A Study on the Effects of Spur Length and Spur Spacings on Sediment Trapping Capacity of Permeable Spurs

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Abstract:
Rivers in the north-eastern region of India originate from the Himalayan foothills and transport large quantities of sediment for most of the year. When these rivers enter the Assam valley, a sudden reduction in bed slope causes a rapid decrease in flow velocity, leading to significant sediment deposition on the riverbed. This results in aggradation, reduction of the effective flow area, and formation of mid-channel sandbars. During the monsoon season, high discharges intensify bank erosion due to strong flow impingement on the riverbanks, necessitating effective river training measures. Porcupine screens are widely used for riverbank protection in the region; however, their performance has often been inconsistent. This may be attributed to the absence of standardized design procedures and the limited consideration of site-specific parameters such as flow characteristics and channel geometry. The present study evaluates the relative performance of different porcupine models based on their effectiveness in promoting near-bank sediment deposition. Scaled porcupine models were developed considering channel dimensions and discharge conditions and were tested in an experimental field channel. Bed-level variations within the porcupine fields were measured using a point gauge under different submergence ratios to identify the most effective configurations.

Keywords: Porcupine, Erosion Control, Permeable spur, Velocity reduction, Sediment deposition

1. INTRODUCTION

1.1 General

Riverbank and in-stream protection is becoming a necessity in many major rivers of India where scouring of the river bed and bank materials leads to change the river course and thereby flooding and causing losses to lives and properties in the nearby areas. Protection measures like dykes, impermeable spur embankments etc. associates with high labour and material cost. Thus, in such reaches of the big Indian rivers it becomes necessary to employ some cost-effective measures which are reliable as well as economical.

1.2 Porcupines

Porcupines are a form of permeable structure designed to reduce flow and trap sediment. They have pole-like projections in all directions, resembling a porcupine with its quills sticking into the air. They are used as flood control structures, and for riverbank and bed protection. Porcupines can be used in a line forming a spur into a river, as silting aprons for larger spurs, and in a longitudinal line along an embankment. Originally such devices were made of timber or bamboo, but these have a limited lifespan. Porcupines can be used as a pro-siltation protection device for a natural river bank or an embankment. The structures are

flexible, which ensures stability against extreme water forces and even earthquakes. Porcupines reduce the flow velocity, intercept and break eddies formed by floodwater, and fill up scour holes with silt.
RCC porcupines are the most widely used. These members are casted in-situ at the site or location near the site. Generally, six members are used to construct one porcupine. The size of one member is generally kept as 3m x 0.1m x 0.1m or 2m x 0.1m x 0.1m. These members are joined together with the help of Nails, GI wire, nylon ropes etc.

1.2.1 Design parameters associated with Porcupine screens

The various functions that are supposed to define the design parameters for porcupines are:
i) River current.
ii) Max. Discharge.
iii) Braided nature of the stream

iv) Average Grain size.
v) Cross sectional dimensions of river, bed slope

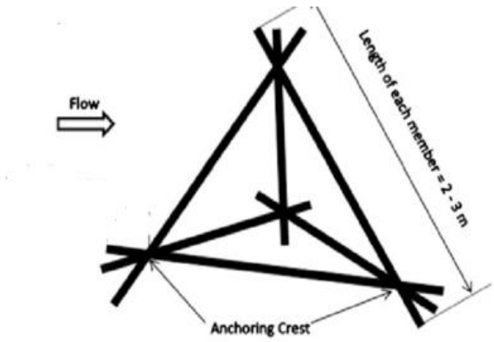

Fig 1: Porcupine model (CWC Manual, 2012)

1.2.2 Classification of Porcupine structures:

Porcupine structures are classified on the basis of the pattern of their lay-out as discussed below:

i) Screens

4 to 6 rows of porcupines are used in a permeable screen. A single permeable screen is generally not found effective. At least two screens are provided for the screen structure. One screen is normally provided at the entrance of the bypass or secondary channel. The second screen is provided at a distance of 1 to 1.5 times width of the screen.an image of a Porcupine screen is given as Fig 2.

Fig 2: Porcupine screen at Afala,Majuli,Assam

ii) Spurs

In such arrangement, the porcupines are laid abutting to each other in a row. Walking space can be provided between the rows for inspection and repairs. Each permeable spur is made up of 3 to 4 rows of porcupines. More rows are laid for higher velocity, deeper flows and flood waves of longer duration etc. On a straight reach, permeable spurs are spaced at 3 to 5 times its length. On a curved channel, depending up on the obliquity of flow, the spurs are spaced at 2 to 4 times the length. Projection of the spurs into the river channel is normally 15 to 20 percent of waterway. However, more projection can be allowed depending up on the velocity and depth of flow.

In order to resist the tendency of outflanking, additional porcupines or cribs are provided along the sloping bank upstream and downstream of the spurs. At least three spurs are provided for a specific reach to be protected. A single permeable spur is generally not found effective. The practice of providing one or two additional spurs upstream and downstream of the eroding reach, alignment pointing towards upstream with reference to the flow, etc has to be followed for the permeable spurs also. Layout, spacing, projection, angle of spurs & their effectiveness should be determined from hydraulic model studies. A typical layout of porcupine spur is shown in the fig 3.

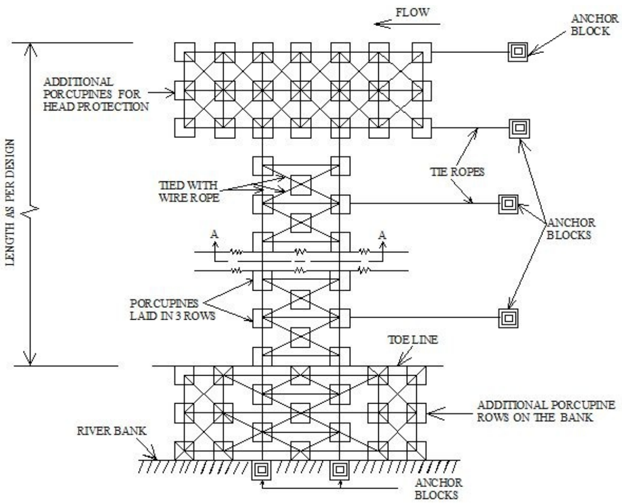

Figure 3: Typical porcupine spurs (CWC Manual, 2012)

iii) Dampeners

For a maximum depth of flow up to 3m, two rows of porcupines are laid along the bank on either side of the toe as dampeners. For a depth of flow between 3 to 6m, rows of porcupines are added across the bank up to the HFL at an interval of 2 to 5 times the elements used. The lower spacing is used for higher velocities, oblique flow and critical locations. The porcupine or crib elements are laid abutting to each other in a row. The rows are also placed abutting to each other. Walking space can be provided along the row for inspection and repairs at an interval of 6-7 elements.

1.3 Sediment Transport in Open Channel Flow

The knowledge of sediment transport is most important to determine whether erosion or deposition will occur, the magnitude of this erosion or deposition and the time and distance over which it will occur. The quantity of sediments entering the channel is an important factor which influences the flow in the channel, cross-section of the channel and a true regime of the channel. The regime theory of channel design does not consider the sediment flow as an important factor. However it has now been realised that the channel design will not be successful unless a detailed study of sediment transport is carried out. Different types of sediment flowing in a channel are mentioned below:

1.3.1 Bed load

These are the load of bed materials that are transported along with the bed of channel. Generally the bed load is transported by sliding, rolling and saltation. Approximately 5% to 20% of total sediment transport is bed load. Bed load is generally consisting of the heavier particles of sand pebbles, gravels and cobbles and all other type of materials, which moved along the bed of the river. Saltation is another type of method of bed load transport. In this process the current lifts up some of the bed load sediment resting on the bed as and when it gains some velocity and carries the same to some distance before it again falls to a rest position. At the place of its fall it may succeed on imparting an impact to another resting particle that may be in turn lifted by the current and moved for some distance. The newly displaced particle may repeat the process.

1.3.2 Suspended load

When part of the sediment is uplifted by the fluid flow and kept in suspension by the turbulence of flow, it is called suspended load. The particles of suspended load are supported by the surrounding fluid. The suspended load is generally consists of smaller particles like clay, silt and fine sands which are lighter enough to be carried by the flow in suspension. When there is a considerable check in the velocity, the suspended sediments starts to deposit.

1.3.3 Dissolved load

These are the particles that are carried in solution by the stream flow. Usually dissolved load is much smaller than suspended load.

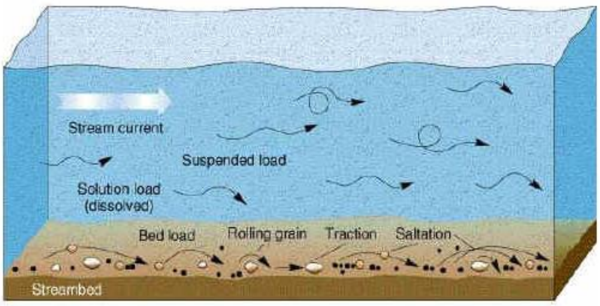

Fig 4: Different types of sediment load
(Source:www.cliffsnotes.com)

1.4 incipient Motion Condition

In the prediction of sediment transport rates the concept of excess shear stress has a major role to play. It is also used in channel erosion and channel design. The concept of incipient motion is based on the shear stress criteria. Incipient motion is the transition state at which the loose sediment resting on the bed just starts moving due to an increase in the hydrodynamic force.

2. MATERIALS USED AND THE METHODOLOGY ADOPTED

2.1 Materials description

2.1.1 Porcupine Model:

The porcupine models used in this study are prepared in reducing scale to match the dimensions of the field channel as per the guidelines of CWC manual 2012. The models are prepared by bamboo sticks of size 5cm in length and 0.5 cm in thickness which were glued together. Extended lengths of 3cm for each member of the model are kept for embedding them into the simulated river bed in the field channel. Photographs of such typical model are shown in the figure below.

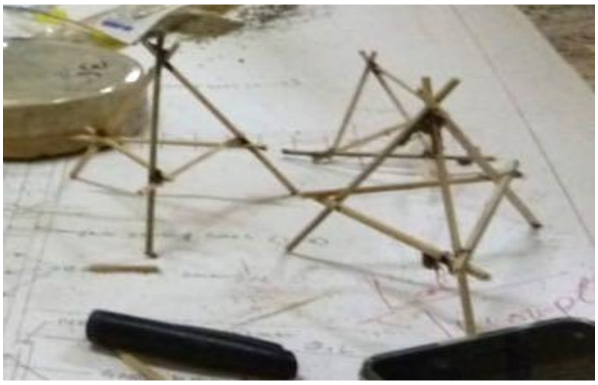

Fig 5: Prepared Porcupine models

2.1.2 Bed materials

The bed material was collected from river Bhogdoi, Jorhat,Assam. After collecting the river bed material sample, they were air dried for evaluating the particle size distribution, Where the material was found to be poorly graded fine sand. The bed of the field channel was filled with this collected sample up to a depth of 15 cm from the cut surface. This depth has been selected on the basis of trial runs in the channel without porcupine models with different discharges and observing the scouring level for such runs. A channel bed with a minimum thickness of 15 cm has been found to withstand significant scouring and subsequent exposure of the cut surface of the channel under any trial run.

2.1.3 The Field Channel:

All the experiments for this study were carried out in a field channel that was developed inside the campus of Jorhat Engineering College, Assam. The field channel that was developed for the study is about 27.0 m long, 1.0 m wide and about 0.4m deep. Out of this 0.4m total depth of the channel, 0.2 m were kept available for flow ,after preparing he channel bed by filling up the bottom 0.15m with collected bed materials and considering a free board of 0.05m.

Fig 6: Prepared field channel

Two 15 HP pumps were installed nearby to collect water from the JEC lake and feed the same into the experimental channel. The water from the pumps was first collected into a chamber (Fig 7). The water released from the collecting chamber then goes through some energy dissipaters (steps) for reducing the turbulence of the flow before

entering the main channel. A foot valve was installed at the bottom of the channel near its u/s face to regulate the quantity of water to be fed to the channel in order to maintain different depths of flow inside it.

Fig 7: Collecting chamber

A steel trolley was installed to support the point gauge above the channel on the side walls that were constructed on both the sides of the channel, as shown in fig below.

Fig 8: Installed point gauge with steel trolley

2.2 Experimental Procedure

Before every experimental run, the channel bed was levelled and flow was introduced for a particular depth of flow. The required depth of flow for maintaining different submergence ratios was achieved by trying out different pump and valve combinations.Then the porcupine model of a particular combination is installed and on the respective nodal points of the Porcupine field the initial point gauge readings are taken. After this flow is again introduced into the channel for about an hour before it is allowed to discharge again. Then again the point gauge readings are observed on the respective nodal points to notice what changes have occurred in the channel bed within the Porcupine field due to installation of the Porcupine models.

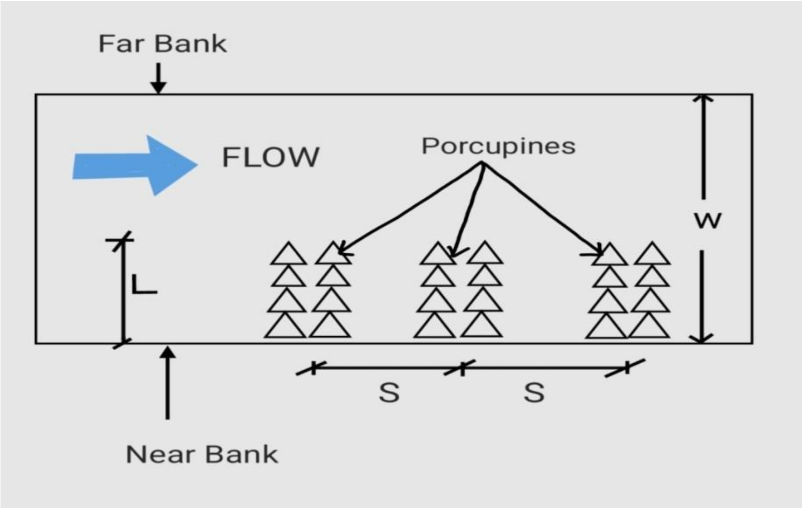

Fig 9: Installation of Porcupine models

Where S=C/C spacing between spurs:W=Width of channel;L=Length of spur

The cycle is repeated for all the models as mentioned below (Table 1) and their cumulative ripple heights are calculated.

Table 1: Different models used

Model	Combinations	
1	3 spur with 3L spacing 3 spur with 3L spacing 3 spur with 3L spacing	1.7 2.0 2.5
2	3 spur with 4L spacing 3 spur with 4L spacing 3 spur with 4L spacing	1.7 2.0 2.5
3	3 spur with 5L spacing 3 spur with 5L spacing 3 spur with 5L spacing	1.7 2.0 2.5
4	4spur with 3L spacing 4spur with 3L spacing 4spur with 3L spacing	1.7 2.0 2.5
5	4spur with 4L spacing 4spur with 4L spacing 4spur with 4L spacing	1.7 2.0 2.5
6	4spur with 5L spacing 4spur with 5L spacing 4spur with 5L spacing	1.7 2.0 2.5
7	5spur with 3L spacing	1.7

	5spur with 3L spacing 5spur with 3L spacing	2.0 2.5
8	5spur with 4L spacing 5spur with 4L spacing 5spur with 4L spacing	1.7 2.0 2.5
9	5spur with 5L spacing 5spur with 5L spacing 5spur with 5L spacing	1.7 2.0 2.5

3. RESULTS AND OBSERVATIONS:

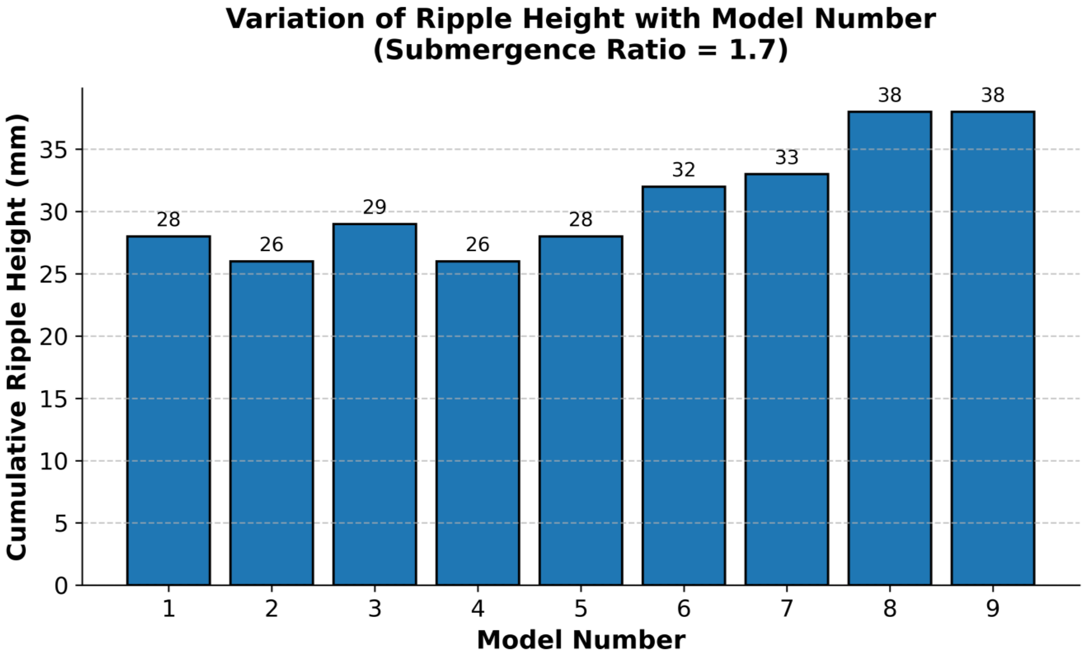

Fig 10: Relation between cumulative ripple heights and the different models used for submergence ratio 1.70

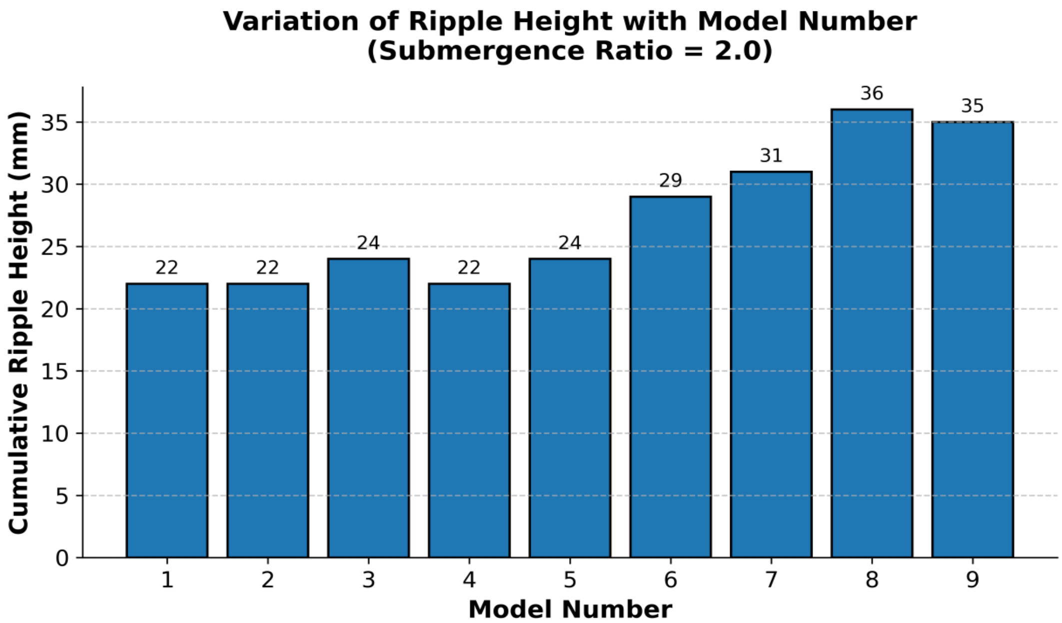

Fig 11: Relation between cumulative ripple heights and the different models used for submergence ratio 2.0

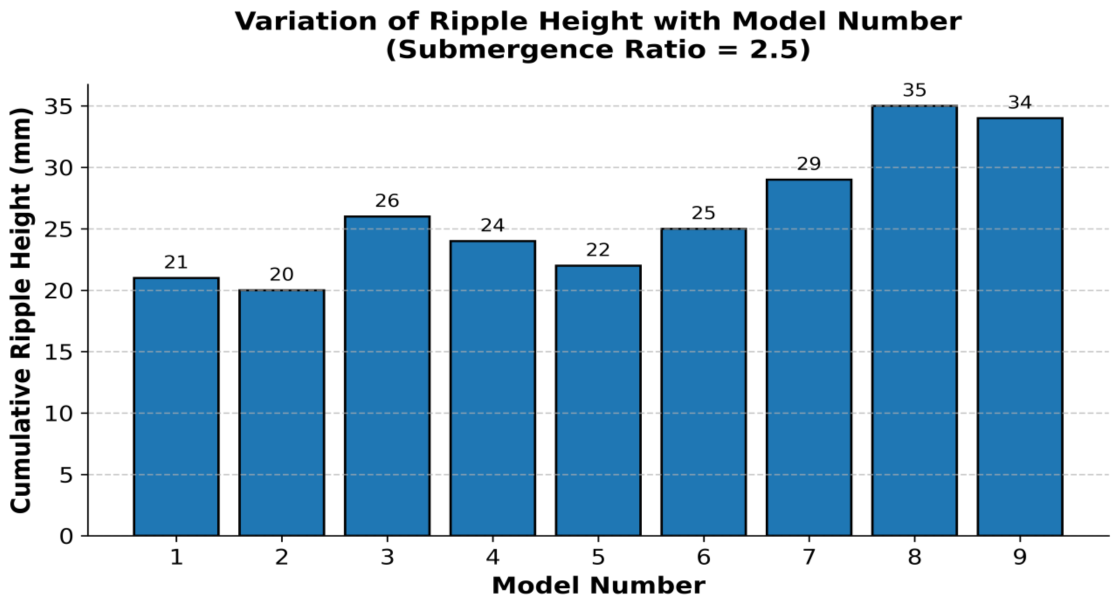

Fig 12: Relation between cumulative ripple heights and the different models used for submergence ratio 2.5

3.1 Effect of Number of Spurs on Sediment Deposition:

The results indicate that sediment deposition increased with an increase in the number of spurs.

- Models with **3 spurs** (Models 1–3) generally exhibited lower ripple heights.
- Models with **4 spurs** (Models 4–6) showed moderate ripple development.
- Models with **5 spurs** (Models 7–9) produced the highest ripple heights and therefore the highest sediment deposition.
- Maximum ripple height for 3-spur arrangements ≈ 29 mm
- Maximum ripple height for 4-spur arrangements ≈ 32 mm
- Maximum ripple height for 5-spur arrangements ≈ 38 mm

3.2 Effect of Spur Spacing on Sediment Deposition

The spacing between spurs significantly influenced ripple formation and sediment deposition patterns.

(a) 3L Spacing

Configurations with 3L spacing generally produced lower ripple heights compared to wider spacings for equivalent spur numbers.

This suggests:

- Stronger flow contraction,
- Increased turbulence flushing and
- Reduced stable sediment accumulation zones.

(b) 4L Spacing

The 4L spacing configurations showed highest ripple heights and higher sediment deposition characteristics. These arrangements appeared to provide a balance between:

- Flow dissipation,
- Sediment trapping and
- Hydraulic stability.

(c) 5L Spacing

For a fixed number of spurs and submergence ratios, the second highest ripple heights were observed in configurations with 5L spacing. Indicating :

- Very high sediment deposition.
- But reduction in spur density impacts the overall sediment trapping capacity

3.3 Most Effective Sediment Deposition Configuration

- **Model 8 (5 spurs with 4L spacing)** produced the highest sediment deposition. This configuration consistently generated the largest cumulative ripple heights for all the tried submergence ratios.

3.4 Least Effective Sediment Deposition Configuration

- **Model 2 (3 spurs with 4L spacing)** exhibited the minimum ripple heights, indicating the least sediment deposition for all the tried submergence ratios.

4. CONCLUSIONS

The present study demonstrates that sediment deposition is influenced not only by spur density but also by the spacing between successive spurs. While increasing the number of spurs generally enhances sediment retention, the results indicate that the effectiveness of a spur field depends on the existence of an optimum inter-spur spacing that promotes favorable hydraulic conditions for sediment settling. Among the configurations investigated, the maximum sediment deposition was achieved for the five-spur arrangement with an inter-spur spacing of 4L, for sediment retention than either the closer or wider spacing arrangements. Suggesting that 4L represents the optimum spacing within the range of conditions considered in this study.

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APPENDIX I

Fig I.1: Channel with installed Porcupine models

Fig I.2: Channel bed before experimental run

Fig I.3: Channel bed after experimental run