

1979

# Design recommendations, Stabilization of Tidal Inlet Channels, October 1979

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Anthony G. Collins

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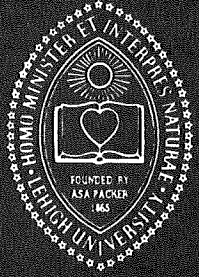
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**Stabilization of Tidal Inlet Channels**

- DESIGN RECOMMENDATIONS

FRITZ ENGINEERING  
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by

Richard N. Weisman

Anthony G. Collins

Fritz Engineering Laboratory Report No. 710.3

Stabilization of Tidal Inlet Channels

DESIGN RECOMMENDATIONS

by

Richard N. Weisman

Anthony G. Collins

Prepared with the support of the New Jersey Marine  
Sciences Consortium via the Sea Grant Program of NOAA.

Department of Civil Engineering

Fritz Engineering Laboratory  
Lehigh University  
Bethlehem, Pennsylvania 18015

October 1979

Fritz Engineering Laboratory Report No. 710.3

DEDICATION

... to Ralph

and Willard

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## 1. INTRODUCTION

Along the barrier islands off the east coast of the U.S. and at other locations, there exist many tidal inlet channels which connect the back bay areas to the ocean. The bay areas are ideal for harbors and marinas; however, navigation through the tidal inlets can be uncertain. The geometry and the stability of the geometry of the inlets is a function of river locations, discharges and sediment loads, offshore topography, onshore-offshore and longshore movement of sediment, tidal flows, and storm action, including setup and abnormal wave action. Thus, although a particular inlet may be a stable geomorphological feature, its geometry, especially its tidal channels, may be changing constantly. The Nautical Charts of the area contain such cautions as, "The entrance channels at inlets not protected by jetties are subject to frequent changes. The buoys are not charted because they are frequently shifted in position."

The historical approach to maintaining a stable navigation channel through a tidal inlet has been (i) construction of jetties, and (ii) frequent dredging. Dredging is an expensive endeavor that needs to be repeated at unpredictable intervals.

This study concerns an alternative to dredging. A pipe with small holes drilled at frequent, uniform, intervals along its entire length is placed in the ebb tide channel at a navigable depth. Several pipes in parallel would probably be necessary. When the channel begins to fill with sediment, water is pumped into the pipe and discharges from the holes in the pipe. At a sufficient flowrate in the pipe the discharge from the holes fluidizes the sand above the pipe. The fluidized sand is removed from the channel by (i) pumping the slurry, (ii) flowing down a gradient,



or (iii) being swept out to the longshore current by the ebb current.

This report presents the results of laboratory studies undertaken to give information useful in the design of a prototype fluidization system in a tidal inlet. Specifically, a prototype design must contain the following points

- (i) pipe size
- (ii) pipe depth
- (iii) fluidization hole size
- (iv) fluidization hole spacing
- (v) flowrate through the system
- (vi) distance between parallel pipes

The choice of these design parameters must be based on a consideration of the following factors:

- (i) sand depth over the fluidization pipe
- (ii) the material properties of the sand
- (iii) the degree of fluidization obtained from a particular configuration of fluidization hole location, size, spacing
- (iv) the effect of the ebb flow through the inlet on the fluidized sediment
- (v) the amount of interaction between parallel pipes and the effect of ebb flow on nonfluidized sand between the pipes

The laboratory study, then, is not an attempt to model a tidal inlet; rather, the experiments are meant to reveal relationships between the flow discharging from the fluidization pipe and the subsequent fluidized channel. Only then can a prototype experiment be designed for further research in an actual tidal inlet.

### 1.1 Historical Background

The first investigators to suggest a fluidizing pipe for removal of sediment were Hagyard et al. (1969). Their concern was with an estuary

and they hoped that the fluidized sand would flow down a slight slope to the ocean. Inman and Harris (1970), Baillard and Inman (1975), and Harris et al. (1976) hoped to achieve removal of sand by pointing the fluidization holes downward. The hole excavated would form a duct under the pipe through which the fluidized sand would flow by gravity. Caving of sand above the pipe would eventually create a channel. These investigators had trouble with "fluid holes", regions of well-fluidized sand with unfluidized sand dams between. These dams do not allow any longitudinal flow of slurry. Wilson and Mudie (1970) had a similar problem even with upward pointing discharges.

## 1.2 Previous Lehigh University Work

1. Kelley (1977) using a two-dimensional (2D) experimental apparatus, tested various fluidization hole configurations to determine which one gives the greatest fluidized width. The two-dimensional effect was achieved by having the depth and width dimensions of the apparatus an order of magnitude larger than the length dimension. Water is fed through a 'distribution' or fluidization pipe sample drilled with 0.238 cm holes at 2.54 cm centers. The distributor was placed at the center-bottom of the apparatus and covered with sand. Flow out of the holes in the distributor fluidized the sand. Kelley concluded that the widest fluidized region for a specific flowrate is given by holes horizontally opposed. Holes pointing upward or downward caused smaller fluidized regions.
2. Murray and Collins (1978) used a large flume to obtain a three-dimensional (3D) effect. The fluidization holes were horizontally opposed, spaced 2.54 cm apart and drilled 0.238 cm (3/32 in) in

diameter. The entire flume was filled with sand to a depth of 15.25 cm above the pipe. Complete fluidization was achieved without the "holes and sand dams" observed by Wilson and Mudie (1970) or Inman and Harris (1970). The fluidized sand migrated down slope, creating a channel width of over 20 inches.

Some of the conclusions reached by Murray and Collins (1978) are as follows:

- (i) The process leading to a fully fluidized channel is quite consistent. As the flowrate is increased through the system, individual areas of boiling sand enlarge and join until the whole channel is fluidized.
- (ii) Fluidization is achievable under a variety of conditions, including (a) horizontal and nonhorizontal pipes, and (b) uniform and nonuniform sand coverage.
- (iii) With the pipe on a slope and a fully fluidized channel, the sediment flows under the influence of gravity to the downstream end of the pipe.
- (iv) The fully fluidized sediment could be rapidly removed by pumping the slurry from the downstream end.
- (v) As the fluidization hole spacing is increased from 1" to 2" to 4", the fluidized width increased as did the pressure required to reach full fluidization.

Murray and Collins (1978) accomplished the intended purpose of their testing, to show that a channel could be completely fluidized along the length of the fluidizing pipe. However, they took little data that could be used for the design of a prototype system. The current investigation is meant to provide the foundation for prototype research.

## 2. TEST PROGRAM

The purpose of this research is twofold:

- (i) to investigate the relationship between flowrate per unit length of fluidization pipe and the width of the fluidized channel,
- (ii) to assess the removal of fluidized sand from the channel by density current, by pumping, or by the scouring action of an overlying flow.

To accomplish the first part, the two-dimensional apparatus used by Kelley (1977) is particularly suitable. Fluidization pipe samples with horizontally opposed holes are used. Each sample has fluidization holes of a particular diameter. The range of fluidization hole diameters tested was determined from practical considerations. By increasing the flowrate through the system, a relationship between flowrate per unit length of fluidization pipe and fluidized channel width can be established for a given fluidization hole size. (For the duration of this report this relationship will simply be referred to as the flowrate/width relationship.) Hence, the effect of fluidization hole size can also be understood by comparison of data.

The effect of sand depth over the fluidization pipe flowrate/width relationship can also be readily investigated in the 2-D apparatus. Once again comparative data analysis will be useful.

The material properties of the sand used in the 2D model can be determined to aid in explanation of the experimental data collected.

To test the second objective of this study, that of sand removal from the fluidized channel, a larger 3D facility is necessary. A fluidization pipe in excess of 1.5 m in length was used to obtain the 3D effect.

Initially it was necessary to establish a correlation between the two models. This was achieved by conducting similar experiments in the 2D and 3D models and comparing the data. The 3D apparatus also allowed further investigation of the fluidization hole spacing by running a series of tests at different spacings. The tests consisted of gathering flowrate per unit length of fluidization pipe and fluidized channel width data and making graphical comparisons.

Once these further aspects of the fluidization channel phenomena had been studied the removal mechanisms of the fluidized sand were tested. Gravity flow and pumping of the fluidized sand slurry were investigated. Most importantly because of the known existence of strong ebb tides in most tidal inlets, scouring by the overlying flow was simulated.

In a similar fashion to the 2D apparatus tests, the material properties of the sand used in the 3D apparatus were determined to aid in the explanation of the data.

The organization of this report is to follow in two separate sections, one dealing with the 2D experiments and results and the other concerning the 3D part.

## 2.1 Part A - 2D Experiment

### 2.1.1 Description of Tests

#### 2.1.1.1 Aims

The 2D apparatus experiment was undertaken to obtain information about the fluidized channel created by discharging water through a fluidization pipe buried in sand. Specifically the following aspects were studied;

- (i) the trend of the flowrate/width relationship
- (ii) the effect of depth of burial of the fluidization pipe on the flowrate/width relationship
- (iii) the effect of different fluidization hole diameters on the flowrate/width relationship.

The fluidized channel width recorded was a relatively arbitrary measurement, subject to individual interpretation. The width was basically that from peak to peak of the berms formed by the sand being ejected from the fluidized channel. At low flowrates, in particular, the berms were often not well formed. Consequently the numbers recorded should be considered only an index of the fluidized channel width.

In addition the experimental runs were observed with the aim of gaining qualitative knowledge about the fluidization process. These observations contribute directly to the design recommendations of a prototype system.

To enable conclusions to be drawn between the 2D and the 3D experiments it was necessary to run an experiment in the 2D apparatus using the 3D apparatus sand. In particular, the flowrate/width relationships were compared for each sand.

#### 2.1.1.2 Apparatus

The model was similar to that used by Kelley (1977) and is shown in Fig. 1. Specifically the model was a box, 122 cm long, 71 cm deep and 7.6 cm thick. It was constructed of 0.63 cm plexiglass with joints glued and screwed together. To provide rigidity to the front and rear faces of the model, 2.54 cm steel box supports span the length of the model at intervals of approximately 23 cm.

Water was introduced into the sand through the fluidization pipe sample (Fig. 1) using pressure-regulated city water as the source. An in-line pump was used at the end of each experimental run to boost the flowrate. The flowrate was determined by collecting the discharge from the weir in a graduated container over a known time.

The sand was placed in the model to the desired depth and packed down by rodding. The rodding was carried out under saturated conditions and was used only to eliminate large voids that may have occurred during placement.

The fluidization pipe samples were constructed from 3.81 cm diameter plastic pipe and were approximately 7 cm long. The fluidization holes were drilled on a horizontal plane spaced at 2.54 cm centers. This resulted in 6 holes per sample. The orientation of the holes on the horizontal plane was selected on the basis of the recommendation of Kelley (1977).

#### 2.1.1.3 Procedure

The following steps were taken for each test;

- (i) Location and clamping of fluidization pipe sample.
- (ii) Placement of the sand, flooding of the model by opening the inlet valve, rodding of the sand to remove voids, leveling and checking the depth of sand coverage.
- (iii) Conducting the experimental run by opening the inlet valve in small increments, measuring the fluidized channel width and flowrate through the fluidization pipe sample.

A typical test run for a given fluidization pipe sample would include about 5 flowrate increments. A brief pause after each flowrate increment was taken to allow equilibrium to be established. Each run was duplicated to provide additional data points and to check the repeatability of the process.

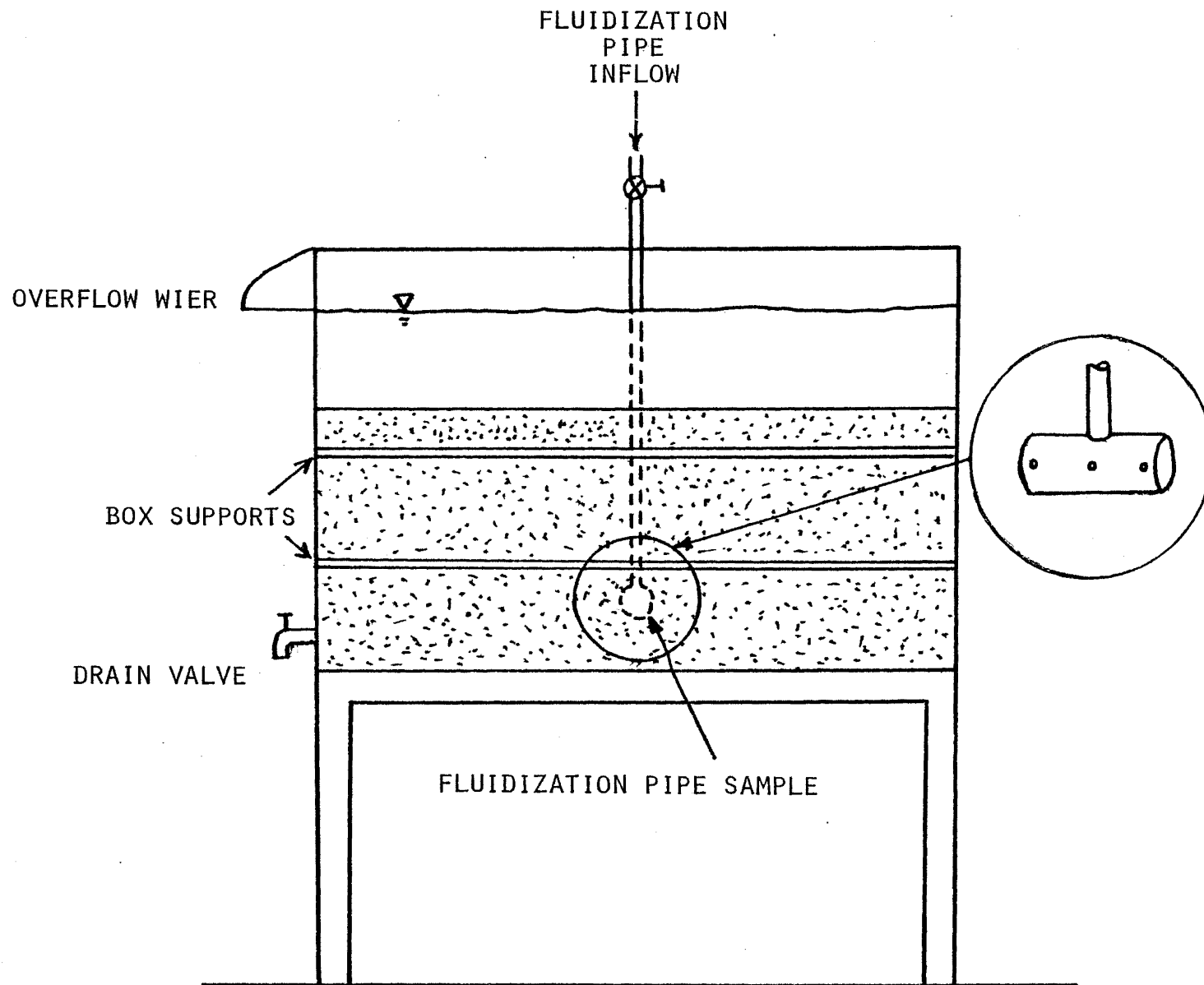


Fig. 1 Experimental Apparatus



### 2.1.2 Test Results

The flowrate/width relationship shows remarkable smoothness and repeatability. The trend of the relationship is identical for all fluidization hole diameters and sand depths tested (Figs. 2, 3, 4, 5, 6, 7).

The variation of the flowrate per unit length of fluidization pipe at which initial fluidization of the channel occurs for the different fluidization pipe samples tested is discussed later. Once the fluidized channel is formed the flowrate/width relationship could be described as having two distinct phases.

Initially the fluidized channel width increases rapidly with small incremental fluidized pipe flowrates. The relationship levels off and large flowrate increments are required for relatively small fluidized channel width increases. This is shown most clearly in Fig. 3 where most data was taken.

There were two different depths of sand tested, namely 20.3 cm and 40.6 cm. Two conclusions could be drawn from the data collected and presented in Figs. 2, 3, 4, 5. The greater depth of sand coverage slightly retards the initiation of fluidization. More importantly, in general, within the limits of the experiment conducted, the flowrate/width relationship was not affected by the depth of sand above the pipe.

Perhaps the most important variable tested was the diameter of the fluidization holes. Four different hole sizes were tested, namely 0.159 cm (2/32 in), 0.316 cm (4/32 in), 0.476 cm (6/32 in), 0.635 cm (8/32 in). The bounds of the range were selected for the following reasons.



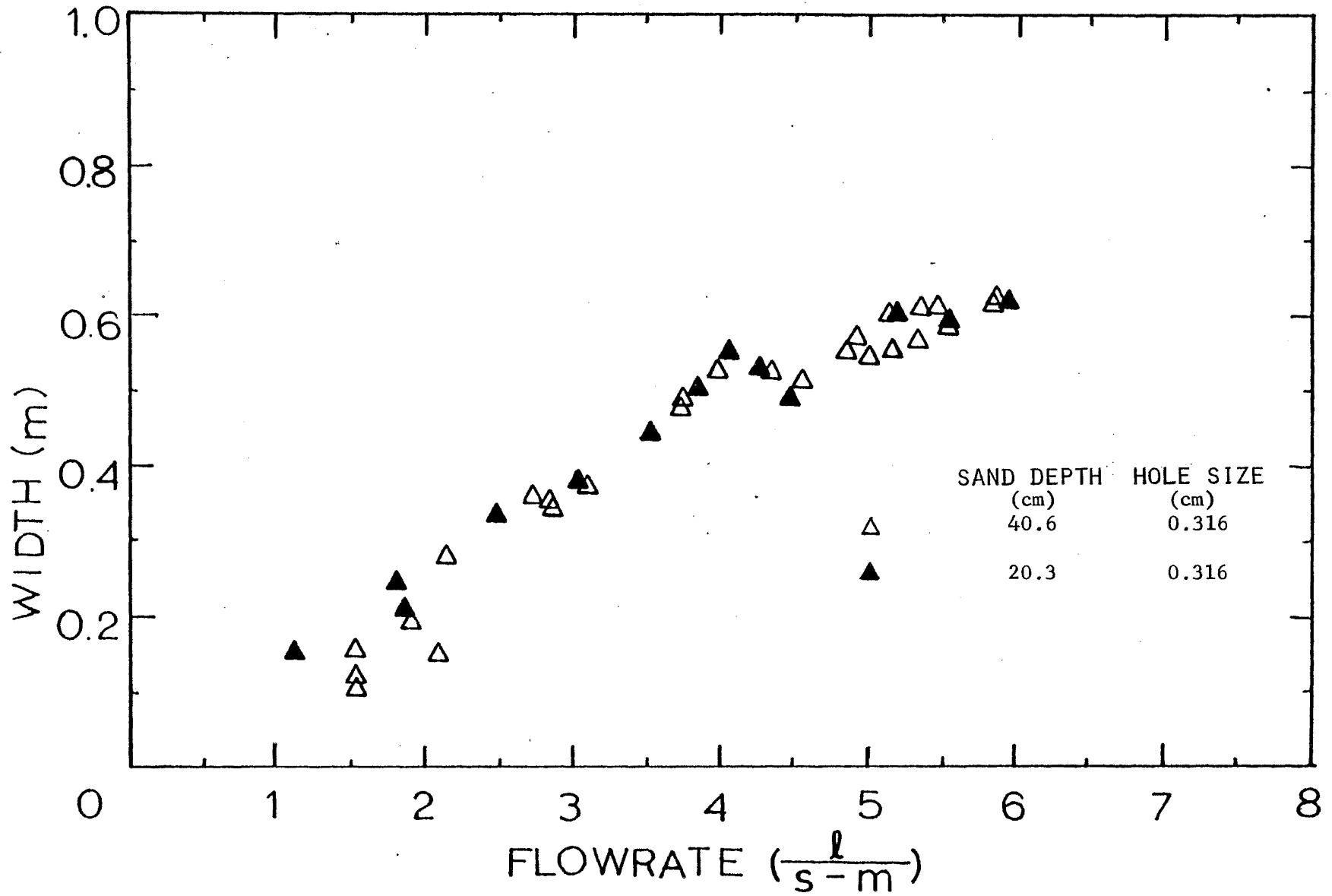


Fig. 3 Flowrate/width relationship for .316 cm hole size and two sand depths in the 2D apparatus

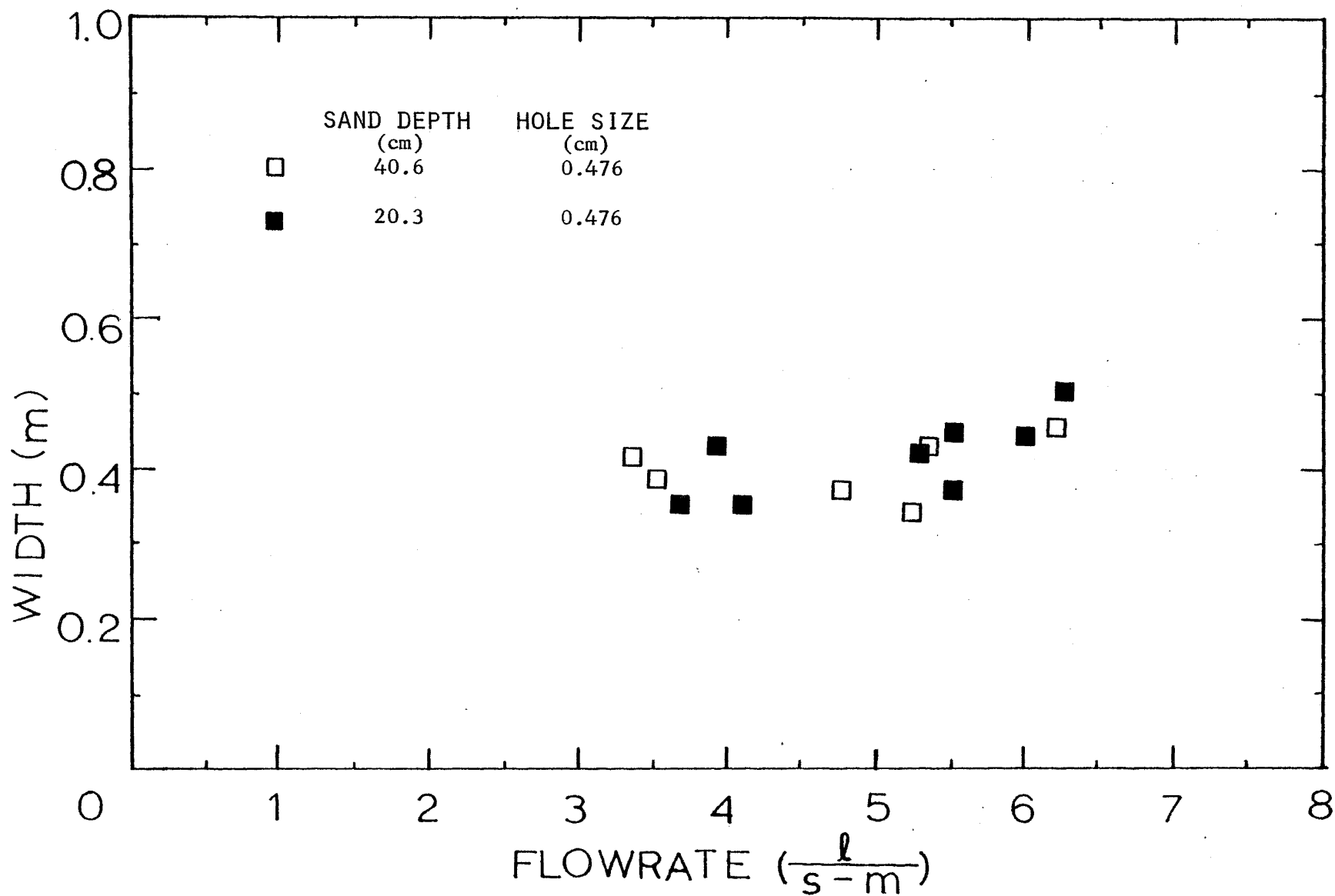


Fig. 4 Flowrate/width relationship for .476 cm hole size and two sand depths in the 2D apparatus

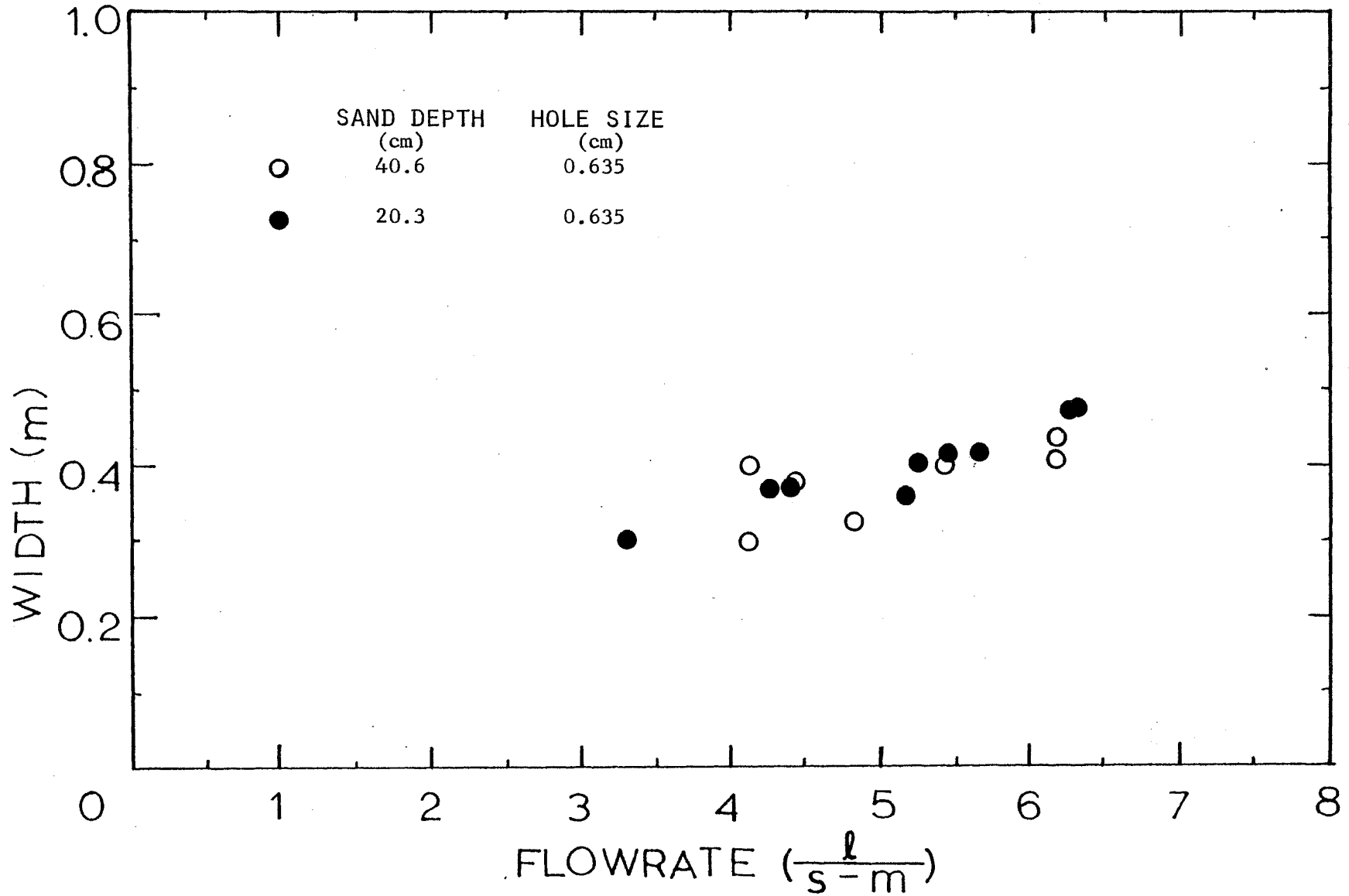


Fig. 5 Flowrate/width relationship for .635 cm hole size and two sand depths in the 2D apparatus

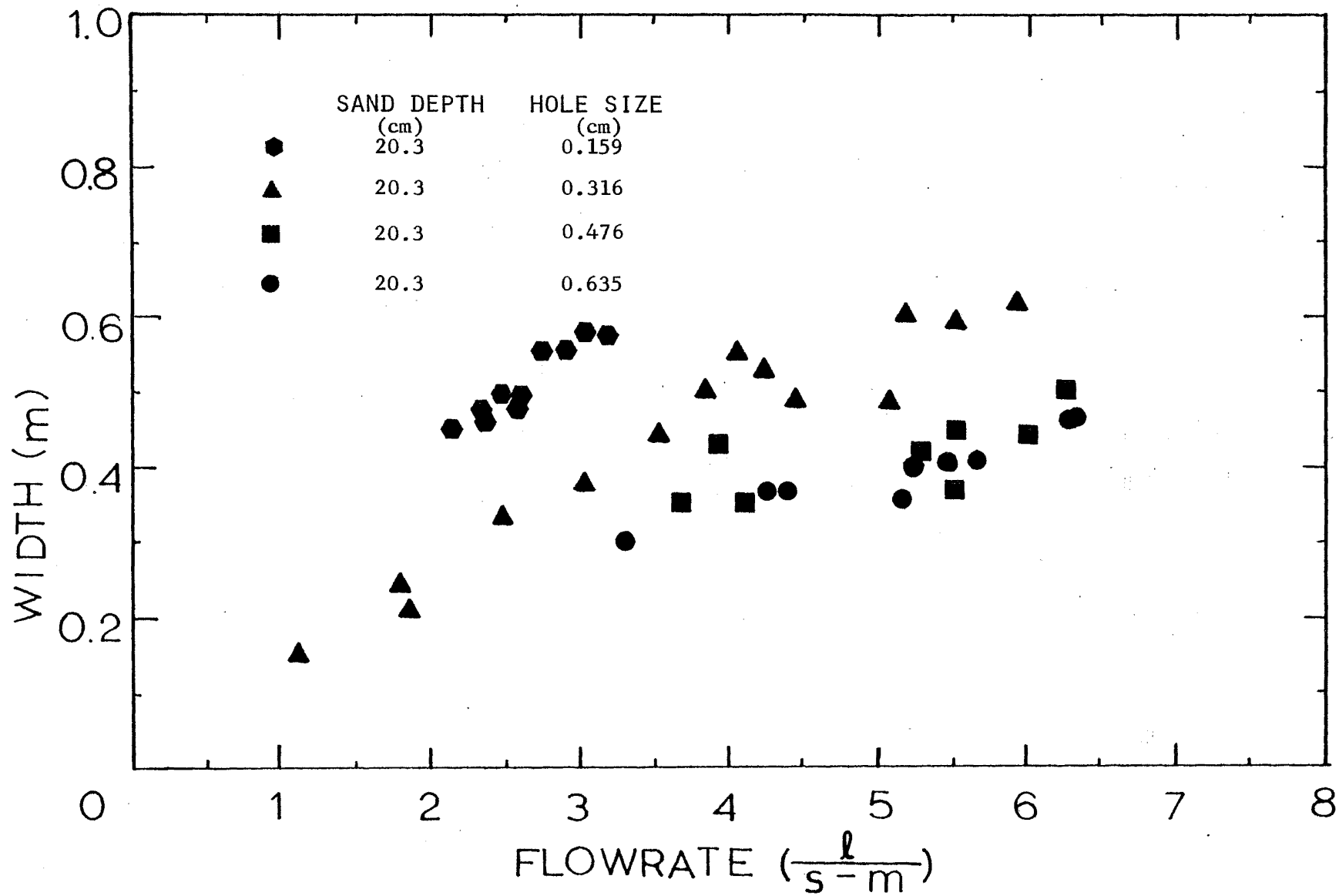


Fig. 6 Flowrate/width data for the four fluidization pipe samples with hole sizes 0.159, 0.316, 0.476, 0.635 cm and sand depth of 20.3 cm in the 2D apparatus.

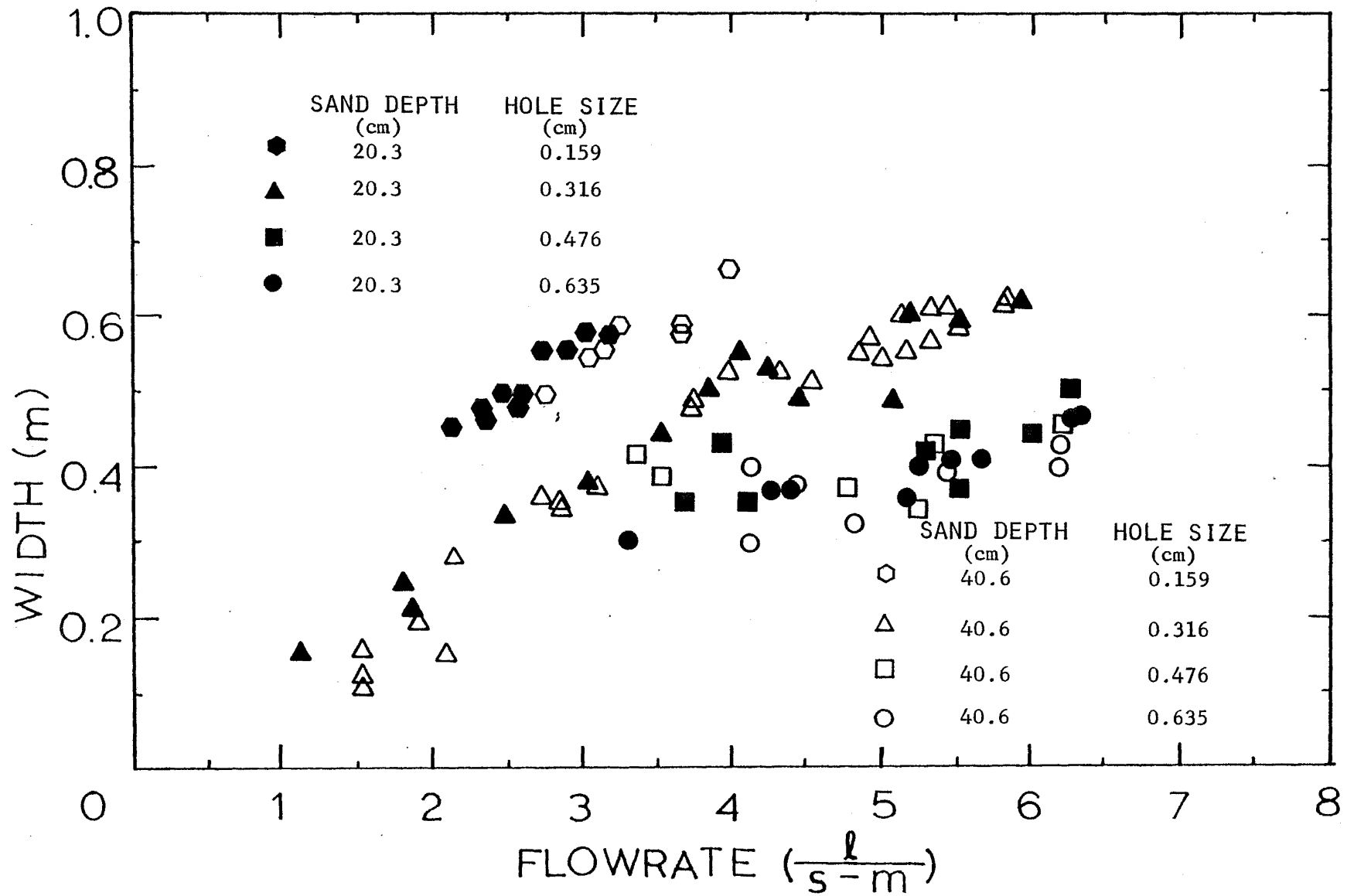


Fig. 7 All flowrate/width data from the 2D apparatus - four hole sizes and two sand depths.

The low bound was set considering the size of the sand grains and the need to provide a jet of water out of the fluidization hole of at least similar size to interact significantly with the grains. From a hydraulic point of view, the smaller the hole size the greater the internal fluidization pipe pressure required to force adequate flowrates through the fluidization holes. For smaller hole diameters than those selected the internal pressure would be impractical.

The high bound was set primarily from hydraulic considerations. Initiation of fluidization is dependent on pressure (Kelley, 1977) in the sand. The total flowrate required in the fluidization pipe for a series of fluidization holes of diameter greater than those tested to achieve the necessary pressure would also be impractical.

Operationally another important consideration in the selection of the fluidization pipe hole diameters is the clogging of the holes. In particular, if the fluidization pipe was to be operated intermittently or with periods of very low flow then sand grains could enter the pipe.

As previously mentioned a number of observations important to the practical application of the fluidization pipe concept were made during the operation of the 2D apparatus.

The rate of increase of flowrate in the fluidization pipe has a very significant effect on both the initiative and manner of fluidization. Relatively large increments of flow in the fluidization pipe cause pressure pulses which initiate the formation of the fluidized channel earlier than if the same flowrate was achieved with very small increments. Also, initially, with small incremental flow increases often only one side of



the final fluidized channel would fluidize. Eventually the other side would erupt and the fully fluidized channel cross section would develop. These effects are more noticeable when comparing the data for the 0.316 cm (4/32 in) fluidization hole diameter sample with the other samples in Figs. 6 and 7. The 0.316 cm (4/32 in) fluidization hole diameter sample data was achieved by more rapid flowrate increments.

The shape of the fluidized channel cross section was extremely interesting. The water discharging from the fluidization holes traveled horizontally, essentially eroding sand grains until it lost its erosive power. At this point the water rose vertically and circulated towards the center of the fluidized channel and then downward once the surface was reached. This process led to a nearly rectangular channel cross section as can be seen in Fig. 8.

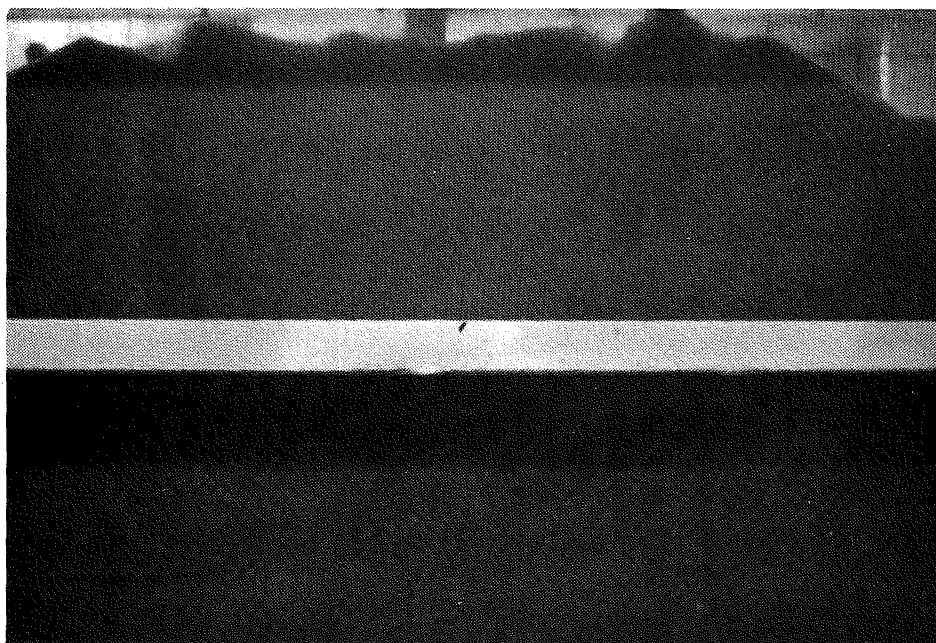


Fig. 8 Fluidized region in 2D apparatus

The berms, previously mentioned, were formed as the finer material was ejected to the edge of the fluidized channel. The height of the berms appeared to be simply a function of the amount of fine material in the fluidized channel. Obviously then, the deeper the fluidized pipe was buried the greater the height of the berms.

The sand used in the 3D model was placed in the 2D model and tested. The comparison of the flowrate/width relationship for both sands is shown in Fig. 9. While the trends are identical in both cases, at any given flowrate per unit length of fluidization pipe the fluidized channel width was about 20% greater for the 3D model sand. This difference can probably be explained by examining the properties of each sand.

The results of a sieve analysis for each sand are shown in Fig. 10. The basic differences between the sands are that the 3D model sand has more fines and is less uniform. A possible explanation of the difference between the flowrate/width relationships would be the ejection of more of the 3D model sand from the fluidized channel. This would result from a combination of lighter material and more fines. With more sand ejected from the channel, there is a tendency for the channel to widen.

The effect on the channel cross section when the fluidized sand was removed was investigated by syphoning the slurry from the middle of the fluidized channel. The slurry syphoned readily and there was a dramatic slumping of the sand into the channel and consequent enlargement of the channel. The original vertical sides of the fluidized channel were completely removed.

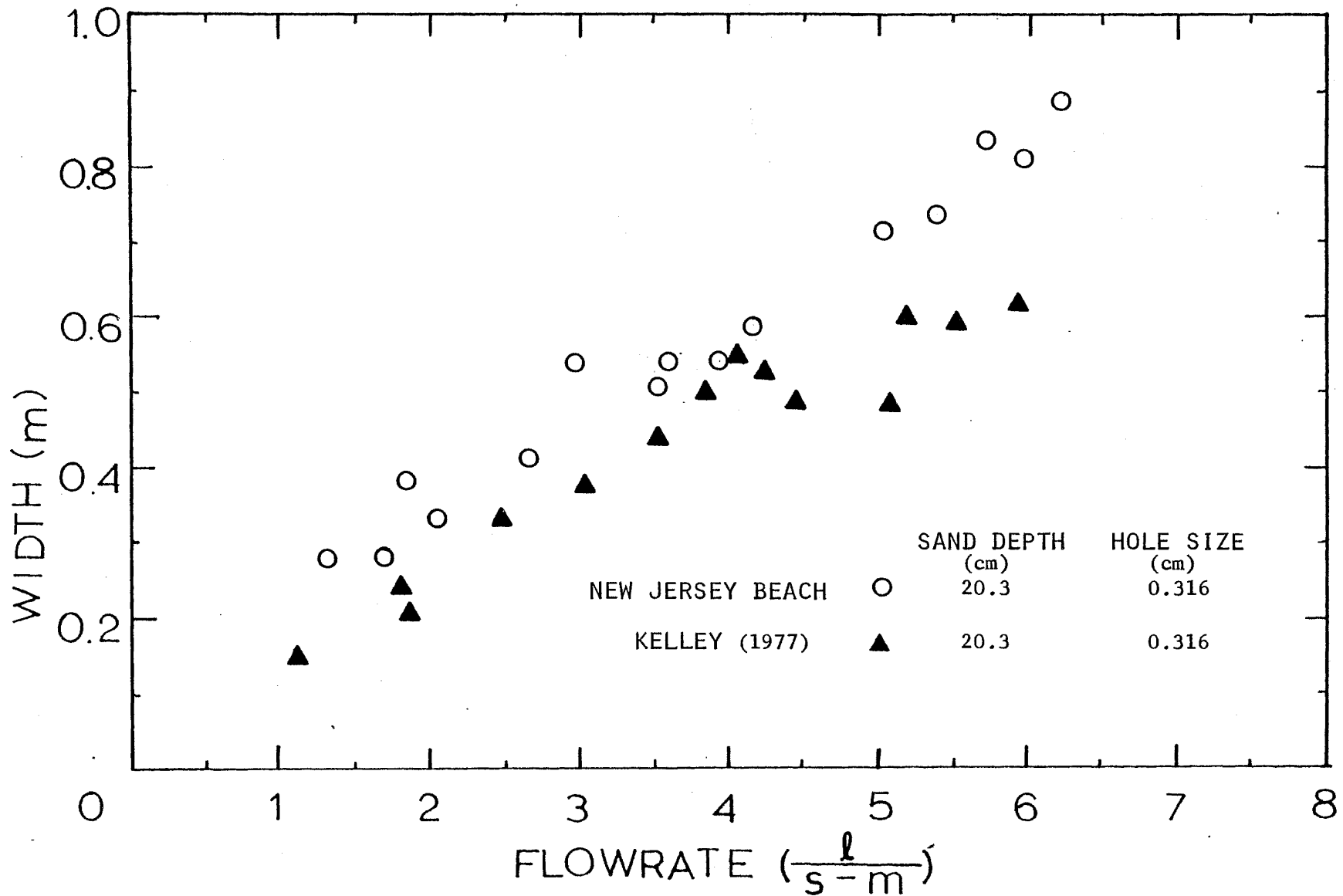
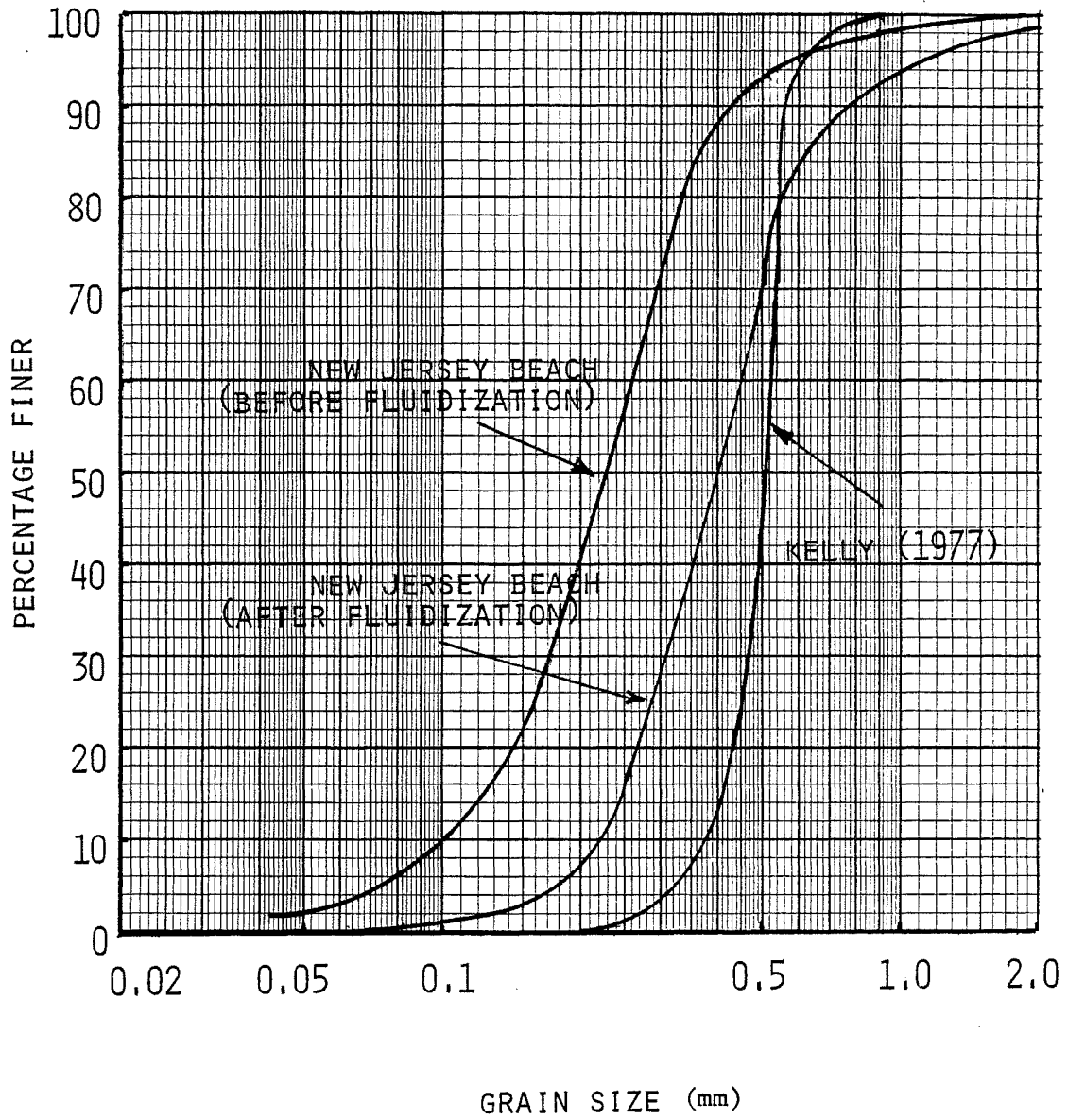


Fig. 9 Comparison of flowrate/width relationship for two different sands in the 2D apparatus.



SPECIFIC GRAVITY:  
 KELLEY (1977) 2.52  
 NEW JERSEY BEACH 2.42

Fig. 10 Sieve analysis for sands.

## 2.2 Part B - 3D Experiment

### 2.2.1 Description of Tests

#### 2.2.1.1 Aims

The 3D experiment was undertaken primarily to investigate the movement of sand in the fluidized channel. At the same time, similar tests to those conducted in the 2D apparatus were run. Hence the validity of the conclusions based on the 2D tests were evaluated on a larger scale application. The 3D tests also provided the opportunity for further investigation of the factors affecting the flowrate per unit length of fluidization pipe to the fluidized channel width relationship. Specifically the following situations were studied;

- (i) a comparison of flowrate/width relationship data for the same (3D) sand for identical tests conducted in the 2D and 3D experiments.
- (ii) the effect at various fluidization hole spacings on the flowrate/width relationship.
- (iii) the movement of the fluidized sand by gravity above a sloped fluidization pipe and any change in channel cross section.
- (iv) the movement of the fluidized sand when removed (pumped) as a slurry from the channel and any change in channel cross section.
- (v) the movement of the fluidized sand when subjected to an overlying flow and any change in channel cross section.

In a similar fashion to the 2D tests the experimental runs were observed with the aim of gaining qualitative knowledge about the fluidization process.

#### 2.2.1.2 Apparatus

The 3D experiments were conducted in a steel tank shown in Fig. 11. The flume was 7.47 m long, 1.52 m wide and 0.61 m deep. The fluidization

pipe was a 3.81 cm diameter galvanized steel pipe, 3.05 m long and was fed by a 5.08 cm diameter galvanized steel pipe.

The water supply was from the city water main and was controlled by a valve at the upstream end of the fluidization pipe. The flowrate was determined by diverting the discharge from the flume to a volumetric tank over a known time interval.

The overlying flow was provided by a 35 HP pump capable of discharging 1600 gpm at 60 ft. The water was pumped to the end of the flume through a 20.32 cm diameter steel pipeline and discharged into a header tank. The flow was streamlined by passing through a basket of gravel and into the flume.

The sand was placed at the desired depth over the fluidization pipe and extended downstream about 0.5 m past the end of the fluidization pipe. Normally the sand was compacted by a combination of the shovelling, leveling, and smoothing processes.

#### 2.2.1.3 Procedure

The following steps were taken for each test;

- (i) Location and taping of the fluidization pipe - the taping being to block unwanted fluidization holes to give the desired fluidization hole spacing.
- (ii) Placement of the sand, leveling, smoothing and checking the depth of sand coverage.
- (iii) Flooding of the model by opening the overlying flow valve to fill the upstream end of the apparatus and placement of hoses to fill the downstream end of the apparatus.
- (iv) Conducting the experimental run by opening the inlet valve to the fluidization pipe in small increments. The fluidized channel width was measured and the flowrate was determined by diversion of the flume discharge to the volumetric tank.

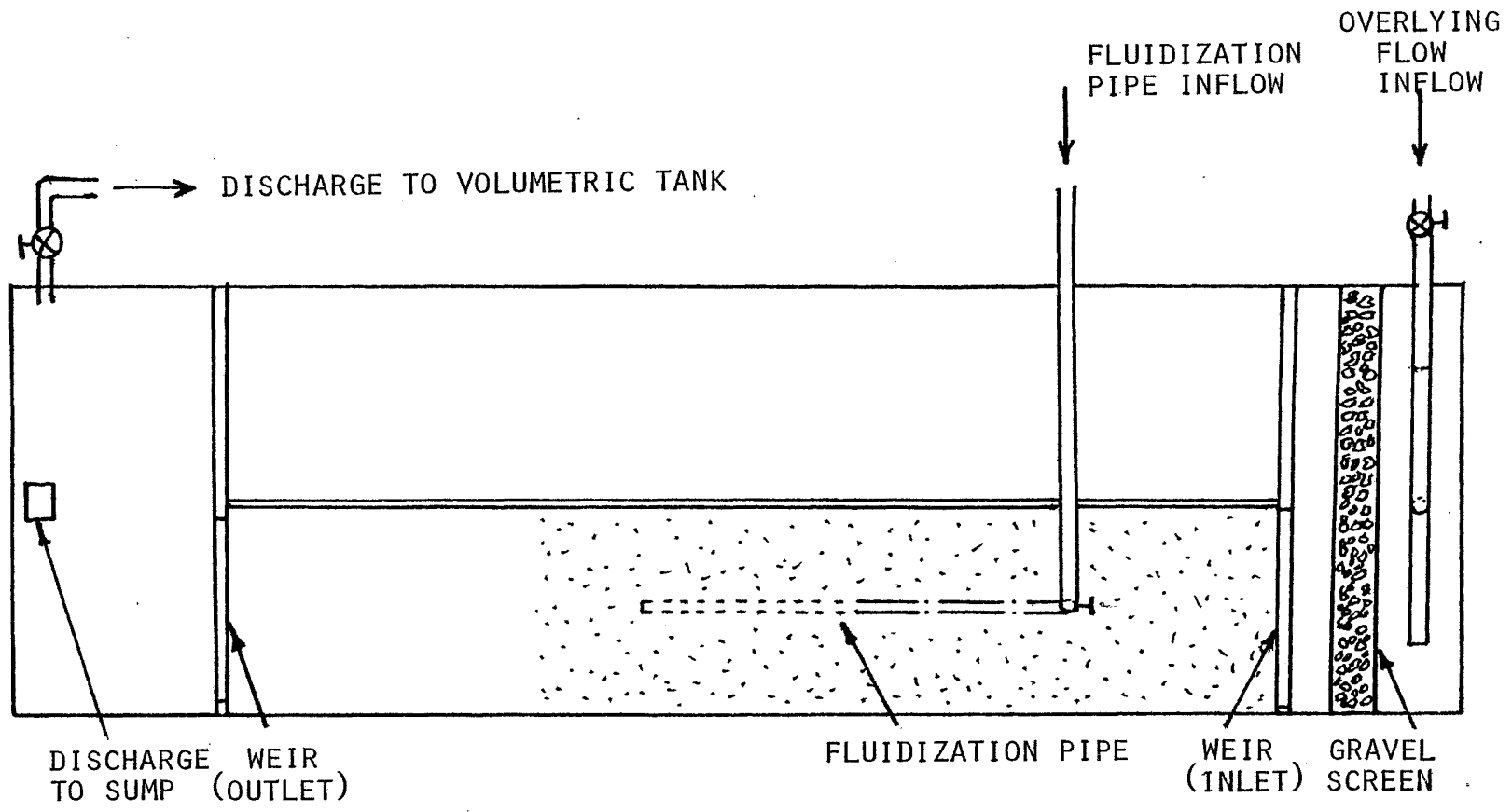


Fig. 11 The 3D experimental apparatus

A typical test run would include about 8 flowrate increments each with detailed observations. The runs would last approximately an hour as substantial pauses were required to allow the flowrate to come to equilibrium after adjustment.

The overlying flow tests were conducted by opening the valve to the header tank and allowing the pumped water to discharge over the surface of the sand. The flowrate was of such a magnitude that the diversion to the volumetric tank was inadequate. Estimates of the scour velocity were made by measuring the surface velocity by timing a float over a set distance. Higher scour velocities were achieved by directing the flow with baffles.

#### 2.2.2 Test Results

The trend of the flowrate/width data for the 3D test is identical to that obtained in the 2D apparatus as can be seen in Fig. 12. This figure compares the flowrate/width data for the same tests conducted in the 2D and 3D models; both tests have a sand coverage of 20.3 cm over the fluidization pipe and fluidization hole spacing of 2.54 cm. The data is almost identical for both tests and the small variation can probably be explained by the 3D aspects of the larger tank. The 3D test shows a slightly wider fluidized channel at the same flowrate compared to the 2D test. The 3D apparatus could be considered to be "unconstrained" when compared to the 2D model whose flow was probably strongly influenced by wall effects. After testing, the flume was drained and this is shown in Figs. 13 and 14. The berms built up by the ejection of finer material can be clearly seen around the perimeter of the fluidized channel area. Particular attention should be taken of the berm built up at the lower end of the fluidized channel (perpendicular to the fluidized pipe). This berm



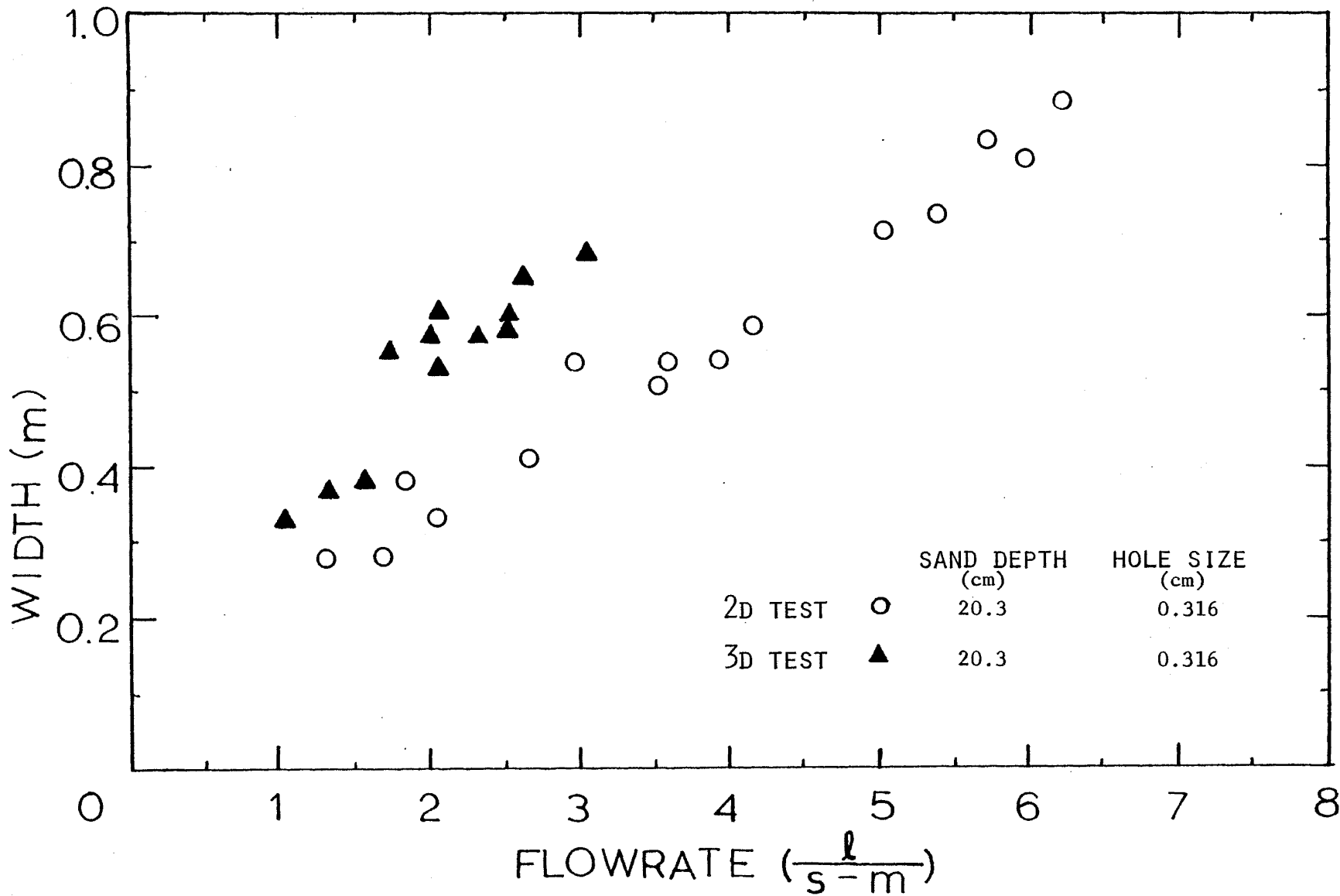


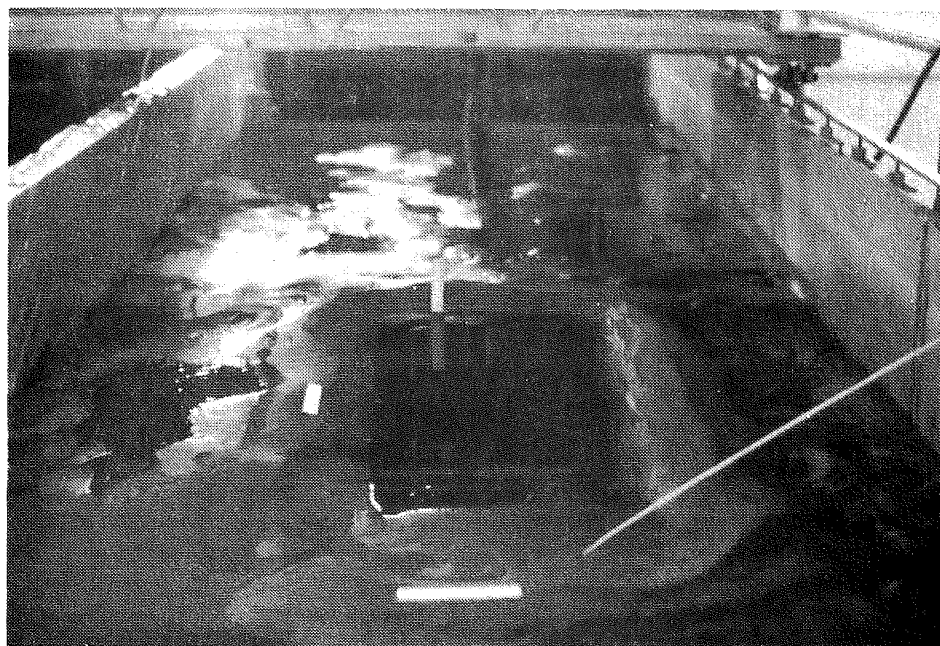
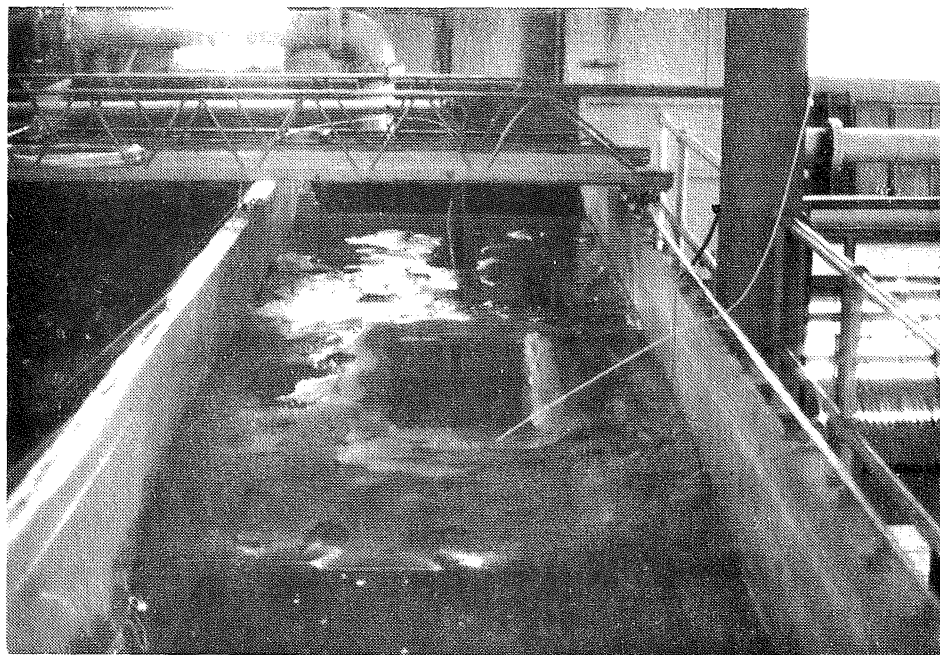
Fig. 12 Comparison of flowrate/width relationship obtained in the 2D and 3D tests.

formed a dam which inhibits the movement of fluidized sand downstream in later tests.

There are three important effects to be noted from the tests with varying fluidization hole spacing. The flowrate/width data from these tests is shown in Fig. 15. First fluidization hole spacing appears to have little influence on the flowrate per unit length of fluidization pipe necessary to initiate a fluidized channel. Second, the flowrate per unit length of fluidization pipe necessary to achieve any given fluidized channel width is independent of fluidization holes spacing. Third, the wider the fluidization hole spacing, the more dense the "fluidized" sand becomes. Given that the aim of the project is to produce the widest possible fluidized channel at the lowest practical flowrate per unit length of fluidization pipe, then the third result appears to be the only one of significance.

The ability to remove the fluidized sand from the channel is of major importance to the successful implementation of the system. The apparatus, as described, was not entirely suitable for full evaluation of this aspect of the project but it was felt that enough work was done to justify considerable optimism. The principal shortcoming of the experimental setup was that only the lower values of the expected ebb tide scour velocity range could be achieved. A number of important conclusions could, however, be drawn.

Initially the fluidization pipe was placed in the flume at a 5% slope with a uniform sand coverage of 20.3 cm over the fluidization holes which were spaced at 5.04 cm centers. The fluidization pipe valve was fully opened. A flowrate of 3.04  $\ell$ /m-sec was obtained and a fluidized channel 0.70 m in width developed. The flow in the fluidization pipe was continued



Figs. 13, 14 Typical configuration of fluidized region and berms.

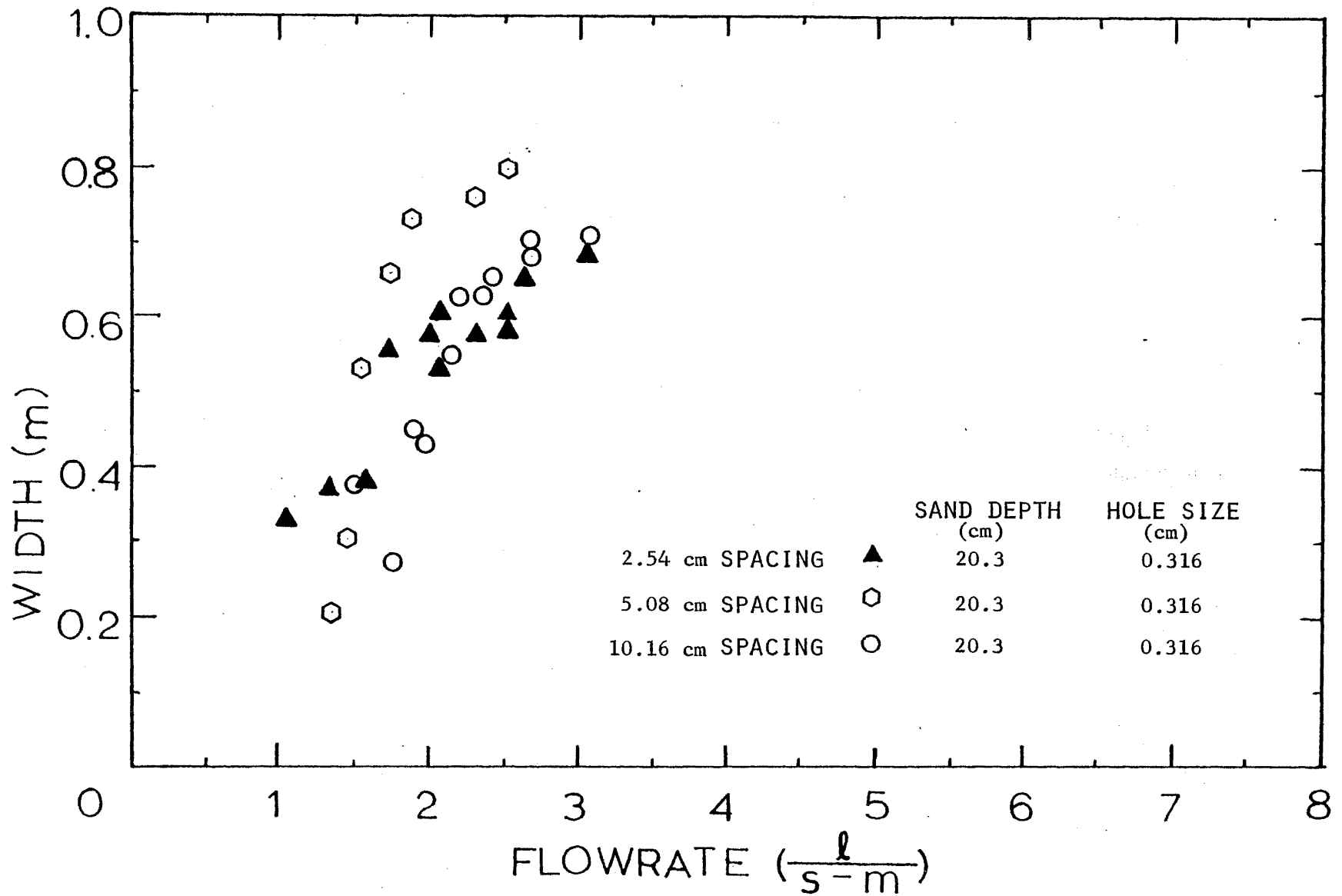
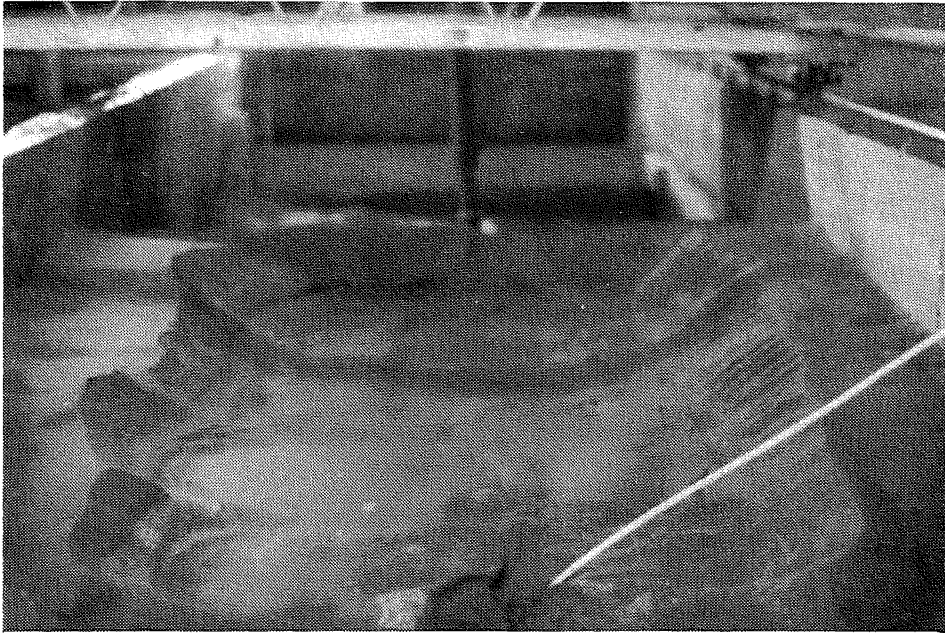
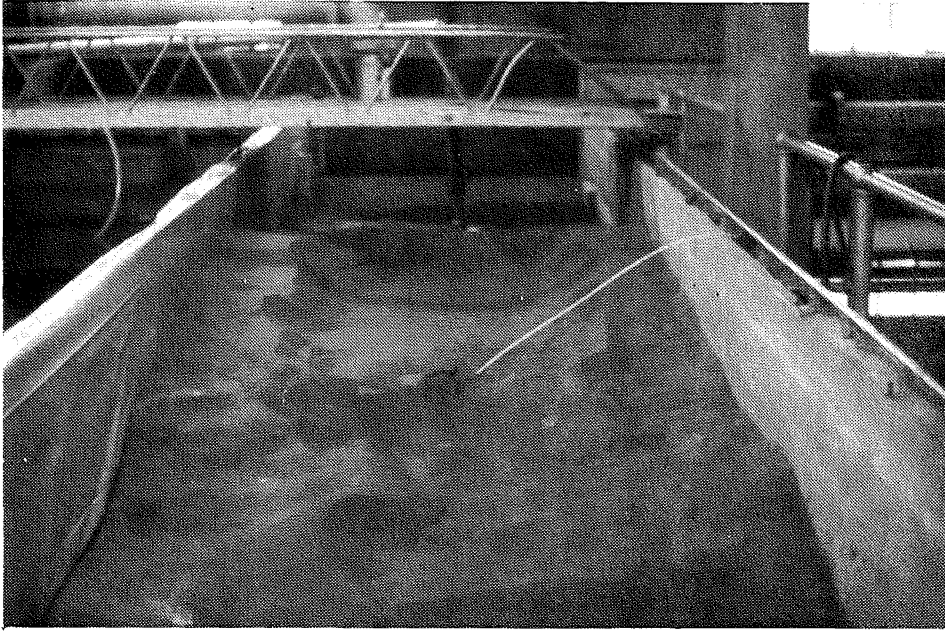


Fig. 15 The effect of hole spacing on the flowrate/width relationship in the 3D experiments.

for about 30 minutes. A sand dam existed at the downstream end of the fluidized channel between the end of the fluidization pipe and the downstream extremity of the sand coverage (refer to Figs. 13 and 14). In addition, a sand delta formed on this dam as the fluidized sand migrated down the channel. This sand dam and the delta were removed by hand so that the transport of the fluidized channel sand would not be hindered. When the run was terminated the flume was drained and the results can be seen in Figs. 16 and 17. Clearly the fluidized sand migrates down the channel under the influence of gravity. The sides of the channel have slumped and the width increased from 0.70 m to 1.04 m.

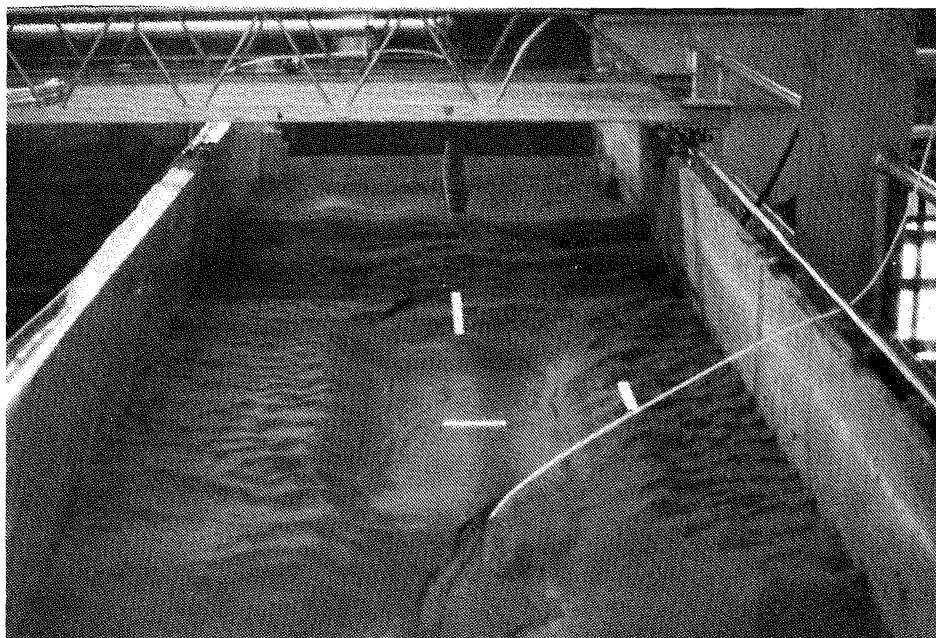
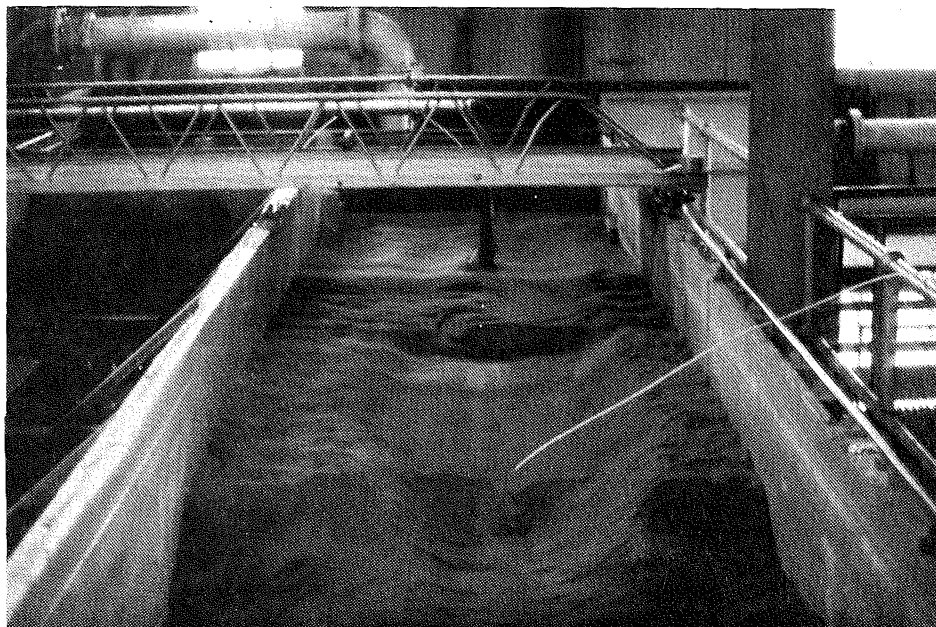
After testing the effect of sloping the pipe, it was returned to the horizontal and set up under the same conditions; 5.04 cm fluidization hole spacing and 20.3 cm sand coverage. The flowrate in the fluidization pipe was set at about 3.0  $\ell$ /m-sec and fully fluidized channel developed. An attempt to pump the sand slurry was made from the downstream end of the fluidized channel. This was unsuccessful as the inlet to the pump was blocked after a time due to the sorting of the sand; passage of the fine material and retention of the larger particles. The overlying flow-apparatus was turned on and once again the dam was broken and the fluidized sand was removed by hand. The overlying flow was estimated at 0.3 m/sec. The fluidization pipe flowrate and the overlying flow were turned off and the flume drained. The results of two similar tests are shown in Figs. 18 and 19 and are similar to the sloped fluidization pipe results. The fluidization sand is so "fluid" that even with the fluidization pipe in the horizontal position, removal of the sand (by pump or other means) at the downstream end of the fluidized channel caused the fluidized sand to



Figs. 16, 17 The effect of sloping the fluidization pipe on the channel configuration.

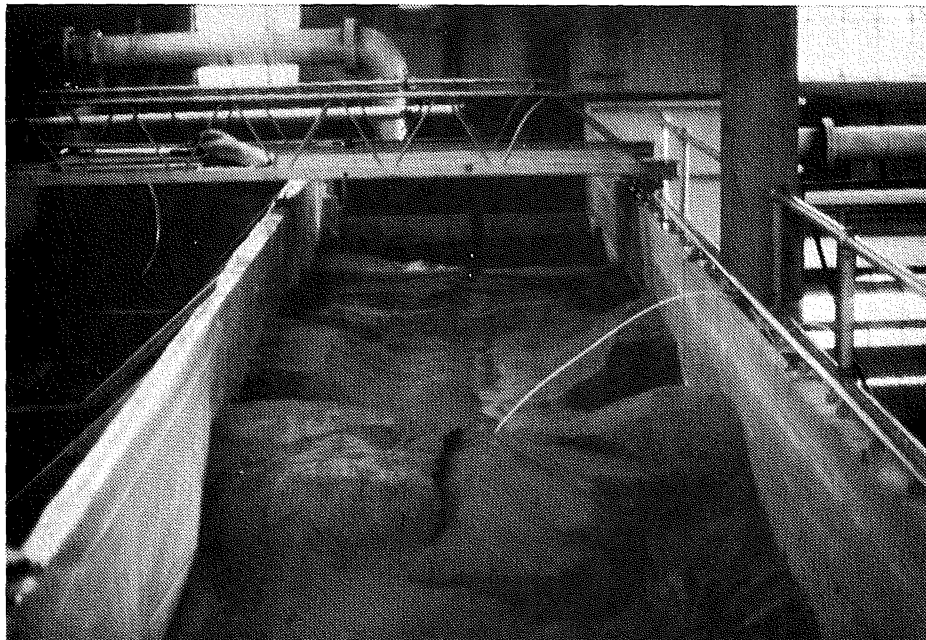
flow out of the channel. In the process, the sides slumped causing an approximate channel width increase of 20%.

Finally, the fluidization pipe was set horizontally with a fluidization hole spacing of 5.04 cm, sand coverage of 20.3 cm, a fluidized channel was created at a fluidization pipe flowrate of 3.06  $\lambda$ /m-s and the overlying flow apparatus was brought into use. Allowing the flow to extend across the entire width of the flume produced a scour velocity of about .3 m/s. The effect on the fluidized channel was similar to previous results; there appeared to be little tendency of the overlying flow to entrain the fluidized sand. Once again the downstream dam was broken by hand and considerable movement of the fluidized sand was achieved. The walls again slumped and the channel width increased. By using baffles the overlying flow was directed over the fluidized channel. The scour velocity was now estimated at 0.8 m/sec; this increase in velocity, dramatically increased the scouring capacity of the overlying flow. All the fluidized sand was swept out and the walls slumped and were scoured away to a much greater depth than previously achieved. The final channel width was about 1.1 m and the drained channel is shown in Figs. 20 and 21. The sand swept downstream formed a delta over the sand dam. When the baffles were moved downstream to direct the flow over the dam and the delta only a small erosive effect was noted. This leads to the conclusion that the fluidized sand in the channel may be scoured away but a mechanism for removal of the sand dam and the delta may be necessary.



Figs. 18, 19 The effect of an overlying flow on channel configuration.





Figs. 20, 21 The effect of a strong overlying flow on channel configuration.

### 3. CONCLUSIONS

#### 3.1 Part A

1. The rate of increase of the flowrate in the fluidization pipe has a significant effect on the initiation of fluidization. Gradually increasing flowrate usually causes fluidization to occur on one side only; at a relatively large flowrate, the second side fluidizes. By sudden impulse, both sides can be fluidized simultaneously at a relatively low flowrate.
2. For a given sand type, sand depth, and fluidization hole size, a well-defined relationship between flowrate per unit length of fluidization pipe and fluidized channel width exists. This relationship is steep at first, i.e. a small change in flowrate per unit length causes a large change in fluidized channel width. Beyond a certain flowrate per unit length, the curve flattens out and a large increase in flow results in only a small increase in width.
3. Sand depth affects the flowrate per unit length necessary for initial fluidization; at greater depths a slightly higher flowrate per unit length is necessary. This is expected from the hydraulic considerations; a greater pressure is required in the sand for fluidization necessitating a greater flowrate in the fluidization pipe. Also, at higher flowrates per unit length, sand depth has a minor effect on the flowrate/width relationship. Similar flowrates per unit length create slightly wider fluidized channels with less sand covering the fluidization pipe.

4. For a given flowrate per unit length, the smaller the fluidization hole diameter the larger the fluidized channel width that will result. This appears to be because of the erosive action of the higher velocity jet emanating from the fluidization hole. This jet can also blow out any clogging sand.
5. A variation in fluidized channel width is achieved for a particular sand and flowrate per unit length over the range of fluidization hole sizes tested; e.g. at a flowrate of about  $4 \text{ l/(s-m)}$  the fluidized channel width varies from 0.4 m to 0.6 m for fluidization hole diameters of 0.635 cm to 0.159 cm respectively.
6. The sand which contained a higher percentage of fines resulted in a wider fluidized channel than the more uniform sand at a given flowrate per unit length. This is due, mainly, to the fine particles being ejected over the berm.
7. By pumping or siphoning the fluidized sediment out of the system, the fluidized region is expanded by about 50%. Slumping of the sides occurs until the angle of repose is reached.
8. If the fluidized sand can be removed and the sides slump then fluidization hole diameter and flowrate per unit length have little influence on the final bed configuration because the fluidized channel width is smaller than the ultimate width.
9. Hence, fluidization hole diameter has a real significance for two reasons:
  - (a) to maintain fluidization with an appropriate flowrate per unit length.
  - (b) to minimize clogging.

10. For design, fluidization hole diameter should be selected to minimize clogging and minimize flowrate per unit length necessary for fluidization.

### 3.2 Part B

1. The trend of the flowrate/width relationship in the 3D test confirmed the results obtained in the 2D apparatus.
2. A comparison of the flowrate/width relationships measured in the 2D and 3D tests showed some variation. At similar flowrates per unit length the fluidized channel in the 3D apparatus was wider. The reason is most likely linked to the 3D aspects of the larger tank.
3. Fluidization hole spacing apparently has no effect on initiation of a fluidized channel.
4. Flow rate per unit length of fluidization pipe necessary to achieve any given fluidized channel width is independent of fluidization hole spacing.
5. If the fluidized sand is removed, the sides slump to the angle of repose and the channel width increases greatly. The sand can be removed by
  - (a) pumping
  - (b) sloping the pipe
  - (c) erosion by overlying flow
6. A strong current running over the fluidization pipe will not only remove sand from the fluidized channel but also scour the 'corners'

away. A delta formed at the downstream end of the fluidized channel and was not removed by the scouring velocity achieved in the experiment.

### 3.3 Design Recommendations

Based on the experiments reported, the following is a list of recommendations for the design of a prototype system.

1. Fluidization hole size: In order to minimize total flowrate, the smallest fluidization hole size as possible is required. However, holes too small in diameter would tend to clog easily when the system is operated intermittently. Hence, a hole size greater than  $D_{90}$  is recommended.
2. Fluidization hole spacing: A spacing of 5.08 cm is probably adequate for full fluidization. Advantage is taken of high individual jet velocity to prevent clogging, while a wider spacing leads to regions of high density fluidized sand.
3. Fluidization pipe flowrate: A flowrate in the order of 4 l/(s-m) is required for good fluidization and sufficient fluidized channel width. This flowrate is selected to be in the region of the flowrate/width relationship where the two phases of the relationship meet (see test results Part A). Hence advantage is taken of the relatively rapid increase in fluidized channel width with flowrate per unit length while not extending into the flatter section of the relationship.

4. The pipe should be sloped seaward and, perhaps, an additional pump provided to pump the fluidized region empty. Removal of the delta formed by the scouring of the fluidized sand should be considered.
5. A special valve at the downstream end should be installed to clear the line of sand when necessary. Maintaining a small flow through the fluidization pipe would also help to keep the fluidization pipe free of sand.
6. To maintain a navigable width of forty feet, it appears that at least two or three parallel pipes must operate.
7. The fluidization pipe diameter is totally independent of the fluidization process and is sized only on hydraulic considerations.
8. Due to the relatively high headloss encountered by the flow discharging through the fluidization holes, the pressure in the fluidization pipe decreases very little along the pipe.
9. The smaller the number of fluidization holes per unit length used to discharge a given flowrate per unit length, the higher the fluidization pipe pressure will be.
10. The pump and pipe system must be designed such that an adequate pressure exists throughout the fluidization pipe to ensure the design flowrate per unit length of fluidization pipe.
11. Fluidization can be initiated by a pressure pulse emanating from rapidly increased fluidization flow. The prototype system should be designed to take advantage of this by having the capability of

applying the entire available pumping capacity sequentially to sections of the fluidization pipe(s).

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