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U. S. Navy Underwater Sound Laboratory
Fort Trumbull, New London, Connecticut

FURTHER COMMENTARY ON NARRAGANSETT BAY SEDIMENTS

by

Donald L. Cole

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11 March 1957

12 p.

INTRODUCTION

This memorandum is concerned primarily with a second evaluation of data reported by the Narragansett Bay Marine Laboratory. The data itself are related to their work on the sediments of Narragansett Bay. The physical parameters of interest to our problems are densities of the sediments and their porosities. The densities are bulk densities in the dry state and in situ. The porosity we are concerned with is the ratio of the voids, presumably filled with water, to the wet bulk volume. These parameters are of interest to us because they are related to attenuation, reflection, and transmission of sound at one boundary of the ocean. What ~~we~~ can learn of them is therefore of importance.

The Narragansett sediment data exhibits a positive correlation between values of dry density determined and the percentage by weight of H_2O associated with the sample. Moreover, if the wet densities calculated on the basis of the determined dry densities be plotted against the per cent by weight of water, an exceptionally smooth curve is formed (Figure 2). This curve suggests a smooth analytical function. It is the purpose of this paper to show that such a function is predictable under the assumptions of a constant dry bulk density and a constant density for the medium. Moreover, two such values can be derived from the Narragansett data. These values used in the proper formulae will produce curves describing the data presented. They imply the nature and magnitude of the curves to be used to obtain a curve more representative of the physical facts.

DEFINITION OF TERMS

Let:-

D_D = Dry Bulk Density

D_M = Density of the Medium

D_S = Wet Bulk Density

P = Porosity = $\frac{\text{Volume of Pore Space}}{\text{Wet Bulk Volume}} \times 100$

W_W = Percentage by Weight of Water in Sample

If one weighed a sample of wet sediment, determined its bulk volume, and then drove off the water by heating the sample and weighing to constant weight, one can obtain the weight of dry material, the loss in weight or the water content, the volume of water in the pore space (no closed pores) and thus be able to determine dry bulk density, wet bulk density and porosity. The assumption made regarding the bulk volume of the material itself is that it does not shrink or expand in the process. This assumption is not strictly true, especially for clays and fine grained materials, as may be readily seen by studying techniques used by the ceramics industry in dealing with these same parameters. We shall not consider this problem here.

For convenience we shall assume a 100 gram sample of wet sediment and derive the necessary relationships as follows, using the symbols defined above. Let us put the quantities involving weight in one column, those of volume in another.

		Weight Quantities	Volume Quantities
Sample	(1)	100	$\frac{(100 - W_W) D_M + W_W D_D}{D_M D_D}$
Water	(2)	W_W	$W_W \div D_M$
Sample − Water	(3)	$100 - W_W$	$(100 - W_W) \div D_D$

From the above all the relationships required are derived:

(4) $$D_S = \frac{100 D_M D_D}{(100 - W_W) D_M + W_W D_D}$$

(5) $$\% P = \frac{100 W_W D_D}{(100 - W_W) D_M + W_W D_D}$$

Rewriting (4) we have for D_D

(6) $$D_D = \frac{(100 - W_W) D_S D_M}{100 D_M - W_W D_S}$$

Assuming D_M as 1.02 gm/cm^3 (as a nominal value for density of sea water) and various values of D_D as through the range 2.3 to 2.7, a family of curves is plotted of D_S vs. W_W. These curves are shown as Figure 1. The range of values for D_D represents the range of values of D_D given in the Narragansett report.

If the values of D_S given in the Narragansett data be plotted against W_W we have a substantially smooth curve of the same form as equation (4) requires, (Figure 2) but superposition of this curve over the family of Figure 1 shows the data curve to cut across the family of curves as the water content increases. Moreover, the transition is a smooth one. Now the roughly parallel curves in the family of Figure 1 can be tilted by changing the value of D_M to some other constant value and this would yield a new family of the same form but with a different aspect reflecting this change in D_M. This suggests the possibility of determining analytically the values of D_D and D_M required to produce the curve of Figure 2. To do this we select two values of D_S from Figure 2 widely separated. Thus when

$$W_W = 15 \qquad D_S = 2.125 \text{ gm/cm}^3$$

$$W_W = 60 \qquad D_S = 1.320 \text{ gm/cm}^3$$

Assuming D_D to be constant but of unknown value and that our equation is of the form of formula (6),

$$(7) \quad D_D = \frac{85 \times 2.125\, D_M}{100\, D_M - 15 \times 2.125} \quad \text{and}$$

$$(8) \quad D_D = \frac{40 \times 1.32\, D_M}{100\, D_M - 60 \times 1.32\, D_M}$$

We assume that D_D is constant for the curve of the data and equate the two quantities solving for D_M whence $D_M = .98744$ gm/cm3. This is not the density of sea water assumed in the report but may be the density of sea water at the temperature at which the sediment dried. The density of water in the pycnometer at the temperature of the determinations is also probably less than unity. However, our interest at the moment is to see whether or not we can fit the data to a curve of the form of equation (4).

The next step is, obviously, to substitute the value of .98744 for D_M in the quantities defined by (7) and (8) and solve for D_D in both cases, though only one is necessary since the value determined for D_M was determined by assuming D_D to be constant. Solving these for D_D yields for D_D a value of 2.667 gm/cm3.

To see how well we have done it is only necessary to compute D_S from formula (4) using these two values for D_M and D_D and plot D_S as a function of W_W. This curve is shown in Figure 3. This curve closely describes the values of D_S reported.

ERROR FUNCTIONS

We can now find the effect on D_S of an error in D_M by finding the derivative of D_S with respect to D_M. This derivative is:

$$(9) \quad \frac{d\,(D_S)}{d\,(D_M)} = \frac{100\, D_D^2\, W_W}{\left[(100 - W_W)\, D_M - W_W\, D_D\right]^2}$$

If we assume that the density of sea water which prevailed when the sample was "in situ" is 1.02 gm/cm3 and the density of the water at the temperature at which the sediment was dried was .98744 grams/cm3, then the error function becomes

$$(10) \quad d\,(D_S) = \frac{100\, D_D^2\, W_W}{\left[(100 - W_W)\, D_M + W_W\, D_D\right]^2} \times .03256$$

This function is plotted against W_W in Figure 4.

It is also of interest to consider the effect of an error in D_M upon the bulk density of the dry material by finding the rate of change of D_D with D_M. Thus we differentiate formula (6) and get -

$$(11) \quad \frac{d\,(D_D)}{d\,(D_M)} = \frac{W_W\, D_S^2\, (100 - W_W)}{(100\, D_M - W_W\, D_S)^2}$$

The error function would then be:-

$$(12) \quad d\,(D_D) = -\frac{W_W\, D_S^2\, (100 - W_W)}{(100\, D_M - W_W\, D_S)^2} \times .03256$$

This function is plotted against W_W in Figure (5).

This plot shows that an error in D_M will result in errors in D_D which are negative and increase as a function of W_W. The error assumed here is .03256, the difference between the density of sea water in situ and the density required to fit the data to a single continuous curve. The magnitude of the errors corresponds to the changes in dry density reported.

INTERPRETATION

The interpretation to be placed on the Narragansett sediment data in consequence of this analysis is hypothetical. One can say that a single value of dry bulk density and another for medium density suffice to determine a self consistent set of formulae with which to describe the published data. The analysis seems to indicate that the water content is the only parameter which needs to be known to establish the wet bulk density and the porosity.

The smooth transition through a range of dry bulk densities evidenced by the Narragansett data when the plot of wet density vs. water content are compared to the families where dry bulk density is the parameter of interest can be reproduced if one plots D_S vs. W_W from the formula:-

$$(13) \qquad D_S = \frac{100 \times .98744 \times 2.667}{(100 - W_W)\ .98744 + 2.667\ W_W}$$

The values of porosity can be determined from the formula:

$$(14) \qquad \%P = \frac{2.667\ W_W}{(100 - W_W)\ .98744 - 2.667\ W_W} \times 100$$

Inspection of (13) and (14) will show that

$$(15) \qquad \%P = \frac{D_S\ W_W}{D_M} \text{ where } D_D \text{ is constant.}$$

CONCLUSION

It seems more reasonable to the author that the smooth function evidenced by plotting the wet densities (reported in the Narragansett analysis) against the percentage by weight of water is explained more simply by the assumption of a constant or mean dry bulk density than the same curve can be explained by accepting a progressive decrease in dry bulk density as a function of water content. If the simpler explanation is reasonable and explanatory of the data, the result is of importance. It indicates a simple law and points to the water content as the important parameter. This would result in a considerable saving in the time required for sediment analysis.

One may speculate that the densities in situ reported are not those of the analysis inasmuch as the formula (13), which describes the data, utilizes a value for the medium density obviously lower than sea water in situ. However, this matter can be set right if one replaces this value by 1.02. The error in D_S arising in this connection is defined by equation (9) and the error function plotted in Figure 4. Thus, the change in aspect between the curves of Figure 1 and that of the data probably are related to physical problems inherent in the processing of the samples.

Donald L. Cole

Donald L. Cole
Physicist

LIST OF REFERENCES

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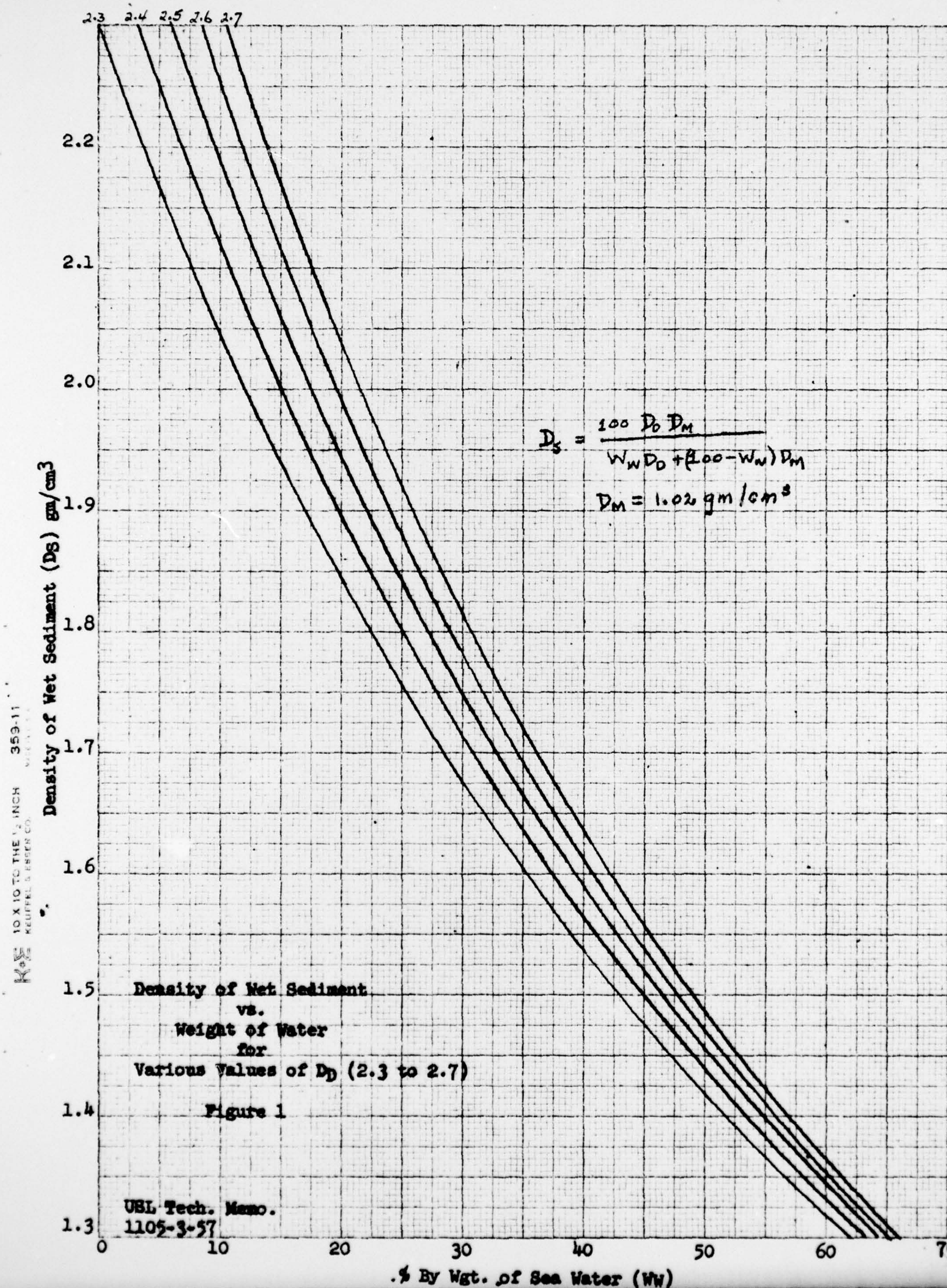
(b) Donald L. Cole, "Commentary on Narragansett Bay Sediments," USL Technical Memorandum No. 1105-3-56, 23 May 1956.

(c) Andrews, "Ceramic Tests and Calculation," John Wiley and Son, New York, July 1950.



Density of Wet Sediment
vs.
Weight of Water
for
Various Values of D_D (2.3 to 2.7)

Figure 1

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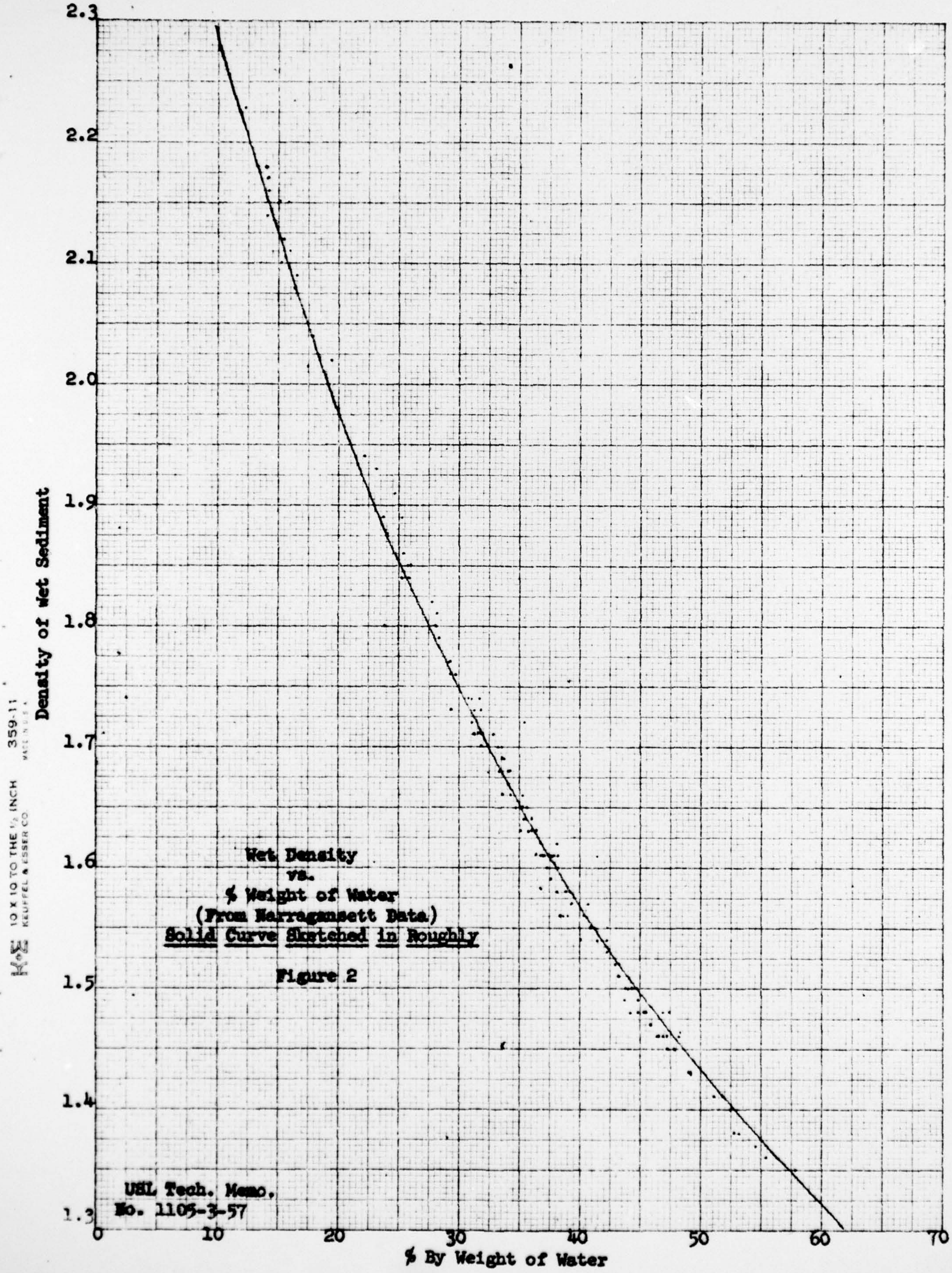
Wet Density
vs.
% Weight of Water
(From Narragansett Data)
Solid Curve Sketched in Roughly
Figure 2
Density of Wet Sediment
% By Weight of Water
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
0
10
20
30
40
50
60
70
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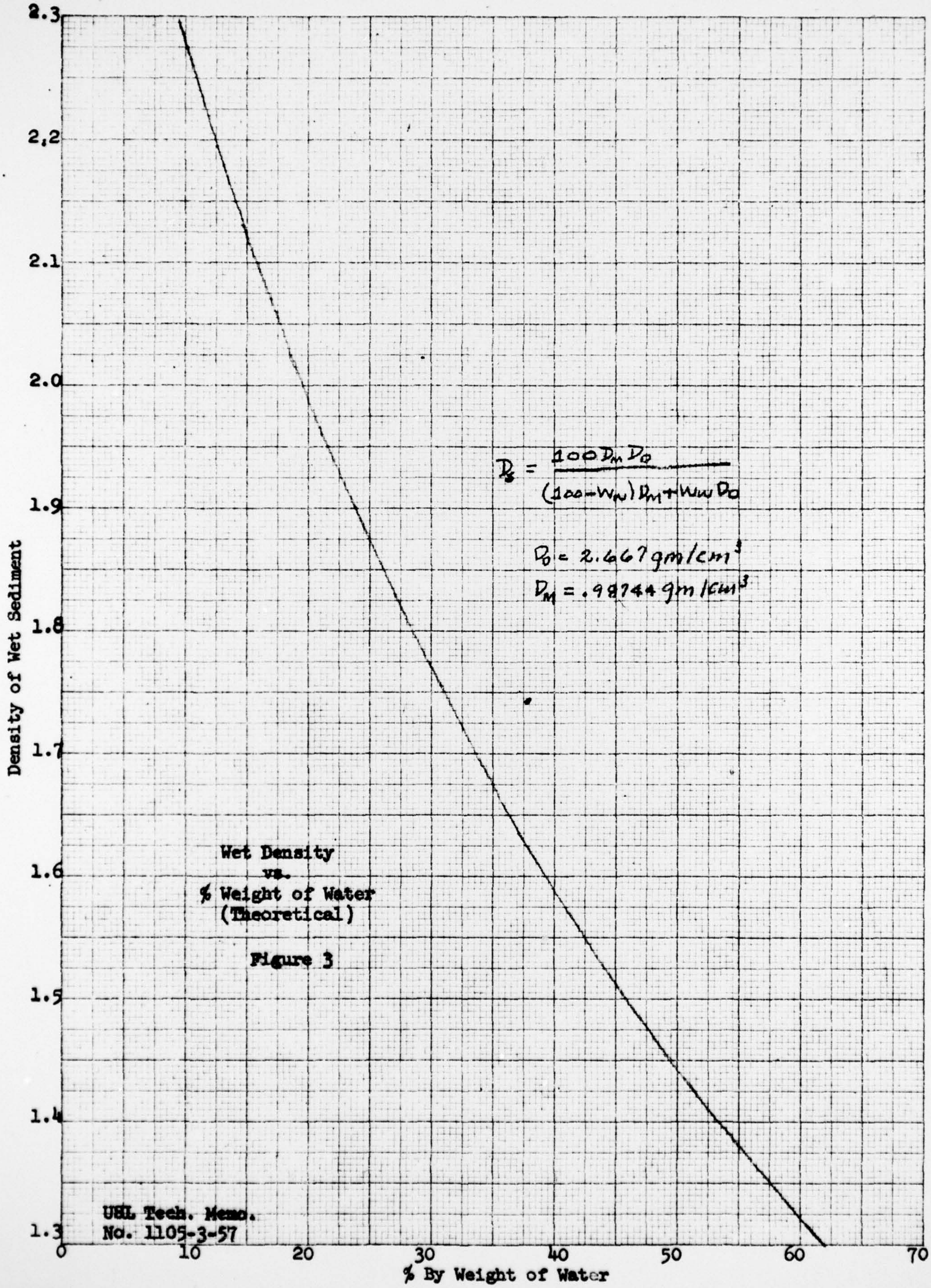

Wet Density
vs.
% Weight of Water
(Theoretical)

Figure 3

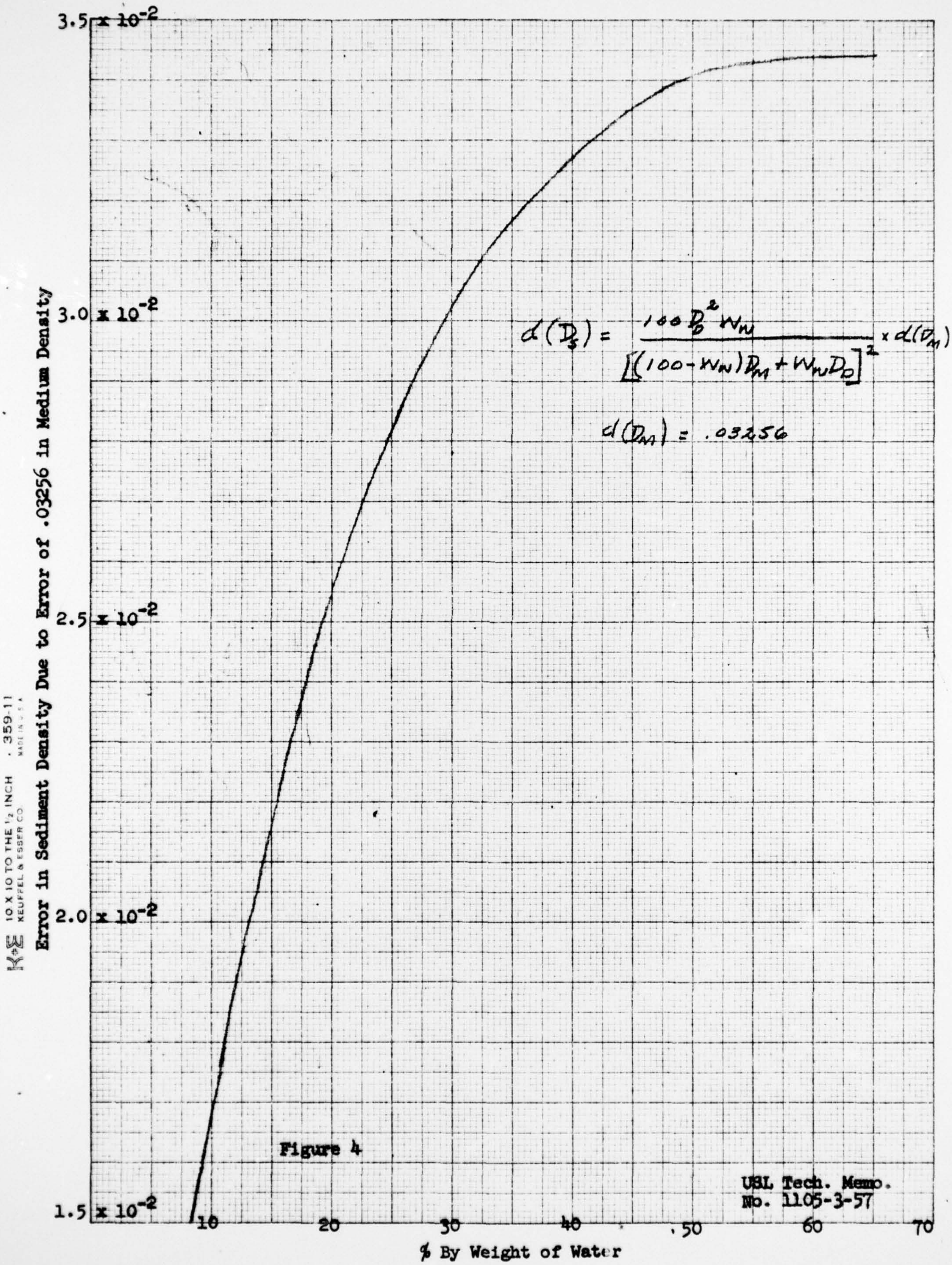
3.5 x 10-2
3.0 x 10-2
2.5 x 10-2
2.0 x 10-2
1.5 x 10-2
Error in Sediment Density Due to Error of .03256 in Medium Density
10
20
30
40
50
60
70
% By Weight of Water
d(Ds) = 100 D0^2 WN / [(100-WN) DM + WN D0]^2 x d(DM)
d(DM) = .03256
10 X 10 TO THE 1/2 INCH 359-11
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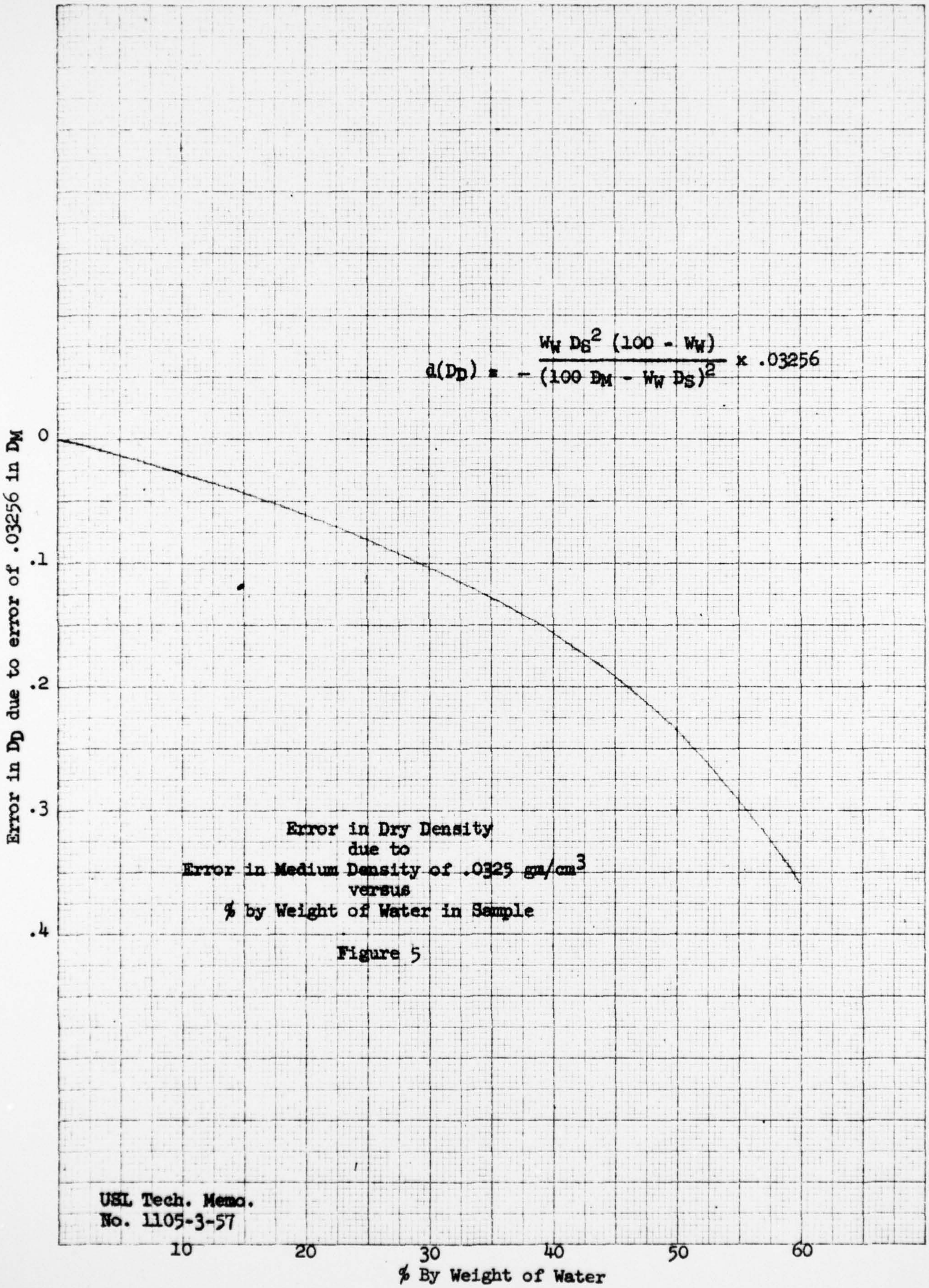
Figure 4



Error in Dry Density
due to
Error in Medium Density of .0325 gm/cm^3
versus
% by Weight of Water in Sample

Figure 5

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