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Technical Report No. 6

**DETERMINATION of BEACH  
CONDITIONS by means of  
AERIAL PHOTOGRAPHIC  
INTERPRETATION**

Volume I

**RELATIONS BETWEEN  
BEACH FEATURES  
and  
BEACH CONDITIONS**

*Cornell University  
Office of Naval Research*

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TECHNICAL REPORT NUMBER 6

DETERMINATION OF BEACH CONDITIONS  
by means of  
AERIAL PHOTOGRAPHIC INTERPRETATION

VOLUME I  
RELATIONS BETWEEN BEACH FEATURES  
and  
BEACH CONDITIONS

In connection with  
a contract between:

Amphibious Branch,                      School of Civil Engineering  
Office of Naval Research                      Cornell University  
U. S. Naval Photographic Interpretation Center, Monitor

Executed by the  
Cornell Center for Integrated Aerial Photographic Studies

Beach Accessibility and Trafficability  
Project No. NR 257 001  
Contract N6onr, Task Order #11

by

D. R. Lueder  
and

W. H. Rockwell

D. J. Belcher, Director

June, 1954  
Ithaca, New York



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CORNELL UNIVERSITY - JUNE 1954

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## KEY TO TECHNICAL REPORT NUMBER 6

Technical Report Number 6 is divided into five Volumes.

The titles of these Volumes are as follows:

- Volume I - Relations Between Beach Features  
and Beach Conditions.
- Volume II - Variation and Stability of Beach  
Features (including an Appendix on  
Wave Tank Tests).
- Volume III - Photographic Gray Tones as an  
Indication of the Size of Beach  
Materials.
- Volume IV - The Cone Penetrometer as an Index  
of Beach Supporting Capacity  
(Moisture, Density and Grain-Size  
Relations).
- Volume V - A Method for Estimating Beach  
Trafficability from Aerial Photo-  
graphs.

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The authors express their appreciation for the cooperation, aid and helpful opinions provided by Colonel J. P. Stafford, U.S.M.C. and Major Carl Hill, U.S.M.C. both of the Amphibious Branch, Office of Naval Research and by Mr. Page Truesdell of the Naval Photographic Interpretation Center. The administration, establishment - and continuance - of this program is due in no small way to the efforts of these men.

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## CAUTIONARY NOTE

It is the ultimate objective of this research program to investigate and report upon a method for estimating beach trafficability by means of aerial photographic analysis. Trafficability is a tenuous term. For the purpose of this study, it has been considered to be related to:

1. Slope of beach
2. Bearing capacity of beach

Outside factors such as vehicle types, loads and tire pressures; driver abilities and surf conditions; and multiple pass effects were not considered.\*

Two things must be emphasized. First, the trafficability diagram appearing as Figure 2 of Volume I and mentioned thereafter, relates slope and penetration values and assigns any given beach to one of five classes. THIS DIAGRAM IS INDICATIVE ONLY AND SHOULD NOT BE USED WITHOUT VERIFICATION OR MODIFICATION IN THE LIGHT OF CURRENT OPERATIONAL TECHNIQUES.

Secondly, the index of beach sand bearing capacity chosen by the authors for use in this investigation was constant weight penetration. The authors believe this to be a reasonable and acceptable index.\*\* However, THE SIGNIFICANCE OF THE INDEX WITH RESPECT TO ACTUAL OPERATIONS MUST BE EVALUATED BY USING AGENCIES.

These statements emphasize the necessity for studies which will correlate penetrations with operating conditions. Only by this means can the research results discussed in Technical Report #6 by utilized to their fullest extent.

---

\* See Progress Report #1, "Relations Between Beach Features Visible on Airphotos and Beach Trafficability".

\*\* See Volume IV (Key).

## LIST OF ABBREVIATIONS

|                     |                                                                    |
|---------------------|--------------------------------------------------------------------|
| AFS                 | - Average foreshore slope (See Appendix A)                         |
| APR                 | - Average penetration reading                                      |
| Bs                  | - Backshore                                                        |
| d                   | - Divergence (See Figure 10)                                       |
| D <sub>50</sub>     | - Median grain-size (See Figure 10 and Appendix A)                 |
| Dec D <sub>50</sub> | - Decimal median grain-size (See Figure 10)                        |
| DFs                 | - Drying foreshore                                                 |
| Fs                  | - Foreshore                                                        |
| Fs MSLW             | - Foreshore mean-sea-level width (See Figure 9b<br>and Appendix A) |
| PR                  | - Penetration readings                                             |
| WFs                 | - Wetted foreshore                                                 |

SECTION I

INTRODUCTION

## SCOPE OF VOLUME

This is concerned with the factual aspects of one subdivision of a current research project conducted for the Amphibious Branch, Office of Naval Research. It describes the methods, analyses and correlations obtained after completing an Empirical Survey of Beaches along the Atlantic Coast of the United States.

A series of conclusions appears as SECTION IV. These conclusions are based, for the most part, on the data, analyses, and discussions included herein. Consequently, they represent the specific conclusions of the report --- not conclusions of the complete research program.

Final conclusions of the complete research program will be limited in nature. Only those factual aspects that are pertinent to the ultimate objectives of the program will appear. These will be published in Volume V.

ULTIMATE OBJECTIVES  
of  
COMPLETE RESEARCH PROGRAM

The ultimate objectives of the complete research program are:

1. The presentation of relations between physical features (visible on aerial photographs) that are associated with beaches, and the trafficability of beaches.\*
2. The formulation, based upon such relations, of a method for estimating the trafficability conditions of beaches from aerial photographs.

---

\* See CAUTIONARY NOTE

## PROBLEMS OF RESEARCH

There are numerous features associated with beaches that may have some relation to trafficability and that can also be seen on aerial photographs. These are:

1. Details of beach profile (width, slope, cusps, scarps).
2. Wave and surf features (length, frequency, shape, direction, refraction, breaker patterns).
3. Gray tones (beach sands, moisture holding capacity, turbidity stains, depth differences).
4. Environment features (offshore and onshore protection, river mouths, sources of supply, indications of littoral current flow).
5. Miscellaneous features (current, ripples, bars).

These features, as well as trafficability itself, reflect the interaction of numerous variables. The variables are:

1. First order variables (independent)
  - a. Location and variations in winds
  - b. Environment
    - (1) Protective underwater features
    - (2) Protective surface features
    - (3) River and tidal mouths
    - (4) Littoral currents
    - (5) Geological sources and types of materials that contribute to beach

(6) General offshore slope

- c. Tides
- 2. Second order variables (dependent upon first order)
  - a. Wave characteristics and variations
- 3. Third order variables (dependent upon first and second order)
  - a. Variations in local offshore slopes, bars and local material supplies.

None of these variables can be controlled by any normal means. Few can be evaluated easily by instrumental devices. Consequently, it is difficult to relate specific beach features to the variable or combination of variables that produce them. To satisfy the practical requirements of the project, it was decided to subordinate the relations between beach features and their causative variables and to emphasize direct relations between features and trafficability conditions.



## SCHEME OF COMPLETE RESEARCH PROGRAM (CURRENT)

The current program was subdivided into various separate activities. This was done in an attempt to circumvent some of the difficulties previously discussed by varying the direction of attack.

The subdivisions established were as follows:\*

### 1. Routine Beach Observations

The collection of routine observations at permanent beach stations for a reasonable period of time. This phase was designed to give information concerning the changes of beach features and conditions on beaches of various types over a period of time. This phase, since it was concerned with time, was expected to throw some light on the relative importance of causative variables such as waves, material characteristics, etc.

### 2. EMPIRICAL BEACH SURVEY (SUBJECT OF THIS REPORT)

THE COLLECTION AND ANALYSIS OF INFORMATION CONCERNING THE PHYSICAL AND PENETROMETER PROFILES AND THE SAND CHARACTERISTICS OF VARIOUS BEACHES PICKED AT RANDOM. THIS PHASE, SINCE IT NEGLECTED TIME, WAVES AND ENVIRONMENT, WAS DESIGNED TO PROVIDE RELATIONS BETWEEN VISIBLE FEATURES AND TRAFFICABILITY CONDITIONS REGARDLESS OF ANY CAUSATIVE VARIABLE EXCEPT BEACH MATERIALS.

---

\* For titles and subject matter of various volumes, see key following title page of this volume.

3. Penetration - Compaction Studies

A small laboratory study of the relations between penetrometer readings, compaction and grain characteristics.

4. Wave Tank Investigation

A small investigation of general relations between slope, slope variations and relative stability as affected by changes in the characteristics of waves acting upon materials of different grain-size.

5. Gray Tone Studies

A densitometric study of gray-tones on the beach as indicators of predominant sizes of beach materials and their relative firmness.

Each of these subdivisions is treated in other Volumes of this report.

SECTION II  
CORRELATIONS  
of  
SIGNIFICANT BEACH CHARACTERISTICS

## GENERAL

This section is concerned with correlations between beach characteristics such as penetrations, slopes, widths, composition, cusps and ripples. These correlations are based upon actual data obtained during this study and upon no other data. (However, a brief evaluation of Technical Report # 2, "Analysis of Beach Sands", is included as Appendix III).

The major factor desired from the correlations is an index of the capacity of the beach materials to support imposed wheel loads without excessive deformation. The index of capacity used in this report is degree of penetration\*. In the following pages, correlations between penetration readings and beach features that are visible on aerial photographs can be considered as "primary" correlations. Other correlations have been included to provide additional information.

---

\* Information concerning the use of penetration readings as an index of supporting capacity is given in:

Progress Report #1, "Relations Between Beach Features Visible on Airphotos and Beach Trafficability"

Technical Report #4, "Use of Penetration Devices on Beaches"

Technical Report #6, Volume 4, "Penetration Readings as an Index of the Supporting Capacity of Beach Sands".

Also see CAUTIONARY NOTE at beginning of this Volume.

## SINGLE VERSUS MULTIPLE CORRELATIONS

When an airphoto interpreter makes an estimation of beach trafficability by evaluating the significance of various beach features, he may proceed in three ways:

1. He may make a single estimation by evaluating a single feature (e.g. slope)
2. He may make several separate estimations by evaluating several features and then make a final estimate by combining his several results (e.g. slope, width, grain-size)
3. He may make a single estimation by evaluating the combined weighted significance of several features (e.g. slope plus width plus grain-size).

In this report, the first two methods are considered to be based upon the use of single correlations. The third method is based upon the use of a multiple correlation.

Multiple correlations appear to provide the best possibility for accurate estimation. Single correlations must be considered because of the occasional times when photographic quality, scale, instrumentation or personnel necessitate prediction based on a single beach feature.

In this section, single and multiple correlations are treated in the following order:

1. Single correlations
  - a. PR\* versus slopes
  - b. PR versus widths
  - c. PR versus sand characteristics
  - d. Sand characteristics versus slopes
  - e. Sand characteristics versus widths
2. Multiple correlations
  - a. PR versus slopes plus widths
  - b. PR versus slopes plus D<sub>50</sub>
  - c. PR versus slopes plus grain-size class
  - d. PR versus slopes plus widths plus D<sub>50</sub>
  - e. PR versus slopes plus widths plus grain-size class
3. Miscellaneous correlations involving cusps, ripples, etc.

---

\*See Glossary and Abbreviations

## SINGLE CORRELATIONS

### PENETRATIONS versus SLOPE

For convenience of discussion, the following correlations involving penetrations and slope are divided into those pertaining to the foreshore and those pertaining to the backshore.

Within each zone, there may be occasionally as many as four different slopes, with the maximums being several percent higher than the minimums. In addition, there may be negative or curving slopes, cusp developments and scarps.

After much preliminary analysis, the average slope within each zone was chosen as the most desirable factor for use in correlation. The average slope is defined in SECTION II. Similarly, the average penetration reading (APR)\* within each zone was chosen as the other factor for correlation. The method of determining the average penetration reading is also described in SECTION II.

#### Drying Foreshore Zone

Figure 1 shows the correlation obtained between APR and AFS\*. This correlation is based upon 85 observations, taken on beaches whose median grain size ranged from fine (0.13mm) to very coarse (1.005mm) and whose divergences ranged from 0.1 to 0.39. (This range covered approximately 90% of the

---

\* See Glossary and Abbreviations

\*\* See Figure 10, Appendix A.



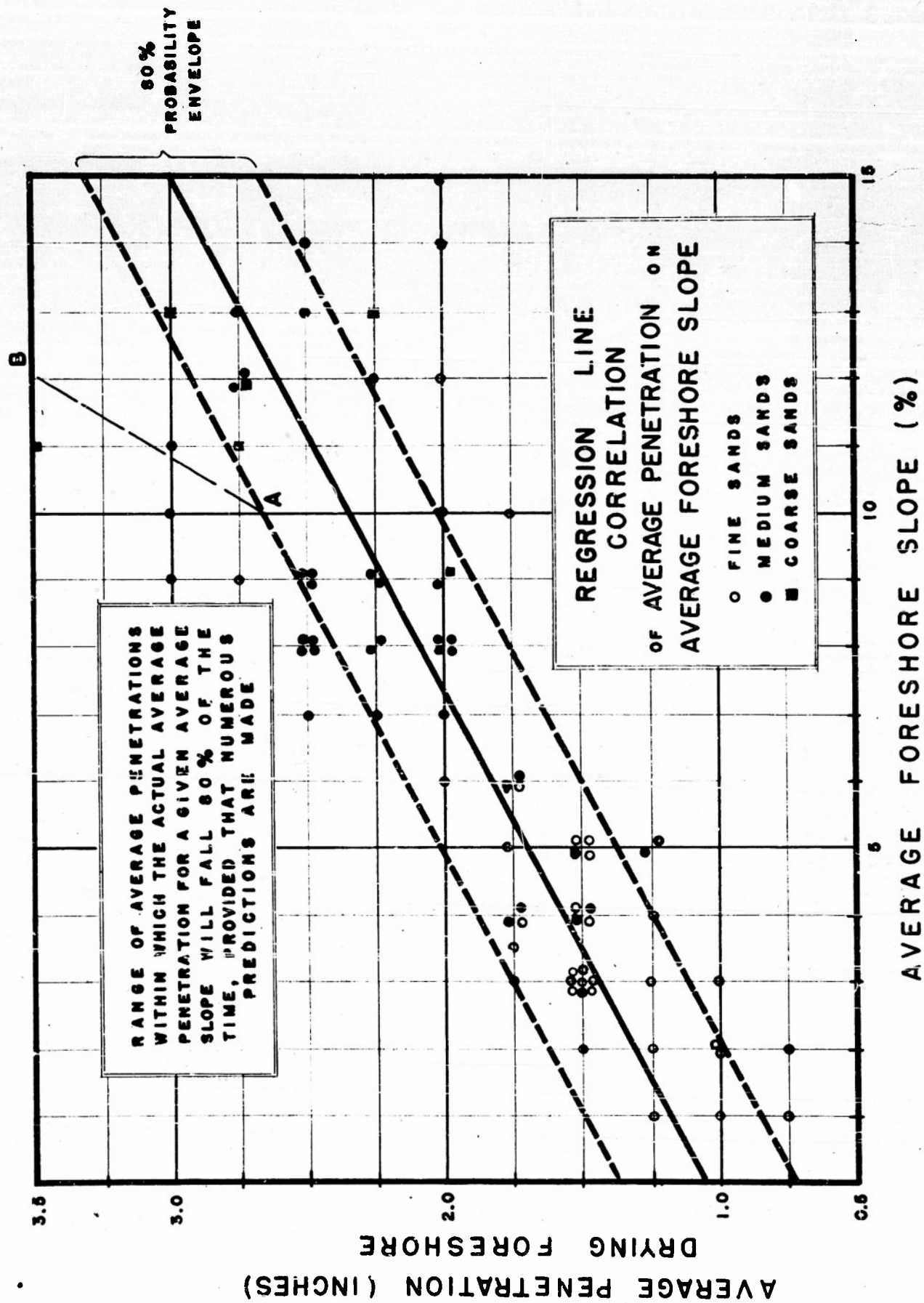


FIGURE 1



divergences observed. See Figures 13, 14 and 15, Appendix B). It may be assumed, therefore, that the correlation is not appreciably affected by variations in median grain-size within the sand range and that it covers a representative variation in uniformity coefficients and grain-size distributions. Actual data relating APR and AFS to grain-size characteristics are included in following sections.

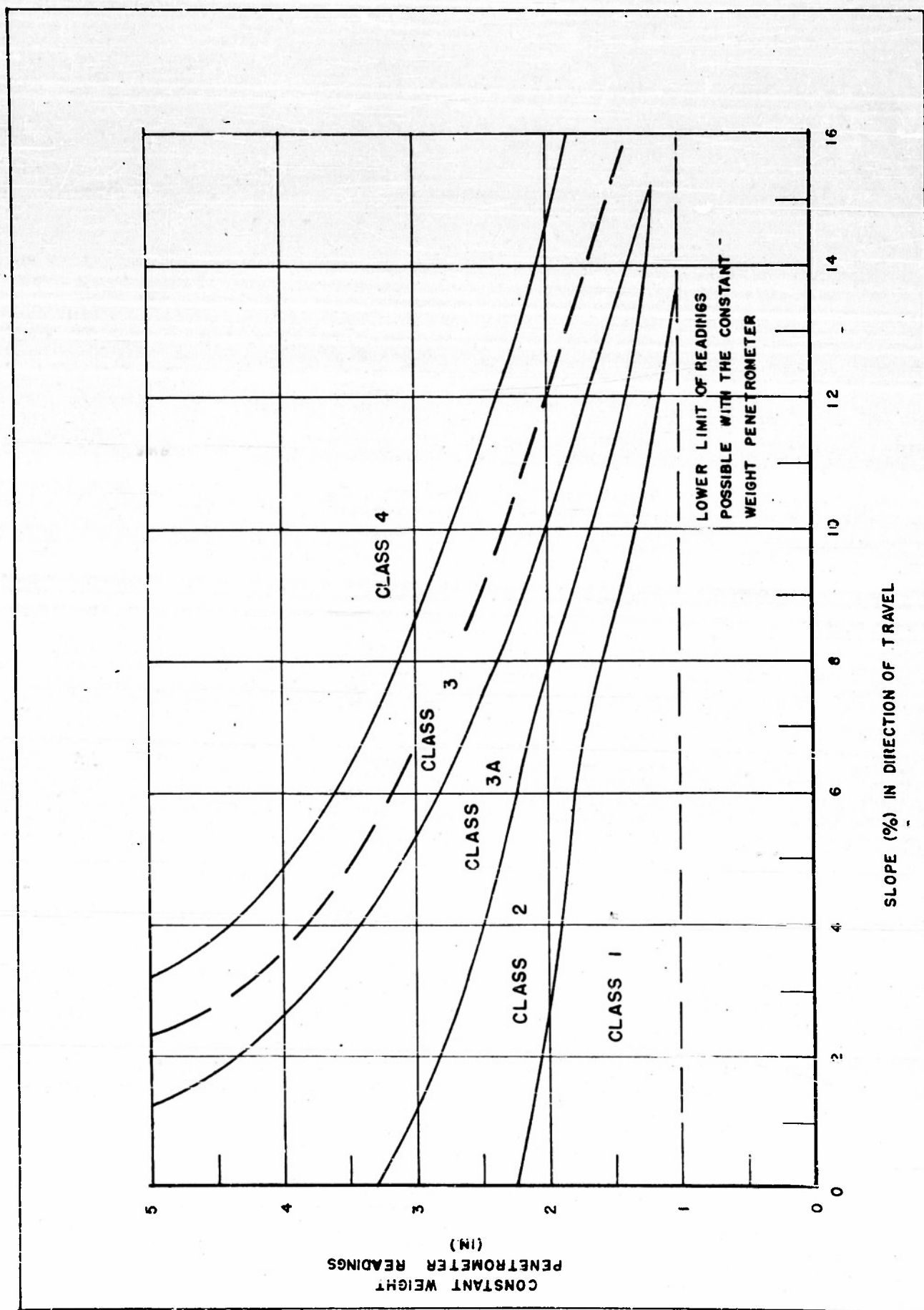
The statistical analysis yielding Figure 1 shows that a first degree regression line of APR on AFS fits the data adequately. The equation of this line is  $Y = 1.04 + 0.13X$ . It is plotted as the center line. The envelope for accurate predictions of 80% probability is plotted on either side of the center line. The statistical analysis yielding this envelope is based upon an assumption regarding the distribution of Y values\* (APR values). The coefficient of correlation is 0.3610\*\*.

Figure 1 shows an excellent correlation between APR and AFS. For a given AFS, the center line APR  $\pm 0.3$  inches will predict the range within which the actual APR will fall 80% of the time, provided that numerous predictions are made. A range of  $\pm 0.3$  inches represents only 15% of the total normal range of penetration readings.

Unfortunately, using a trafficability diagram of the general type shown in Figure 2 it is desirable to enter the

\* This assumption and its validity are discussed in Appendix C.

\*\* Equations and descriptive coefficients are tabulated for all correlations in Appendix D.



left side with as narrow an accurate range of penetration readings as feasible. The desired range is not that of average penetrations, but rather that between the significant minimum and maximum penetrations for the zone in question, i.e. those penetrations on either side of the APR which extend for significant distances and are not the result of local variations.

An analysis of the data regarding ranges of PR has shown that for a given slope, the APR indicated by the center line of Figure 1,  $\pm 0.5$ " will indicate the range of significant PR for entry into a trafficability diagram of the type shown in Figure 2. As an example, for AFS of 7%, Figure 1 gives a center line APR of two inches. Two inches  $\pm 0.5$  inch gives a range of 1.5 - 2.5 inches for entry into a trafficability diagram. The actual range is generally somewhat less. As mentioned in Volume 2 of this report, experience has indicated that the upper limit of the range should be broadened for slopes in excess of 10%. This broadening is indicated by AB.

During the process of analysis, correlations between the minimum penetration and AFS and between the range of penetrations and AFS were plotted. They were essentially similar to Figure 1 and are not included in this report.

#### Backshore Zone

Figure 3 shows the correlation between average backshore penetrations and average backshore slope. There is a slight



trend of the same nature as that shown for the drying foreshore. However, a lack of wave-action and the resultant low moisture content in the surface layers creates a condition such that the backshore penetrations are relatively constant regardless of grain-size, i.e., grain-size becomes important only where there is wave-wash and resultant moisture. Figure 3 substantiates the statement made previously\* that the backshore penetration ranges between 2 - 3.5 inches unless the backshore has been recently rained upon or has developed a crust. In both of these cases, penetrations are lower.

---

\*Progress Report #1, "Relations Between Beach Features Visible on Airphotos and Beach Trafficability". Also see Volume 4 of this report.



## SINGLE CORRELATIONS

### PENETRATIONS versus WIDTH

The beach width for use in correlation must be chosen with care. Only the exposed width can be seen on airphotos. However, this width may vary:

1. It may vary from time to time in response to processes of deposition and erosion.
2. It may have total widths that are great only because the backshore zone is wide. In many cases, the backshore width is a function of factors other than those which normally affect the beach face (the normal yearly variations of these tides, wave-heights and currents).
3. It may vary due to the tide level. Two beaches of significantly different widths and slopes may show identical exposed widths at different tidal levels within areas of different tidal range.

In this study, the first variation is disregarded because all beaches were observed "out of time". The second variation is cancelled because the backshore is subtracted from all width observations and because observations were taken between low and mid-tides. The third variation can be neglected because all widths are expressed as "mean-sea-level-widths" (MSLW).

The method of obtaining the MSLW for a given observation is described in Appendix A and illustrated in Figure 9b.

#### Drying Foreshore Zone

Figure 4 shows the correlation obtained between APR and foreshore MSLW (Fs MSLW). This correlation, like those preceding it, is based upon observations taken on 85 beaches whose materials showed reasonable spreads of median grain-size and grain-distributions. The resulting correlation may be considered to be relatively independent of these factors. Data relating APR and Fs MSLW is included in following sections.

The statistical analysis yielding Figure 4 shows that a first degree regression line of APR on Fs MSLW fits the data adequately. The equation of this line is  $Y = 2.583 + 0.0055Z$ . The envelope for accurate predictions of 80% probability is plotted on either side of the center line. The statistical analysis yielding this envelope is based upon the usual assumption regarding the distribution of Y-values (APR values). The coefficient of correlation is 0.6303 (minus). The standard error of estimate is 0.47.

The correlation between APR and Fs MSLW is not as good as that between APR and AFS. For a given Fs MSLW, the center line value of APR  $\pm 0.5$  inch will predict the range within which the actual APR will fall 80% of the time provided that numerous predictions are made. However, a range of  $\pm 0.5$  inch

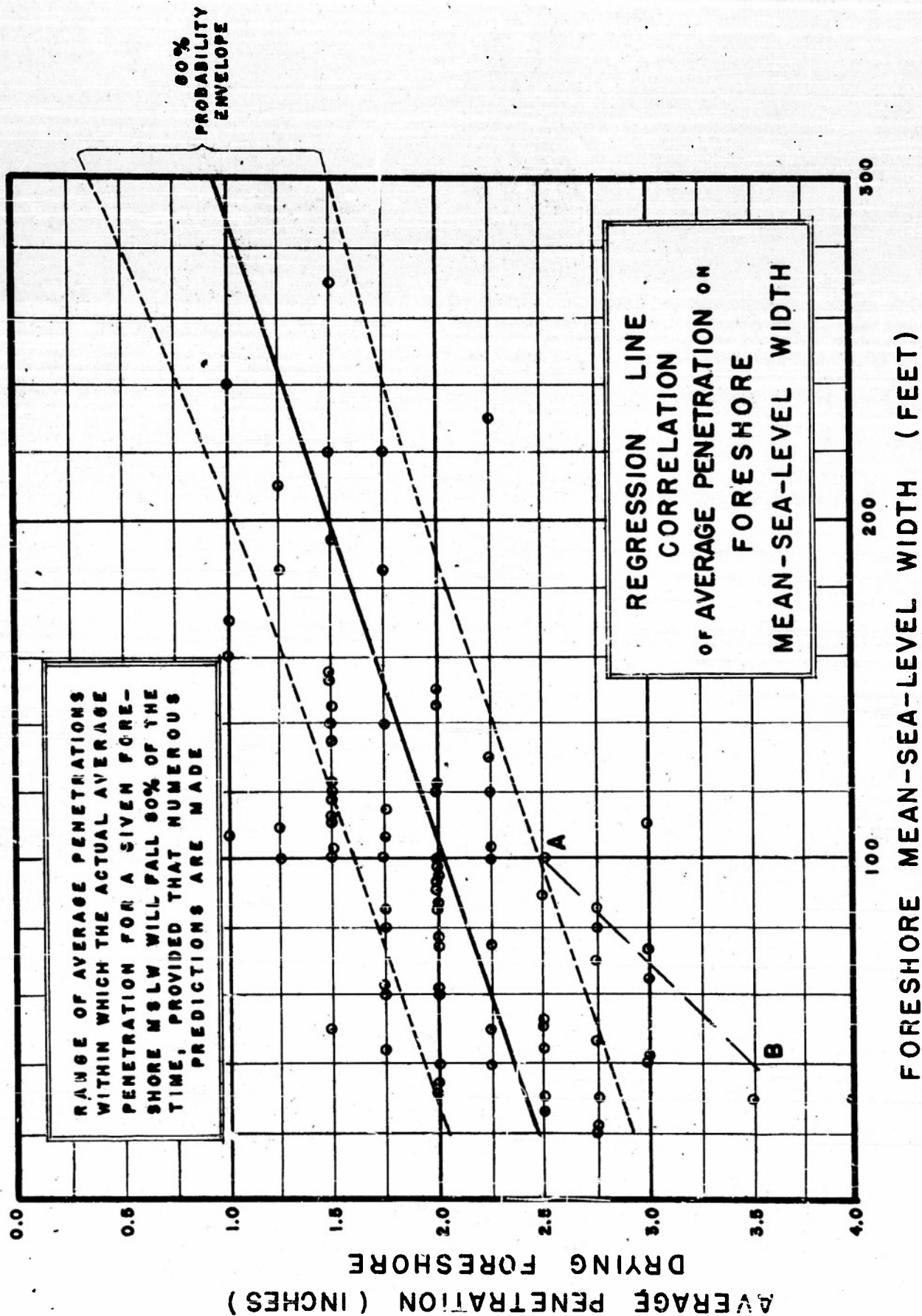


FIGURE 4



represents 25% of the total normal range of penetration readings.

It is fortunate that, in using the above correlation to predict trafficability, a range of significant drying foreshore PR, not a range of drying foreshore APR is required. An analysis of the data regarding ranges of PR has shown that, for a given Fs MSLW, the APR indicated by the center line of Figure 4  $\pm$  0.6" will indicate a range of significant PR for entry into a trafficability diagram of the type shown in Figure 2.

As mentioned in Volume 2 of this report, experience has indicated that the lower limit of the range should be broadened for widths less than 100 feet. This broadening is indicated by line AB.

A correlation was obtained between total MSLW and APR. It had essentially the same characteristics as that shown in Figure 4. Other correlations, between APR and total MSLW and between range of PR and total MSLW showed the same trends as that of Figure 4.

#### Backshore Zone

As indicated by Figure 4, there is no apparent relation between APR and backshore width. In view of the constant range of PR that can be assigned to the backshore, such a relation is not to be expected.

## SINGLE CORRELATIONS

### PENETRATION READINGS versus SAND CHARACTERISTICS

There are several prominent characteristics of beach materials that can be used in correlation. These include:

1. Grain-sizes
2. Grain-size distributions
3. Grain shapes
4. Grain composition

A correlation involving one of these factors is complex, even when using special materials prepared and tested under laboratory controls. For example, a given beach material is composed of numerous grain-sizes altogether yielding a grain-size distribution. Which grain-size should be used for correlation - the smallest, largest or middle one? Which characteristic of the grain distribution "curve" should be treated as an index of the entire "curve" shape? The authors believe that such a correlation, in terms of beach materials, would be a complex project even if it were the major objective of investigation. In this study, correlations with grain characteristics were given a supplementary position in relation to those involving visible features such as slope and width. Consequently, some of the following "correlations" are actually surveys of variations with indicated trends.

In the following paragraphs, the only correlation for

the backshore zone that has been included is that relating backshore APR to backshore D<sub>50</sub>.

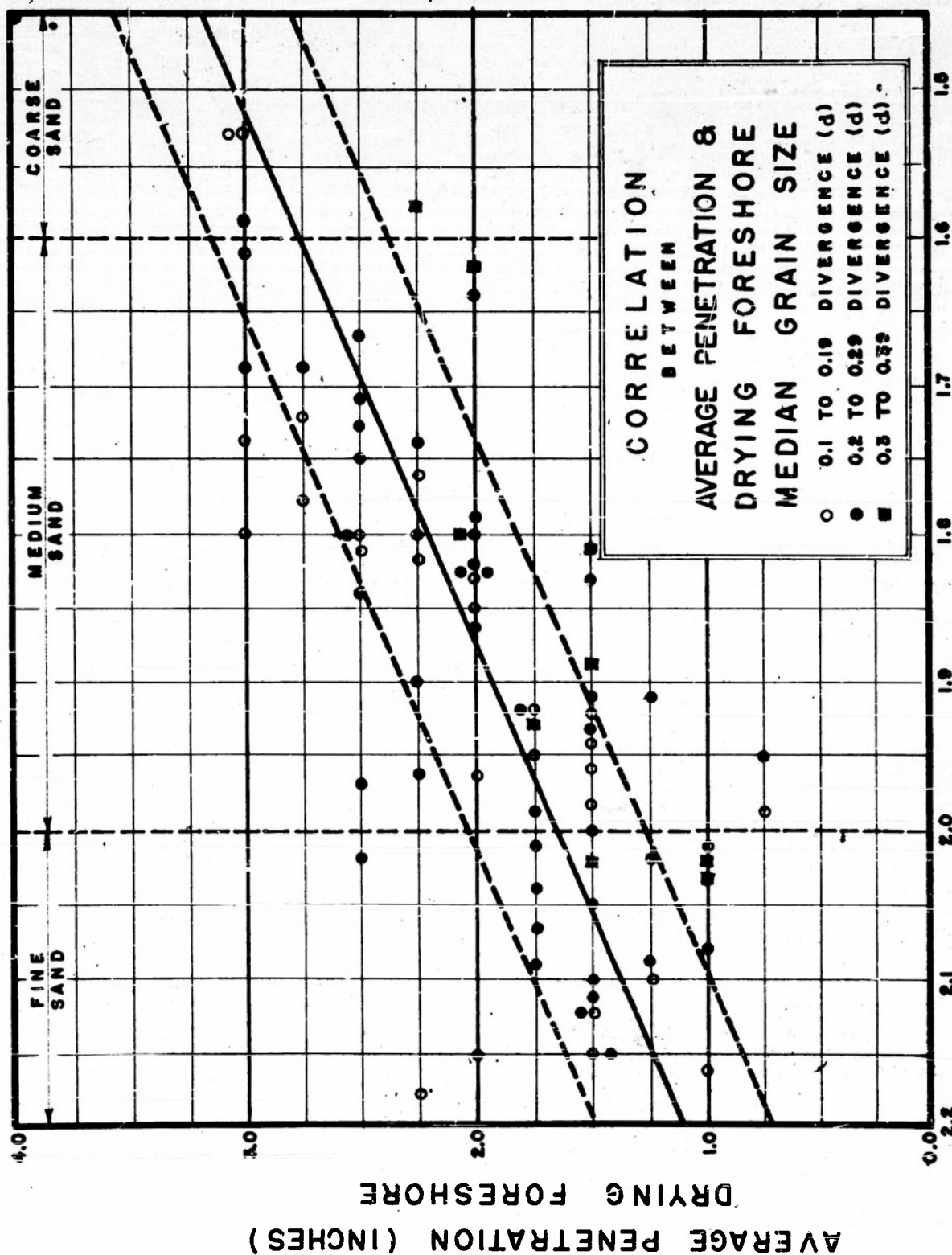
#### Drying Foreshore Penetrations versus Median Grain-Size

Figure 5 shows the correlation obtained between APR and median grain size (D<sub>50</sub>) of sands composing the foreshores. D<sub>50</sub> is given only in terms of vertical decimal intercepts, (see Figure 10, Appendix A).

The statistical analysis yielding Figure 5 shows that a first degree regression line of APR on D<sub>50</sub> fits the data adequately. The equation of this line is  $Y = 7.1879 + 2.7671W$ . It is plotted as the center line. The envelope for accurate predictions of 80% probability is plotted on either side of the center line. The statistical analysis yielding this line is based upon the usual assumption. The coefficient of correlation is 0.7588 and the standard error of estimate is 0.3943.

This correlation appears to be quite good, being almost as satisfactory as that obtained between penetrations and slopes. For a given D<sub>50</sub> the center line reading  $\pm 0.375$ " will give the actual range of average penetration readings 80% of the time, provided numerous predictions are made.

As mentioned in discussions of previous correlations, the range of average penetrations is of little use in estimating trafficability. A range defining all significant penetrations on the foreshore is desired. Although the data was not thor-



(DECIMAL VALUES — SEE FIGURE 10)

oughly analyzed, a hasty inspection indicated, that for a given  $D_{50}$  the center line reading  $\pm 0.5$ " provides such a range.

Unfortunately, the correlation of Figure 5 is of little use for practical purposes unless a representative sample of the beach sand is available for grain-size distribution analysis.

Figure 6 shows a correlation between backshore APR and  $D_{50}$ . It was not analyzed statistically, the correlation line being fitted by eye. Although there is a trend of the same nature as that shown in Figure 5, it is approximately half as pronounced. This indicates, similarly to Figure 5, that while grain-size has an effect upon PR, it is not as pronounced as the effect in the presence of moisture .

#### Drying Foreshore Penetrations versus Grain-Size Penetrations

It is logical to expect that PR will decrease as a beach material approaches a better graded condition. A trend to this effect is shown on Figure 6. Results are tabulated below:

| TABLE I<br>PROBABLE TREND of RELATION between APR and SAND GRADATION |            |                      |                                 |
|----------------------------------------------------------------------|------------|----------------------|---------------------------------|
| Gradation Characteristics                                            |            | Percentage of Points |                                 |
| Description                                                          | Divergence | Above Average Line   | Below Average Line              |
| Most uniformly graded (poor gradation)                               | 0.1-0.19   | 54%                  | 46%                             |
| Next most uniformly graded (slightly better gradation)               | 0.2-0.29   | 45%                  | 55%                             |
| Least uniformly graded (best gradation)                              | 0.3-0.39   | 0%                   | 100% (67% below range envelope) |

The preceding table shows that the best graded materials are associated with penetrations that are less than average, often considerably so.



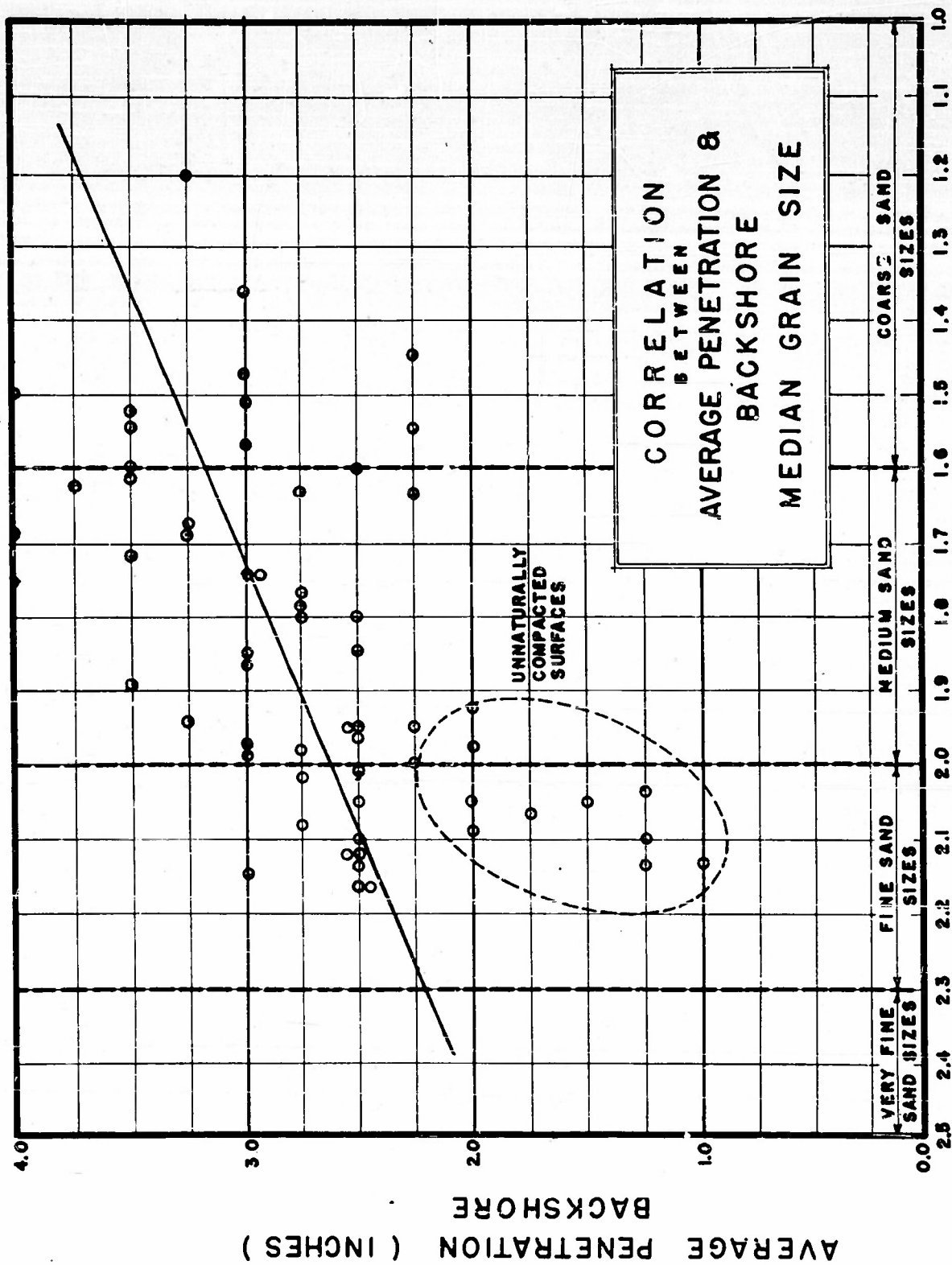


FIGURE 6



## SINGLE CORRELATIONS

### SLOPE versus SAND CHARACTERISTICS

#### Median Grain-Size

Figure 7 shows the correlation obtained between AFS and  $D_{50}$  for grain-size distributions whose divergences ranged from 0.1 to 0.39.

The statistical analysis yielding Figure 7 shows that a first degree regression line of  $D_{50}$  on AFS fits the data. The equation of this line is  $W = 0.033X - 2.11$ . No envelope of 80% probability is plotted on this diagram due to the apparently skewed distribution of  $D_{50}$  values (See Figure 11, Appendix B). This distribution invalidates the usual assumption regarding Y values.

From the standpoint of experience, the dashed line in the fine sand range of Figure 7 fits the data better than the indicated regression line. In using this chart, it is recommended that two regression lines be determined and joined. One of these lines would be computed for data in the fine sand range. The other would be based upon data in the medium and coarse ranges. These lines would agree with experience better than the indicated line.

The correlation between slopes and median grain sizes on the backshore was not investigated.

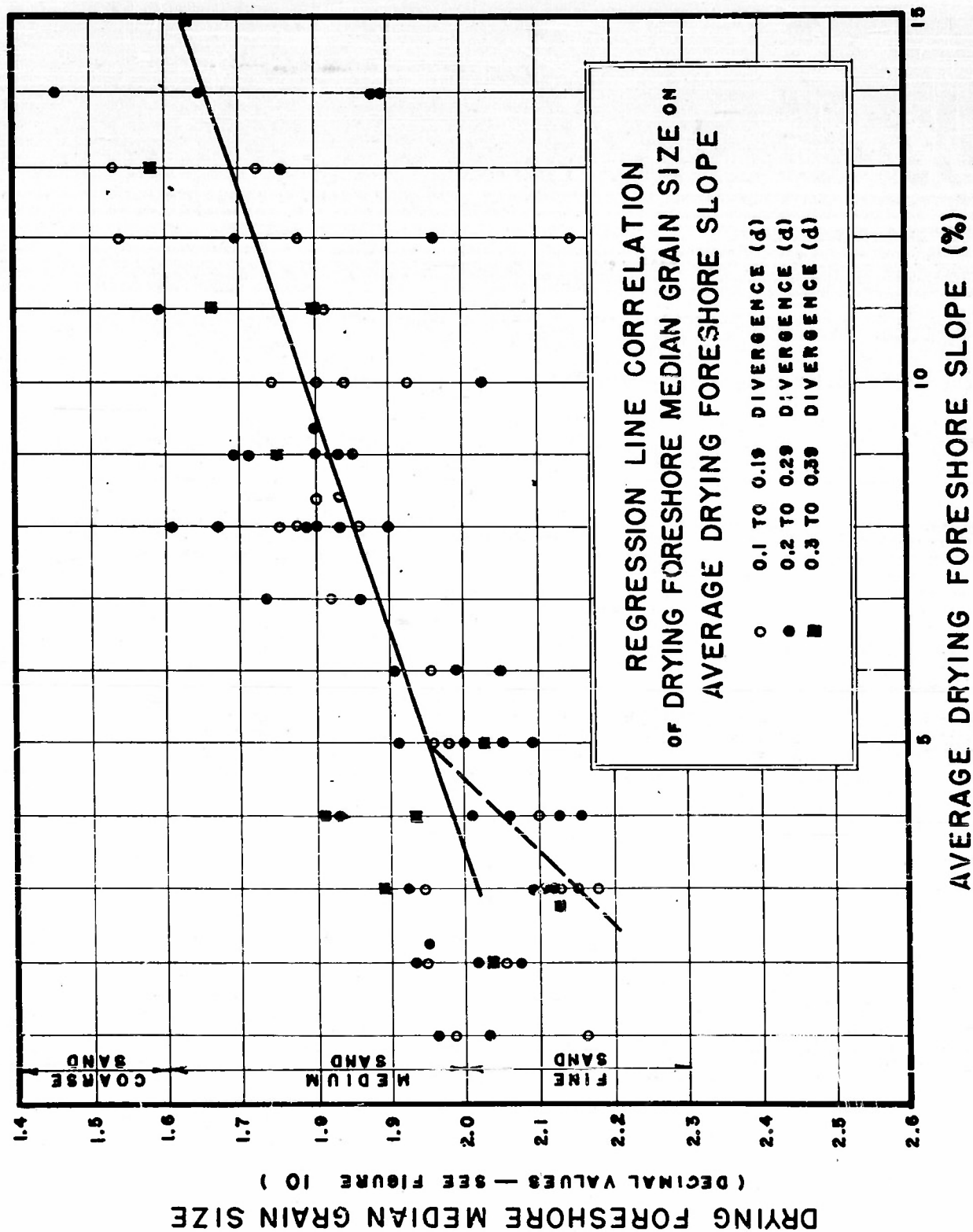


FIGURE 7

### Grain-Size Distribution

It is to be expected that better graded beach materials will tend to be associated with firmer foreshores, i.e., foreshores with lower slopes. Table II, based upon Figure 7, indicates such a trend.

| TABLE II                                                  |            |                      |                    |
|-----------------------------------------------------------|------------|----------------------|--------------------|
| PROBABLE TREND of RELATION between AFS and SAND GRADATION |            |                      |                    |
| Gradation Characteristics                                 |            | Percentage of Points |                    |
| Description                                               | Divergence | Above Average Line   | Below Average Line |
| Most uniformly graded (poor gradation)                    | 0.1-0.19   | 62%                  | 38%                |
| Next most uniformly graded (slightly better gradation)    | 0.2-0.29   | 53%                  | 47%                |
| Least uniformly graded (best gradation)                   | 0.3-0.39   | 33%                  | 67%                |
| This table indicates the same trend as Table I.           |            |                      |                    |

### Grain-Shapes and Composition

Twenty five samples were selected for analysis of grain-shapes and composition. These samples were picked from the drying foreshores of beaches whose slopes, widths, penetration readings and grain-sizes showed wide variations.

Regardless of the variations, the analysis of shapes and compositions displayed great uniformity. This is shown in Table III.

| TABLE III                                                                    |       |        |        |        |         |
|------------------------------------------------------------------------------|-------|--------|--------|--------|---------|
| RESULTS of ANALYSES of GRAIN-SHAPE and<br>COMPOSITION for SELECTED SAMPLES   |       |        |        |        |         |
| Number of samples having indicated Per-<br>cent in each shape or composition |       |        |        |        |         |
| SHAPES:                                                                      | 5-10% | 10-25% | 70-80% | 80-90% | 90-100% |
| Angular                                                                      | 1     | 6      |        |        |         |
| Round                                                                        | 1     | 2      |        |        |         |
| Sub-angular to<br>sub-round                                                  |       |        | 4      | 2      | 19      |
| Flat or thin                                                                 |       | 2      |        |        |         |
| Elongated or<br>cylindrical                                                  |       |        |        |        |         |
| COMPOSITION:                                                                 |       |        |        |        |         |
| Quartz or<br>Feldspar                                                        | 1     |        |        | 3      | 21      |
| Calcareous<br>grains (includ-<br>ing shell)                                  | 4     | 1      |        | 1      |         |
| Undifferentiated<br>igneous                                                  | 6     |        |        |        |         |
| Undifferentiated<br>sedimentary                                              |       |        |        |        |         |
| Dark minerals                                                                | 2     |        |        |        |         |

Table III shows that most of the samples consisted predominantly of sub-angular to sub-round grains of quartz. The only differences occurred where fresh rock was exposed to wave attack. However, even then, the differences were not pronounced. The study does not yield positive results by itself. However, the study, combined with experience, indicates that grain-shapes have some relation to beach features and trafficability. Flat shapes appear to be associated with steep, soft beaches, whereas angular, sub-angular, round and sub-round

shapes are associated with a wide variation in both features and firmness. Round and sub-round shapes appear to be associated with steeper beaches while angular shapes have more of a tendency to be associated with gentle beaches. Except in areas of nearby fresh rock erosion, or obvious unfavorable environment, the predominant grain characteristics may be expected to be quartz and/or feldspar composition with a predominance of sub-round to sub-angular shapes.

## SINGLE CORRELATIONS

### WIDTH versus SAND CHARACTERISTICS

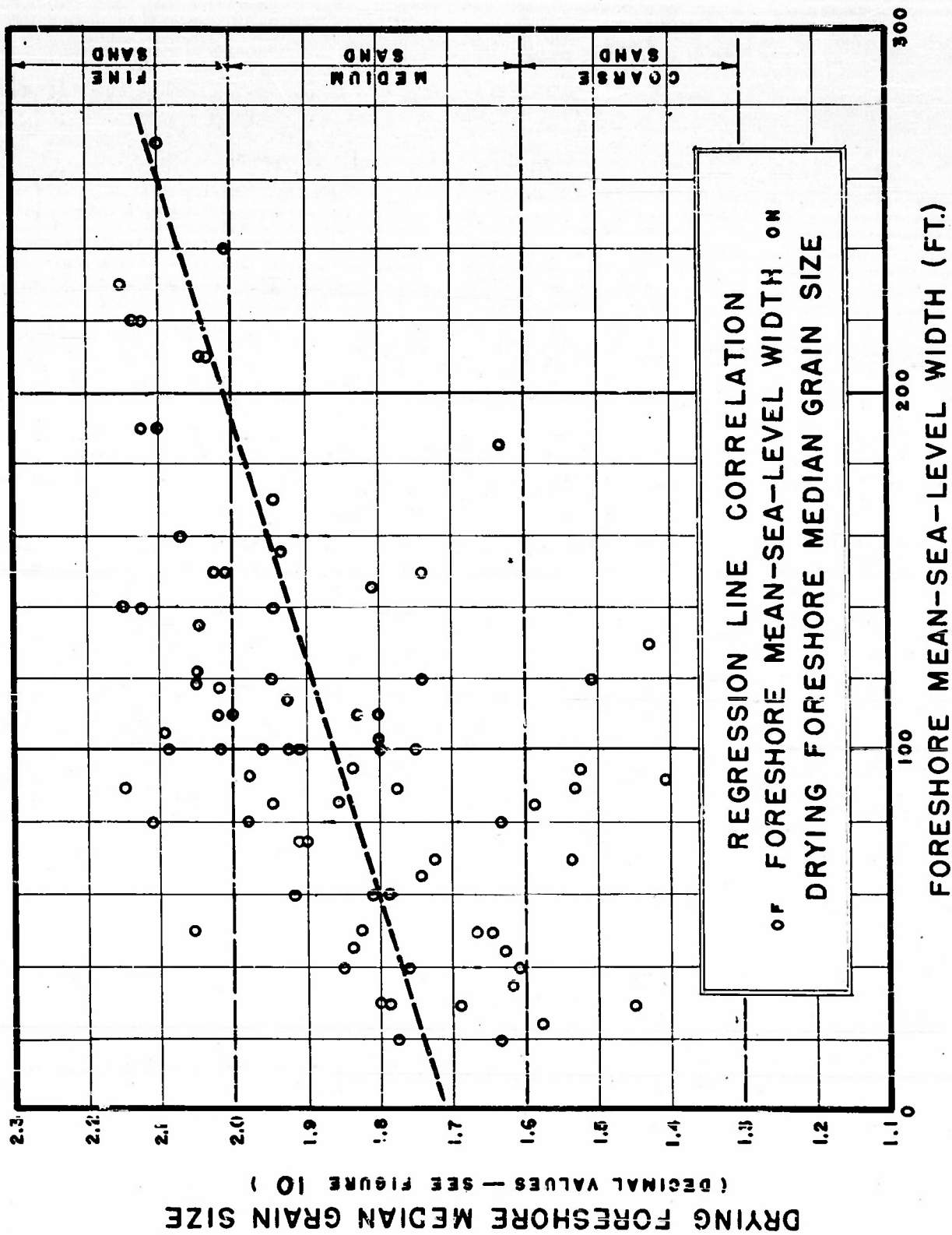
#### Median Grain-Size

Figure 8 shows the correlation obtained between  $F_s$  MSLW and  $D_{50}$  for grain-size distributions whose divergences ranged from 0.1 to 0.39.

The statistical analysis yielding Figure 8 shows that a first degree regression line of  $D_{50}$  on  $F_s$  MSLW fits the data adequately. The equation of this line is  $W = 1.71 + 0.0015Z$ . No envelope of 80% probability is plotted on this diagram due to the skewed nature of the  $D_{50}$  distribution (See Figure 11, Appendix B).

#### Other Sand Characteristics

Direct correlations between width and grain-size distribution, grain shapes and grain composition were not investigated.



**FIGURE 8**



## MULTIPLE CORRELATIONS

### GENERAL

As previously explained, a multiple correlation is considered as one in which the prediction of a given factor is based upon the correlation of it and a combination of two or more other factors.

These correlations may be used when two or more beach features can be evaluated, either from aerial photographs or by other means.

Since multiple correlations involve, in effect, three or more dimensions, they are presented in the form of tables rather than graphs.

#### Drying Foreshore Penetrations versus AFS plus Fs MSLW

Table IV shows the correlation between APR and AFS + Fs MSLW for selected values of AFS and Fs MSLW. Estimates of APR for values of AFS and Fs MSLW other than those shown must be computed in accordance with the equation and formulas tabulated in Appendix D. The table also gives the minimum and maximum values of the range in which the actual APR will fall 80% of the time, provided numerous predictions are made. It is based upon the usual assumption regarding the distribution of Y values (APR - values). The coefficient of this correlation is 0.8190 and the standard error of estimate is .3501.

| TABLE IV                                                       |      |      |      |      |      |      |      |      |      |      |      |      |  |
|----------------------------------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|--|
| CORRELATION BETWEEN APR AND SELECTED VALUES OF AFS AND FS MSLW |      |      |      |      |      |      |      |      |      |      |      |      |  |
| AFS →                                                          | 1%   |      |      | 5%   |      |      | 10%  |      |      | 15%  |      |      |  |
| FS MSLW ↓                                                      | Min  | Av   | Max  | Min  | Av   | Max  | Min  | Av   | Max  | Min  | Av   | Max  |  |
| 20'                                                            | 1.08 | 1.40 | 1.72 | 1.53 | 1.84 | 2.15 | 1.65 | 1.95 | 2.25 | 2.63 | 2.94 | 3.25 |  |
| 100'                                                           | 0.98 | 1.29 | 1.60 | 1.43 | 1.73 | 2.03 | 1.99 | 2.28 | 2.58 | 2.52 | 2.83 | 3.14 |  |
| 150'                                                           | 0.92 | 1.22 | 1.52 | 1.36 | 1.66 | 1.96 | 1.91 | 2.21 | 2.51 | 2.44 | 2.76 | 3.08 |  |
| 200'                                                           | 0.85 | 1.15 | 1.45 | 1.29 | 1.59 | 1.89 | 1.83 | 2.14 | 2.45 | 2.36 | 2.69 | 3.02 |  |
| 250'                                                           | 0.77 | 1.08 | 1.38 | 1.21 | 1.52 | 1.82 | 1.74 | 2.07 | 2.40 | 2.28 | 2.62 | 2.96 |  |
| 300'                                                           | 0.70 | 1.01 | 1.32 | 1.13 | 1.45 | 1.77 | 1.67 | 2.00 | 2.32 | 2.19 | 2.55 | 2.90 |  |

A comparison of Table IV with Figures 1 and 4 shows that PR can be estimated almost as well by evaluating either AFS or Fs MSLW, alone as they can by evaluating AFS plus Fs MSLW. Either factor when used by itself, will give a good estimation of foreshore APR, but when used in combination, the additional accuracy added to one by the other is slight. This can be shown by example. Assuming an AFS of 7% and a Fs MSLW of 150 feet, estimations of APR are as given in Table V.

| TABLE V                                                       |                           |         |         |
|---------------------------------------------------------------|---------------------------|---------|---------|
| COMPARISON of PR PREDICTIONS OBTAINED from THREE CORRELATIONS |                           |         |         |
| Correlated Factors                                            | Estimate of DFs APR (in.) |         |         |
|                                                               | Minimum                   | Average | Maximum |
| APR vs. AFS Fs MSLW<br>(Table IV)                             | 1.58"                     | 1.88"   | 2.18"   |
| APR vs. AFS (Figure 1)                                        | 1.62"                     | 1.92"   | 2.22"   |
| APR vs. Fs MSLW (Figure 4)                                    | 1.34"                     | 1.75"   | 2.16"   |

The maximum difference in any one column between the predictions obtained by the three methods is 0.24" or slightly more than 6% of the normal overall range of penetrometer readings. The minimum error is 0.06" or less than 1%.

#### Drying Foreshore - Other Multiple Correlations

Additional multiple correlations were computed. These are shown in Table VI together with their coefficients of correlation

(a perfect correlation is indicated by a coefficient of 1).

Actual values of APR, in terms of the various factors listed in Table VI, have not been included in this report. Appropriate tables can be prepared by using the formulae listed in Appendix D.

| TABLE VI<br>COMPARISON of VALUE of VARIOUS MULTIPLE CORRELATIONS   |                            |
|--------------------------------------------------------------------|----------------------------|
| Factors in Multiple Correlations                                   | Coefficient of Correlation |
| APR vs. AFS Fs MSLW<br>(discussed above and shown in Table IV).    | 0.8190                     |
| APR vs. AFS + D <sub>50</sub>                                      | 0.8418                     |
| APR vs. AFS + Grain-size class<br>(whether fine, medium or coarse) | 0.8254                     |
| APR vs. AFS + Fs MSLW + D <sub>50</sub>                            | 0.8470                     |
| APR vs. AFS + Fs MSLW + Grain-size class                           | 0.8276                     |

It is believed that APR, in terms of the multiple correlations listed in Table VI do not require tabulation. Table VI shows that the coefficients of correlation range between 0.8190 and 0.8470. This very slight difference is further minimized if the actual value of D<sub>50</sub> is unavailable, the maximum coefficient then being 0.8276. This latter correlation, involving AFS, Fs MSLW and grain-size class appears to be the best obtainable without other indications such as cusps, ripples,

wave-patterns, etc.. However, the correlation between APR and AFS + Fs MSLW is almost as good (0.8190) and the single correlation between APR and AFS is not far behind (0.8140). For most practical purposes, therefore, an estimate of APR as indicated by AFS and/or Fs MSLW may be expected to be close to the best obtainable. Other variables such as D<sub>50</sub>, grain-size class, cusps, ripples, wave effects, etc., will add to its accuracy, and supplement the interpreter's judgment.

## MISCELLANEOUS CORRELATIONS

### Cusps

The results of the Atlantic Coast Survey show a definite correlation between cusp development and beach trafficability. This correlation is important in light of the fact that when cusps appear on beaches, they are easily seen and readily identified on aerial photography of almost any scale.

Although this study indicates that cusping is more frequently associated with beaches of poor trafficability, this should not be taken to mean that all beaches having cusps have poor trafficability characteristics. Conversely, beaches without cusps are not always trafficable. Table VII indicates that all classes of beaches may be found to have cusps, but the tendency for cusps to appear on poor beaches is sufficiently strong to warrant its use as an aid in the interpretation of trafficability. The presence of cusps on a beach should be viewed as a qualitative indicator, to be used in conjunction with other visual indicators in aiding the interpreter to arrive at an estimation of trafficability.

The presence or absence of cusps on a beach is not as reliable an indicator of trafficability as is their configuration when they do appear. It was found without exception, that cusps on beaches with good trafficability characteristics were poorly developed, shallow and broad. (See Illustration 1).



Although their size and depth was dependent upon their stage of development, it was found that cusps on beaches with poor trafficability characteristics were deeper, more pronounced, and more closely spaced (See Illustration 2).

| TABLE VII                                                     |                                 |                                    |
|---------------------------------------------------------------|---------------------------------|------------------------------------|
| NUMBER OF BEACHES IN EACH TRAFFICABILITY CLASS                |                                 |                                    |
| WITH AND WITHOUT CUSPS                                        |                                 |                                    |
| Trafficability*<br>Class                                      | Number of Beaches<br>with cusps | Number of Beaches<br>without cusps |
| I                                                             | 5                               | 22                                 |
| II                                                            | 1                               | 6                                  |
| IIIA                                                          | 1                               | 3                                  |
| IIIB                                                          | 15                              | 4                                  |
| IV                                                            | 20                              | 9                                  |
| * See Figure 2 representing a typical trafficability diagram. |                                 |                                    |

Tables VIII, IX, and X show the relation between the occurrence of cusps and various beach characteristics. Of all beaches observed, 45% were found to have cusps in some stage of development.





Illustration I

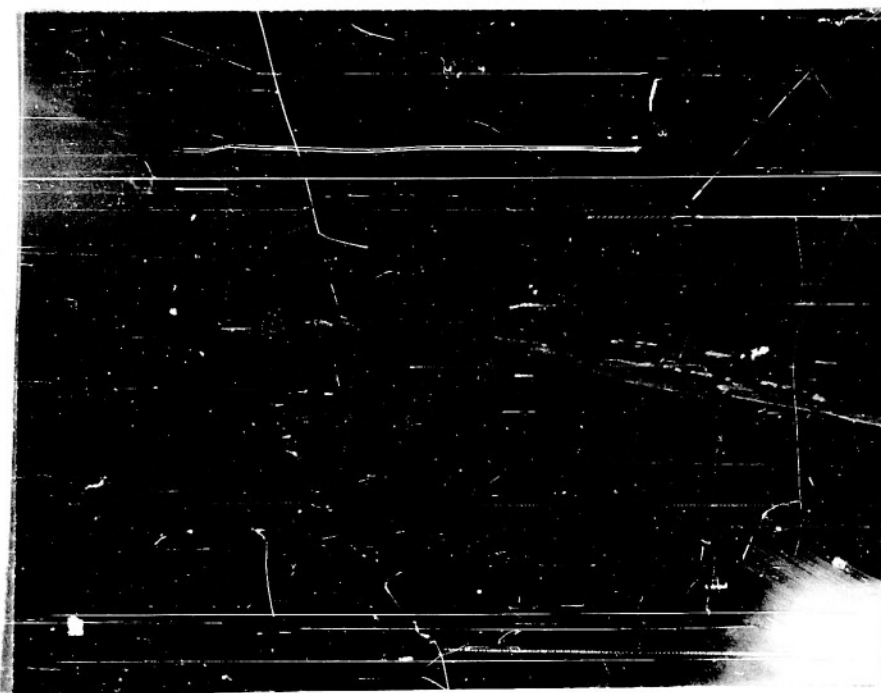


Illustration II

| TABLE VIII                                           |                   |            |                       |            |
|------------------------------------------------------|-------------------|------------|-----------------------|------------|
| AVERAGE PENETRATION READINGS ON THE DRYING FORESHORE |                   |            |                       |            |
| ON BEACHES WITH AND WITHOUT CUSPS                    |                   |            |                       |            |
| BEACHES WITH CUSPS                                   |                   |            | BEACHES WITHOUT CUSPS |            |
| APR - DFs                                            | Number of Beaches | % of Total | Number of Beaches     | % of Total |
| Less than 1"                                         | -                 | -          | 2                     | 4.0        |
| 1"                                                   | -                 | -          | 4                     | 8.0        |
| 1.25"                                                | 3                 | 7.5        | 1                     | 2.0        |
| 1.50"                                                | 4                 | 10.0       | 16                    | 32.0       |
| 1.75"                                                | 5                 | 12.5       | 6                     | 12.0       |
| 2.00"                                                | 12                | 30.0       | 6                     | 12.0       |
| 2.25"                                                | 5                 | 12.5       | 4                     | 8.0        |
| 2.50"                                                | 8                 | 20.0       | 2                     | 4.0        |
| 2.75"                                                | 1                 | 2.5        | 4                     | 8.0        |
| 3.00"                                                | 2                 | 5.0        | 3                     | 6.0        |
| 3.25"                                                | -                 | -          | -                     | -          |
| 3.50"                                                | -                 | -          | 1                     | 2.0        |
| 3.75"                                                | -                 | -          | -                     | -          |
| Over 3.75"                                           | -                 | -          | 1                     | 2.0        |

From the Table above it is seen that 70% of all beaches with cusps had average drying foreshore penetrations not less than 2 inches. Of those beaches without cusps, 70% had average drying foreshore readings not greater than two inches. This

indicates that cusps are more often associated with medium and soft beaches.

| TABLE IX<br>NUMBER OF BEACHES IN DIFFERENT SLOPE CLASSES<br>WITH AND WITHOUT CUSPS |                   |            |                       |            |
|------------------------------------------------------------------------------------|-------------------|------------|-----------------------|------------|
| BEACHES WITH CUSPS                                                                 |                   |            | BEACHES WITHOUT CUSPS |            |
| AFS Percent                                                                        | Number of Beaches | % of Total | Number of Beaches     | % of Total |
| 0 to 4                                                                             | 5                 | 12.5       | 24                    | 48         |
| 5 to 8                                                                             | 19                | 47.5       | 8                     | 16         |
| 9 to 12                                                                            | 13                | 32.5       | 12                    | 24         |
| over 12                                                                            | 3                 | 7.5        | 6                     | 12         |

It is seen from Table IX that 87.5% of all beaches with cusps had average foreshore slopes of 5% or greater, while 48% of all beaches without cusps had average foreshore slope of less than 5%. This indicates that cusps are more often found on beaches with steep to medium gradients.

Table X shows that 74% of all beaches with cusps were composed of medium sand sizes. Of all beaches without cusps, 40% were composed of fine sand, 40% were composed of medium sand and 20%, of coarse sand.

| TABLE X                                       |                   |            |                       |            |
|-----------------------------------------------|-------------------|------------|-----------------------|------------|
| NUMBER OF BEACHES HAVING DIFFERENT SAND SIZES |                   |            |                       |            |
| WITH AND WITHOUT CUSPS                        |                   |            |                       |            |
| BEACHES WITH CUSPS                            |                   |            | BEACHES WITHOUT CUSPS |            |
| DFs D <sub>50</sub>                           | Number of Beaches | % of Total | Number of Beaches     | % of Total |
| COARSE SAND                                   |                   |            |                       |            |
| Below 1.5                                     | -                 | -          | 5                     | 10         |
| 1.5-1.59                                      | 2                 | 5.0        | 5                     | 10         |
| MEDIUM SAND                                   |                   |            |                       |            |
| 1.6-1.69                                      | 9                 | 22.5       | 3                     | 6          |
| 1.7-1.79                                      | 5                 | 12.5       | 5                     | 10         |
| 1.8-1.89                                      | 10                | 25.0       | 3                     | 6          |
| 1.9-1.99                                      | 6                 | 15.0       | 9                     | 18         |
| FINE SAND                                     |                   |            |                       |            |
| 2.0-2.09                                      | 5                 | 12.5       | 10                    | 20         |
| 2.1-2.19                                      | 3                 | 7.5        | 10                    | 20         |

The preceding Tables and observations indicate that the presence, rather than the absence of cusps is a better indicator of trafficability. When cusps do not appear on a beach there are no reasonable conclusions that can be drawn from this information alone. When they do appear they are a useful indication of trafficability conditions, but must be used with judgment in conjunction with other visible indicators.

### Ripple Marks

Although ripple marks can only be observed on aerial photography of high quality and large scale, they are mentioned here because of the high degree of correlation between their occurrence and excellent trafficability characteristics. It is felt that when they can be observed, they provide a definite key to beach trafficability.

Caution should be used in the interpretation of this beach feature, since two distinct types of ripples can be observed.

Wind ripples in the dry, loose sand of the backshore, and water ripples in low depressions bear no apparent relation to beach trafficability. They appear on all types of beaches. Water ripples within depressions are shown in Illustration 3.

The type of ripples which are significant are shown in Illustration 4. They appear only on the foreshore and are broad, very flat, fairly regular, and parallel to the waterline.

This type of ripple appeared on 20% of all beaches observed.

Like cusps, ripples are a good indicator of trafficability only when they can be identified. Every beach on which these ripple marks appeared was firm. In view of this, it is felt that these correlations can sometimes be useful in arriving at an estimation of beach trafficability.\*

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\* Corroborative data, based upon wave tank tests, appears in Appendix B, Volume 2 of this report.



Illustration III



Illustration IV



| TABLE XI<br>AVERAGE DRYING FORESHORE PENETRATION READINGS<br>ON BEACHES WITH RIPPLES |                                   |
|--------------------------------------------------------------------------------------|-----------------------------------|
| APR - DFs                                                                            | Number of Beaches<br>with Ripples |
| Less than 1.00"                                                                      | 1                                 |
| 1.00"                                                                                | 5                                 |
| 1.25"                                                                                | 2                                 |
| 1.50"                                                                                | 7                                 |
| 1.75"                                                                                | 4                                 |

No beaches with ripples had a foreshore average penetration reading greater than 1.75 inches.

| TABLE XII<br>AVERAGE FORESHORE SLOPES ON BEACHES WITH RIPPLES |                                   |
|---------------------------------------------------------------|-----------------------------------|
| AFS Percent                                                   | Number of Beaches<br>with Ripples |
| 1                                                             | 3                                 |
| 2                                                             | 4                                 |
| 3                                                             | 7                                 |
| 4                                                             | 3                                 |
| 5                                                             | 2                                 |

No beach with ripples had an average foreshore slope greater than 5%.



| TABLE XIII<br>SAND GRAIN SIZES ON BEACHES WITH RIPPLES |                                   |
|--------------------------------------------------------|-----------------------------------|
| D <sub>50</sub>                                        | Number of Beaches<br>with Ripples |
| MEDIUM SAND                                            |                                   |
| 1.80 - 1.89                                            | 2                                 |
| 1.90 - 1.99                                            | 2                                 |
| FINE SAND                                              |                                   |
| 2.00 - 2.09                                            | 8                                 |
| 2.10 - 2.19                                            | 7                                 |

Most of the beaches with ripples were composed of material falling in the fine sand range, the remaining few falling in the low end of the medium sand range.

#### Scarps

Very few beaches had scarps at the time of observation, so no definite conclusions or correlations can be related to this easily recognized beach feature. However, regardless of the trafficability condition of the beach as a whole, a scarp may seriously impede or stop wheeled vehicle movement.

Scarps are an erosional feature and like cusps, appear to be more frequently associated with, and of greater magnitude on beaches having poor trafficability characteristics. This is probably due to the fact that the loosely compacted material composing such beaches is more readily eroded by wave attack.

SECTION III

CONCLUSIONS

## GENERAL

As mentioned in SECTION I, the conclusions listed in this section are based solely upon data included in this report. Consequently, they should not be considered as final conclusions regarding a method of trafficability estimation from aerial photographs. Rather, they are tentative conclusions subject to revision in the light of other phases of the project. The practical conclusions that bear upon an estimation of trafficability from aerial photographs appear in Volume 5 of this report.

The conclusions do not include any quantitative data or comparisons. This information is presented in SECTION II.

## CONCLUSIONS

1. Certain physical characteristics of a beach can be used effectively to estimate its vehicular supporting capacity in terms of penetration readings.
2. These characteristics are - in order of decreasing importance: \*
  - a. Average foreshore slope
  - b. Median grain-size of foreshore material
  - c. Grain-size class of foreshore material
  - d. Foreshore mean-sea-level width
  - e. Foreshore current ripple marks
  - f. Cusps
3. The above characteristics may be used singly, to estimate trafficability. They can also be used in a multiple way. The multiple combinations are - in order of decreasing importance (ripple marks and cusps not included):
  - a. Average foreshore slope  
plus foreshore median grain-size  
plus foreshore mean-sea-level width
  - b. Average foreshore slope  
plus foreshore median grain-size
  - c. Average foreshore slope  
plus foreshore grain-size class  
plus foreshore mean-sea-level width

---

\* It is possible that other aspects of slope, width, and grain-size would prove to be just as valuable.

- d. Average foreshore slope  
plus foreshore grain-size class
  - e. Average foreshore slope  
plus foreshore mean-sea-level width
4. The advantage, from a statistical standpoint, of using any one of the multiple correlations in preference to average foreshore slope alone, is very slight. (The practical advantage, to an interpreter faced with the necessity of making a specific evaluation is considerably greater, if only from a psychological standpoint).
5. Current ripple marks and cusps are useful but not infallible indicators of beach conditions when they are present. Their absence has no significance.
6. It was not the purpose of this report to consider the feasibility of obtaining a satisfactory measurement of the listed quantities from aerial photographs. This subject will be considered in later reports. The following general statements, however, represent the authors' current opinion:
- a. Foreshore slopes will require measurement to  $\pm 2\%$ .
  - b. Such measurements will probably require large scale photography of good quality.
  - c. Foreshore widths will be obtainable with little difficulty, and can be corrected to mean-sea-level with tide tables if time of photography is available. However, whenever possible, photography should be completed during low tide stages.

- d. Foreshore median grain-size will not be available from aerial photography. However, it can be estimated in terms of both slope and width.
- e. Foreshore grain-size class may be susceptible to estimation by an analysis of gray tones.
- f. Current ripple marks will not be discernible except on large scale photography, and then probably will be visible only at certain sun angles.
- g. Cusps, if present, will always be visible.

APPENDIX A

FIELD, LABORATORY AND ANALYSIS PROCEDURES



## FIELD PROCEDURES

The beach survey, upon which this study is based, comprised observations of 95 Atlantic Coast Beaches. Only beaches exposed to direct attack by ocean waves were investigated. Beaches in bays, harbors and other bodies of water, adjacent to the Ocean but protected from wave attack, were not included. A small number of beaches were of the pocket type\* although exposed to the direct action of ocean waves. The remaining beaches were of the coastal plain type\*.

Where beaches were continuous along the coast, observations were taken at intervals of from six to ten miles, the exact distance usually depending upon accessibility. In addition, observations were taken at several points where there was a noticeable apparent change in beach characteristics and materials. In a few instances of extreme uniformity, intervals of twenty miles were used. It is believed that the system of sampling was essentially random in character, being influenced by little except distance intervals and accessibility. Possibly statisticians will not agree.

The various kinds of data collected on the beaches at all observation sites are discussed briefly in the following paragraphs.

---

\* See Technical Report #3, "A Photo-Analysis Key for the Determination of Ground Conditions", Beach Series, Volumes 1 and 2.

### Beach Profile

At each site a line of observation was established perpendicular to the shoreline, extending from the dune apron to the waterline and into the water for a reasonable distance.

Elevations were taken with a rod and level along this line at intervals of ten, twenty or forty feet, depending on the width and topography of the beach. Elevations were also taken between regular stations wherever there was an abrupt change in slope.

These profiles were independent of any established bench marks, but were referred to mean-sea-level by means of tide tables.

### Sand Samples

Sand samples were taken on each beach for the purpose of determining the moisture content, grain shape, material composition, and mechanical analysis. The usual procedure was to take three representative samples on each beach, one from each major beach zone, i.e., backshore, drying foreshore and wetted foreshore. Density measurements were taken at the same points where these samples were taken.

On some beaches, sand samples and density measurements were taken at regular intervals across the beach. With this data it was possible to plot the variations in density, moisture content, grain-size, etc. across the beach.

All samples were placed in cans, sealed and returned to the laboratory for analysis.

For the determination of in-place wet sand densities, a thin-walled brass cylinder of known volume (79.25 cu. in.) was jacked into the sand to a depth of 4.25 inches, dug out and struck off evenly. The cylinder and contents were weighed and the wet density determined in pounds per cubic foot.

#### Penetrometer Profiles

At each regular profile station (intervals of 10, 20 or 40 feet) across the beach, a reading with a constant weight cone penetrometer\* was recorded. The values tabulated were the average of three readings at each station.

#### Miscellaneous Data

Information concerning cusps, scarps, bars, current ripples and shell was noted wherever these features were observed.

#### Ground Photography

Several views of each beach were photographed with a 4" X 5" press camera as a permanent record of beach characteristics visible on the ground.

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\*See Technical Report # 5, "Use of Penetration Devices on Beaches".

## LABORATORY PROCEDURES

The only laboratory procedures involved were those concerned with the analysis of sand samples and the determination of natural moisture contents for use in computing the field dry densities.

The sand sample analysis consisted of a determination of the grain-size distribution as described by ASTM Designation D422-39 (Hydrometer Test Omitted). U.S. Standard Sieve Numbers 4, 10, 20, 40, 60, 80, 140 and 200 were used. The grain shape distribution was estimated by quartering each sample and examining several views of one quarter through a microscope. Predominant composition was estimated concurrently. Only 25 samples, selected from beaches in such a manner that a range of physical features was represented, were analyzed for grain shape and composition.

The moisture content was determined in accordance with ASTM Designation D426-39.

## ANALYSIS PROCEDURES

### Profile Data

After the beach profiles were plotted accurately on cross-section paper, the following data was determined and tabulated for each beach:

1. Mean-sea-level-width (MSLW)

The total width of the beach with the tide stage corrected to mean sea level. In order to preclude the effects of tide, this method was used in determining the relative widths of beaches to be used in correlations with other factors. Figure 9b illustrates the method of determining MSLW.

2. Foreshore Mean-sea-level-width

The total MSLW less the width of the backshore.

3. Average Foreshore slope

The average slope of the foreshore neglecting minor irregularities caused by cusps, scarps, etc. The selection of AFS involved a certain amount of judgment. For example, if there were a significant length of slope having a high value (say 15%) coupled with an equal amount having 5%, the AFS was not selected as simple graphical average (10%) but a slight

weight was placed upon the high slope.

The AFS was chosen as 11% or 12%. This procedure was always followed.

4. Average backshore slope

The average slope from the backshore-foreshore boundary to the toe of the dune apron, again neglecting minor irregularities.

5. Maximum Foreshore slope

The maximum significant slope on the foreshore (disregarding scarps, cusps, etc.)

6. First and Second Foreshore slopes

The slope of the beach from the waterline to the first significant change in slope, and from the first to the second change in slope.

7. Difference between first and second foreshore slopes

8. Slope at each point where sand samples were taken for sieve analysis, moisture and density determination.

Penetration Data

The penetrometer profile for each beach was plotted on cross-section paper immediately above the physical profile (See Figure 9a). Values for the following data were determined from the penetrometer profiles:

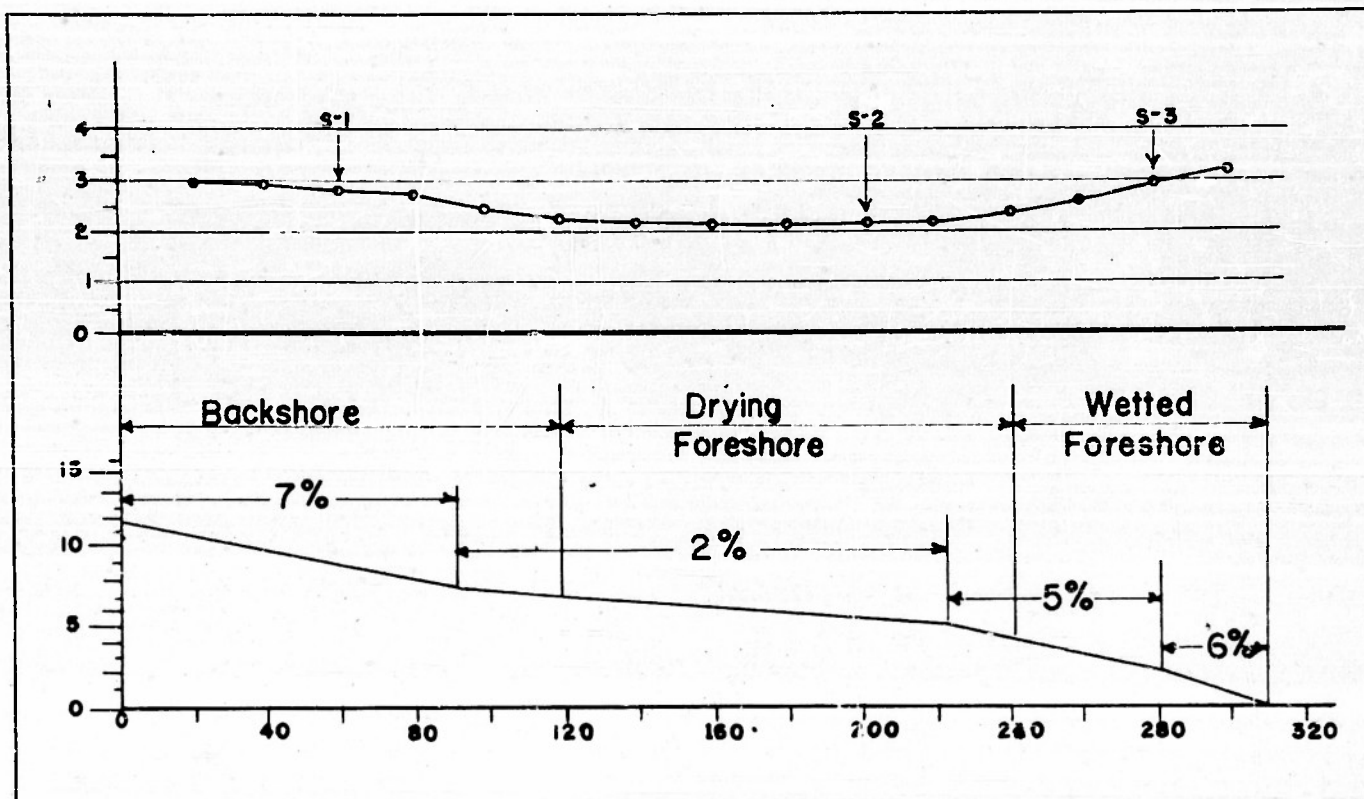


FIGURE 9A

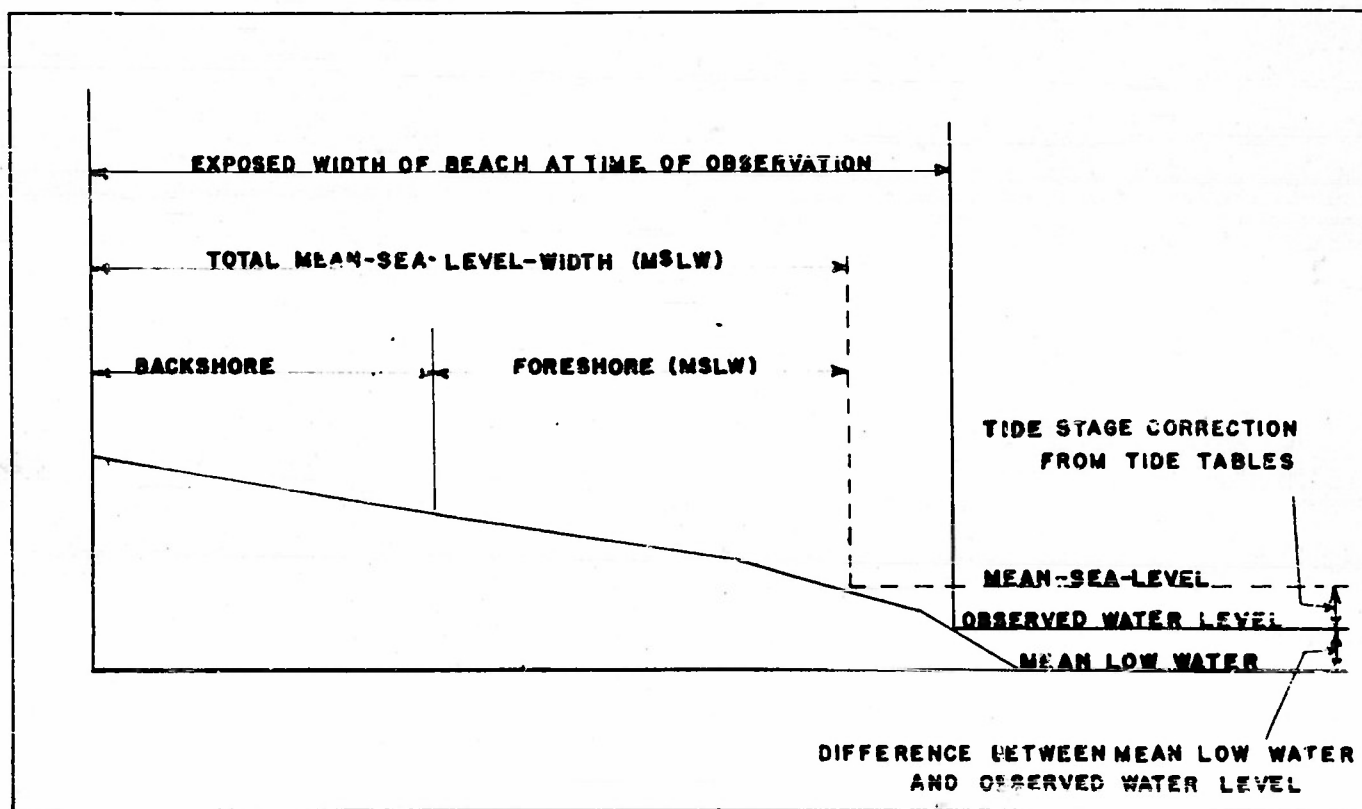


FIGURE 9B



1. Penetrometer readings at sample sites

Penetration values were tabulated for all sites where sand samples were taken.

2. Average drying foreshore penetration

The average of all penetrometer readings across the drying foreshore were computed and tabulated for each beach.

3. Significant minimum foreshore penetration

The lowest penetrometer readings which extended for a significant distance across the foreshore were tabulated for each beach.

4. Average backshore penetration

The average of all penetrometer readings across the backshore.

5. Range of drying foreshore penetration

The total range of drying foreshore penetrometer readings on each beach.

Mechanical Analysis of Sand Samples

Grain-size distribution curves were plotted on standard semi-log sieve analysis paper (per cent finer by weight vs. grain-size in mm.). In addition, a linear decimal scale was added so that the distribution curves could be more completely and accurately described in terms of numerical quantities. Figure 10 is an illustration of the sieve analysis curves and shows the quantities used to describe the curves.

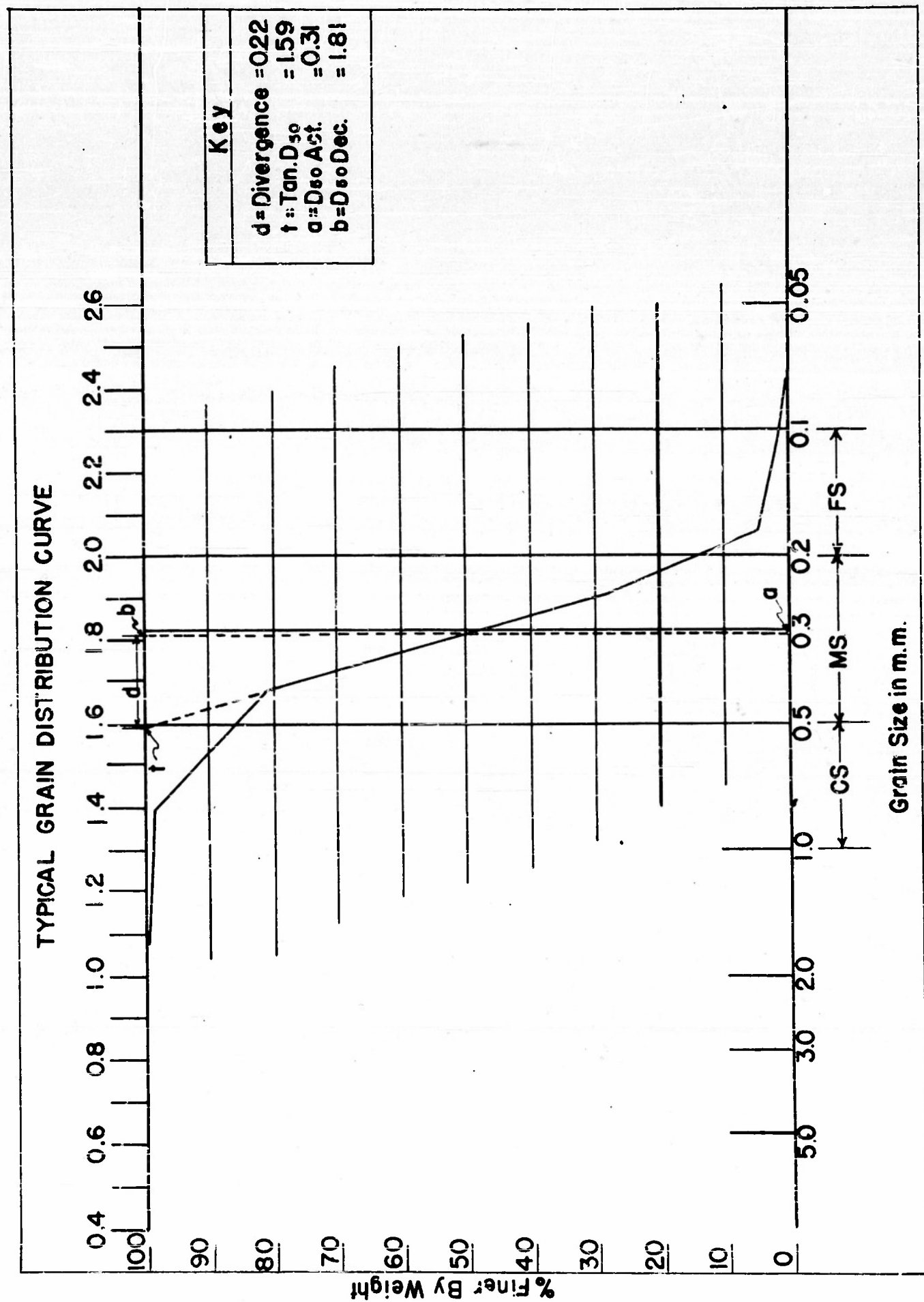


FIGURE 10

### Dry Density Determination

With the moisture content and in-place wet density known, the natural dry density of the material composing the beach was computed for each station where a wet density determination was made. The dry densities were tabulated in pounds per cubic foot.

### Keysort Cards

All data was entered on McBee Keysort Cards for ease in correlation and statistical analysis.

APPENDIX B

DISTRIBUTION AND VARIATION OF MAJOR VARIABLES

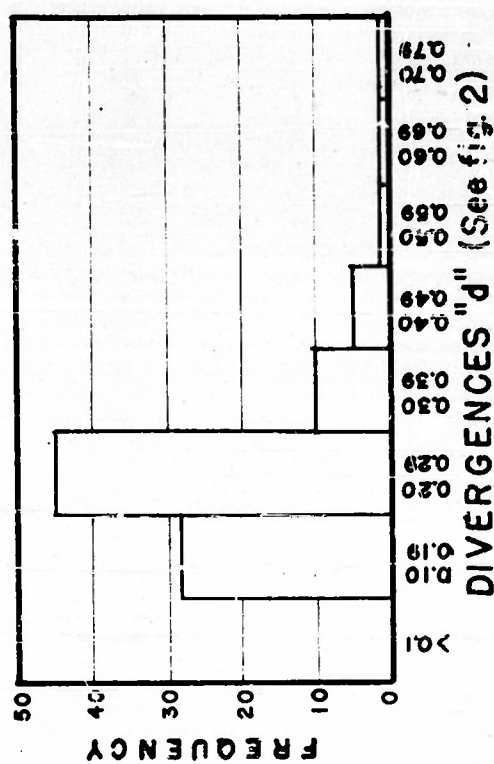
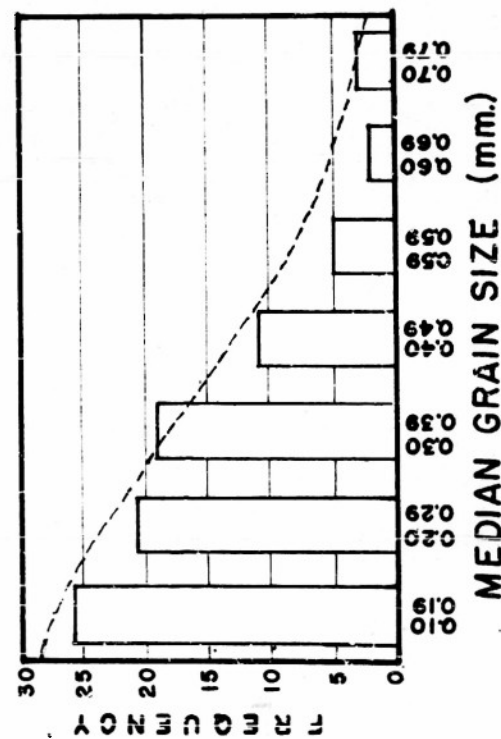
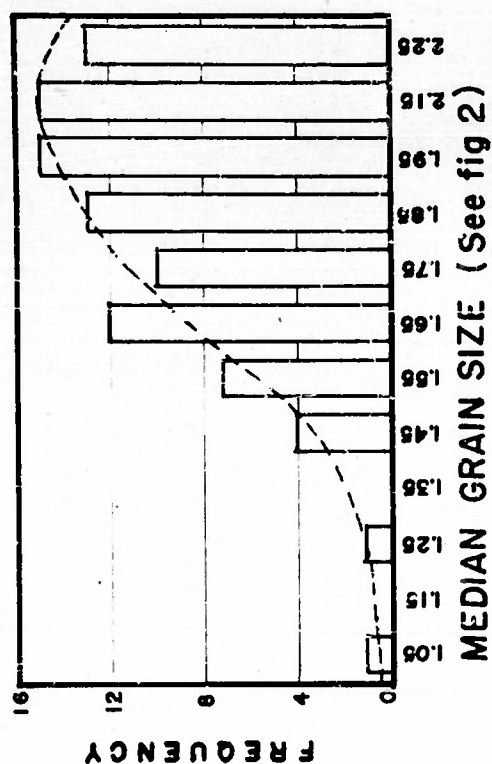
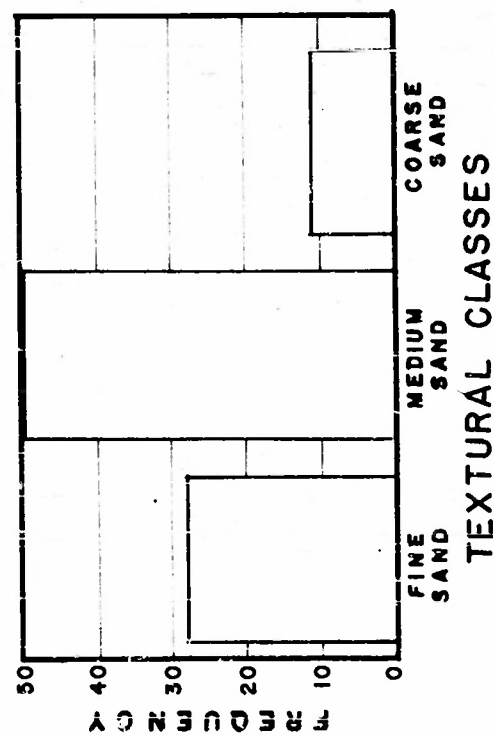
## GENERAL

This section includes a number of figures showing the distribution and variation of major beach features and quantities as they were observed in this study.

The purposes of the section are:

1. To show the range of variation for each variable that is included in the correlations presented in SECTION II.
2. To help the reader evaluate the correlations.

The figures are self-explanatory and require no discussion.

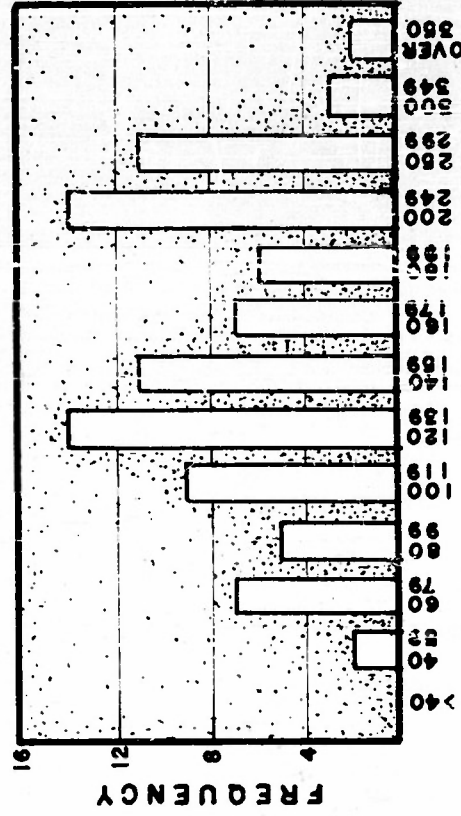


**FREQUENCY DISTRIBUTIONS OF  
BEACH SAND CHARACTERISTICS**

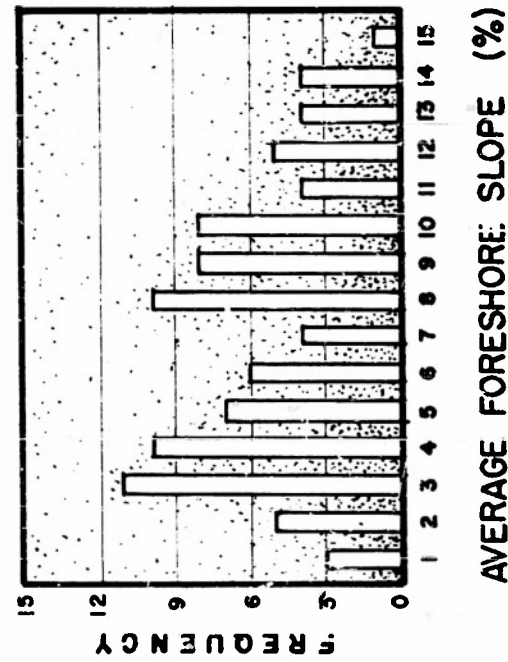
**FIGURE 11**



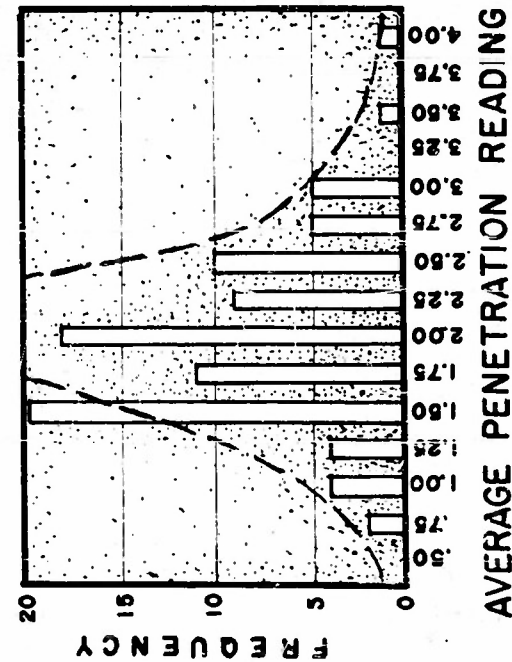
FORESHORE MSLW



TOTAL MSLW



AVERAGE FORESHORE SLOPE (%)

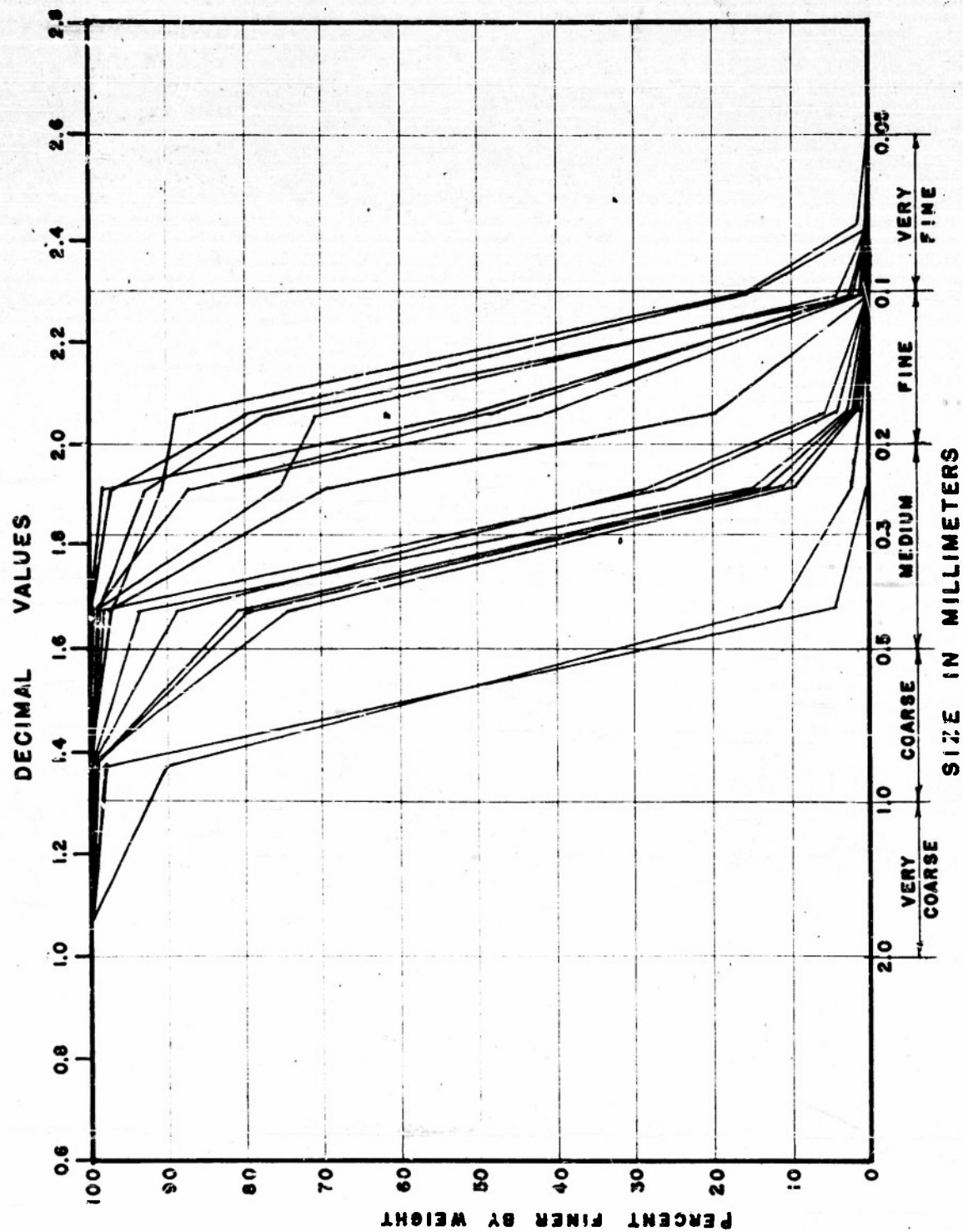


AVERAGE PENETRATION READING

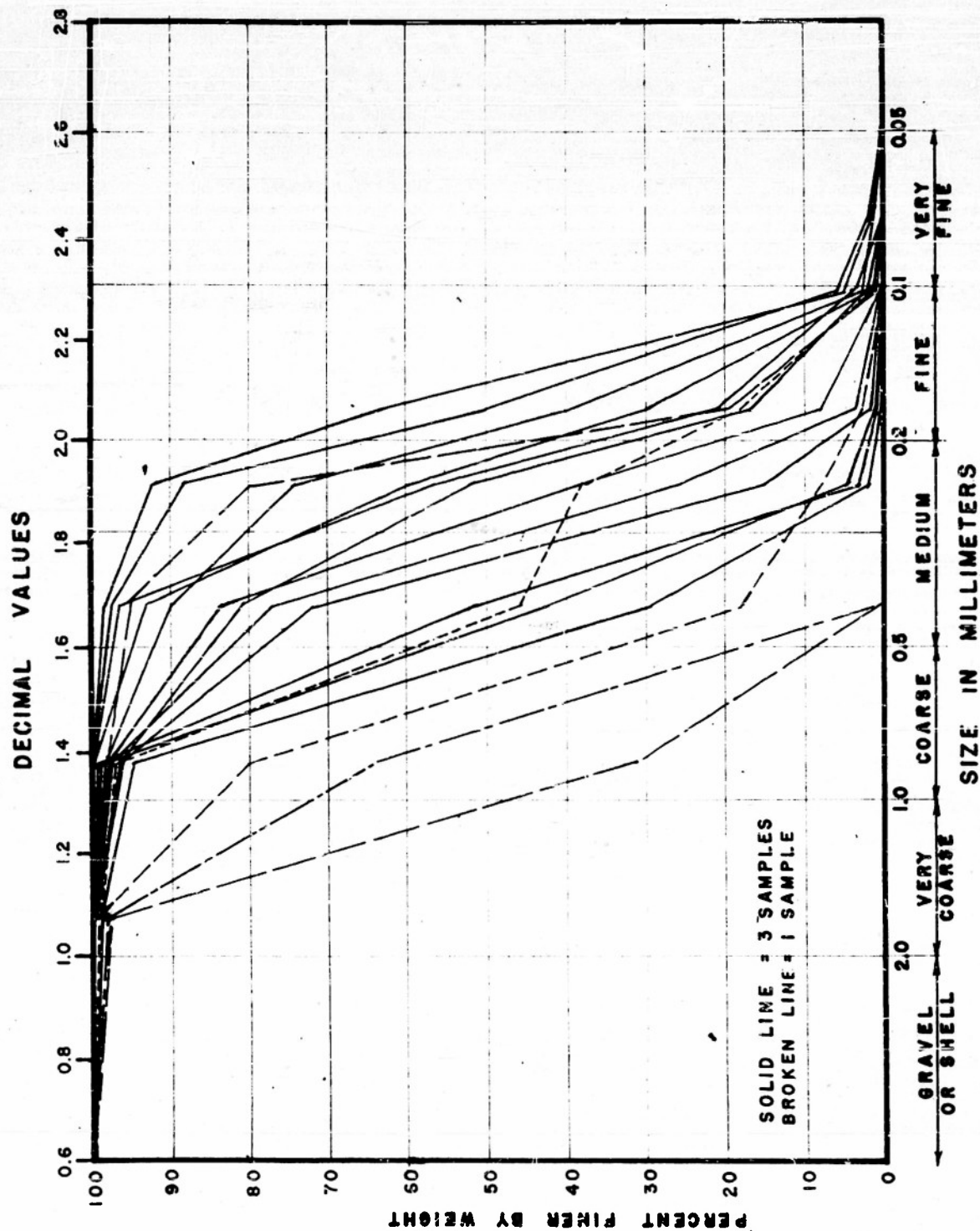
FREQUENCY DISTRIBUTIONS OF IMPORTANT SLOPE, WIDTH, & PENETRATION FACTORS.

FIGURE 12

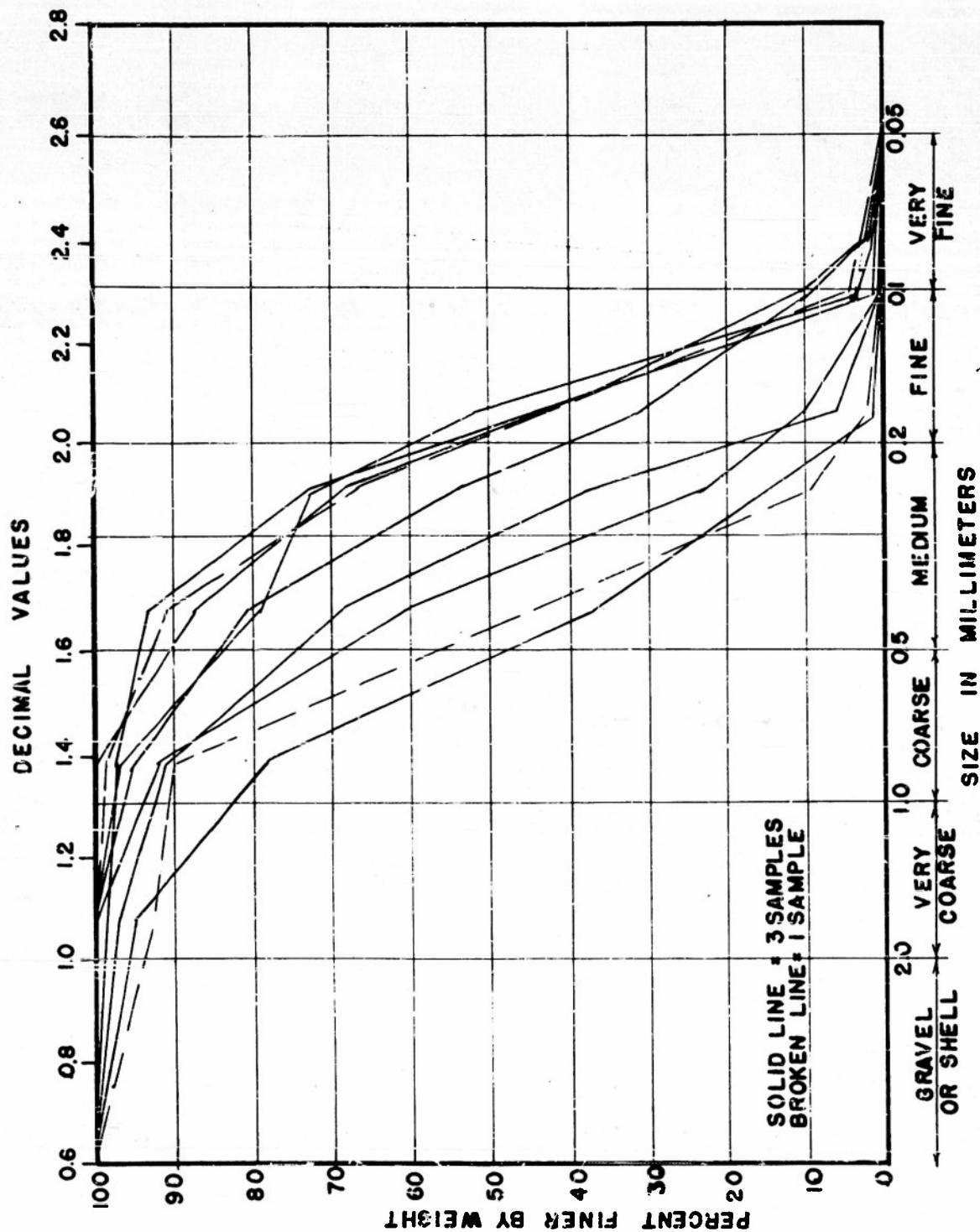




GRAIN SIZE DISTRIBUTION CURVES  
FORESHORE SAMPLES WITH DIVERGENCE ( $d$ ) OF 0.1 TO 0.18



GRAIN SIZE DISTRIBUTION CURVES  
FORESHORE SAMPLES WITH DIVERGENCE (d) OF 0.2 TO 0.29



GRAIN SIZE DISTRIBUTION CURVES  
FORESHORE SAMPLES WITH DIVERGENCE (1) OF 0.3 TO 0.39

APPENDIX C

STATISTICAL COMMENTS ON THE USE OF  
LINEAR REGRESSION EQUATIONS FOR PREDICTING VALUES  
FROM RELATED BEACH CHARACTERISTICS

By

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Cornell University

When there is an existing relationship between various measured characteristics it is possible to predict values for the characteristic in which we are interested from observed values of the related characteristics. On the basis of data observed in the past it is possible to estimate the form of the relationship thought to exist between the variables and to set an interval in which we are reasonably sure the predicted values will lie.

In this study, the observed characteristics were: APR (Y), AFS (X), Fs MSLW (Z), D<sub>50</sub> (W) and grain-size class (T).

We are here interested in using observed relationships between the factors, Y, X, Z, W and T to predict values for Y and to assign a measure of reliability to our prediction of Y.

A sample of values of Y, X, Z, W and T were jointly observed and from this sample, relationships were established and various prediction equations calculated. A linear relationship between the Y values and combinations of the characteristics was found to be a suitable representation for the data. An example of this relationship is:

$$Y = a + bX + cZ + dW$$

To estimate the constants a, b, c and d we used the criteria that the sum of the squares of the deviations of the Y values calculated from the above equation and the observed Y values from the sample will be a minimum.



Since we are working with a sample of values we cannot expect our prediction to be exact but must allow for both the inherent variability in the material with which we are dealing, and the fact that the sample on which we are basing our predicting equations may not be representative of the population we are studying.

To take both of these sources of error into account, our prediction will be in the form of an interval in which we may be confident the true Y value lies. This confidence can be expressed in the form of a probability statement as follows: If we compute relationships between the above mentioned variables, and on the basis of these relationships repeatedly make a prediction for the Y value corresponding to different values of the related variables, then in the long run, 80% (say) of our predicted intervals will contain the true Y value. The percentage of times we wish to be correct, the inherent variability in the characteristic we are predicting, and the size of the sample, will determine the length of the prediction interval, i.e., the greater the risk of making an incorrect prediction we are willing to take, the less variability in the variable we are predicting, and the larger the sample, the shorter will be the length of the interval.

There are certain assumptions involved in making this type of a probability statement and they can be stated as follows:

The deviations of the predicted Y values from the observed Y values should be a random sample from a normally distributed population with a common variance, i.e., our Y value used in estimating our prediction equation must have been a random sample from a normal population where the variation in the Y's does not change as the values of the other characteristics change.

In order to examine the assumption of normality made in placing our prediction range on each new prediction made, it would be necessary to have a very large sample size in order to detect all but the most violent departures from normality.

It will probably suffice to examine a histogram (See Figure 12) of the observed APR and observe that the form is fairly symmetric about its central values and that neither large nor small deviations from the central values predominate. It can also be noted that in most non-normal distributions encountered in practice, unless the distribution is markedly skew, no serious error is introduced into using the usual significance levels of the t-test (see references 1, 2, and 3). It is also thought that by using the usual tabulated probability tables we will be underestimating the length of our confidence interval, i.e., our prediction interval will cover

- 
- 1 Bartlett, M.S., "Effects of Non-Normality on the t-distribution", Proceedings, Cambridge Philos. Society, Vol. 31, 1935.
  - 2 Hay, G.B., "A New Method of Experimental Sampling Illustrated on Certain Non-Normal Populations", Biometrika, Vol. 30, 1938.
  - 3 Cochran, W.G., "Some Consequences When the Assumptions for the Analysis of Variance Are Not Satisfied", Biometrics, Vol. 3, 1947.



the true APR slightly less than 80% of the time. It has been estimated (see reference 3) that for the 95% level, when the distribution is not normal, one is really using between 93% and 96% levels, and at the 99% level, one is really using between the 98% and 99.5% level.

The strength of a linear relationship between Y and any factor or combination of factors is measured by the correlation coefficient. The correlation coefficient measures the extent Y will vary as other factors vary. When only one other factor is involved, say X, there is a simple correlation between Y and X. When Y and X are perfectly linearly related there is obtained a correlation of + 1 if high values of Y are associated with low values of X. To measure the relationship of Y and more than one other factor it is necessary to use the multiple correlation coefficient which measures the relationship between the observed Y values and the values of Y calculated from a linear combination of the other factors.

As a measure of the total variability of the Y values, we calculate the variance  $s_y^2$ . If there were no correlation between Y and any of the other factors then this value would account for all the variation in the Y values. If correlations do exist then we can explain some of the variation in Y by the fact that the variation in Y is influenced by the way in which its correlated factors vary. After we have eliminated the source of variation in Y due to related factors the residual

is that which is due to extraneous or random causes and which is not accounted for by the correlation of Y with the other factor or factors. This residual quantity is known as "The Standard Error of Estimate" and is used as a measure of reliability for the prediction of Y from other related factors.

The correlation coefficient R (Simple or Multiple), the total variance of Y,  $s_y^2$ , and the square of the Standard Error of Estimate are related in the following manner:

$$s_y^2 = R^2 s_y^2 + (1 - R^2) s_y^2$$

where

$s_y^2$  = total variance of Y

$R^2 s_y^2$  = variation due to correlation of Y with other factors

$(1 - R^2) s_y^2$  = variation in Y not explained by correlation =  
square of Standard Error of Estimate.

Obviously, the better the correlation between Y and the other factors, the smaller will be the Standard Error of Estimate, and consequently, the greater the reliability in our predicted Y value, where reliability is measured in terms of shortness of the prediction interval.

In this study, it was found that there was a significant relationship existing between all characteristics and that the prediction equation giving the shortest prediction interval for Y will be the equation involving Y, X, Z and W although the

interval is not reduced very greatly from the interval we obtain using Y alone. Equations, formulae and coefficients are tabulated in Appendix D.

APPENDIX D

COMPUTATIONAL DATA AND COEFFICIENTS

FOR

CORRELATIONS DESCRIBED IN THIS REPORT

| SINGLE CORRELATIONS                                                                       |                         |                                                                  |                            |                            |  |
|-------------------------------------------------------------------------------------------|-------------------------|------------------------------------------------------------------|----------------------------|----------------------------|--|
| Correlation Description                                                                   | Prediction Equation     | Formula for 80% Confidence Limits                                | Coefficient of Correlation | Standard Error of Estimate |  |
| APR(Y) vs. AFS(X)                                                                         | $Y = 1.04 + 0.13X$      | $\pm 0.85(0.361) \quad 1.013 + \frac{(x-6.88)^2}{1117.09}$       | 0.8104                     | 0.3610                     |  |
| APR(Y) vs. $F_s$ MSLW(Z)                                                                  | $Y = -2.583 + 0.00549Z$ | $\pm 0.85(0.486) \quad 1.0118 + \frac{(Z-108.87)^2}{404,535.60}$ | 0.6303(-)                  | 0.4700                     |  |
| APR(Y) vs. D50(W)                                                                         | $Y = 7.1879 + 2.7671W$  | $\pm 0.85(0.459) \quad 1.0125 + \frac{(W-1.8798)^2}{2.6175}$     | 0.7588                     | 0.3943                     |  |
| APR(Y) vs. grain-size class (T)<br>coarse sand, T=0<br>medium sand, T=1<br>fine sand, T=2 | $Y = 2.76 - 0.65T$      | $\pm 0.85(0.455) \quad 1.013 + \frac{(T-1.27)^2}{29.35}$         | 0.6651(-)                  | 0.4550                     |  |
| D50(W) vs. AFS(X)                                                                         | $W = -2.11 + 0.033X$    | Not applicable because of D50 frequency distribution             | ---                        | ---                        |  |
| D50(W) vs. $F_s$ MSLW(Z)                                                                  | $W =$                   | Not applicable because of D50 frequency distribution             | ---                        | ---                        |  |

# MULTIPLE CORRELATIONS

| Correlation Description                              | Prediction Equation                       | Formula for 80% Confidence Limits                                                                                                                                                                                                                 | Coefficient of Correlation | Standard Error of Estimate |
|------------------------------------------------------|-------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|----------------------------|
| APR(Y) vs. AFS(X) + Fs MSLW(Z)                       | $Y = 1.32 + 0.11X - 0.0014Z$              | $\pm 0.85(0.35) \times \text{square root of:}$ $1.013 + \frac{(X-6.88)^2}{D} (397,855.05) + \frac{(Z-110.58)^2}{D} (1117.09) + \frac{2(X-6.88)(Z-110.58)K}{D} \text{ where}$ $D = (1,117.09)(397,855.05) - (13,958.51)^2 \text{ and } K=13958.51$ | 0.8190                     | 0.3501                     |
| APR(Y) vs. AFS(X) + D <sub>50</sub> (W)              | $Y = 3.3973 + 0.0871X - 1.0992W$          | $\pm 0.85(0.3291) \times \text{square root of:}$ $1.013 + 0.0021(X-6.88)^2 + 0.8366(W-1.88)^2 + 0.0622(X-6.88)(W-1.88)$                                                                                                                           | 0.8418                     | 0.3291                     |
| APR(Y) vs. AFS(X) + grain-size class(T)              | $Y = 1.4708 + 0.1051X - 0.2078T$          | $\pm 0.85(0.3441) \times \text{square root of:}$ $1.013 + 0.0017(X-6.88)^2 + 0.0632(T-1.27)^2 + 0.0139(X-6.88)(T-1.27)$                                                                                                                           | 0.8254                     | 0.3441                     |
| APR(Y) vs. AFS(X) + Fs MSLW(Z) + D <sub>50</sub> (W) | $Y = 3.4779 + 0.076X - 1.0368W - 0.0011Z$ | $\pm 0.85(0.3237) \times \text{square root of:}$ $1.013 + 0.0026(X-6.88)^2 + 0.8786(W-1.88)^2 + 0.0000047(Z-110.58)^2 - 0.0586(X-1.88)(Z-110.58) + 0.00054(W-1.88)(Z-110.58)$                                                                     | 0.8470                     | 0.3237                     |

| MULTIPLE CORRELATIONS<br>(continued)                   |                                              |                                                                                                                                                                                                                                                        |                                  |                                  |
|--------------------------------------------------------|----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|----------------------------------|
| Correlation<br>Description                             | Prediction<br>Equation                       | Formula for 80% Confidence<br>Limits                                                                                                                                                                                                                   | Coefficient<br>of<br>Correlation | Standard<br>Error of<br>Estimate |
| APR(Y) vs. AFS(X)<br>+ FS MSLW(Z) +<br>grain class (T) | $Y = 1.7114 + 0.0896X$<br>- $0.2T - 0.0013Z$ | $\pm 0.85(0.3440) \times \text{square root of:}$<br>$1.013 + 0.00213(X-6.88)^2 +$<br>$0.0589(T-1.27)^2 + 0.0000042$<br>$(Z-110.58)^2 + 2(0.00617)(X-6.88)$<br>$(Z-110.58) + 2(0.0000049)$<br>$(X-5.88)(Z-110.58) + 2(0.00083)$<br>$(T-1.27)(Z-110.58)$ | 0.8276                           | 0.3440                           |



APPENDIX E

INVESTIGATION OF THE CORRELATION  
BETWEEN SAND SIZE AND ESTIMATED BEACH FIRMNESS  
ON BEACHES THROUGHOUT THE WORLD

Technical Report #2\* is a survey of sand-grain characteristics and estimated firmness of beaches in various regions of the world. Data contained in the report includes mechanical, petrographic and mineralogical analysis of sand samples and an estimation of the firmness of beaches from which the samples came. No information concerning other physical features of the beaches such as slope, width, etc. was reported.

In this Appendix, the data contained in Technical Report #2 is analyzed to see if the correlation between sand size and beach firmness found on Atlantic Coast beaches prevails on other beaches throughout the world.

Unfortunately, no standard procedure for the estimation of beach firmness was adopted during the field investigations for Technical Report #2. Various observers used different methods and devices such as heel imprint, jeep tracks, penetrometer readings, etc. in formulating their estimation of beach firmness - beaches were classified only as soft, medium or firm. For this reason only, a very general comparison of the observations in Technical Report #2 and in this report can be made.

The following tables indicate the number of beaches in each firmness group and their corresponding sand sizes.

---

\* Analysis of Beach Sand, Part 1 and Part 2.

| TABLE XVa                                                                                            |                           |                             |                           |
|------------------------------------------------------------------------------------------------------|---------------------------|-----------------------------|---------------------------|
| BEACHES IN THE PHILIPPINE ISLANDS, CALIFORNIA, VIEQUES,<br>JAPAN, BRAZIL, NORTH CAROLINA AND OKINAWA |                           |                             |                           |
| Sand Size: D <sub>50</sub>                                                                           | Number of<br>Firm Beaches | Number of<br>Medium Beaches | Number of<br>Soft Beaches |
| COARSE SAND                                                                                          |                           |                             |                           |
| 1.39 and below                                                                                       | 2                         | 3                           | 3                         |
| 1.40 - 1.49                                                                                          | -                         | 1                           | 3                         |
| 1.50 - 1.59                                                                                          | 1                         | 1                           | 3                         |
| MEDIUM SAND                                                                                          |                           |                             |                           |
| 1.60 - 1.69                                                                                          | 2                         | 2                           | 3                         |
| 1.70 - 1.79                                                                                          | 4                         | 3                           | 5                         |
| 1.80 - 1.89                                                                                          | 2                         | 1                           | 5                         |
| 1.90 - 1.99                                                                                          | 1                         | 3                           | 4                         |
| FINE SAND                                                                                            |                           |                             |                           |
| 2.00 - 2.09                                                                                          | 12                        | 2                           | 3                         |
| 2.10 - 2.19                                                                                          | -                         | 2                           | 1                         |
| 2.20 and above                                                                                       | 2                         | 1                           | -                         |

| TABLE XVb                  |                           |                             |                           |
|----------------------------|---------------------------|-----------------------------|---------------------------|
| BEACHES IN HAWAII          |                           |                             |                           |
| Sand Size: D <sub>50</sub> | Number of<br>Firm Beaches | Number of<br>Medium Beaches | Number of<br>Soft Beaches |
| FINE                       | 10                        | 1                           | 0                         |
| MEDIUM                     | 14                        | 19                          | 14                        |
| COARSE                     | 6                         | 11                          | 12                        |

The preceding tables indicate that the correlation between sand size and beach firmness on these beaches is in close agreement with a like correlation found on Atlantic Coast beaches.

An examination of the data in Technical Report #2 pertaining to mineral composition of beach sand indicated no correlation between that factor and beach firmness.

# Armed Services Technical Information Agency

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