FINAL PROJECT REPORT

LABORATORY INVESTIGATION

ARMOR LAYER FOR PROTECTIVE CAP
MANISTIQUE RIVER AND HARBOR, MICHIGAN

Report UMCEE 95-16

By

Steven J. Wright, Ph.D., P.E. &
Chayong Kim

THE UNIVERSITY OF MICHIGAN

DEPARTMENT OF CIVIL AND
ENVIRONMENTAL ENGINEERING

ANN ARBOR, MICHIGAN

July, 1995

For

Blasland, Bouck, & Lee

Syracuse, NY

TABLE OF CONTENTS

LABORATORY INVESTIGATION

ARMOR LAYER FOR PROTECTIVE CAP
MANISTIQUE RIVER AND HARBOR, MICHIGAN

INTRODUCTION

A protective cap of sand is to be placed over sediments containing PCBs in the Manistique River and Harbor, Michigan. In order to prevent erosion of the protective cap and underlying sediments, an armor stone layer is to be installed over the cap. Analyses utilizing second order cnoidal wave theory by Clausner (1994) indicated maximum wave induced velocities of 5.8 ft/s. Independent analysis by LTI (1994) obtained slightly higher velocities using fifth order Stokes wave theory, but Ebbesmeyer (1974) suggests that the Stokes wave theory should not be used for the conditions associated with the estimated maximum wave heights in Manistique Harbor. Consequently, the velocity of 5.8 ft/s was considered to be the design velocity in the present investigation. Although the armor stone had been sized to withstand such a velocity (it has been estimated by Blasland, Bouck & Lee, 1994 that a minimum armor stone diameter of about three inches would be required), it was uncertain whether the sand beneath would be scoured through the pore spaces in the armor stone. A previous study at the University of Iowa (Manamperi, 1952) showed that an armor layer with multiple layers satisfying filter media design criteria can withstand higher velocities than a single uniform layer of the same thickness. In order to provide the same adequate protection of the underlying sand, the depth of a uniform armor layer must be about four times greater than the thickness of the multiple layer system. The purpose of this laboratory investigation was to provide additional information to support the development of an appropriate design for the armor layer that will meet the objective of preventing erosion of the sand cap beneath the armor stone under velocities up to about six ft/s.

The laboratory investigation was conducted with materials obtained from a quarry near Manistique that are representative of what are expected to be used in the actual protective cap and armor stone layer. The study was conducted on a test section of the cap/armor stone layer with the actual size of sand and stone recommended in the preliminary design. Since it is not feasible to generate waves of sufficient height to create the hypothetical design condition, the wave induced velocities were modeled by uni-directional velocities of the same magnitude. In general, experiments were conducted on a particular armor layer design by starting at a relatively low velocity and gradually increasing the velocity over the armor layer until either significant erosion of cap material occurred or until the maximum velocity of the experimental setup was exceeded (somewhat over six ft/s).

CONCLUSIONS AND RECOMMENDATIONS

The simplest armor layer configuration tested consisted of four inches of 2-4 inch armor stone overlain by eight inches of 4-8 inch stone. Under this condition, sand comprising the protective cap began to move at a velocity between 3.5 to 4 ft/s. Significant erosion of the sand was observed at a velocity of 5 ft/s. All other armor layers tested were essentially stable up to the maximum velocity tested (approximately six ft/s).

A proposed final armor layer design consists of a mixture of small (1/2 to 1 inch stone) and the 4 to 8 inch stone. The smaller stone tends to fill the pore spaces between the larger stones and reduces velocities at the top of the protective sand cap. Under this configuration, it was observed that the smaller stone at the top of the armor layer could be moved at velocities exceeding about 4 ft/s. This stone will be rearranged under high velocities to fill any remaining gaps between the larger armor stone and any excess would presumably be removed from the armor layer. However, any of the smaller stone that was sheltered by the larger armor stone was stable up to a velocity of 6 ft/s and a stable layer the thickness of the larger stone was developed. If the smaller stone is allowed to fill the pore spaces between placed larger stone, approximately twenty percent by weight is required. This proportion could be used to develop a design for a mix in which both stone sizes are placed simultaneously.

With a stable design consisting of larger armor stone in conjunction with the smaller 1/2 to 1 inch stone, the materials comprising the protective sand cap are apparently immaterial with regard to system stability. No indication of any movement in the sand layer was observed with this armor layer configuration even at the maximum velocity tested of 6 ft/s. The differences in size between the two sands proposed for the cap are minor and either would be stable at the design conditions.

EXPERIMENTAL INVESTIGATION

Testing Facilities

The laboratory study was conducted in the Civil and Environmental Engineering Hydraulics Laboratory located in the G.G. Brown Building at the North Campus of the University of Michigan. Tests were conducted in a 30 ft long, 2 ft wide Plexiglas flume with a constant head water supply. The Plexiglas walls allowed the visual inspection of the behavior of cap and armor stone materials along the flume sides.

Model Construction

Materials that are representative of those that will potentially be used in the protective cap and armor layer for Manistique Harbor were placed into a test section ten feet long. These materials were supplied from a quarry near Manistique (the quarry and specific material stocks for testing were identified by Blasland Bouck, & Lee, Inc.) in quantities generally sufficient to produce a layer thickness of about four inches in this test section. The exception to this was the 4 - 8 inch stone of which there was twice this volume. Specific materials provided are referred to in this report according to the following classification:

- Dolomite sand;
- High calcium sand;
- 1/2 - 1 inch high calcium;
- 2 - 4 inch dolomite;
- 4 - 8 inch dolomite.

Proposals for the armor layer have generally proceeded under the assumption of a twelve inch layer thickness and therefore test sections consisted of combinations of two of the latter three stone sizes to provide an armor layer with this thickness.

Samples of both sands were submitted to Aquatec Laboratories, Colchester Vermont for purposes of determining the grain size distribution and total organic carbon (TOC). Grain size distributions are presented in Figures 1 and 2. From the standpoint of cap stability characteristics, both sands are essentially the same because of their similar grain size distributions. Because of this similarity, testing was not performed on both sands and all tests were performed with the dolomite sand with its slightly smaller d_{50} (0.9 mm versus 1.2 mm).

A ten-foot section of the flume was used to install the test section. A schematic of the overall flume setup is indicated in Figure 3. The flow depth in the test section was controlled by the downstream overflow weir which also served to trap any sand that was eroded from the test section. By adjusting the flow rate into the channel and the weir height, it was possible to control the flow velocity over the armor layer; the weir height of nine inches was selected to obtain a flow velocity of 6 ft/s with a fifteen inch cap/armor layer and the maximum discharge obtainable from the constant head supply. This resulted in a flow depth of approximately six inches above the top of the armor layer at the maximum discharge.

Approximately 3.5 inches of the protective cap thickness was reproduced in the test section; since erosion would be from the top of the cap, the exact sand thickness is immaterial. The sand was confined at either end of the ten foot test section with Plexiglas plates; this forced erosion from the top of the sand layer as opposed to scouring from the end of the test section.

This procedure was felt to be necessary to reproduce the conditions within the actual cap which, of course, is much longer than ten feet and end effects will not be important. The sand was poured into the flume and leveled to the top of the Plexiglas plates. Figure 4a is a photograph of the leveled sand and the Plexiglas plate at the downstream end of the test section is just visible at the left side of the photograph. The armor layer was added to the top of the sand with the exact procedure dependent on the type of stone to be placed. The small stone was simply poured into the flume while the two larger stone sizes had to be placed by hand to avoid damage to the flume walls. Figures 4b and 4c are photographs indicating typical stages of the test section construction.

Originally, it was planned to place wire mesh screens at both the upstream and downstream ends of the test section in order to retain armor stone material in the test section. However the large armor stone was fairly rectangular in shape and it was possible to place this at nearly a vertical angle without significant stability problems. Even when the smaller 1/2 - 1 inch stone was placed in the pore spaces between the larger stone, only a few were washed from the downstream end at the beginning of the experiment and the mesh screens were not necessary to stabilize the layer and were omitted from later experiments.

Several factors were considered in deciding how to minimize the effects of the finite ends of the test section with regards to water flow within the armor stone layer. It was judged to be inappropriate to extend the Plexiglas plates to the top of the armor stone since this would tend to exclude flow from the armor layer and the test would under-estimate the tendency for cap material scour. By placing no obstruction on either end, the scour tendency will probably be over-estimated since the approach flow and that leaving the test section can extend deeper into the armor layer than would actually be the case in flow over a cap of large horizontal extent. However, during the implementation of the test, it was observed that there was a decline in flow depth across the test section due to head losses in the flow through the armor stone and over the rough surface. Associated with the decreasing depth was a corresponding increase in velocity in the direction of flow. Figure 5 is a photograph of the flow through the test section indicating the change in water surface elevation. The largest velocities were always near the downstream end of the test section, no scour was ever observed at the upstream end, and therefore the entrance condition was judged to not be important as the flow had nearly ten feet of flow across and through the armor layer to develop a flow profile within the armor stone. The outflow at the downstream end of the test section provides less resistance to flow than a continuation of the cap and armor layer and this would tend to provide higher velocities on the cap. This approach provides a conservative approach to the determination of cap stability. The end condition influence is probably not significant as experiments where there was erosion of cap material indicated similar rates of sand movement at the downstream end of the section as there was a few feet upstream with a slightly lower velocity.

Instrumentation

Flow velocities were measured using a mini-propeller meter which has an automatic counter circuit to determine revolutions per unit of time. The indicator readings were interpreted from the Nixon Streamflo Probe calibration chart, which provides a velocity vs. revolution frequency relation. The accuracy of these readings was verified with a larger rotating cup velocity meter (mini-Gurley meter) and the two indicated the same velocity within differences associated with the meter placement relative to individual armor units. The meter was normally installed in center of the last 2.5 ft of the test section although occasionally velocity measurements were made at upstream locations. As noted above, the highest velocities were always observed near the downstream end of the test section. The probe was placed two to three inches above the top of an armor stone unit with a reasonable flat upper surface so that velocity measurements in zones of separated flow were avoided. Measurements at different depths and position across the flume were within about twenty percent, this magnitude of difference would be expected with the irregular armor layer surface.

Many of the observations in the flume were visual in nature and were recorded on videotape and photographs. A copy of a videotape of selected portions of the testing is available.

TEST PROCEDURE

Water was slowly added to the flume during the testing to raise the level to the downstream weir crest. This prevented the initial water flow from rushing through the air-filled pores of the armor stone and scouring the sand at low flow rates. The downstream water level and discharge were then adjusted to obtain the desired flow velocity and observations were made. Then the flow was readjusted to obtain a higher velocity. The initial tests were performed starting with an initial velocity of two ft/s. However, once it became clear that no scour occurred with this velocity for any armor layer configuration, subsequent tests were initiated at higher velocities. For some of the final configurations tested, where it was likely that there would be no scour observed, the maximum velocity of 6 ft/s was produced at the outset.

Observations made for any flow condition simply involved recording the velocity and noting whether any sand was transported into the five foot section behind the weir downstream of the test section and whether any sand motion could be observed through the Plexiglas walls near the flume sides. It was often the case that a small amount of sand was eroded from the test section as the flow was initiated and the flow subsequently stabilized with no further erosion. This occurrence was assumed to be associated with the migration of a few unstable sand grains at the top of the cap near the downstream end and not indicative of the long term stability of the cap. Instability was defined as a continued erosion process with no indication of a stabilization. Observations indicated that near the stability limit, individual sand grains moved to more stable locations but were not generally transported downstream. If the flow velocity was increased by less than an additional 0.5 ft/s, sand was clearly transported downstream, so the identification of the stability limit was fairly well defined.

TEST CONDITIONS

There are five different armor stone cap configurations that were tested. These are:

1. Bottom Layer : Dolomite sand
   Middle Layer : 2-4" Dolomite stone
   Top Layer : 4-8" Dolomite stone

2. Bottom Layer : Dolomite sand
   Middle Layer : 1/2 - 1" High Calcium stone
   Top Layer : 4-8" Dolomite stone

3. Bottom Layer : Dolomite sand
   Second Layer : 4-8" Dolomite stone
   Third Layer : 1/2 - 1" High Calcium stone
   Top Layer : 4-8" Dolomite stone

4. Bottom Layer : Dolomite sand
   Middle Layer : 4-8" Dolomite stone
   Top Layer : 1/2 - 1" High Calcium stone

5. Bottom Layer : Dolomite sand
   Top Layer : mixture of 1/2 - 1" High Calcium stone
   & 4-8" Dolomite stone

For tests conditions 3 and 4, the intention was to produce an armor layer with combined small (1/2 - 1") and large (4 - 8") stone. This was performed by first placing the larger stone by hand and pouring the smaller stone over the top. The smaller stone filled most of the pore spaces in the larger stone. Test condition 5 was similar except that the procedure was repeated in two steps; first one layer of large stone was placed, followed by pouring of the small stone and this process was repeated for a second layer. There was no convenient way to represent what might actually develop as these materials are placed in water of fifteen foot depth or so.

TEST RESULTS

The following results are from the visual observations for each cap design configuration tested.

1. Configuration 1 was tested under an initial flow velocity of 2 ft/s and gradually increased. When the velocity reached around 4 ft/s, the sand layer started to move. It was transported out of the test section at a velocity of 4.5 ft/s. There was continuous erosion of material from the protective cap at a velocity of 5 ft/s with settlement of the overlying armor stone.

2. For configuration 2 under the same flow conditions, no movement of the sand layer was observed. There was no movement of sand or stone up to the maximum flow velocity of 6 ft/s.

3. When the velocity was above 4 ft/s for configuration 3, local rearrangement of the 1/2 - 1" stone was observed. Once isolated stones stabilized, there was no movement within the armor layer. No motion was detected in the sand layer at any velocity ranging from 2 to 6 ft/s.

4. Slight motion of the sand layer was observed in configuration 4 at a velocity of 4 ft/s but no transport of sand was observed up to the maximum velocity. The smaller stone at the armor layer surface rearranged to fill spaces between the larger stone. At a flow velocity above 5 ft/s, some of the smaller stones were carried out of the test section. It could not be said that there was any significant loss of material.

5. When configuration 5 was tested, there was no movement of small stone up to the velocity of 4 ft/s. After increasing the flow velocity, some local rearrangement of smaller stone was detected and some fell off the edge of the cap. There was no notable motion in the sand layer at any velocity tested except some rearrangement in the test section near the maximum velocity.

The amount of the smaller 1/2 - 1" stone required to fill the pore spaces of the larger armor stone in configuration 5 was estimated in order to develop a design for a mix in which both stone sizes are placed simultaneously. Assuming that the smaller stones would fill the pore spaces between the larger stone when both are placed simultaneously, the ratio of the weight of the larger stone to that of the smaller stone was found by packing smaller stones in between the larger ones to a depth of about 10 inches in a 20" x 16.5" box and weighing each size fraction separately. The smaller stone should be approximately twenty percent of the weight of the larger stone for this packing arrangement.

REFERENCES

Blasland, Bouck & Lee, Inc., (1994) "*Cap Integrity*," Report prepared for Manistique Papers, Inc. and Edison Sault Electric Co., October 1994.

J.E. Clausner, (1994) U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, "*Comments on Detroit District Letter Report - Manistique River/Harbor Michigan - Sediment Transport Modeling Study*," Memorandum dated March 24, 1994.

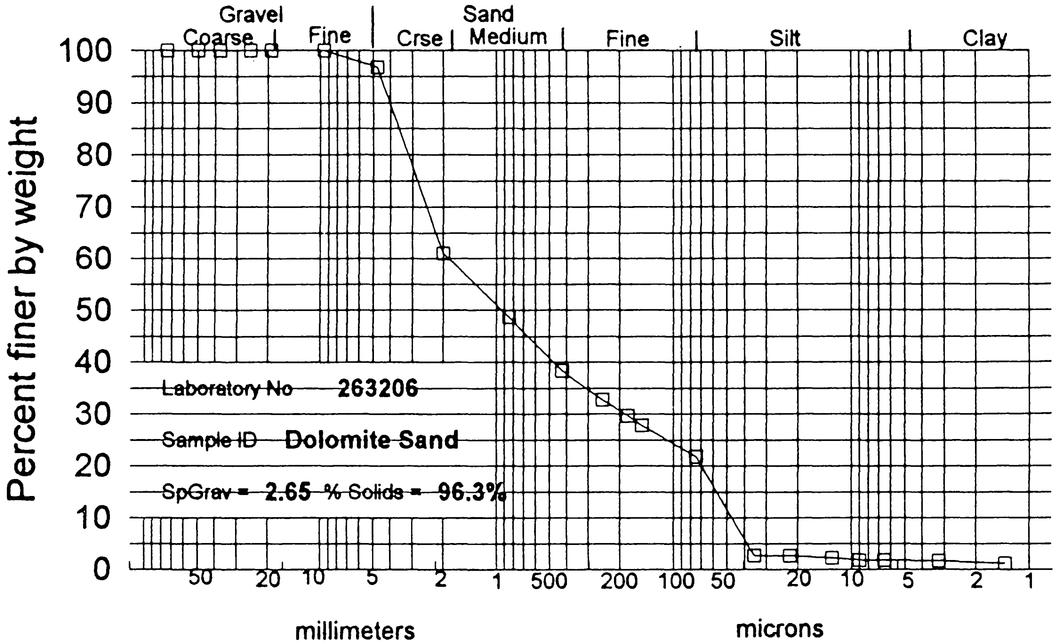
Ebbesmeyer, C.E. (1974) *"Fifth Order Stokes Wave Profiles,"* Journal of the Waterways, Harbors, and Coastal Engineering Division, ASCE, WW3, pp. 264-265.

LTI, (1994) "*Manistique Harbor EE/CA - Technical Review of Design Wave Calculations,"* Memorandum dated April 11, 1994.

Manamperi, H. d. S. (1952), "*Test of Graded Riprap for Protection of Erodible Material*," M.S. thesis, University of Iowa, Iowa City, Iowa, June, 1952.

Inchcape ASTM D422 Particle Size Analysis Sample ID **Dolomite Sand**

Sample preparation by: D2217



Particle Size, millimeters (mm) and microns (um)

Maximum particle size: 9.5 mm

Shape and hardness (>#10): rounded soft to brittle

Sieve size	Particle Size	Percent finer	Incremental percent	Specific Gravity assumed
3 inch	75.00 mm	100.0	0.0	
2 inch	50.00	100.0	0.0	
1.5 inch	37.50	100.0	0.0	
1 inch	25.00	100.0	0.0	
3/4 inch	19.00	100.0	0.0	
3/8 inch	9.50	100.0	0.0	
#4	4.75	96.8	3.2	
#10	2.00	61.0	35.8	
#20	850.0 um	48.6	12.4	
#40	425.0	38.3	10.3	
#60	250.0	32.8	5.5	
#80	180.0	29.7	3.1	
#100	150.0	27.9	1.8	
#200	75.0	21.7	6.1	
Hydrometer	35.2	2.7	19.1	Dispersion of soil
|	22.2	2.7	0.0	for hydrometer test
|	12.9	2.2	0.4	by mechanical mixer
|	9.0	1.8	0.5	with metal paddle
|	6.6	1.7	0.1	operated for five
|	3.2	1.6	0.1	five minutes within a
V	1.4	1.1	0.5	dispersion cup

Printed by [signature] 13:00 on 12-Jul-95

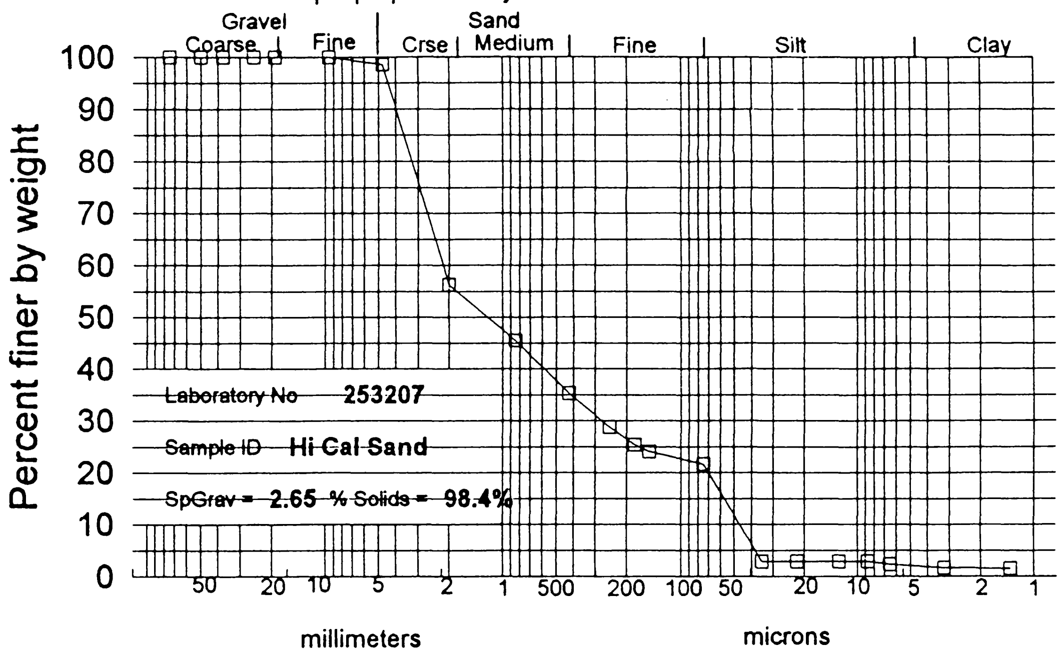
Set 143
Lab No. 263206

000003

Figure 1. Grain Size Distribution for Dolomite Sand.

Inchcape ASTM D422 Particle Size Analysis Sample ID Hi Cal Sand

Sample preparation by: D2217



Maximum particle size: 9.5 mm

Shape and hardness (>#10): rounded hard to soft

Sieve size	Particle Size	Percent finer	Incremental percent	Specific Gravity assumed
3 inch	75.00 mm	100.0	0.0	
2 inch	50.00	100.0	0.0	
1.5 inch	37.50	100.0	0.0	
1 inch	25.00	100.0	0.0	
3/4 inch	19.00	100.0	0.0	
3/8 inch	9.50	100.0	0.0	
#4	4.75	98.6	1.4	
#10	2.00	56.2	42.4	
#20	850.0 um	45.5	10.7	
#40	425.0	35.3	10.2	
#60	250.0	28.8	6.5	
#80	180.0	25.4	3.3	
#100	150.0	24.1	1.3	
#200	75.0	21.6	2.5	
Hydrometer	34.9	2.9	18.8	Dispersion of soil
|	22.1	2.9	0.0	for hydrometer test
|	12.8	2.9	0.0	by mechanical mixer
|	8.7	2.8	0.0	with metal paddle
|	6.6	2.3	0.5	operated for five
|	3.2	1.7	0.6	five minutes within a
V	1.4	1.6	0.1	dispersion cup

Printed by [signature] 13:01 on 12-Jul-95

Set 143
Lab No. 253207

000004

Figure 2. Grain Size Distribution for High Calcium Sand.

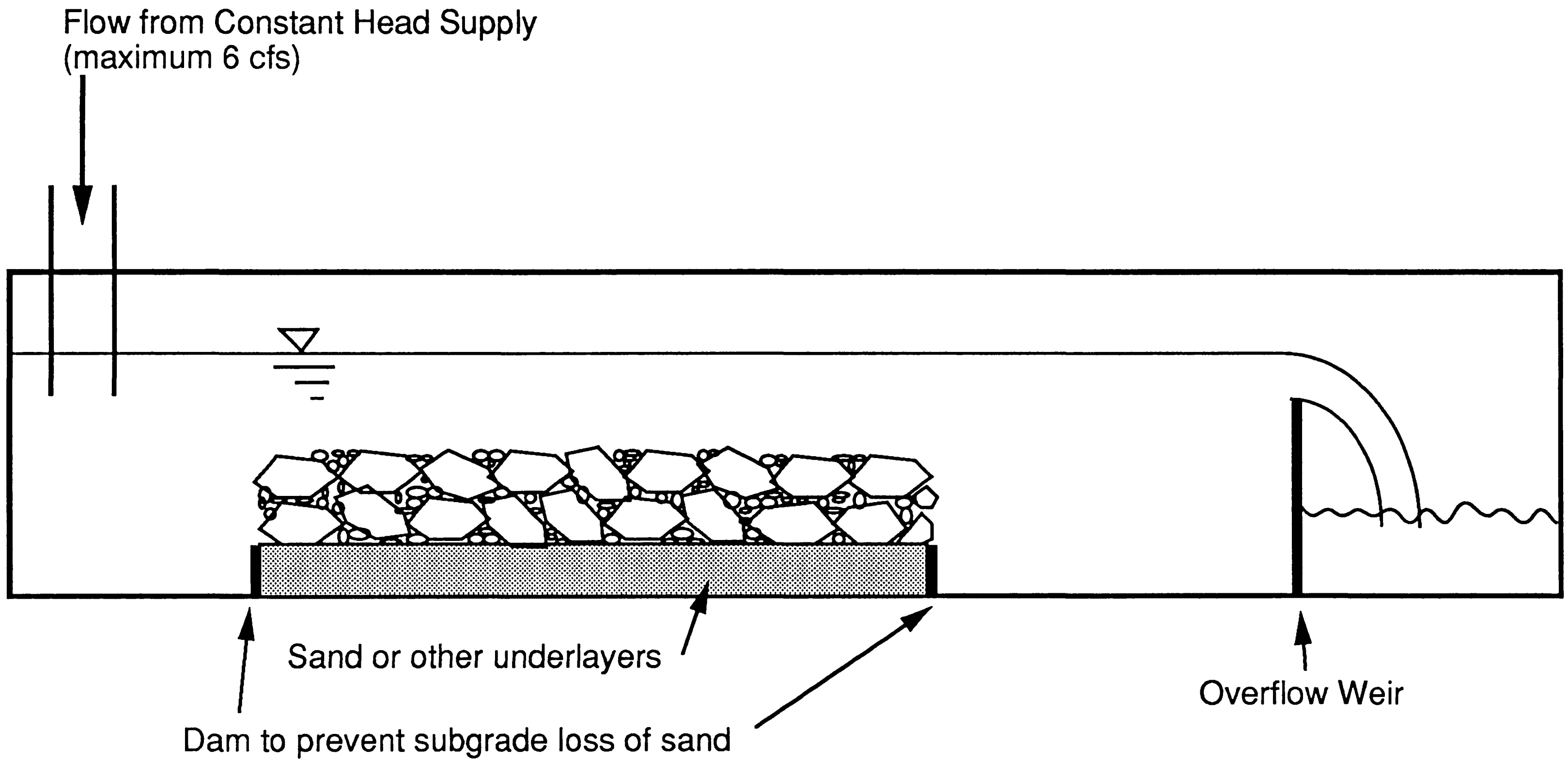
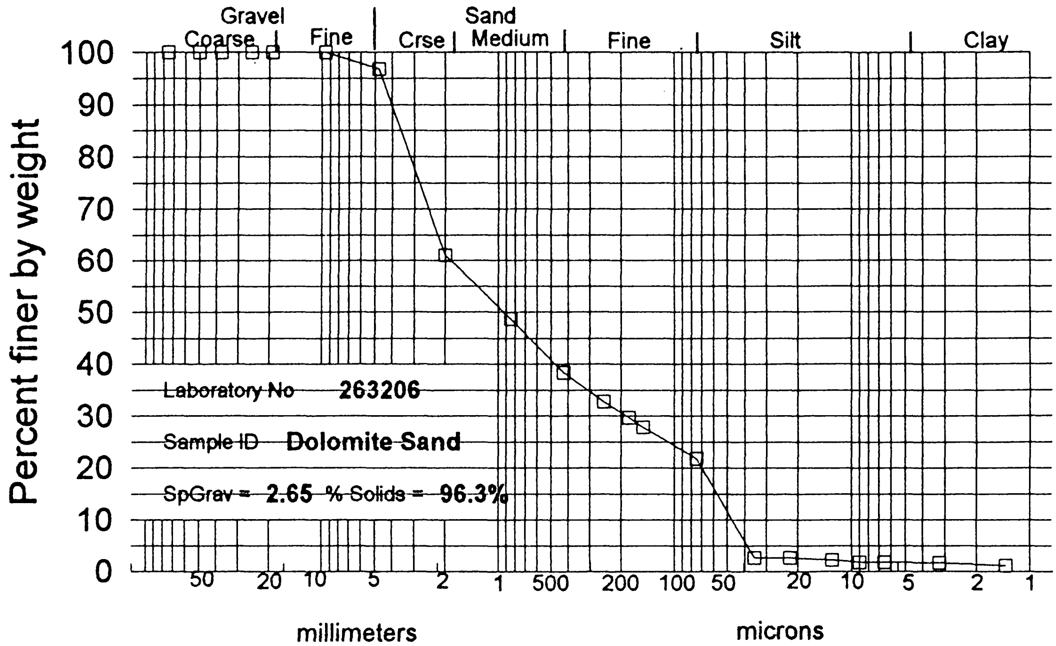


FIGURE 3 The Overall Flume Setup

Inchcape ASTM D422 Particle Size Analysis Sample ID **Dolomite Sand**

Sample preparation by: D2217



Particle Size, millimeters (mm) and microns (um)

Maximum particle size: 9.5 mm

Shape and hardness (>#10): rounded soft to brittle

Sieve size	Particle Size	Percent finer	Incremental percent	Specific Gravity assumed
3 inch	75.00 mm	100.0	0.0	
2 inch	50.00	100.0	0.0	
1.5 inch	37.50	100.0	0.0	
1 inch	25.00	100.0	0.0	
3/4 inch	19.00	100.0	0.0	
3/8 inch	9.50	100.0	0.0	
#4	4.75	96.8	3.2	
#10	2.00	61.0	35.8	
#20	850.0 um	48.6	12.4	
#40	425.0	38.3	10.3	
#60	250.0	32.8	5.5	
#80	180.0	29.7	3.1	
#100	150.0	27.9	1.8	
#200	75.0	21.7	6.1	
Hydrometer	35.2	2.7	19.1	Dispersion of soil
|	22.2	2.7	0.0	for hydrometer test
|	12.9	2.2	0.4	by mechanical mixer
|	9.0	1.8	0.5	with metal paddle
|	6.6	1.7	0.1	operated for five
|	3.2	1.6	0.1	five minutes within a
V	1.4	1.1	0.5	dispersion cup

Printed by [signature] 13:00 on 12-Jul-95

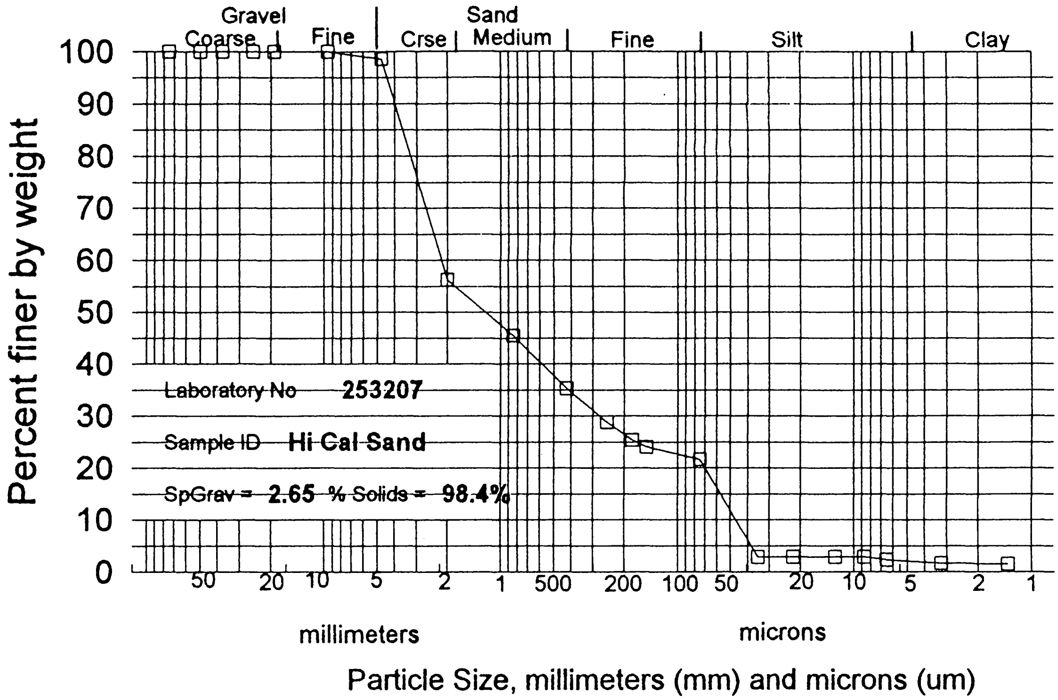
Set 143
Lab No. 263206

000003

Figure 1. Grain Size Distribution for Dolomite Sand.

Inchcape ASTM D422 Particle Size Analysis Sample ID **Hi Cal Sand**

Sample preparation by: D2217



Maximum particle size: 9.5 mm

Shape and hardness (>#10): rounded hard to soft

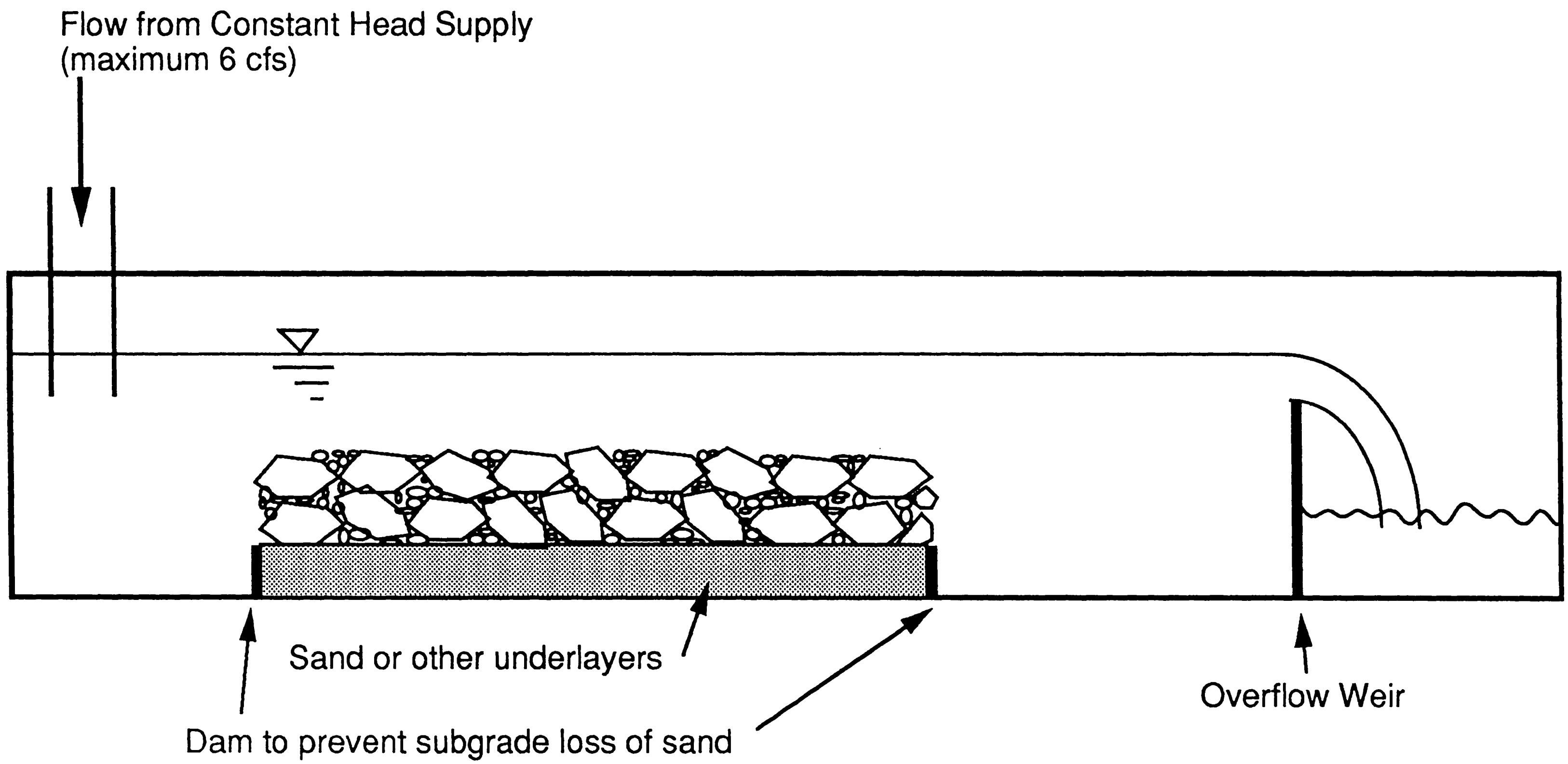
Sieve size	Particle Size	Percent finer	Incremental percent	Specific Gravity assumed
3 inch	75.00 mm	100.0	0.0	
2 inch	50.00	100.0	0.0	
1.5 inch	37.50	100.0	0.0	
1 inch	25.00	100.0	0.0	
3/4 inch	19.00	100.0	0.0	
3/8 inch	9.50	100.0	0.0	
#4	4.75	98.6	1.4	
#10	2.00	56.2	42.4	
#20	850.0 um	45.5	10.7	
#40	425.0	35.3	10.2	
#60	250.0	28.8	6.5	
#80	180.0	25.4	3.3	
#100	150.0	24.1	1.3	
#200	75.0	21.6	2.5	
Hydrometer	34.9	2.9	18.8	Dispersion of soil
	22.1	2.9	0.0	for hydrometer test
	12.8	2.9	0.0	by mechanical mixer
	8.7	2.8	0.0	with metal paddle
	6.6	2.3	0.5	operated for five
	3.2	1.7	0.6	five minutes within a
V	1.4	1.6	0.1	dispersion cup

Set 143

Printed by [signature] 13:01 on 12-Jul-95 Lab No. 253207

000004

Figure 2. Grain Size Distribution for High Calcium Sand.



COAS 17 (1)
Art#16 60 %
WRIGHT Fig# 01

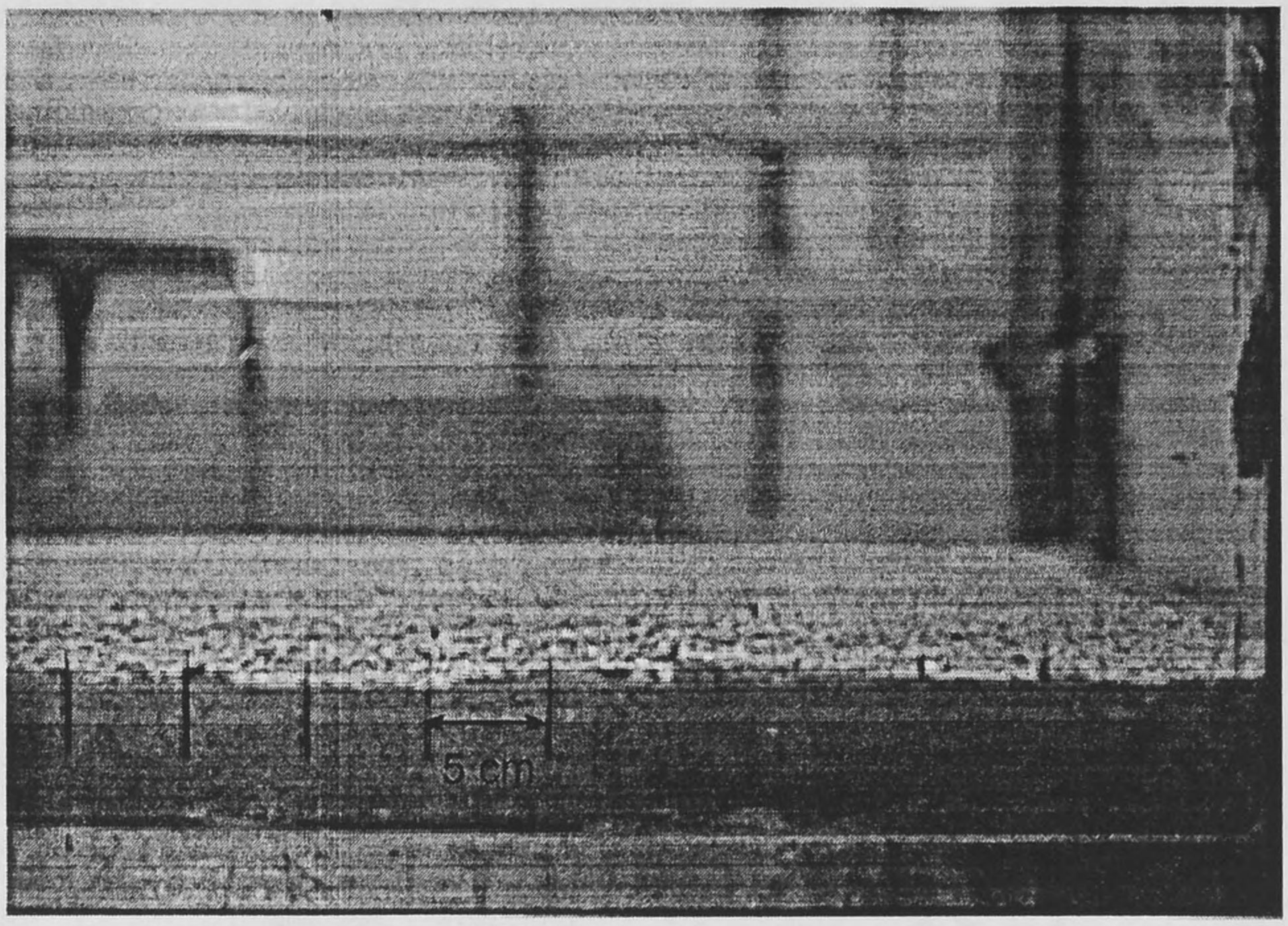


FIGURE 4a. Preliminary stage of test section construction; placement of 3.5 inches of protective cap sand.

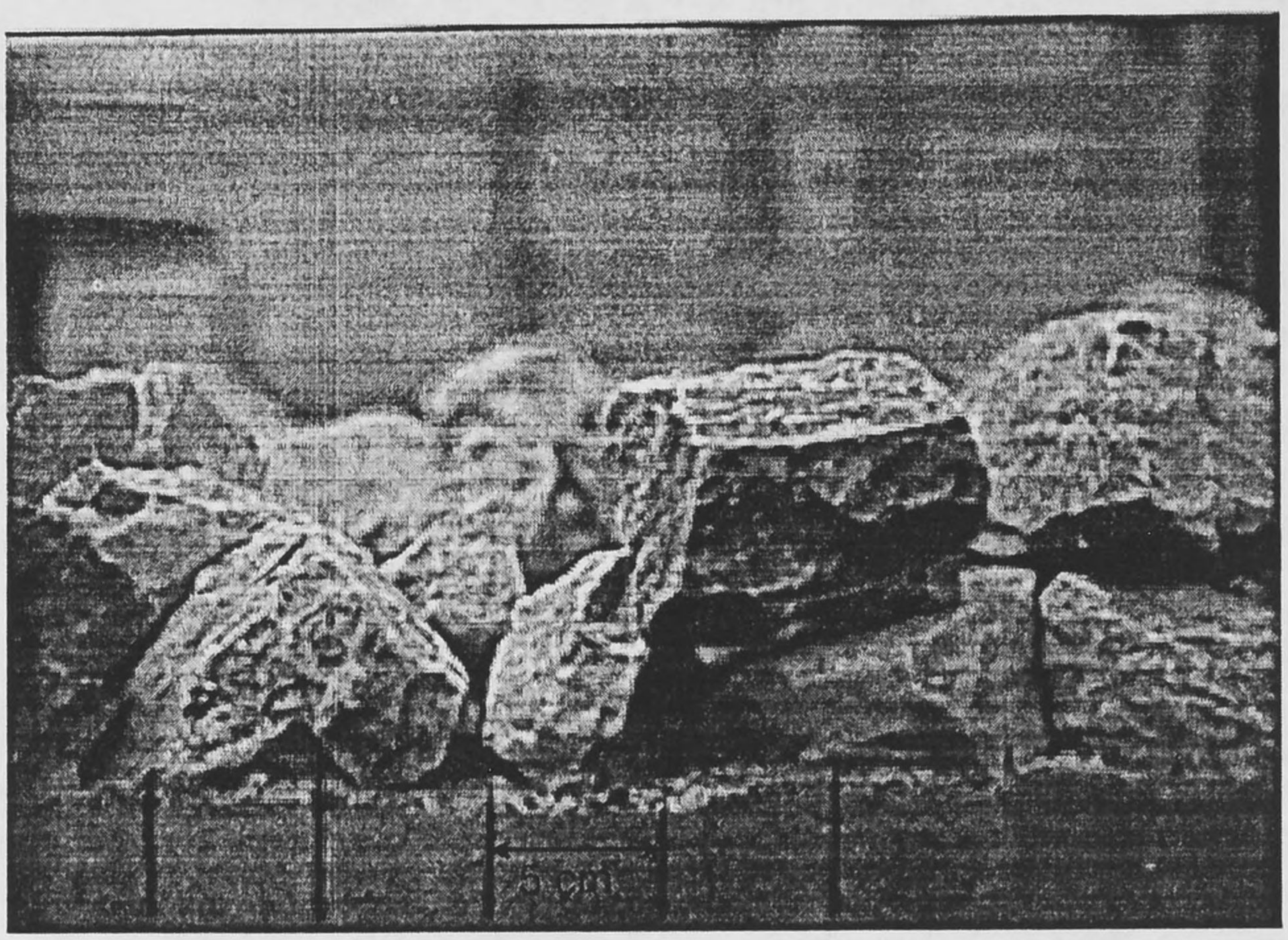


FIGURE 4b. Intermediate stage of test section construction; 4 inches of 2-4 inch dolomite over protective cap sand.

COAS 17 (1)
Art#16 100 %
WRIGHT Fig# 02

FIG. 2. Preliminary Stage of Test Section Construction (Placement of 3.5 inches of the Sand Isolation Layer)

FIG. 3. Intermediate Stage of Test Section Construction (Placement of 4 inches of 2-4 inch Armor over Sand Isolation Layer)

COAS 17 (1)
Art#16 100 %
WRIGHT Fig# 03

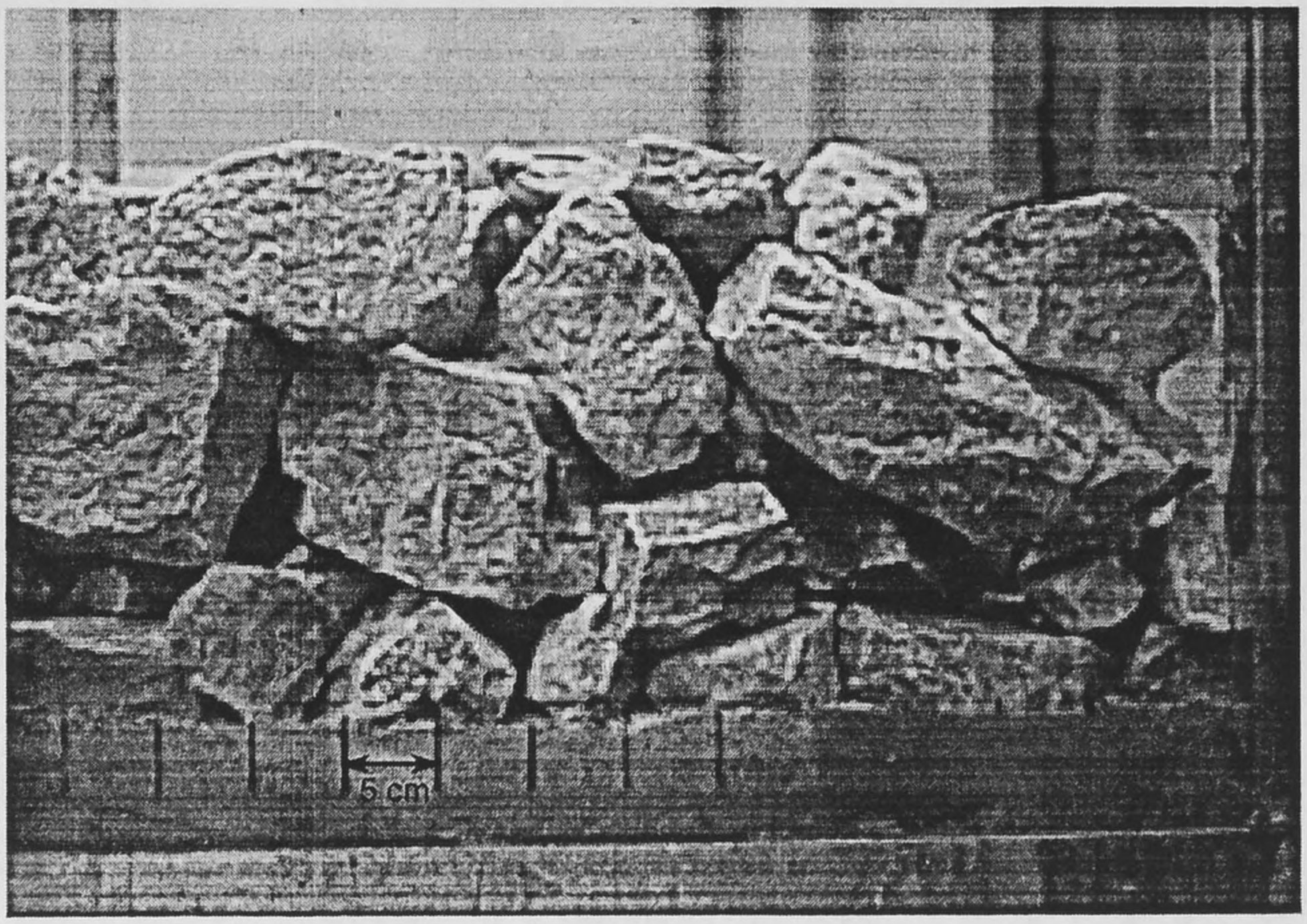


FIGURE 4c. Completed test section with final layer of 4-8 inch dolomite.

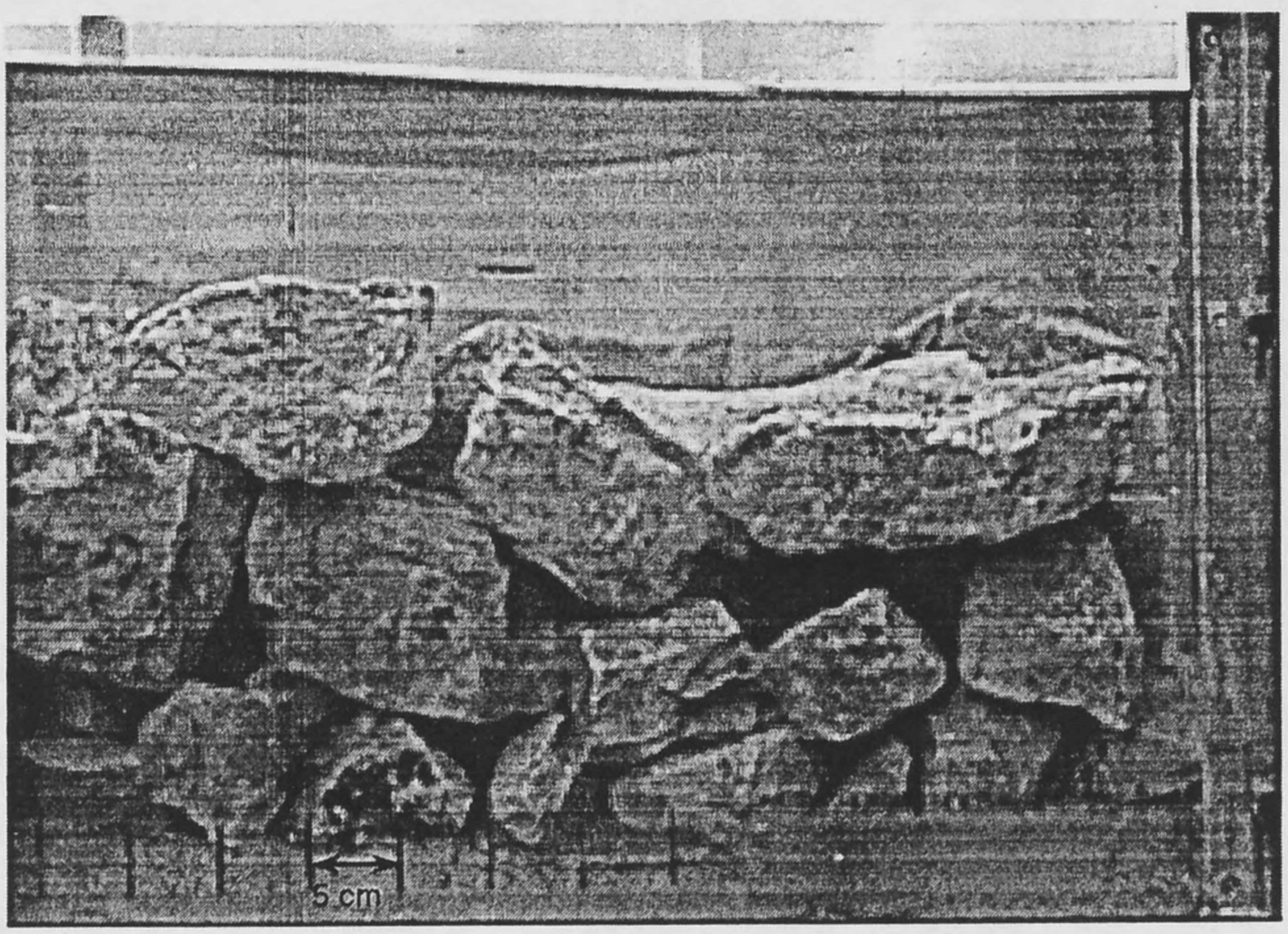


FIGURE 5. Test section during testing showing water surface level decline in direction of flow.

COAS 17 (1)
Art#16 100 %
WRIGHT Fig# 04

FIG. 4. Completed Test Section
(With Final Layer of 4-8 inch Armor Layer)

FIG. 5. Test Section During the Experiment
(Showing Water Surface Level Decline in the Direction of Flow)

COAS 17 (1)
Art#16 100 %
WRIGHT Fig# 05

Figure 6 Relationship between 15% Passing Size and 50% Passing Size for Filters

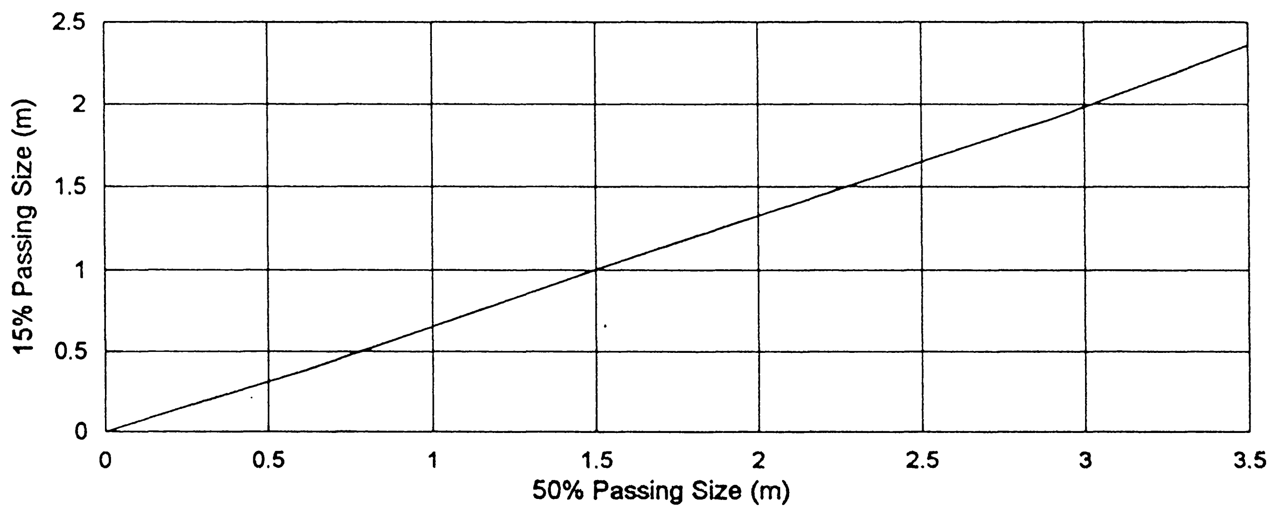
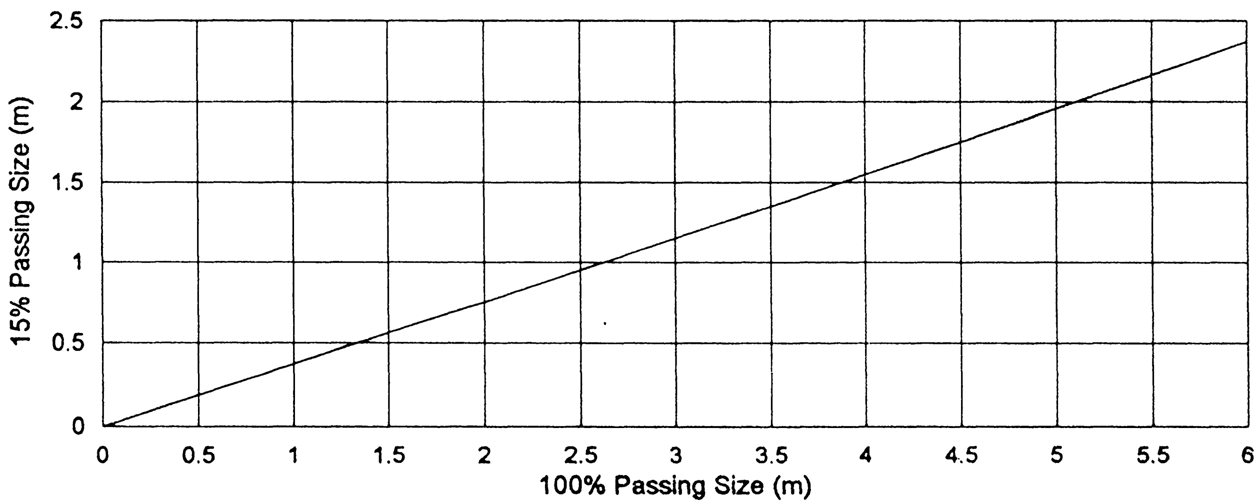


Figure 7 Relationship between 15% Passing Size and 100% Passing Size for Filters



COAS 17 (1)
Art#16 51 %
WRIGHT Fig# 09

Figure 9. Relationship between Vel...ickness Ratio and Base-Filter Size Ratio

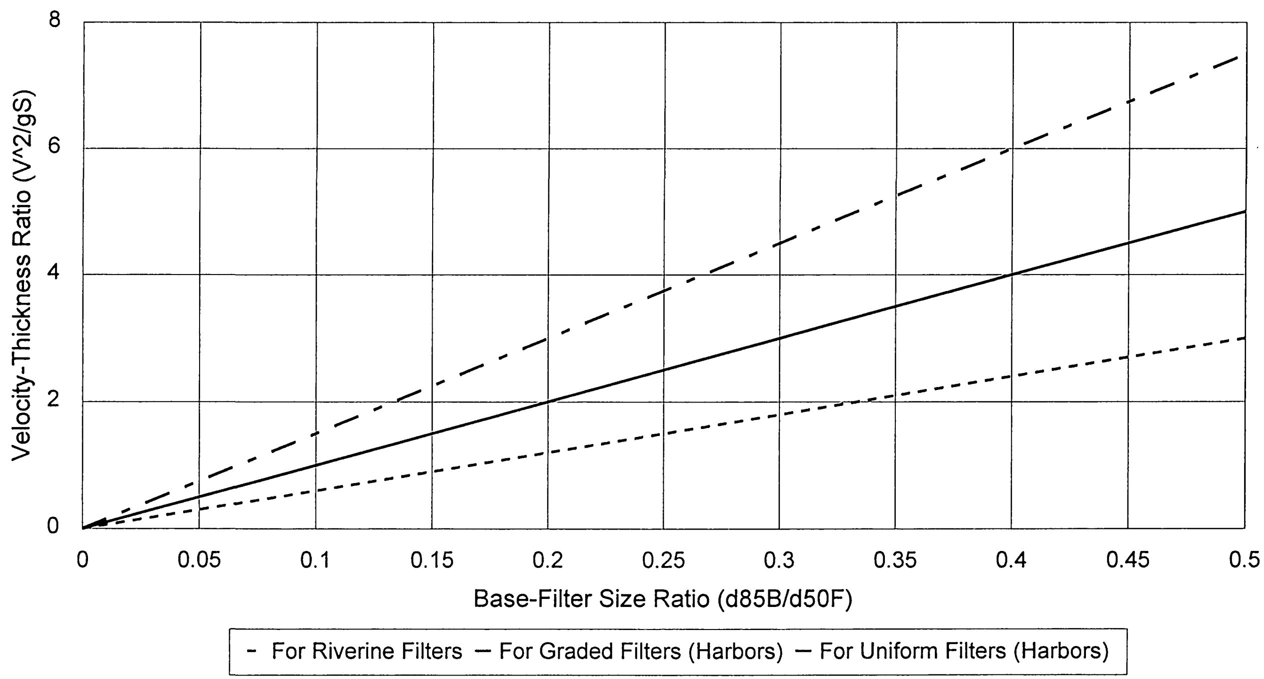
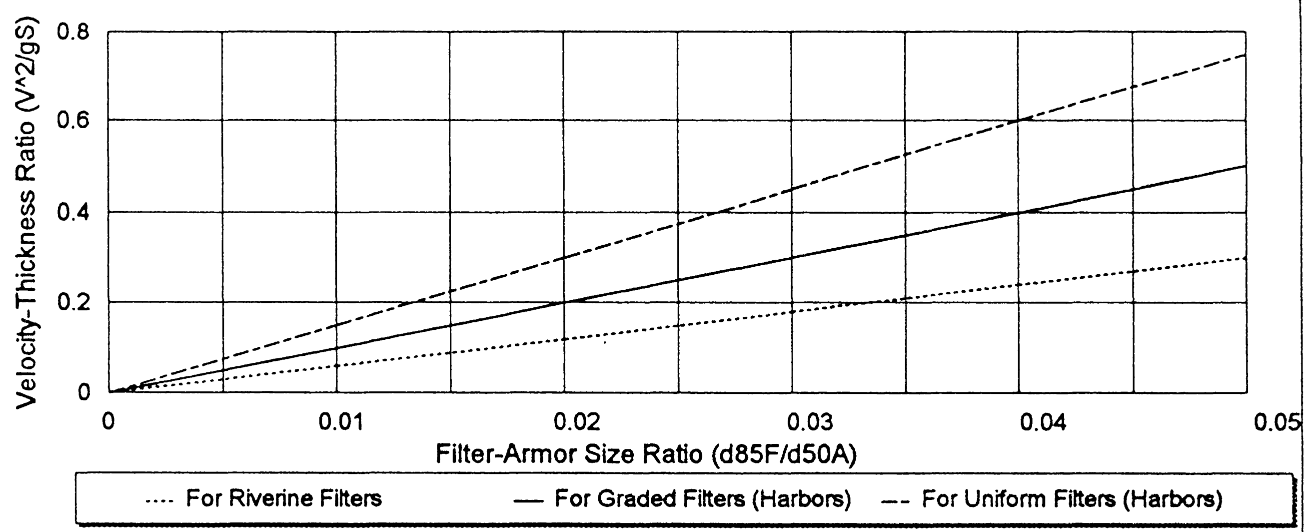


Figure 10 Relationship between Velocity-Thickness Ratio and Filter-Armor Size Ratio



A4 Page 6543210

AIIM SCANNER TEST CHART # 2

Spectra

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

Times Roman

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

Century Schoolbook Bold

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

News Gothic Bold Reversed

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

Bodoni Italic

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789

Greek and Math Symbols

4 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⋫⋪⋗⋖≡
6 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⋫⋪⋗⋖≡
8 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⋫⋪⋗⋖≡
10 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⋫⋪⋗⋖≡

White

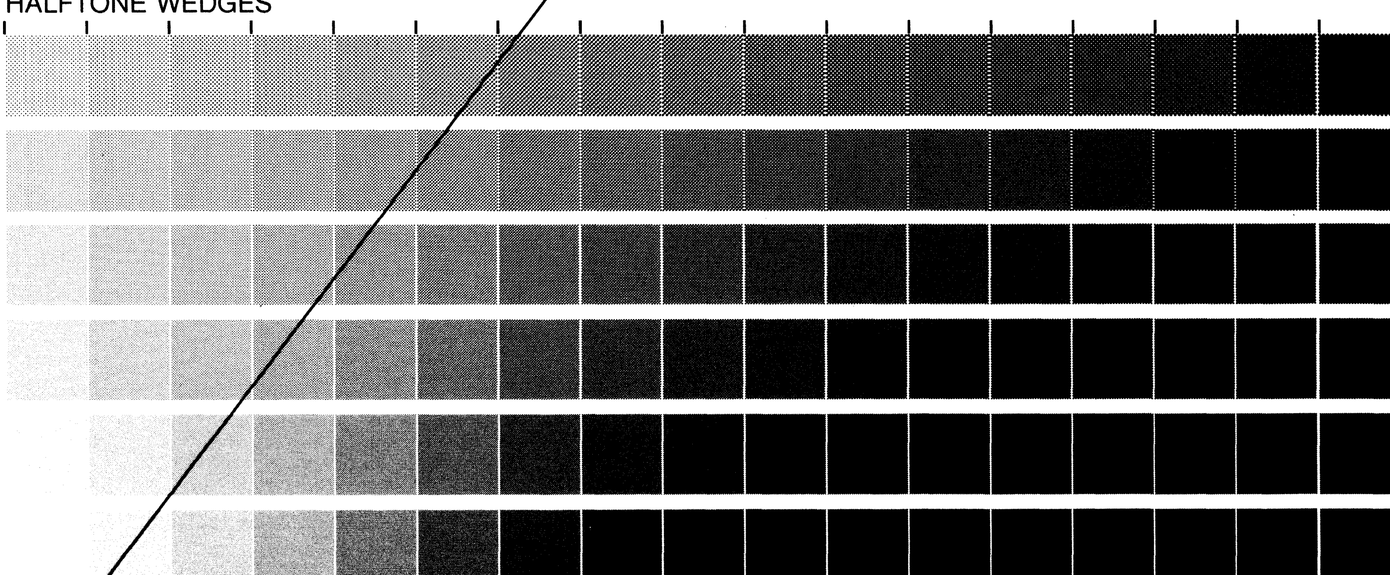
Black

Isolated Characters

e	m	1	2	3	a
4	5	6	7	o	•
8	9	0	h	I	B

A4 Page 6543210

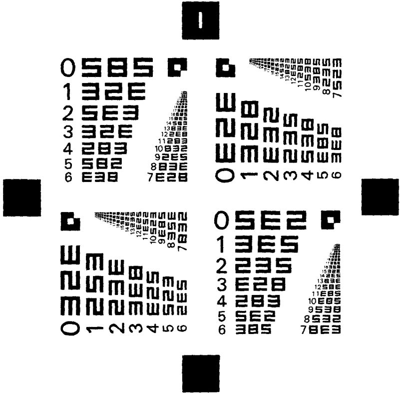
MESH HALFTONE WEDGES



65
85
100
110
133
150

A4 Page 6543210

RIT ALPHANUMERIC RESOLUTION TEST OBJECT, RT-1-71



PRODUCED BY GRAPHIC ARTS RESEARCH CENTER
ROCHESTER INSTITUTE OF TECHNOLOGY, ONE LOMB
MEMORIAL DRIVE, ROCHESTER, NEW YORK 14623