

EXPERIMENTAL SIMULATION OF RIVER PLANFORMS IN COHESION MIXED FLOOD PLAIN

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Various river planforms like straight, meandering and braiding on the laboratory condition using layered sediments were reproduced in the small flume with small flow conditions. The mixture of cohesive sediment and fine sand in different ratios were selected to ensure good meandering, high sinuosity as well as to describe the role of cohesion. Experimental results proved the dominant role of cohesion and its sensitivity towards the planforms. The increasing percentage of the clay on the banks would retain braiding, meandering and the straight channels with many similarities as of natural conditions. Also, the associated phenomenon of the bank erosion with slump failures due to cohesive contents demonstrates unique characteristics. The slump blocks dampens the erosion speed on the outer bank, thus creates a situation almost equal with the deposition speed in the inner bank and ultimately caused nearly constant migration as found in nature.

Keywords: *Laboratory experiments, planforms, meandering, slump blocks, cohesion, sinuosity etc*

1. INTRODUCTION

Simulation of river planforms specially meandering in the laboratory conditions has been great interest of research among the scientists since last century. Though the importance and significant role of the cohesive sediment on the meandering channel was recognized since many years, there were not enough studies existed from the past using cohesive material to understand the influence of the cohesion on the planforms both in the natural channel or laboratory flume. To extend and broaden knowledge about the river planform generation and cohesive sediments influence, recently series of experiments were conducted. This paper presents the results from those experiments using cohesive mixed sediments in layered flood-plains.

From the many empirical studies of the river^{1), 2), 3), 4)}, with the observation about the strong presence of the cohesive material on the channel bed and banks, the relation was developed for meander properties and cohesion content of the bank and bed sediments. These studies led to the conclusion that inclusions of the cohesion on the channel cross section are able to define the relations between river

planform shapes and sediment characteristics.

Cohesive sediments were used in the planform simulation experiments since many years in a different role. It was first tested in the experiments⁵⁾ using kaolinite as the suspended load at preformed sinuous thalweg with cohesionless sediment to stabilize the alternate bars. However, considering the layered floodplain with cohesive sediment in the upper layer in the experimental condition was able to generate high sinuosity meanders⁶⁾. Various light, fine grained materials were used in the small laboratory flume and simulated the formation of well defined, highly sinuous meanders⁷⁾. The most recent study⁸⁾, based on experiments using silica flour to represent the fine grained tail of the distribution of the prototype, demonstrated that cohesion is the key variable in the development and maintenance of single-thread channels. Numbers of experiments^{9), 10)} were conducted on the cohesive mixed sediments with rather different objective than meandering in Japan. They described the erosion process in the cohesive mixed sediments due to simulated rainfall as well as proposed an erosion rate formula considering factor like cohesion content, water content, frictional velocity etc.

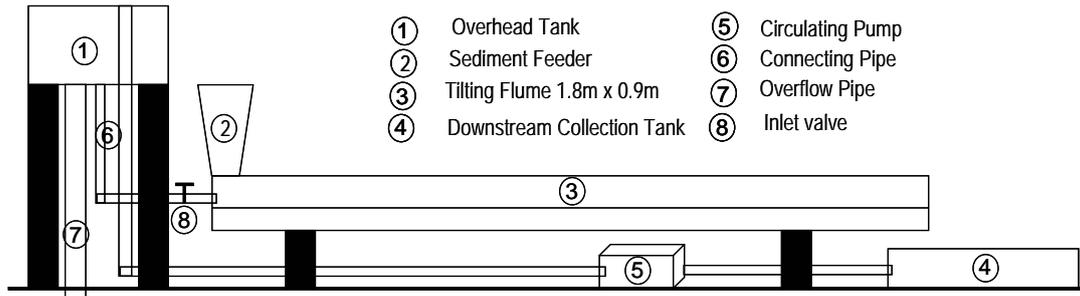


Fig. 1 Schematic diagram of experimental setup

To represent natural conditions with layered flood-plain in the meandering channel, experiments were conducted with multilayered sediments using different percentage of the cohesion with fine sand in the top layer. Though cohesion was judged by changing the depth of both layers defined by bank-height ratio in the earlier study⁶⁾, but direct variation of cohesion in the top layer with same depth for both layers were used in the present experiments.

2. EXPERIMENTAL DESCRIPTION

The experiments were conducted in a flume of 1.8m long and 0.9m wide made of wood with sides of 0.25m height. The flume slope was maintained up to 10% by an adjustable jack support. The discharge flowing in the flume was provided by a constant head tank and it was measured downstream by collecting the water and measuring the time for any specific volume. The water discharge was regulated with a valve provided in the inlet pipe from the overhead tank, so that the excess water from the pump was directly diverted to the outlet tank through the overflow pipe. Sediment was released from the sediment feeder fixed close to the inlet. Water and sediment were collected at the outlet tank, while the water was re-circulated to overhead tank with a small pump (discharge range up to 2 l/s). Figure 1 shows schematic representation of experimental set up.

The mean diameter (d_{50}) of the sand was 0.11mm in the upper layer and 0.28mm in the bottom layer. The industrially available white kaolinite had the particle distribution of more than 99% falling in the range between 5-44 micrometer size and 0.26 of bulk density. The flood-plain was prepared with total thickness of 5cm with double

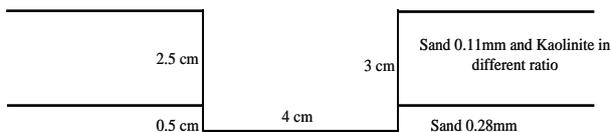


Fig.2 Initial channel cross section in layered sediment used for every experimental runs.

layers of equal depth. The bottom layer was prepared by adding enough amount of water to raise the saturation before loading it by upper layer. The materials for the upper layer were well mixed and massaged by slowly adding small amount of water. The prepared mixture was placed on top of the bottom layer in the flume and the surface was smoothed by hand compaction or by a small trowel. The small initial channel of 4cm * 3cm was cut in the centre of the flume for every experiment run which is shown in Figure 2. Initial attack angle of flow was adjusted to 30 degrees to accelerate the evolution process.

Table 1. Experimental parameters

Run	Discharge	Duration	Clay	Slope
08-I	52 ml/s	84 hr	50 %	0.015
08-II	55 ml/s	132 hr	20 %	0.015
08-III	47 ml/s	50 hr	10 %	0.015

Water was introduced at about 50 ml/s for all runs and the flow is kept at constant rate during the experiments. Details about the experimental parameters are given in Table 1. Few hours after the start of experiment, the sediment is added from the sediment feeder approximately at the same rate as it exits the flume from the outlet. To reduce the cohesive scaling effect, only dry fine sand up to 1.5 gm/min is allowed to pass with the flow, for the generation of instability as well as to recover the sediment deficit. Part of suspended load was derived from bank erosion as channel progressed⁶⁾ which mixed with non cohesive sediment from entry.

3. GENERAL OBSERVATIONS

Three different cohesion ratio i.e. Kaolinite content of 50%, 20% and 10% in the mixture with fine sand were tested for the same initial geometry and nearly same hydraulic conditions. With the equal ratio of clay and fine sand on the upper layer, the bank developed higher resistance against erosion due to binding of cohesive and non cohesive

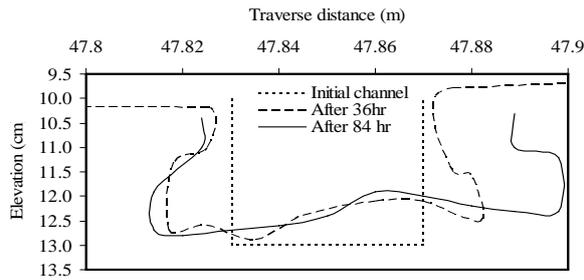


Fig.3 Cross section for the run with equal cohesion (Run 08-I) in top layer. Flow direction is away from observer.

materials. Slow bank erosion happened which changed the initial geometry into haphazard widening in whole length. The bank erosion observed was in the form of blocks with some irregular shape which are called slump blocks^(11),12). These blocks are highly dependent on the cohesion content of the bank for its formation, size, shape as well as decomposition with the flow. The sizes of the slump blocks obtained were in the range of 5-12 cm in length, 0.5-1.5cm in width and about 2cm in height. The strength of the flood plain against resistance to erosion led towards the cantilever failure⁽¹¹⁾ due to the time lag between the erosion below water level and slump block above water level in the flood plain. This created cross section (Fig. 3) with toe erosion and hanging part above water level in the flood plain. Large numbers of tension cracks were formed with width up to 2mm size in the banks before slump failure. The formation of tension cracks indicates the strength of the banks against erosion as observed by Sekine. et. al.⁽⁹⁾ for different cohesive mixtures.

The decrease of cohesion in the flood plain i.e. 20% with fine sand produced slump blocks with smaller sizes which decomposed faster with the flow. The sizes of the blocks obtained were 3-8cm in length, 0.5-1.5cm in width and about 2.5cm in height. The failed slump blocks near the edge of the banks helps to increase flow diversion towards opposite bank which accelerate alternate bank caving. This led to progression of the bank erosion and the flow slowly formed meandering path. The detachment from the slump and re-suspension of the cohesive sediment settled down and deposited in the bars. This further mixed with non-cohesive sediment and increased its strength with the time. Not only the size and decomposition was regulated from the cohesion content but also the variation in the shape of detachment like thin sheets, pellets or spherical particles were observed. Two sets of alternate bend formation were observed in 24 hours with wave length of about 60cm and the amplitude of 30cm. The bars were continuously increasing in

height and some portions were observed above water after 40 hours. The very interesting and important observation for the slump failure was the damping of the bank erosion after the failure. The failed block restricts the active flow towards the outer side which ceases further erosion, so that a constant migration of bank occurs in nature⁽¹²⁾.

Further reduction in the cohesion ratio i.e. 10% in the mixture on upper layer caused a decrease in binding strength and showed faster bank erosion process⁽¹⁰⁾ with slump failures as well as faster decomposition. The size of the blocks retained were less than 4cm in length, 0.4-1.2cm in width and about 1.5cm in height. The clay from the decomposed blocks washed and exited from the flume so that the bar lacked required cohesion portions for strengthening. Also the faster decomposition of the slump blocks does not support flow deviation process like in higher cohesive run, thus unable to create meandering path and supports other planforms.

4. RESULTS AND DISCUSSIONS

The inclusion of appropriate cohesion was effective on producing well defined meandering channel. The most effective clay percentage was found at 20% of total weight of the mixture in upper layer under the flow rate of 55 ml/s. Average values of hydraulic parameters for all experimental runs including velocity, depth etc are given in Table 2.

Table 2. Hydraulic Parameter of the experiment

	Run 08 - I	Run 08 - II	Run 08 - III
Discharge(ml/s)	52	55	47
Depth(cm)	0.6 - 1.0	0.5 - 1.1	0.4 - 0.80
Velocity(cm/s)	26 - 34	19 - 22	20 - 23
Froude Nos	0.93 - 1.21	0.68 - 0.79	0.82 - 0.95
Reynolds Nos	2000 - 2750	1500 - 1750	1200 - 1400

The decreasing levels of cohesion such as 50%, 20% and 10% on the experiments were able to produce straight and wide channel as shown in Figure 4, complete meandering with moderate sinuosity as shown in Figure 5(i) and shallow channel nearly like braiding as shown in Figure 5(ii). The cohesion levels demonstrated very sensitive dependence as 20% and 10% produced drastically different progression of the outer banks as shown in Figure 6 for temporal evolutions of outer banks. The Froude number was usually less than unity, this means the flow was sub-critical and the wide variation of Reynolds number during the experimental run shows variation from laminar to turbulent. The distinguishing feature of these

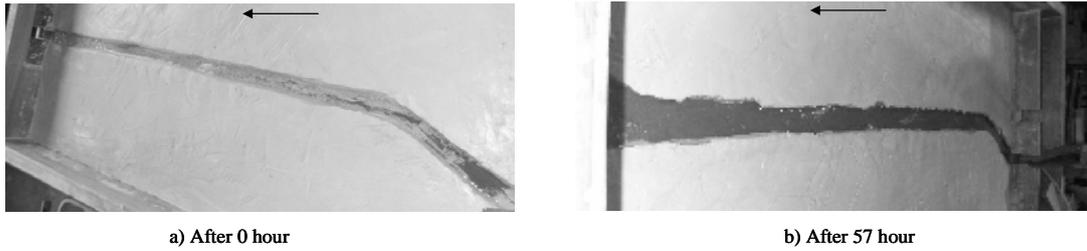


Fig.4 Photograph showing bedform evolution for experimental Run 08-I. Flow direction is from right to left.

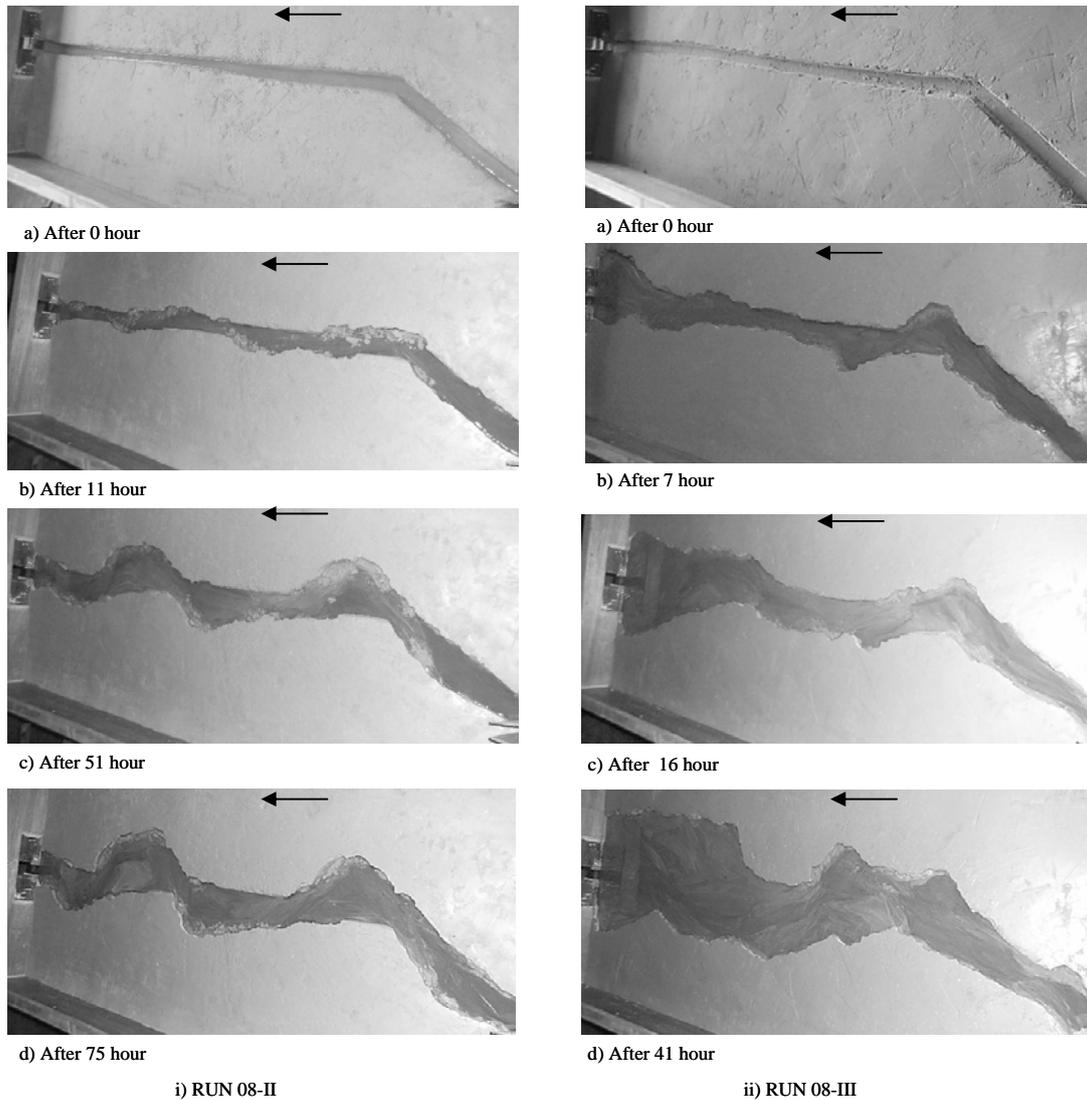


Fig.5 Photograph showing temporal evolution of bedform in experimental Run 08-II and 08-III. Flow direction is from right to left.

experiments was the transformation of the point bars and complete separation of the channel and bars. At some points, the point bars were observed above water which would lead towards transforming of flood-plain by strengthening due to cohesion. The variation of bank-height ratio on the previous experiment⁶⁾ reported the variation of characteristics of meandering i.e. sinuosity and curvature whereas direct variation of cohesion content in the upper

layer of the present experiments produced the variations in the planforms as straight, meandering and braiding. This agrees with the findings from the large number of field observations about the bank sediment contents and the river planforms^{1), 2)}. Also the argument about the transformation of meandering in the laboratory condition requires certain level of cohesion to divert the channel to a single thread channel¹³⁾ was supported by this work.

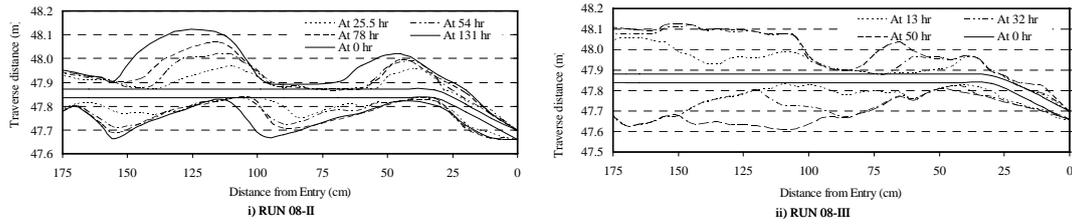


Fig.6 Bank outer line movement on Run 08-II and 08-III. Flow direction is from right to left.

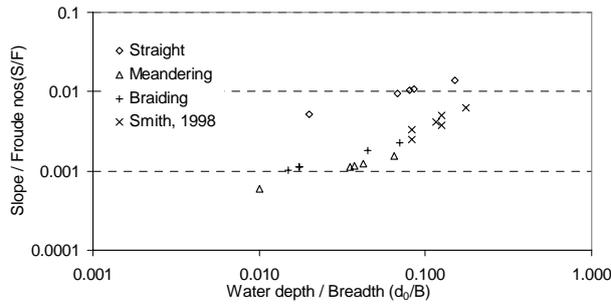


Fig.7 Regime condition on present experiments

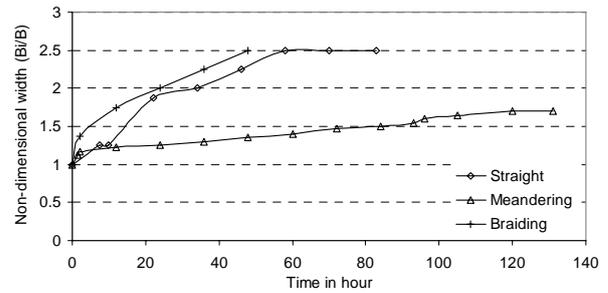


Fig.8 Evolution of non-dimensional width

The sediment role was found significant for changing slope, building the bars, stabilizing with the cohesive particles as found in earlier work⁵⁾. The bedload transport was the dominant mode of the sediment transport whereas suspension mode was often observed during slump failure and decomposition. The turbid water in the vicinity confirmed the presence of clay particles on the suspension. These particles were partly washed away from the flume and partly deposited in the bar. The initiation of the alternate bank caving in the present experiment was solely due to slump failure mechanism. This is in contrast with earlier researcher's findings about sediment movement as the key phenomena to initiate meandering^{5), 14), 15)}. The incidence that led alternate flow path was the slump failure by bank erosion and deviation of flow towards opposite banks due to obstruction of failed block. Later on, sediment movement on bed stabilized the bars faster and transform towards point bars and clear meander channels. Smith⁷⁾ pointed out limited range of water flow for the formation of defined channel and meandering in his experiments and increase in discharge from that range would result in braiding. Nearly constant discharge was maintained in these experiments to produce the bed shear stress more than the critical stress so it would ease the movement of sediments in all runs.

Slope is another important parameter as noted earlier by other researchers¹⁵⁾. The various trials of the recent experiments made clear that sufficient longitudinal slope was necessary to form well defined meandering channels. Also slope is adjusted

with the bedform changes and the variation in sediment transport. The observation regarding the water surface in these experiments indicated that slope is decreasing as the flow path changed or increased by sinuous thalweg. The evolutions of planforms in this experiment did not fully support the classifications for different planforms described by Parker¹⁶⁾ for the meandering river or experiments with cohesionless soil. Fig. 7 shows results from present experiment including earlier work with meandering results⁷⁾. But the reasons pointed out by Fredsoe¹⁷⁾ for the generation of meandering is still valid provided with the rough banks, which is the case here due to the mixture of cohesion.

Some Initial trials show that reproducibility is possible qualitatively with same geometry and hydraulic conditions as observed earlier¹⁵⁾. The evolution of non-dimensional width for every case is presented in Figure 8. The meandering width progress slowly in comparison with straight and braided forms. Almost equilibrium stage is observed in straight and meandering simulations while braiding planforms looks far from the equilibrium stage. The measured meandering properties from present experiments are compared with the real meandering river observations and shown in Figure 9. The final meandering properties from the experiments are similar with the meandering properties of natural observations for stable meandering rivers^{3),4)} and good agreements with one of the earlier experiments⁶⁾.

5. CONCLUSIONS

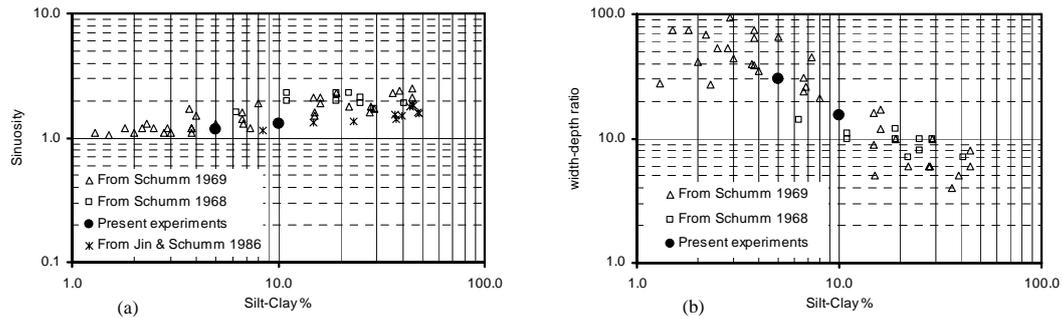


Fig.9 Comparison of experimental and theoretical results of meandering properties (a) sinuosity (b) width-depth ratio

The transformation of planforms with the layered sediments based on recent experiments using cohesion as the variable parameter was proposed. The different percentage of cohesion on the upper layer clearly differentiates the planforms like straight channel, meandering and braiding. The cohesion influence on the slump block failure and decomposition was discussed for the first time on the bed form evolutions. Similarly the sensitivity of the cohesion percentage towards the formation of different channel pattern was judged and described. These experiments are the first to define the bed form evolutions with full dependency parameters on the cohesion. It's able to replicate the bedforms with changing the bank sediment composition and keeping the hydraulics constant.

Though these experiments are not sufficient to prove all the clay influences on channel behavior, but this study can help to understand the mechanism and process for future work concerning basically the behavior and the effects of the cohesion on the channel evolution phenomena. The more studies relating reproducibility with similar hydraulic and bed conditions as well as diminishing the clay behavior due to scaling effect on small flumes will be interesting and focus for future.

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