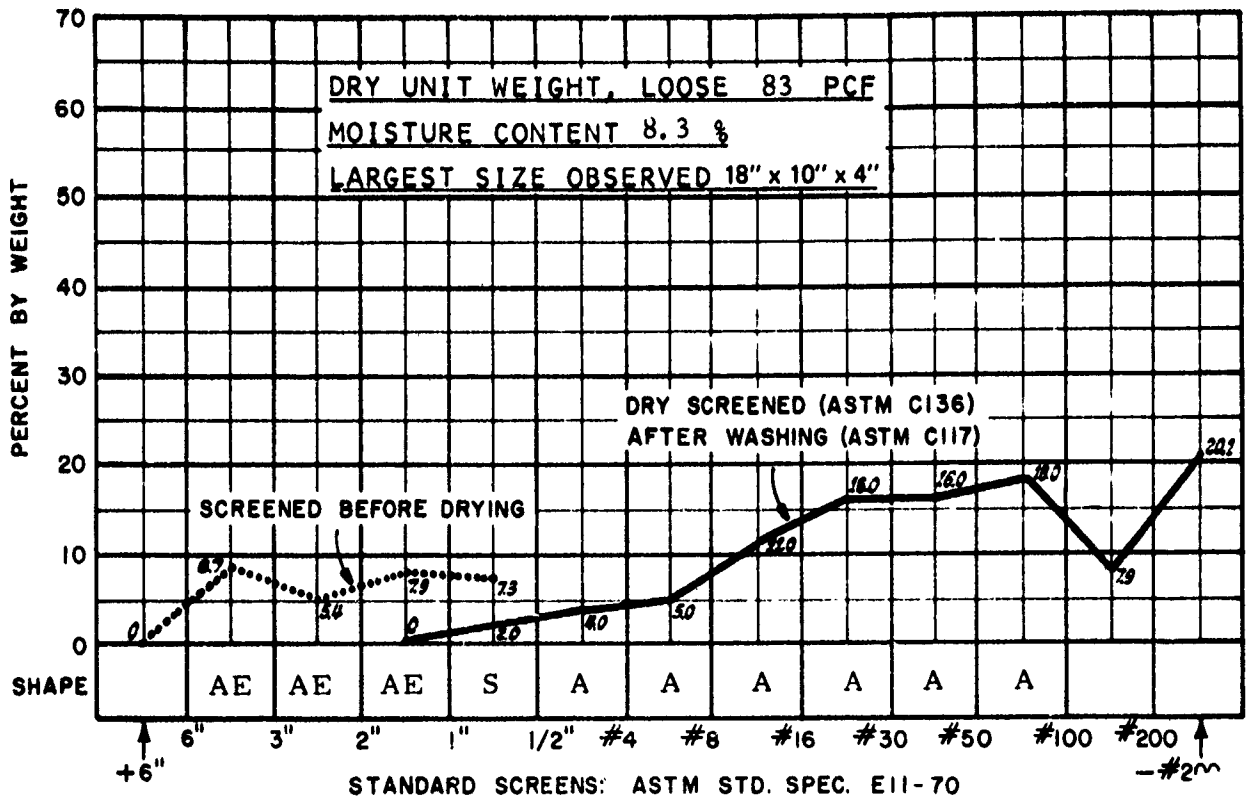
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size -0.056" : 0	Size -0.075" : 2.72

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 25.25 %	Plastic Limit 24.74 %	Shrinkage Limit 23.37 %
Plasticity Index 0.51 %	Toughness Index 0.13	Flow Index 4.00

MATERIAL SIZE (-)2.0 IN.

Angle/Repose 1 In. Drop @ 9.0 % Moisture, 32°	Apparent Cohesion PSF @ 9 % Moisture, 0	Angle/Repose 10 In. Drop @ 9.0% Moisture, 31°
Angle Slide Steel Plate @ 9.0 % Moisture, 40°	Bulk Density PCF @ 0.0 % Moisture, 86	Angle Internal Friction @ 9 % Moisture, 28°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary: Sandstone, coarse grained, poorly consolidated, arkosic, minor thin seamed siltstone, varying replacement silica. Very low strength. RQD: (Est.) 30%. DUW: 125 PCF. Ground water: Saturated. Hardness: NA.

System Class: Conventional Scraper-Rail. 5' wide x 9' high, rectangular. Airleg jackhammer, 18-6' holes, burn cut. PF 5#/CY. Mucking: Scraper to raise. Haulage: rail cars - skip to surface. Support: Normally none.

ROCK DATA:

Lithology: Sedimentary, sandstone, arkosic, irregularly bedded, loosely consolidated with layers and lenses of silty mudstone.
Uniaxial Compressive Strength: Less than one KPSI.
RQD: (Estimated) 0 to 35%.
Dry Unit Weight: 113 PCF
Ground Water: Saturated; water table above tunnel, heading is drained in advanced by lateral pilot holes in ribs.
Hardness: NA 1/11/72

TUNNEL DATA:

Size: 21 ft., diameter. Grade: (+) 0.2%.
Ventilation System: 20 KCFM, 36" pipe, pressure at face, exhaust in access.
Utility System: 6" air line, 6" pump line.
Water Inflow: 200 gpm.
Power System: 4160/480V.
Haulage System: Muck, personnel, supplies by rail cars.
Support System: Continuous, precast concrete rings 8" and 10" thick, erected in four-4' segments.

EXCAVATION DATA:

Shield: Robbins 221S ripper, Total weight: 285 tons
Thrust: 3,500 tons total.
Muck Collection System: Muck is ripped from the face by a ripper tooth and drawn through the shield to a 6' conveyor by hydraulic ram with a bucket opposite the ripper tooth.
Power System: Hydraulic.
Guidance System: Laser

MUCK DATA

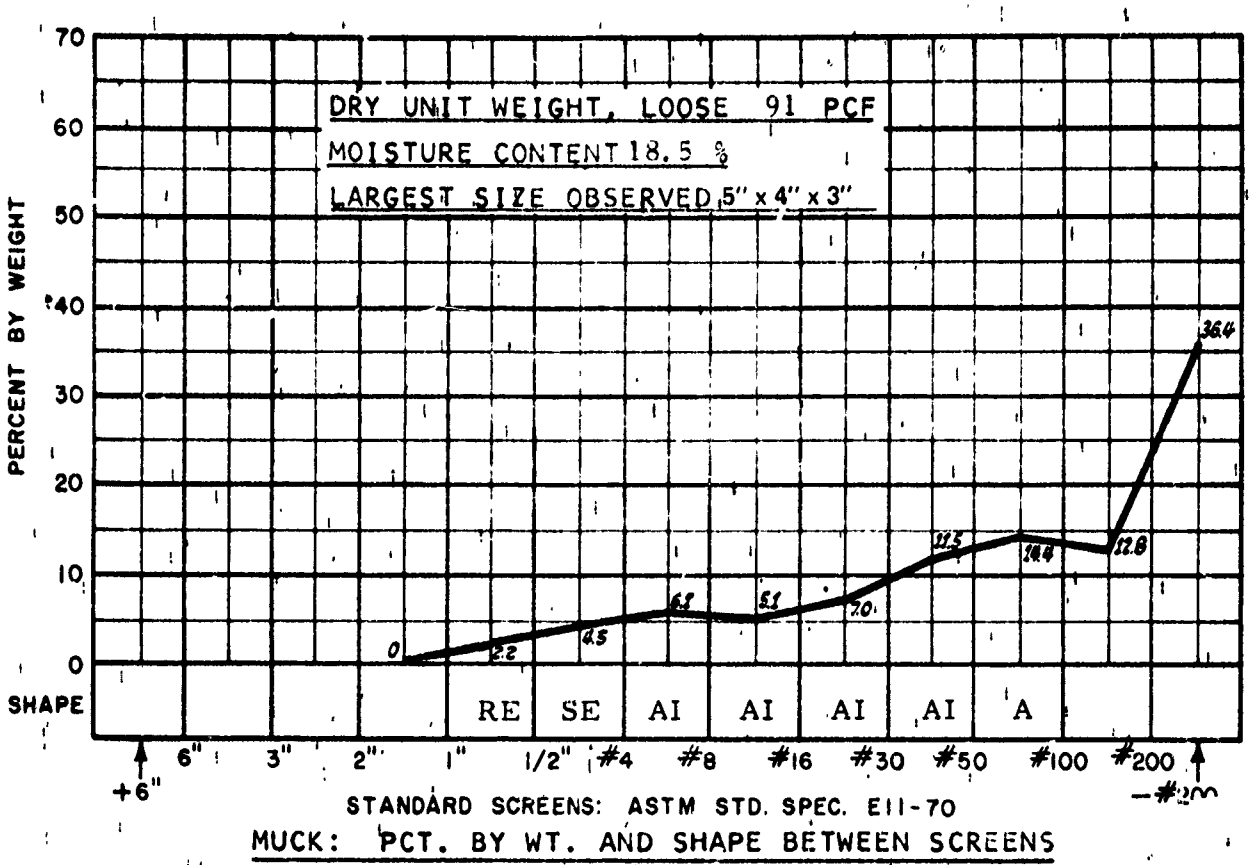
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N. A. 1/11/72	Size -0.065" : 0	Size -0.185" : 2.86

ATTERBERG LIMITS, MATERIAL SIZE (-)0.185 IN.

Liquid Limit 17.75 %	Plastic Limit 16.19 %	Shrinkage Limit 13.94 %
Plasticity Index 1.56 %	Toughness Index 0.27	Flow Index 5.8

MATERIAL SIZE(-)0.185IN.

Angle/Repose 1 In. Drop @14.3% Moisture, 38°	Apparent Cohesion PSF @ % Moisture, NA	Angle/Repose 10 In. Drop @14.3% Moisture, 33°
Angle Slide Steel Plate @12.5% Moisture, 36°	Bulk Density PCF @ % Moisture, NA	Angle Internal Friction @ 13 % Moisture, 42°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary, sandstone, arkosic, loosely consolidated, with layers and lenses of silty mudstone. Very low strength. RQD:(Est.) 0-35%.
DUW: 113 PCF. Ground water: saturated. Hardness: NA.
System Class: Shield, Robbins 221S ripper, 21' dia. Thrust 3,500 tons.
Mucking: Hydraulic boom operated bucket scraper to conveyor. Haulage: Rail.
Support: Continuous, precast concrete ring segments.

MDN STUDY SYSTEM DATA SHEET MDN T-S7 Ident. No. SF-1 Sheet 2

ROCK DATA:

Lithology: Sedimentary, sandstone, biotite rich siltstone, poorly to well consolidated, poorly to well sorted.
Uniaxial Compressive Strength: 2 KPSI
RQD: (Estimated) 50%
Dry Unit Weight: 142 PCF
Ground Water: Sandstone saturated, water table above tunnel, heading drained in advanced by lateral pilot holes in ribs.
Hardness: NA 1/11/72

TUNNEL DATA:

Size: 21 ft., round, Grade: (+) 0.2 pct.
Ventilation System: 20 KCFM, 36" pipe, pressure at face, exhaust in access.
Utility System: 6" air line, 6" pump line.
Water Inflow: 20 gpm
Power System: 4160/480V
Haulage System: Muck, personnel, supplies by rail cars.
Support System: Continuous, precast concrete rings 8" and 10" thick, erected in four 4' segments.

EXCAVATION DATA:

Shield: Robbins 221S ripper, total weight: 285 tons,
Thrust: 3,500 tons total.
Muck Collection System: Muck is ripped from face by a ripper tooth and drawn through the shield to a 6' conveyor by hydraulic ram with a bucket opposite the ripper tooth.
Power System: Hydraulic
Guidance System: Laser

MDN STUDY SYSTEM DATA SHEET T-S5 Ident. No. SF-2 Sheet 1

MUCK DATA

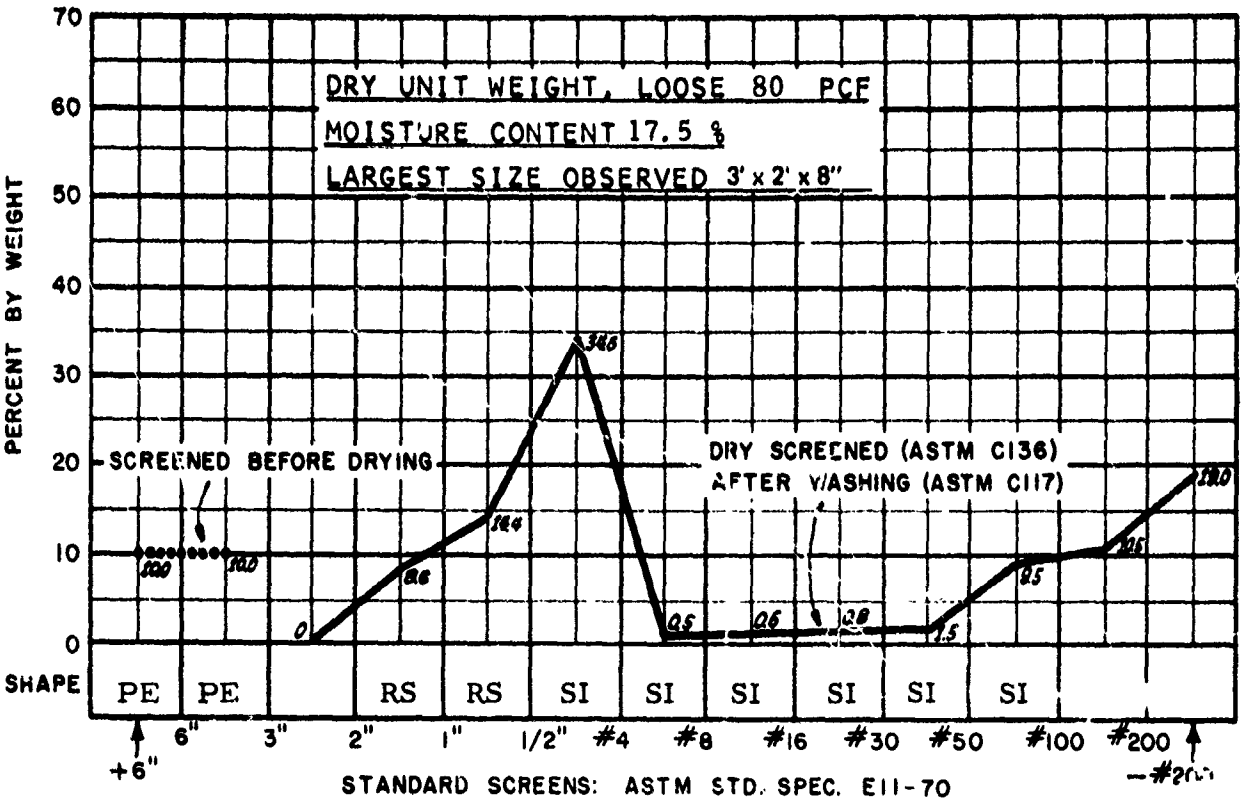
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size -0.056" : 0	Size -0.75" : 3.02

ATTERBERG LIMITS, MATERIAL SIZE (-)0.056 IN.

Liquid Limit 31.5 %	Plastic Limit 26.8 %	Shrinkage Limit 21.5 %
Plasticity Index 4.7 %	Toughness Index 0.61	Flow Index 7.6

MATERIAL SIZE (-)1.0 IN.

Angle/Repose 1 In. Drop @15.1% Moisture, 38°	Apparent Cohesion PSF @ % Moisture, NA	Angle/Repose 10 In. Drop @15.1% Moisture, 36°
Angle Slide Steel Plate @15.1% Moisture, 30°	Bulk Density PCF @ % Moisture, NA	Angle Internal Friction @ 15 % Moisture, 27°



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary, sandstone and siltstone, poorly to well consolidated. Very low strength. RQD: (Est.) 50%. DUW: 142 PCF. Ground water: saturated. Hardness: NA.

System Class: Shield, Robbins 221S ripper, 21' dia. Thrust 3,500 tons.

Mucking: Hydraulic boom operated bucket scraper to conveyor. Haulage: Rail.

Support: Continuous, precast concrete ring segments.

MDN STUDY SYSTEM DATA SHEET MDN T-S5 Ident. No. SF2 Sheet 2

ROCK DATA:

Lithology: Sedimentary, mudstone, dark gray, fine grained, massive.
Uniaxial Compressive Strength: 11 KPSI dry.
RQD: (Estimated) 90%.
Dry Unit Weight: 144 PCF.
Ground Water: Generally dry.
Hardness: NA 1-11-72

TUNNEL DATA:

Size: 10' high x 9' wide (7'-6" top, 9'-6" bottom). Grade: (+) 1/2%.
Ventilation System: 5 KCFM, exhaust from face, pressure to venthole, 16" flexhaust, 24" vent tube, 2-25 HP Axivane fans.
Power System: Muck, personnel and supplies by rail cars, 36" gage, 45# rail.
Support: 4" WF steel sets at 3' or 6'.

EXCAVATION DATA:

Machine: Alpine Miner, Type F6-A. Total Weight: 11 tons.
Cutters. 40 Kennametal U43KF, Carbide tipped, "pick" type. Cutters mounted on twin ripper heads, rotating about a horizontal axis at 90° to a boom which moves heads vertically and horizontally.
Rotation: 78 RPM, motor and gear box integral with boom.
Torque: 50.4 HP.
Thrust: Sumping thrust from crawler motors, 2 @ 20.4 HP, vertical and horizontal by hydraulic cylinders powered by a 10.4 HP electro-hydraulic system.
Anchor Pressure: Crawlers only.
Muck Collection: Central 14" flight conveyor fed by two gathering arms mounted on an inclined apron, discharges on an 18" elevating conveyor loading rail cars.
Power System: 440V, trailing cable.
Guidance System: Transit/Laser.

MDN STUDY SYSTEM DATA SHEET T-M6 Ident. No. KM-1 Sheet 1

MUCK DATA

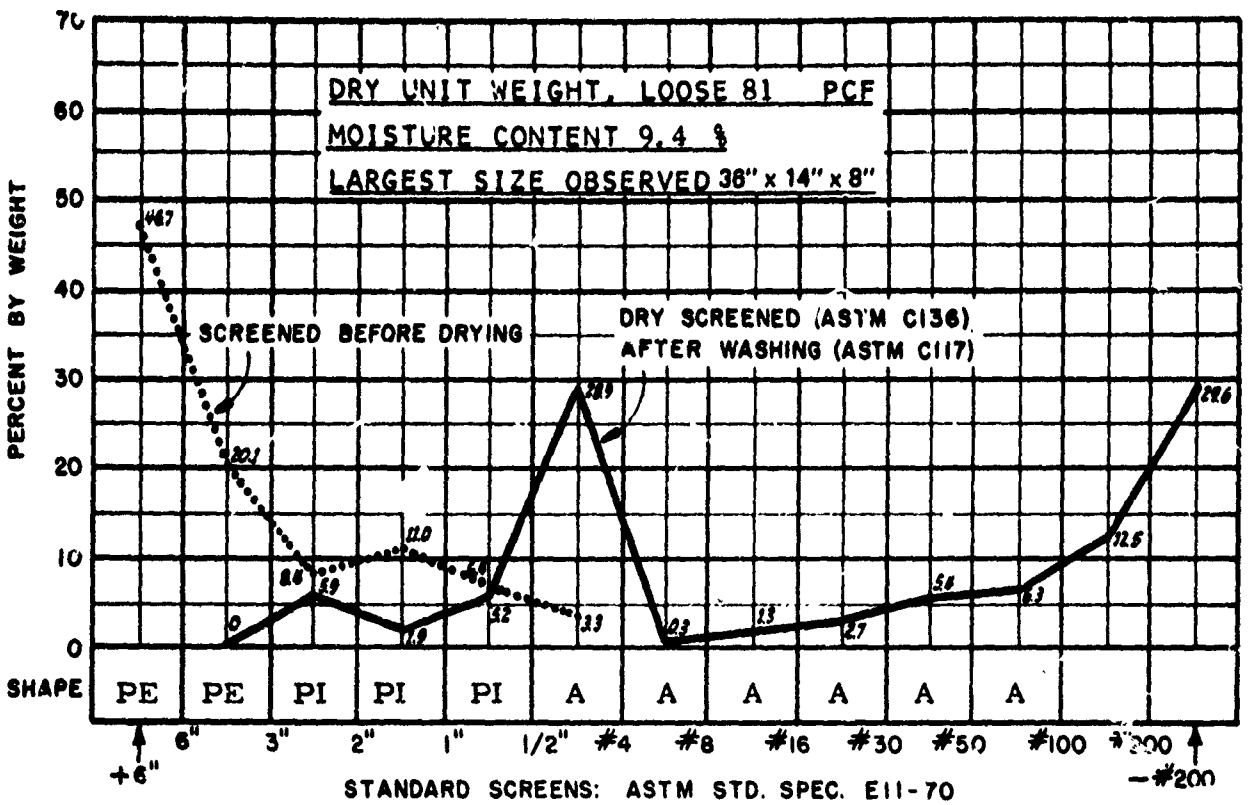
Abrasiveness	Pot. Vol. Change, Material	Spec. Gravity, Material
N.A. 1/11/72	Size : NA	Size : NA

ATTERBFPG LIMITS, MATERIAL SIZE IN.

Liquid Limit NA %	Plastic Limit NA %	Shrinkage Limit NA %
Plasticity Index NA %	Toughness Index NA	Flow Index NA

MATERIAL SIZE IN.

Angle/Repose 1 In. Drop	Apparent Cohesion PSF	Angle/Repose 10 In. Drop
@ % Moisture, NA	@ % Moisture, NA	@ % Moisture, NA
Angle Slide Steel Plate	Bulk Density PCF	Angle Internal Friction
@ % Moisture, NA	@ % Moisture, NA	@ % Moisture, NA



MUCK: PCT. BY WT. AND SHAPE BETWEEN SCREENS

SUMMARY

Rock Class: Sedimentary: Mudstone ("shale") fine grained, massive. Medium strength. RQD: (Est.) 90%. DUW: 144 PCF. Ground water: Dry. Hardness: NA.

System Class: TBM, Alpine F6A, twin head, 10' high x 9' heading. 40 Kennametal TCBI pick type bits. 78 RPM, 50.4 HP head torque, 10.4 HP boom power, 40.8 HP sumping thrust. Mucking: Gathering arms - flight conveyor. Haulage: Elevating conveyor-rail cars. Support: Steel sets at 3' or 6', continuous.

MDN STUDY SYSTEM DATA SHEET MDN T-M6 Ident. No. KM-1 Sheet 2