EXPERIMENTAL FORMATION OF ALLUVIAL DEPOSITS IN A WIDE RECTANGULAR FLUME

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ACKNOWLEDGEMENTS

We are very grateful to M. Guy Berthault who not only provided financial support for the experimental program but manifested great enthusiasm during the review of the experimental program. We also thank Mr. Nils R. Olsen for his assistance in collecting data during the experiments and preparing photos for the report.

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LIST OF SYMBOLS

D_{10} Particle size for which 10% of the sand mixture is finer

D_{25} Particle size for which 25% of the sand mixture is finer

D_{50} Particle size for which 50% of the sand mixture is finer

D_{75} Particle size for which 75% of the sand mixture is finer

D_{90} Particle size for which 90% of the sand mixture is finer

f Darcy-Weisbach friction coefficient

Fr Froude number

h Averaged flow depth

Q Water discharge

S Water surface slope

U* Friction velocity

Vm Mean velocity

PART I LAMINATION PROCESSES

I.1 INTRODUCTION

The processes of formation of laminae in mixtures of sand particles is very common in many aqueous environments. Laminae are composed of many thin layers, ranging from fractions of a millimeter to several millimeters, of slightly different thickness. The finer laminae are often darker than coarser ones, due to relatively larger proportions of clay, mica, and heavy minerals (Bridge, 1978; Mcbride et al., 1975.).

Horizontal lamination was observed under laboratory and field conditions at different flow regimes. For instance, upper flow regime flow conditions and lower flow regime near critical flow conditions were investigated by Berthault (1986 and 1988); Bridge (1978); Cheel and Middleton (1986); Allen (1984); Smith (1971); Mcbride et al. (1975); Paola et al. (1989); etc. Paola et al. (1989), along with Bridge and Best's (1988) experiment, explained that lamination results from the superposition of two processes: high-frequency erosion and deposition due to turbulence; and migration of low-amplitude bed forms that are in neither upper-regime nor lower-regime solely. A detailed literature review of possible explanations of horizontal lamination processes was presented by Julien and Chen (1989).

Experimental studies of horizontal lamination has been extended recently by Julien and Chen (1989). In their experiments, various types of sediment mixtures have been tested under variety of flow conditions in a small recirculating flume. The results of their experiments confirmed those of previous investigations by Berthault (1988) and others. However, none of these studies was conducted in a large flume.

The proposed lamination study in a large flume extends the recent investigation of Julien and Chen. It is the primary objective of this study to examine the possible formation of horizontal laminae under different flow conditions in a large flume.

I.2 EXPERIMENTAL PROCEDURE

I.2.1 Equipment

The experiments are carried out in a broad flume: 2.20m wide, 0.16m deep, and 6.0m long, as sketched in Fig. 1. With this design, both water and sediment can be recirculated whenever needed. The recirculating pipe is actually designed to recirculate the sediments trapped in the tailbox shown in Fig. 1 and Picture 2 and the oncoming pipe ensures a sufficient supply of water to the flume. The flow rate is controlled by two valves and measured by a Venturi tube in the recirculating pipe and an orifice in the oncoming pipe. The deposition is controlled by tailgate logs which can be varied from .00m to 0.16m (See Fig. 1). Details of the experiment facilities are also illustrated in Pictures 1 and 2.

I.2.2. Sand Material

The sands used in these experiments are similar to those of Julien and Chen (1989). To simplify the problem only two types of sand, one black and one white, were used in run #1.

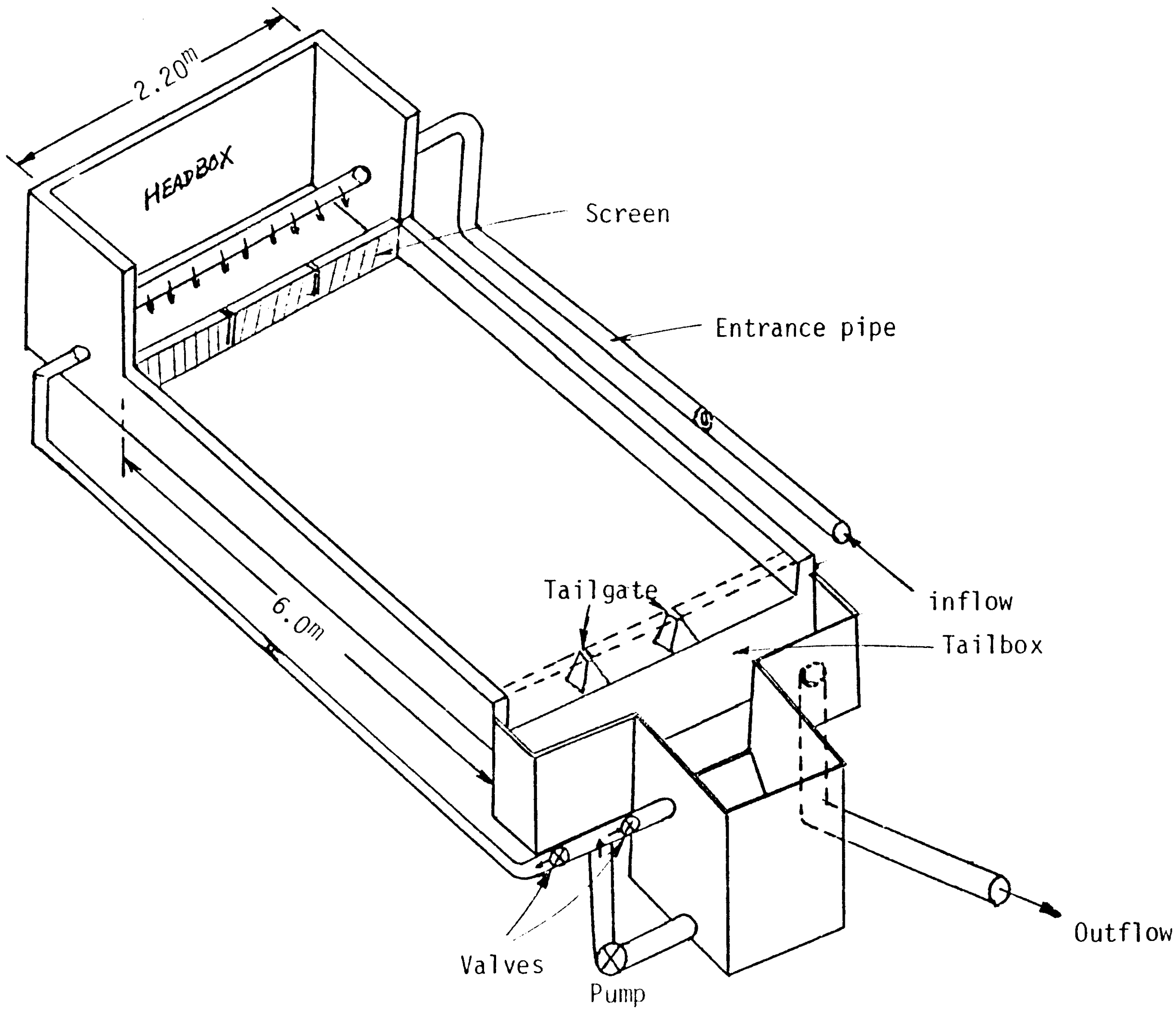
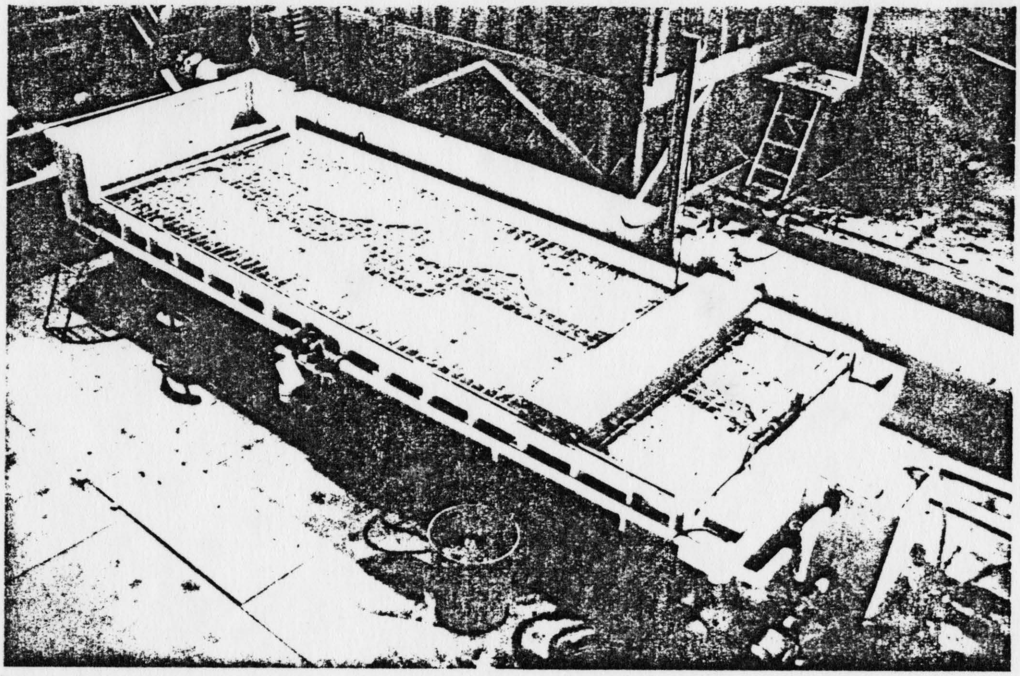
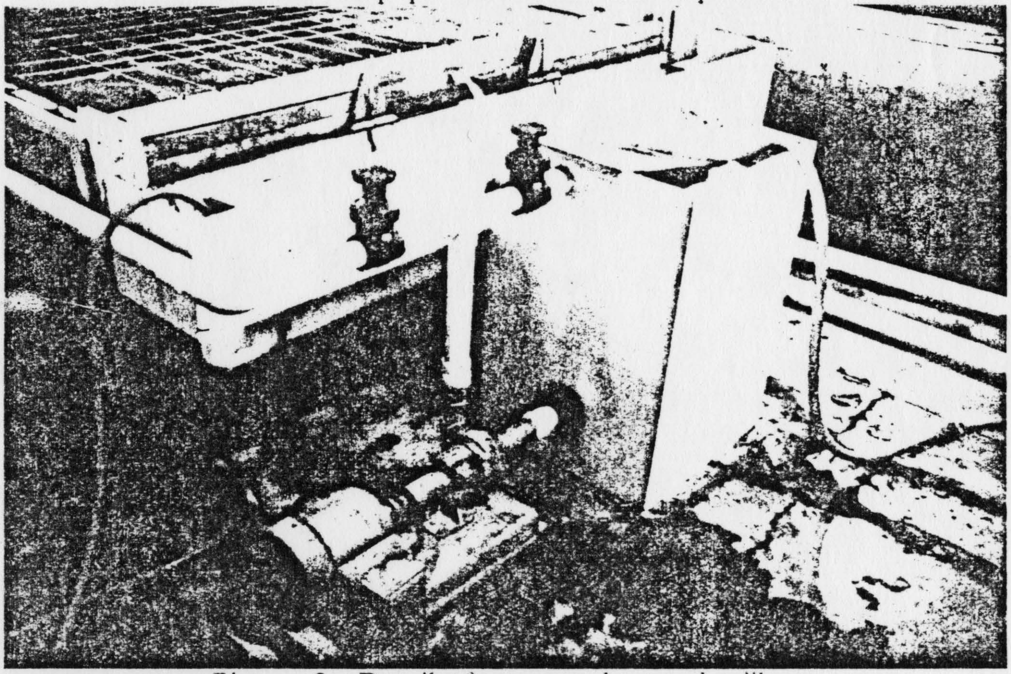


Fig. 1 Equipment used for the experiments



Picture 1. Equipment used for the experiment



Picture 2. Detail of pump, valves and tailbox

The characteristics of these two types of sands are summarized in Table 1, and the particle size distributions are showed in Fig. 2.

Table 1 Characteristics of sands

Type	color	Density	D_{10}	D_{25}	D_{50}	D_{75}	D_{90}
B3060	Black	2.70	.14mm	.205mm	.335mm	.55mm	.62mm
ERC#5	white	2.65	.084mm	.110mm	.130mm	.155mm	.180mm

The following experiment is primarily intended to verify that the results of Julien and Chen in a small flume are also applicable for a wide rectangular flume. Only one mixture has been examined in this experiment. It is assumed that if the results of Julien and Chen could be reproduced for a single mixture, similar good agreement would be obtained for the other mixtures as well. The proportion of black and white sands in this mixture is 1:4. According to Julien and Chen's experiment, this mixture would provide excellent visualization of the laminae.

I.2.3 Procedure

At the very beginning of the experiment, a constant value of water discharge is selected and controlled by adjusting the two valves in the oncoming pipe and the recirculating pipe. Without the control of the tailgate, the sand is shoveled into the headbox shown in Picture 3 at a rate which is as uniform as possible, the turbulence generated from the water exiting the entrance pipe induces excellent mixing condition for the sand. The inflow of sediment passing the screen

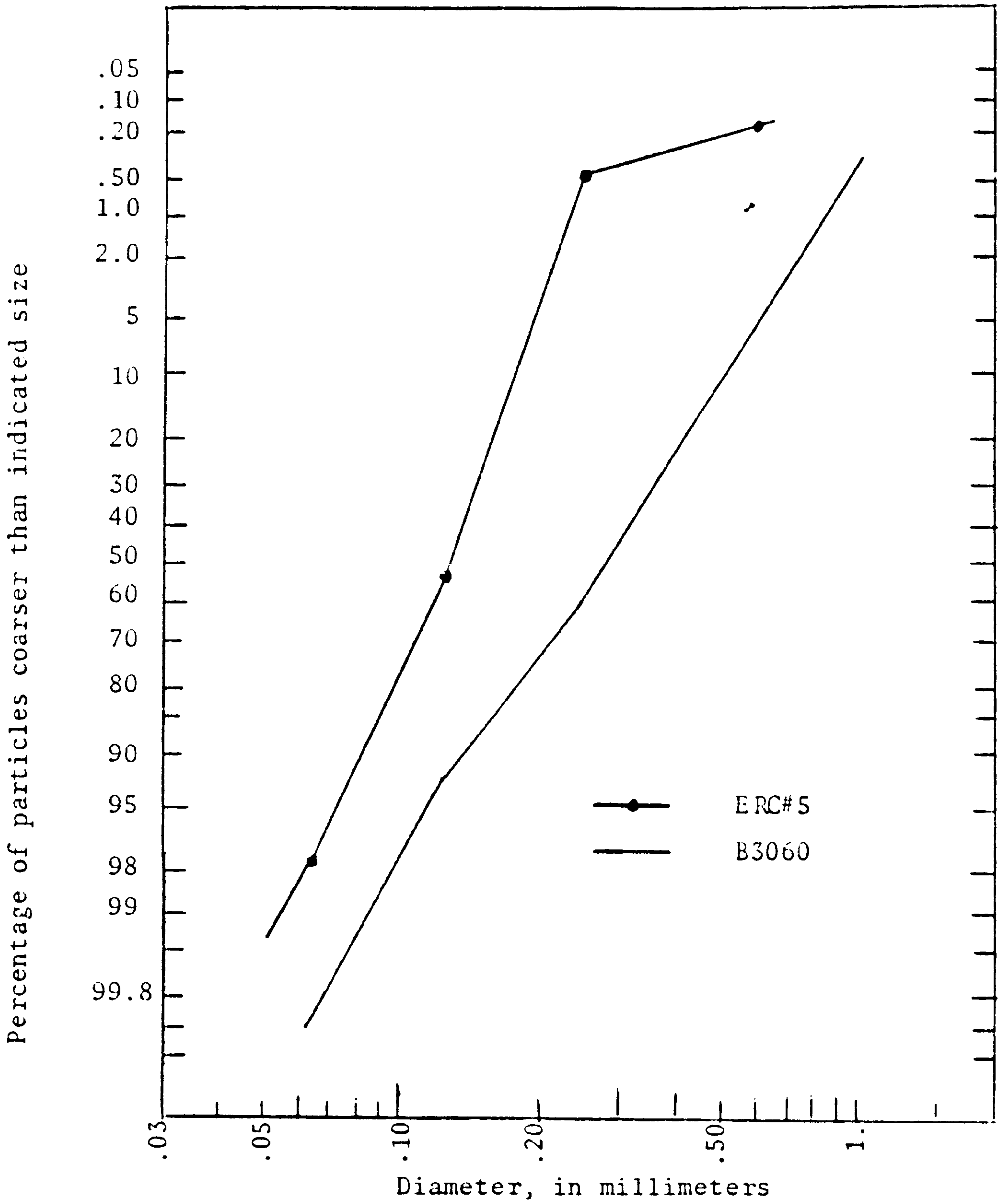
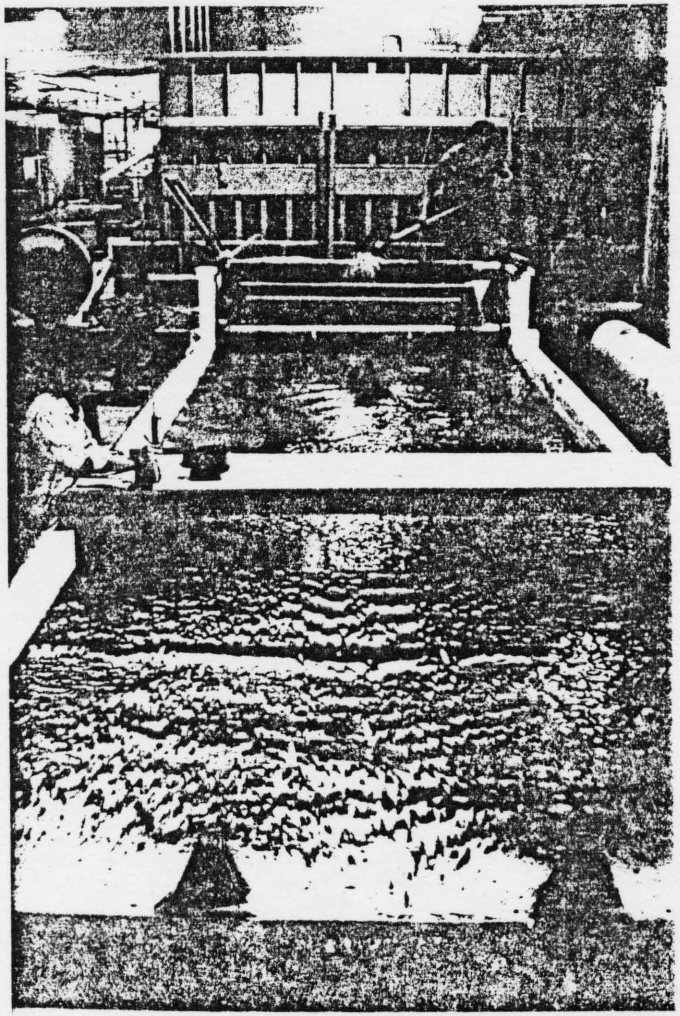
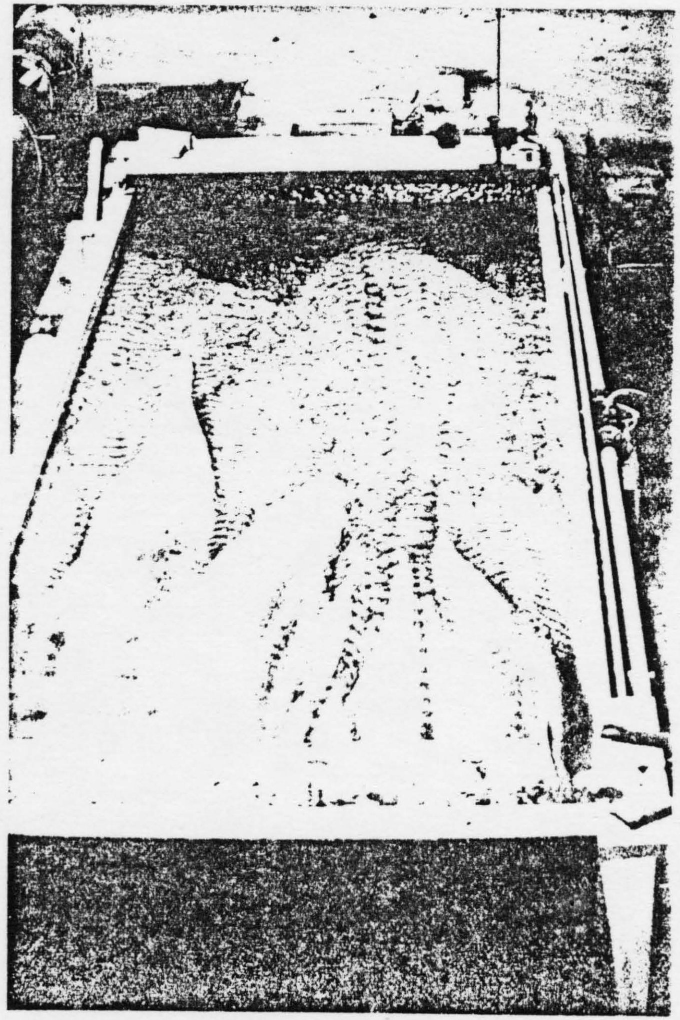


Fig. 2. Particle size distributions of two sands used



Picture 3. Sand feeding and waterlevel measuring



Picture 4. Alluvial developing during the experiment

shown in Fig. 1 is quite steady and spreads very uniformly across the entire width of the flume. When the front of the deposit approached the tailgate, the water level at the gate is raised about 5 cm by controlling the tailgate elevation, in order to increase the deposited layer thickness and provide better visualization of the laminae. At equilibrium conditions, the water surface slopes and water surface elevations at different cross section are measured for the calculation of flow velocity and flow depth. Meanwhile, photos were taken to record the bedform configuration and the movement of sands. At the end of the experiment, the bed elevation at different cross section is measured after shutting off the two valves and after the water in the flume is drained.

After the experiment the deposits are dried on the flume, then cut vertically at some sections both in the streamwise direction and the cross stream direction. Photographs are taken to examined the configuration of laminae.

I.3 EXPERIMENTAL RESULTS

The hydraulic data for this run is summarized in Table 2. The flow depth and velocity are the cross-section averages.

The pattern of sediment movement during aggradation was observed in Pictures 4-6. It was interesting to see that coarser grains (black) kept rolling on the surface of the deposits as it progressed downstream, although more black sand deposited near the downstream end of flume.

Table 2. Hydraulic data summary

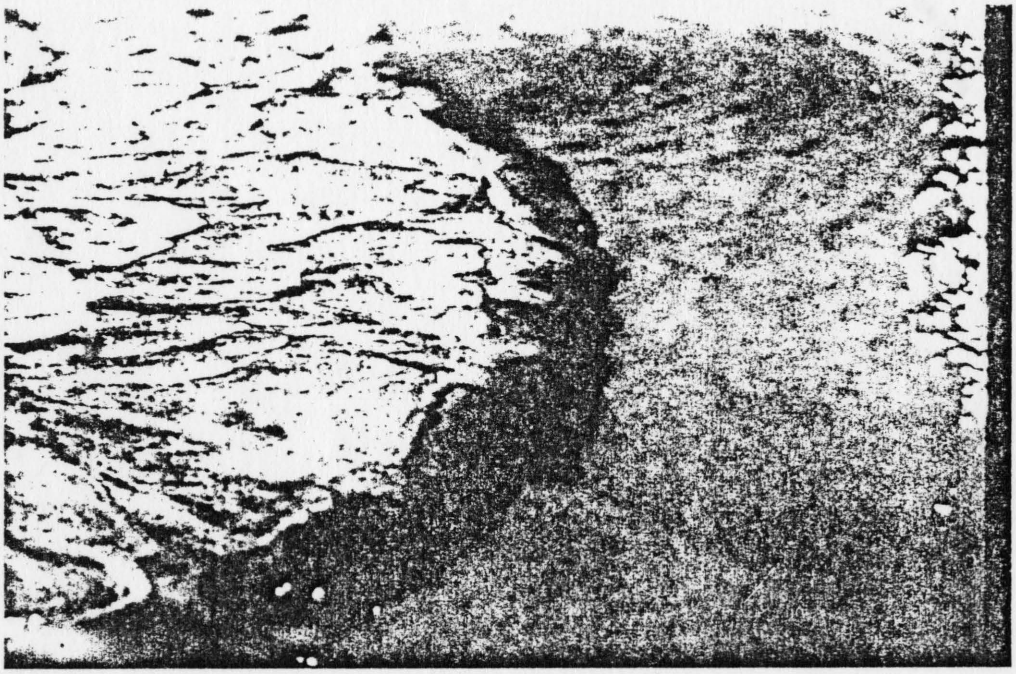
Gate Height	Q(l/s)	h(cm)	Vm (cm/s)	Slope	Fr	U*(cm/s)	f
0.5cm	5.773	1.33	26	0.0081	.72	3.25	.125

Q=flow discharge; h=averaged flow depth; Vm=averaged flow velocity; Fr=Froude number; U*=friction velocity; f=Darcy-Weisbach friction coefficient.

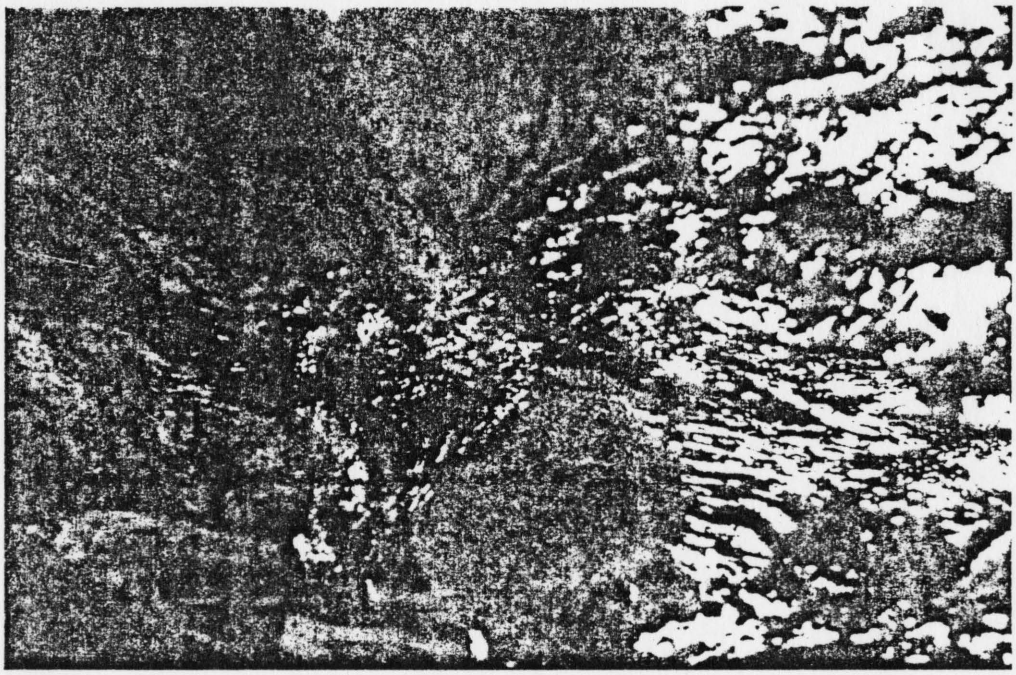
The lamination is examined at three places, respectively the upstream, middle, and downstream section of the flume. Their positions and the related pictures taken are illustrated in Fig. 3 and the laminae are shown in Pictures 7 - 14.

Table 3. Description of Pictures 7-14.

Pic no.	position	orientation	comment
7	upstream	streamwise	
8	upstream	streamwise	clear lamination has observed, with
9	upstream	cross-stream	a distinct layer of black sand
10	upstream	streamwise	closest to the bottom of the flume.
11	middle	cross-stream	
12	middle	cross-stream	bottom layer has more distinct
13	middle	cross-stream	lamination
14	downstream	cross-stream	Laminae is less distinct



Picture 5. Front of delta deposition



Picture 6. Rolling of black sand on the surface of the bedform

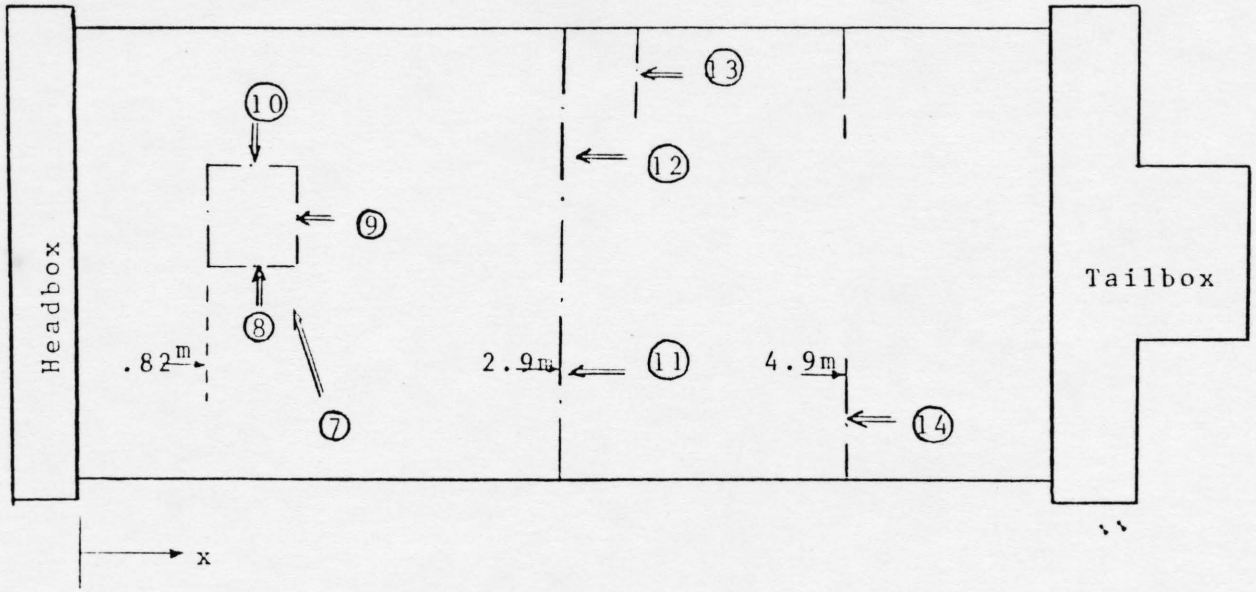
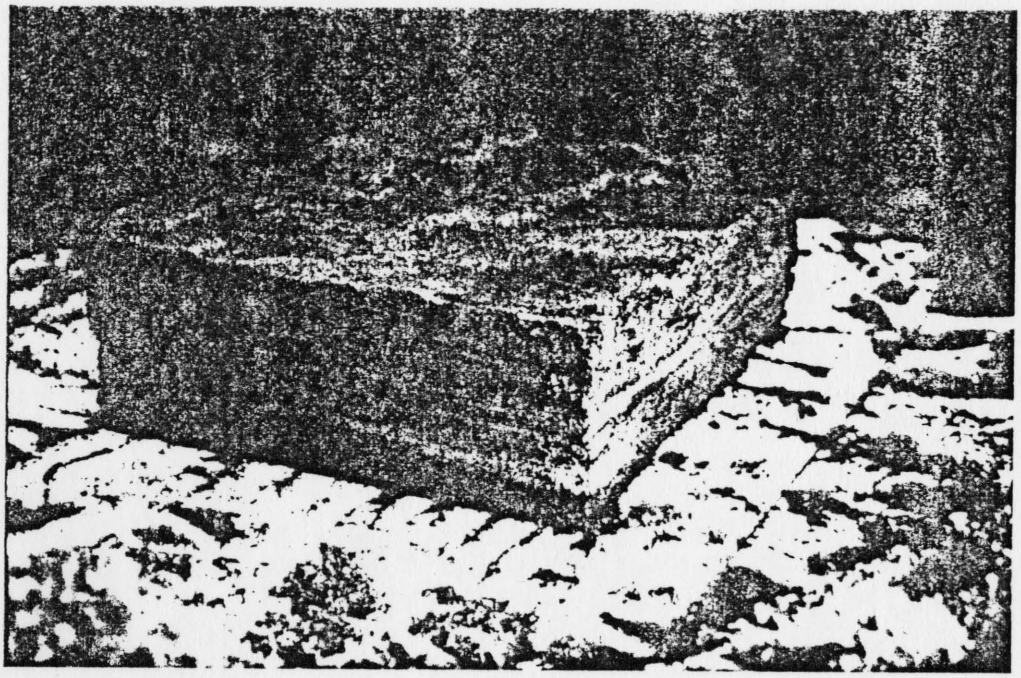
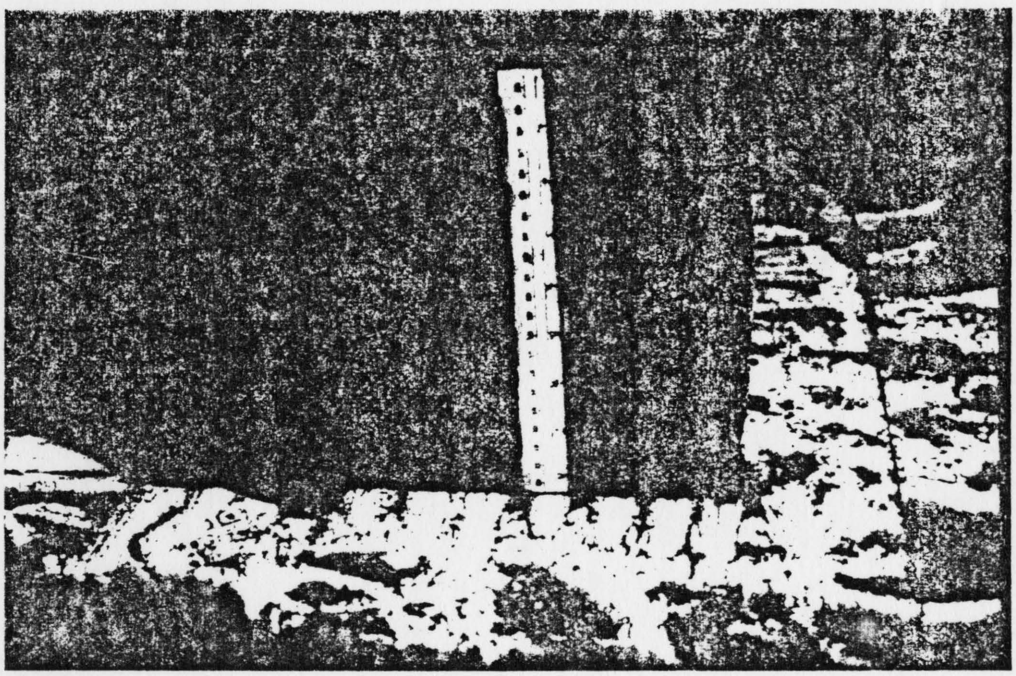


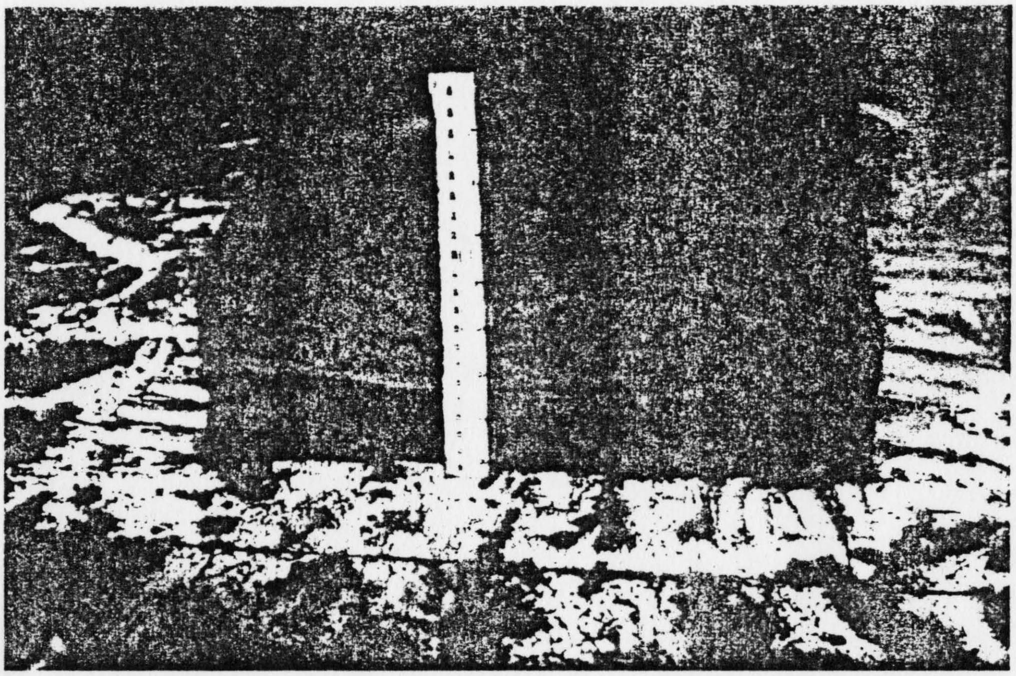
Fig. 3. Locations of cross-sections where deposits are examined (Number in circle refers to the picture no., and blank arrow refers to the direction the picture is taken)



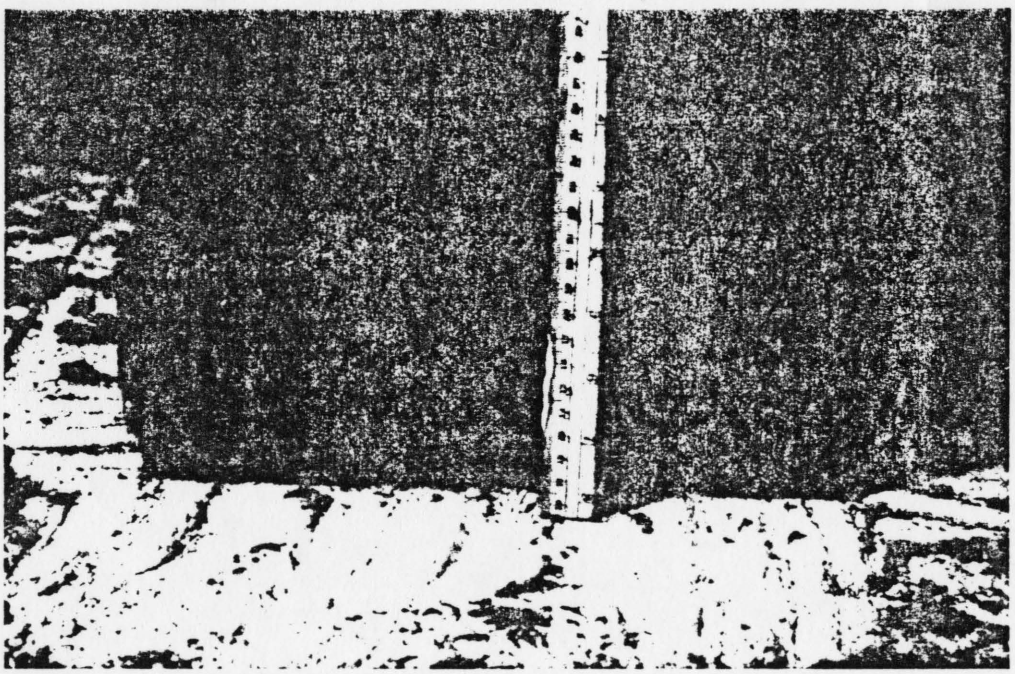
Picture 7. Profile of laminae at upstream



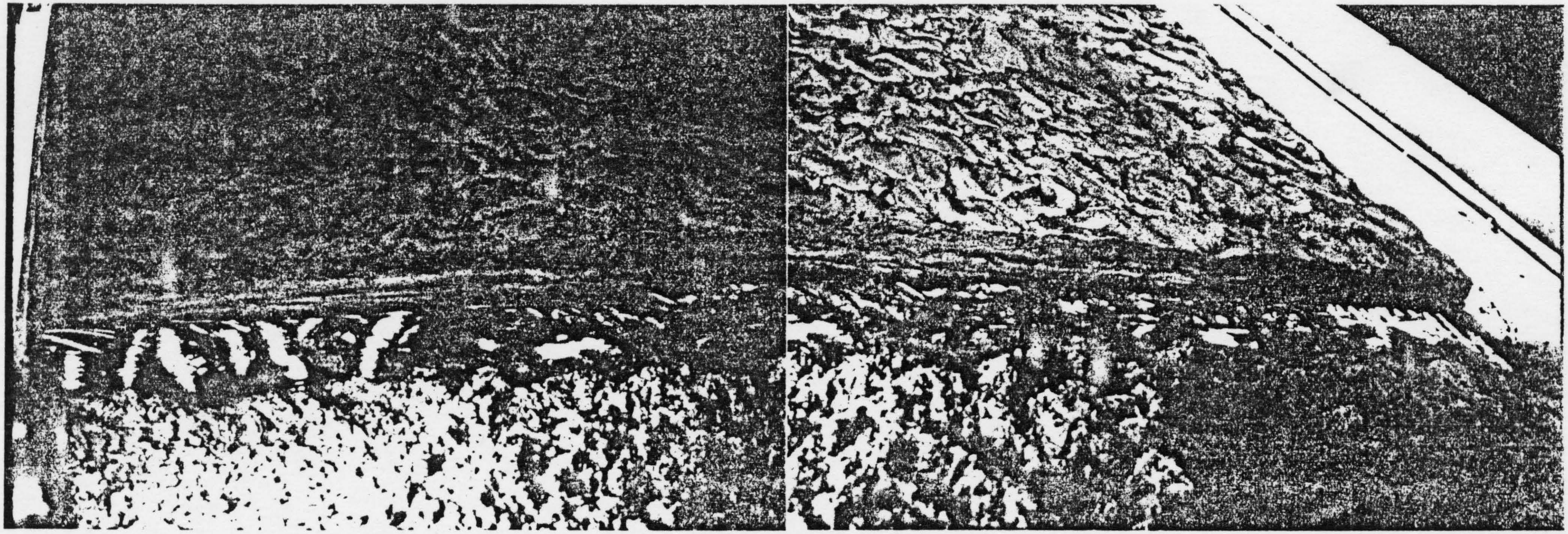
Picture 8. Profile of laminae at upstream



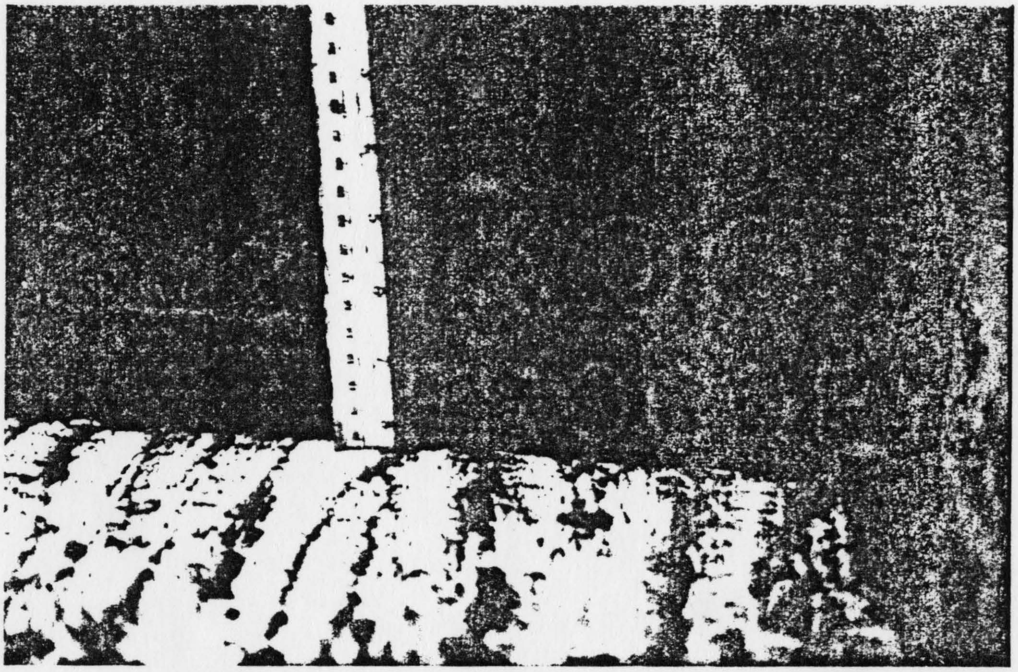
Picture 9. Profile of laminae at upstream



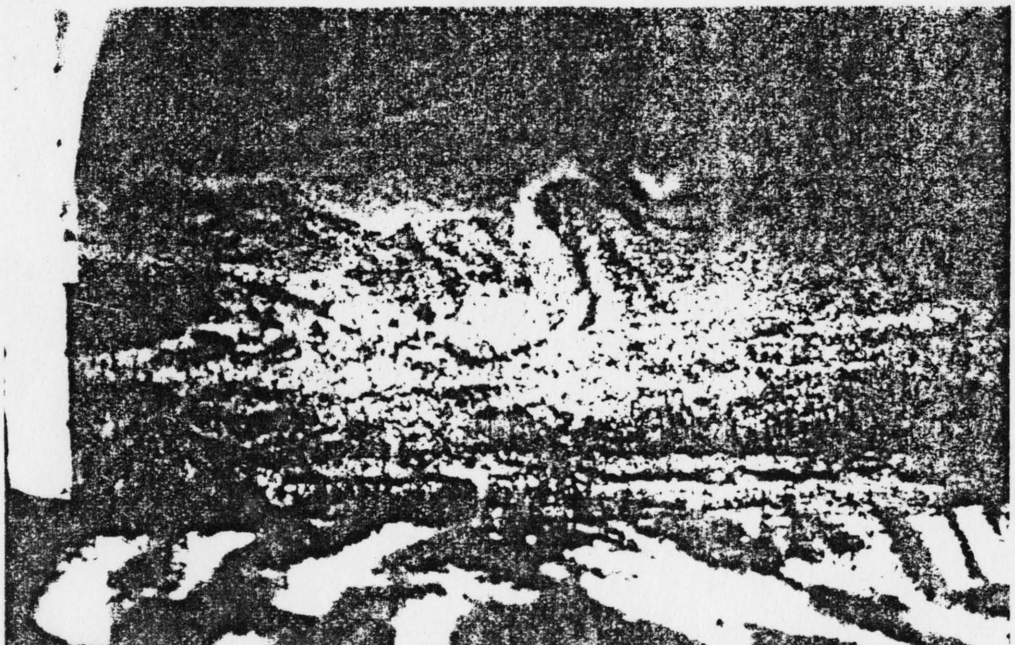
Picture 10. Profile of laminae at upstream



Picture 11-12. Profile of laminae at middle section



Picture 13. Profile of laminae at middle section



Picture 14. Profile of laminae at downstream

The upstream pictures (Pictures 7-10) show that there is a layer of black sand closest to the flume bed at the upstream position. This is in accordance with the observations that the black sand moves at a lower shear stress than the white sand. At the beginning of the test, the black sand moved further out than the white sand, and created this layer.

Pictures 11 and 12 show the laminae of the entire cross section at the middle reach (about 2.9 meters from the headbox). The laminae are still quite distinct as compared with the laminae in the upstream. However, Picture 14 from the downstream position does not show lamination as clear as those from upstream and middle positions, due to the decrease of flow velocity near the tailgate.

Another conclusion to be drawn from the pictures is that the lamination is more distinct at the upstream end of the flume, and less distinct at the downstream end. This may be explained in terms of lamination being the result of a sorting process. The sorting effect will be stronger for increasing velocities, and we have higher velocities at the upstream end of the flume because the slope is higher as we feed in sediments. The velocity at the downstream end of the flume will be lower, and hence a smaller sorting effect and lamination. This can also explain why the layer of black sand closest to the flume bed is less distinct than at the upstream position.

IV. SUMMARY AND CONCLUSIONS ON LAMINATION PROCESSES

Horizontal laminae can be reproduced in a large flume as well as in small flume. The results shows very good agreement with the previous findings of Julien and Chen, and Berthault

(1988) from small flume experiment. Although we can not yet conclude from this single experiment that the thickness of the laminae increases with flow velocity, the observations showed that the coarser particles (black) kept rolling on a deposit of finer particles. It also showed that the gradual thickening of the deposits of finer particles is accompanied by the rolling of coarser particles on the surface.

An important observation is that the black sand grains move at a lower shear stress than the white grains. Considering that the black grains have larger diameter and higher density than the white grains, this seem to contradict Shields diagram. However, the most probable explanation is that the black grain has a much lower degree of roundness than the white grain, and therefore it has also a higher drag coefficient. This can be verified in the further research by measuring the fall velocities in quiescent water.

We should also make an attempt to try to explain the lamination process. When the sand mixture is inserted in the flume, we will have waves of sand progressing downstream in the flume. This is shown in picture 3 and 4. Because the black grains move at a lower critical shear stress than the white sand, there will be black sand in the front of the wave. The black sand will deposit in the front of the wave, and the mainly white sand in the body of the wave will deposit over the black layer. This gives the horizontal lamination.

It should be pointed out here that further experiments ought to be carried out in order to substantiate this intriguing observation. It must be kept in mind, however, that the observation of Julien and Chen (1989), and the video tape of the experiment in the small flume lead to the same conclusive statement. Perhaps additional tests involving several types of sediment mixture, at least one more mixture with more black sand should be investigated. The thickness of the laminae along the dune or antidune seems also worth further experiments.

PART II. CHANNEL FORMATION PROCESSES

II.1 INTRODUCTION.

From glacial regions to alluvial areas, rivers and tidal channels in estuaries do not always follow straight paths, rather they often take on shapes characterized by sequences of smooth bends. Some sequences of bends together generally form the meandering pattern of natural rivers. Because of its popularity in nature, the meandering of rivers has been a central concern in geology and civil engineering for many years, not only because channel migration has practical implications in land use, sediment budgets, and navigation, but also because explanation and prediction of the meandering process has remained elusive.

Studies of meandering channels, which include original of meandering, planimetric prediction of meandering channels, flow in curved channels, sediment transport (sorting) and bed topography of meandering channels, deformation of meanders, etc., have been conducted exclusively in both field and laboratory for the last few decades. Through these theoretical or empirical investigations, fundamental mechanism of river meandering has been obtained, although not satisfactory. The explanation of the complex nature of river meandering, therefore, needs more efforts committed (Lan, 1989).

The purpose of this experimental study on meandering alluvial channels is to investigate the growing and decaying, or in other words, the planimetric deformation of river meanders. The process of river meandering will then be used to compare with a numerical model developed by Lan (1989).

II.2 EXPERIMENTAL PROCEDURES.

Investigations of meandering deformation are conducted on the same flume shown in Figure 1. After the horizontal lamination was examined in the deposits, the surface of the deposits is graded and smoothed to a slope of 1% in the downstream direction. A small straight, trapezoidal channel with the dimensions shown in Figure 4 is incised into the alluvial deposit.

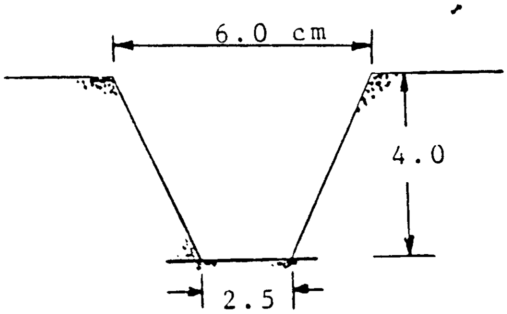


Fig. 4. Cross-section dimensions of original channel

Water is then introduced into the channel through a recirculating pipe at a 20 degree angle with a discharge of 0.17 litre per second. The sediment discharged into the tailbox is recirculated into the headbox and eventually forwarded back into the channel. During the course of the experiment, the suspended load which is very limited and most of the bed load originate from bank erosion, as the channel develops. Therefore, it is not necessary to add sediment to the water at the entrance of the channel.

As the experiment progresses, the rate deformation of the channel is recorded by periodically taking pictures above the flume. A string mesh with 10 cm spacing in both directions has been stretched 5 cm above the floodplain. This mesh is used to locate the position of the meandering channel, and then to calculate the deformation rate of the channel.

The first experiment took nine days until satisfactory results are obtained. After this first experiment, we figured that some cohesive material should be mixed with the sediment on the floodplain to obtain a narrower meandering channel. A 5-10% of bentonite has been added to the central part of the floodplain where the channel is supposed to form. The meandering process is then recorded as in the course of the first experiment.

II.3 EXPERIMENTAL RESULTS

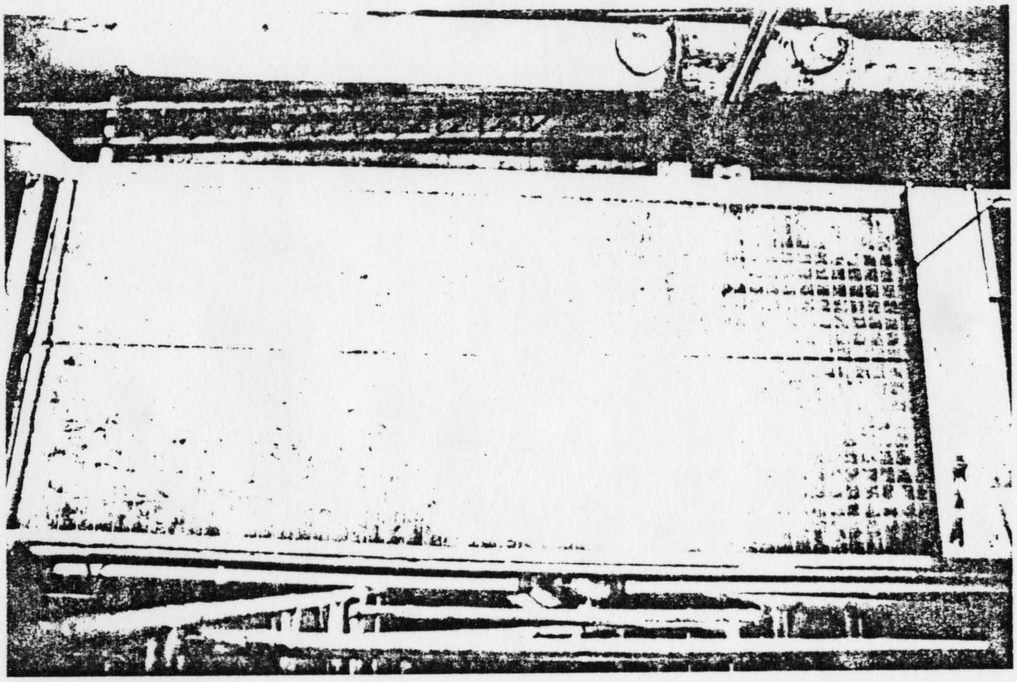
3.1 Experiment without bentonite in the alluvium.

The original straight channel is shown in Picture 15. After 30 hours, a truly meandering channel developed in the flume (as seen in Picture 16). From a series of picture taken (not included in this report), the development of the channel was determined (Figure 5). The comparison of the meandering process with Lan's numerical model will be presented in another report.

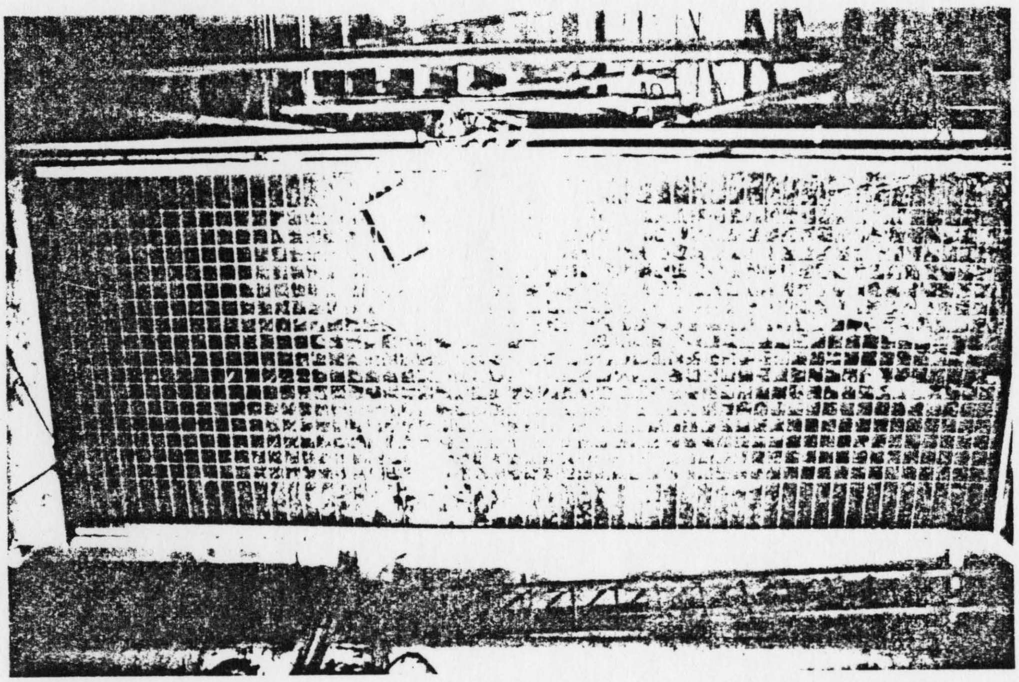
Figure 6 shows a typical cross-section at a meander apex. The figure indicates that the channel bed was extremely irregular although the flow is deeper near the outside bank. We concluded that the irregular-shaped cross-section is due to the bedforms on the channel bed.

3.2 Experiment with bentonite in the alluvium.

The beginning of this experiment is shown in Picture 17. Since there is about 5-10% bentonite in the alluvium, the rate of deformation of the channel was very slow at the beginning.



Picture 15. Original channel on alluvium without bentonite



Picture 16. Channel after 30 hours

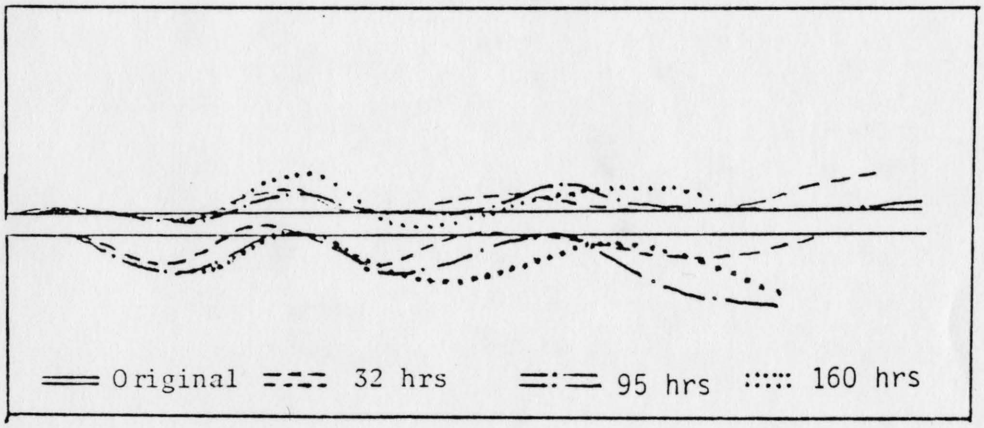
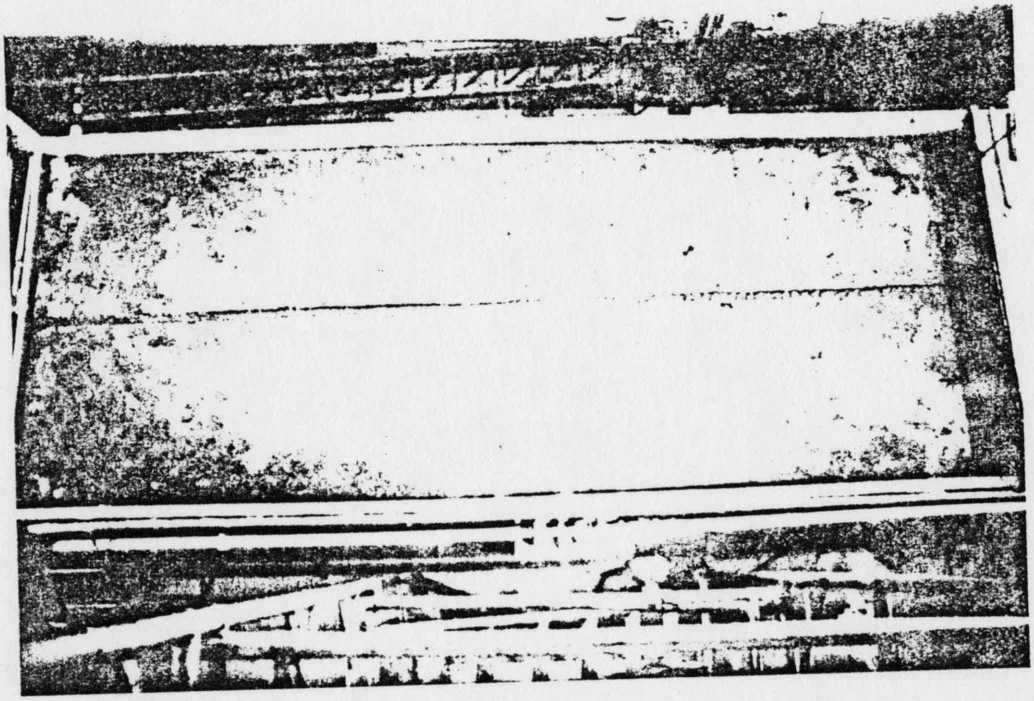
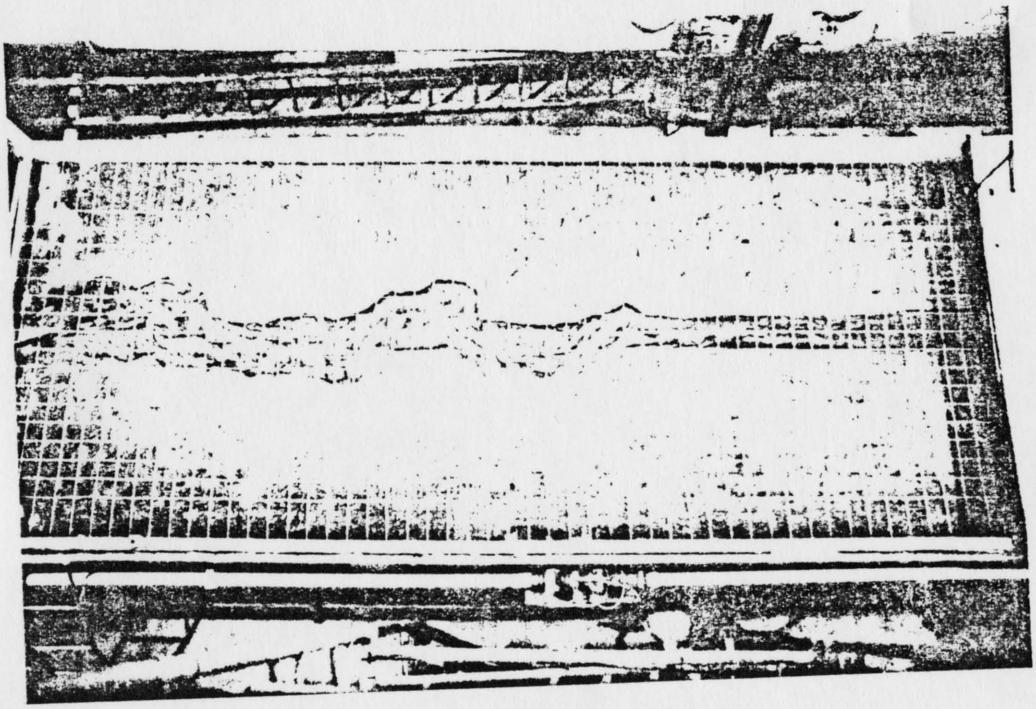


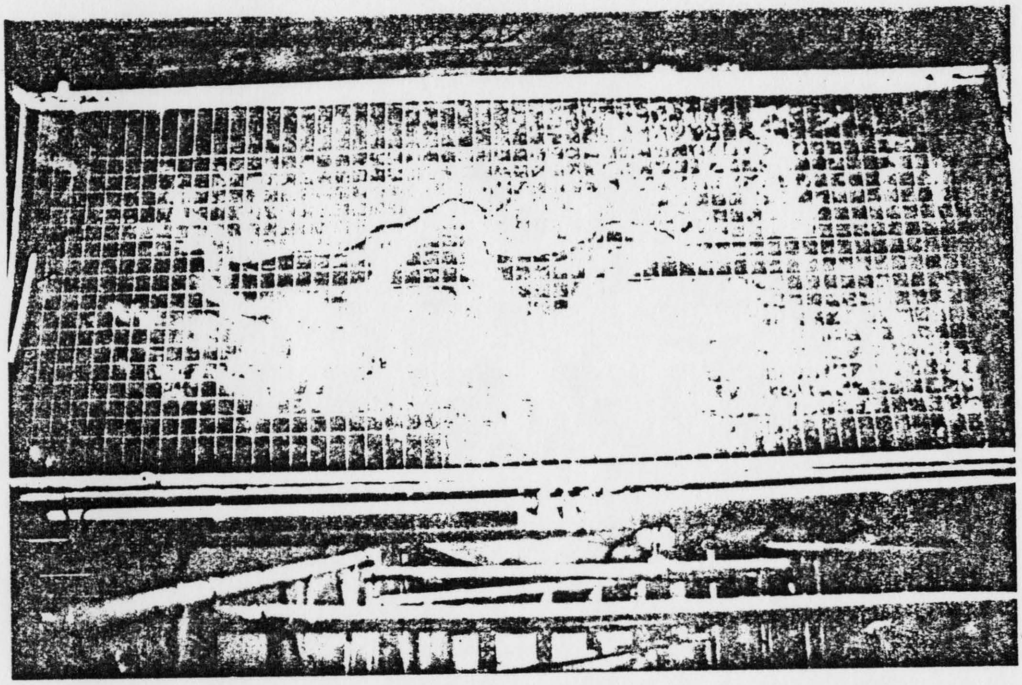
Fig. 5 Development of meandering channel in alluvium without cohesive materials



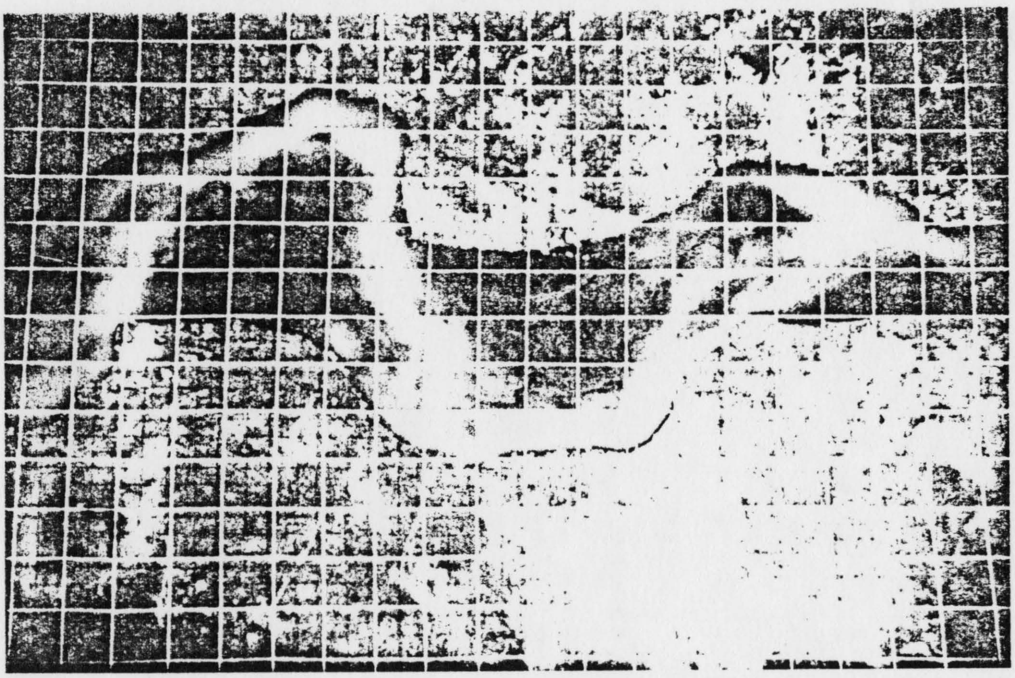
Picture 17. Original channel on alluvium with bentonite



Picture 18. Channel after 100 hours



Picture 19. Channel after 125 hours



Picture 20. Close look of channel bends after 125 hours

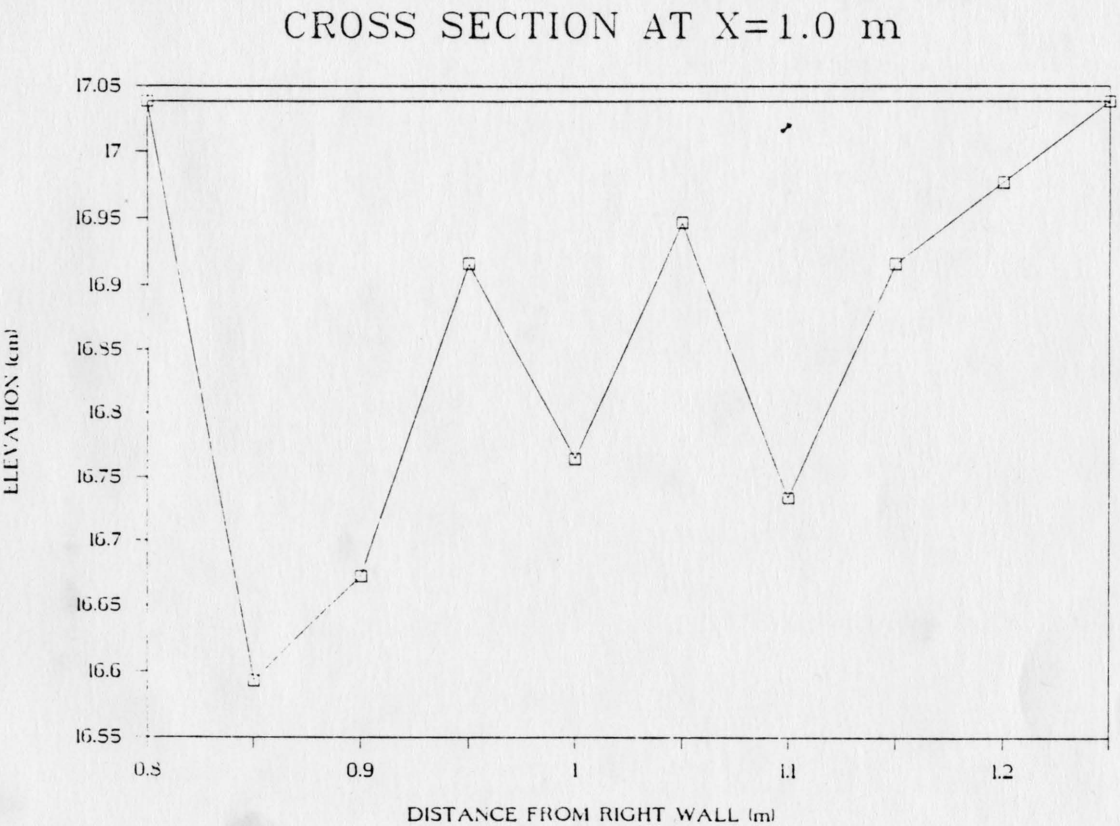


Fig. 6. Characteristics of cross-section of meandering channel at apex

After about 80 hours, a slightly meandering channel developed. Picture 18 was taken at 100 hours after the experiment started. And Pictures 19 and 20 were taken 25 hours later. The experiment is still on going at the time this report is being written. A final analysis of this experiment will be reported by Lan (1989) upon the completion of the experiment.

It is observed that a narrower channel has resulted from adding cohesive to the alluvium. We envisage that this experiment will provide better results than the previous one.

II.4 SUMMARY AND PRELIMINARY CONCLUSION ON CHANNEL FORMATION

The formation of a meandering alluvial channel has been simulated in a laboratory model with and without cohesive material in the alluvium. The deformations rate of the simulated alluvial channels is recorded and compares with previous experiments on alluvial channels.

Although a final conclusion for this study for meandering characteristics has not yet been obtained, the experimental work has shown that truly meandering channels can be simulated in alluvial floodplain with or without cohesive materials. Alluvium with cohesive materials seem to generate more realistic meandering channels.

More work is needed to collect data from more experiments and to analyze the existing data. Prediction from a numerical model has been undertaken to compare with these experimental results. This work should be completed in Mr. Lan's dissertation in final preparation at Colorado State University.

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