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MODEL TESTS ON GEOBAGS FOR EROSION PROTECTION

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Sand-filled geotextile bags (geobags) are being used at selected sites on the large rivers of Bangladesh as an economically feasible means of riverbank and scour protection. Hydraulic laboratory tests were conducted on small-scale bags to examine various aspects of design and placement, and to compare their behaviour with that of rock riprap. The paper focuses on two aspects: i) relationships between local velocities for incipient motion and geobag properties such as dimensions, shape and density, and ii) the use of geobags in "launching" or "falling" aprons to prevent undermining of protected bank slopes by scour at the toe. It is shown that incipient motion relationships can be expressed using a modified version of a well-known equation for rock riprap design. Used in falling aprons, model geobags after launching appeared to produce a somewhat less regular covering layer than rock riprap. Launching behaviour may have been affected to some extent by the reduced flexibility of model bags compared to full-size ones.

Key Words : *geobags, river engineering, scour, erosion, bank protection, falling aprons*

1. INTRODUCTION

In Bangladesh, several large rivers originating outside the country flow through deep fine-grained deltaic deposits at depths of up to 30 m or more. Without erosion protection, the rivers are subject to unpredictable lateral shifts that can quickly destroy communities and infrastructure.Traditional materials for river bank protection are scarce and are economically justifiable only for local zones with high-value on-shore developments. Past attempts to control erosion and channel shifting have often failed due to undermining of protective works by river-bed scour at the toe of the bank.

For protection of predominantly agricultural areas, geobags have been developed in recent years as a cost-effective alternative to riprap or concrete blocks. Geobags are locally fabricated geotextile bags, filled near the placement site with river sand. Geobags have been used for emergency protection at various locations, and in the Jamuna-Meghna River Erosion Mitigation Project (JMREMP) they have been installed along two lengths totaling about 10 km where river encroachment was threatening crucial flood control levees. Fabrication and placement methods have been described by Oberhagemann and Sharif-Al-Kamal1) and by Oberhagemann et al.2). The geobags are placed under water to form a sloping revetment, and extended as a flexible apron on the river bed to protect the revetment toe against undermining by scour (**Fig. 1**).

To develop design criteria for geobag stability in river flows and to investigate their use as toe aprons under controlled conditions, physical model tests were conducted during 2005 in the hydraulic laboratory of Northwest Hydraulic Consultants in Vancouver, Canada. Attention is confined here to two aspects of the test program: (1) velocity criteria for incipient displacement of protective elements on bank slopes, and (2) "launching" behaviour of toe

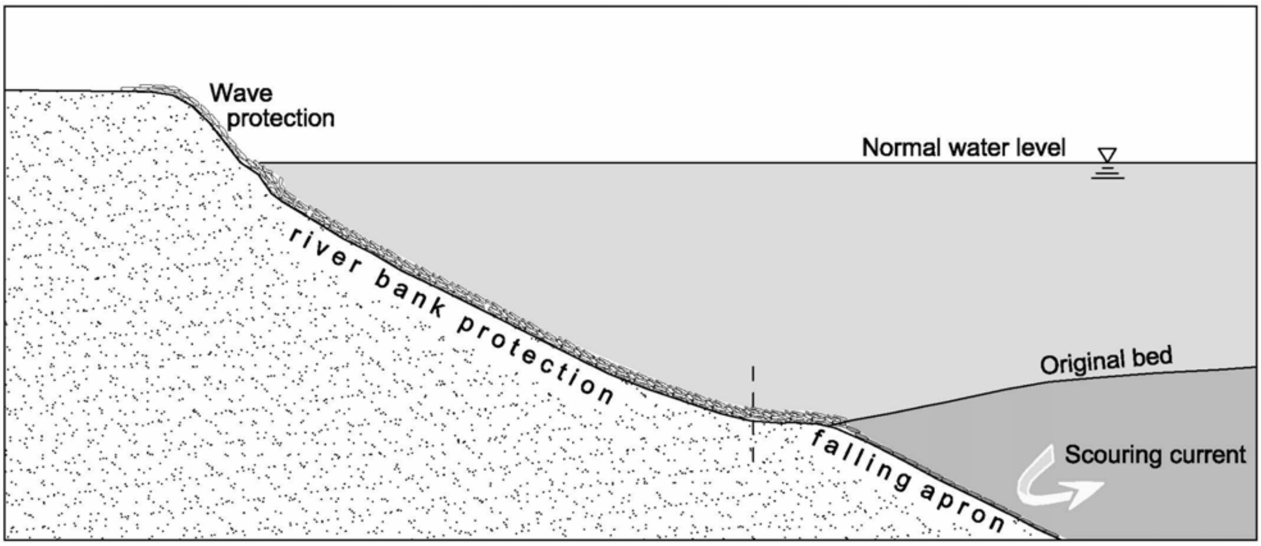

Fig. 1 Geobag slope revetment with falling apron.

aprons when undermined by scour.

In this paper, mass and weight are used interchangeably and expressed in kg. A more extensive report on the tests is available[3)].

2. TEST FACILITY AND SCALING

The tests were conducted in a re-circulating flume 3 m wide x 10 m long, with adjustable inlet arrangements to permit both parallel and slightly oblique flow alongside the test slope. A strip of channel width alongside the protected slope was modeled at a scale of 1:20, without vertical exaggeration. The mobile bed as initially placed provided an equivalent prototype depth of 10 m (a typical average alongside the field lengths) but was thick enough to allow for an additional 10 m of scour during the tests.

As is common in scale model testing of sand-bed rivers, the channel bed was formed in low-density non-cohesive material, in this case ground walnut shell of approximately 0.5 mm average diameter and submerged relative density of 0.35. This was designed to represent so far as practicable the mobility of sand in the prototype river, while maintaining a workably stable bed in the model.

The model geobags were scaled geometrically and formed of porous fabric filled with fine sand. In addition to model geobags, model riprap and concrete blocks were also tested to a limited degree, in order to provide a basis for comparison and to check whether the geobag results could be interpreted in the framework of an accepted system for testing and analysis. Angular and rounded rock riprap were represented by crushed rock and natural gravel, also scaled geometrically. The concrete block tests are not covered in this paper.

A scale effect that may be significant is that the model bags were quite stiff compared to the prototypes and did not deform significantly to increase bag-on-bag friction – probably because the grain size of the model filling material was much too large in terms of model scale. Inter-bag friction may be relatively unimportant for incipient motion, where hydraulic lift plays a major role in displacing single bags from the surface, but it could be significant with respect to launching.

3. INCIPIENT-MOTION TESTS

(1) Materials and placement

a) Geobags

Most of the incipient-motion tests used scaled-down representations of the following prototype geobags:

Type	Dimensions (mm)	Filled weight in air (kg)
Grade1a	750 x 560 x 190	126
Grade 2	670 x 500 x 170	90
Grade 3	500 x 380 x 130	38

Limited tests on other Grade 1b (longer than 1a) and Grade 4 (smaller than 3) are not reported here.

Geobag slope revetment was tested using both single sizes and mixtures. Bags were generally placed flatwise, randomly and overlapping on the slope to form a layer approximately 1.5 bags thick on average. Model bags parallel to a slope were found to resist sliding over other bags up to an angle of around 50 degrees to the horizontal – which is considerably steeper than a geotechnically stable bank slope.

When prototype or model geobags are placed under water their effective weight is first reduced by the weight of the displaced water. Then the bags become saturated as initial air voids in the sand fill are filled with water percolating through the fabric, so that part of the lost weight is restored. The submerged density of saturated model bags was found to be approximately 1100 kg/m^3. The submerged density of saturated geobags in the field varies with moisture content of the fill sand and quality control of the filling operation. It appears to average about 950 kg/m^3, significantly less than for the model bags.

b) Rock riprap

The tests used scaled representations of the following prototype gradations:

	Percentage smaller than			
	85%	50%	30%	15%
Angular:	300 mm	250 mm	230 mm	200 mm
	38 kg	22 kg	17 kg	11 kg
Rounded:	420 mm	330 mm	280 mm	240 mm
	100 kg	50 kg	31 kg	19 kg

Quoted dimensions in mm refer to intermediate diameters, and kg refer to weights in air. Angles of repose averaged about 38 degrees for angular and 35 degrees for rounded material. The submerged density was approximately 1600 kg/m^3.

(2) Tests and measurements

The principal tests covered the following conditions:

Bank slope: 1V/1.5H	1V/2H
Single-size geobags:	
Grades 1a, 2, 3	Grade 1a
Geobag mixtures:	
1a-2-3	none
1a-2	none
Angular rock:	Gradings as described above
Rounded rock:	Gradings as described above

Vertically averaged velocities, based on measurements at 0.2 and 0.8 x depth, were determined at two locations on each cross-section: i) at the toe of the slope, and ii) at one-third of the slope length inshore from the toe (**Fig. 2**). The second location was generally used for analysis. In the tests, velocities were increased in 0.2 m/s (prototype) steps.

Under steady flow conditions, incipient motion of the revetment material was defined arbitrarily as the condition when about 10 isolated rocks or bags had become displaced from the slope surface - which for each type of coverage represented a prototype length of about 20 m. This rather conservative condition was well short of revetment failure. First displacement of bags tended to begin at about one-third of the slope length inshore from the toe (that is, the second velocity measurement location), and to progress upslope as velocities were stepped up.

Selected incipient-motion velocities for the geobags, in prototype equivalents and vertically-averaged at the 1/3 point as described above, are as follows:

Bag type	D_{50}= (abc)$^{1/3}$ mm	Side slope V/H	Velocity m/s
Grade 1a	440	1/2	2.9
Grade 1a	440	1/1.5	2.6
Grade 2	390	1/1.5	2.4
Grade 3	300	1/1.5	2.2
Mixture 1a/2/3	390	1/1.5	2.4

It can be seen that the incipient-motion velocity for the 3-grade mixture is the same as for its middle Grade 2 when used singly.

(3) Analysis of results

Experimental incipient-motion velocities for both riprap and geobags were analyzed in terms of a slightly simplified version of the USACE equation$^{4)}$, which is based on extensive large-scale model testing of riprap. The USACE equation relates the required size of riprap stones to local flow velocity, flow depth, stone density, and a set of dimensionless coefficients related to layer thickness, stone shape and other factors. It is similar in form to earlier equations by Inglis$^{5)}$, Neill$^{6)}$ and Maynord et al.$^{7)}$, but includes additional coefficients to allow for a range of flow and placement conditions. A significant difference from earlier equations is that the characteristic size of a riprap gradation is defined by USACE as D_{30} instead of D_{50}, but the difference is of little importance for narrowly graded mixtures.

Re-arranged to express incipient-motion velocity directly, the simplified form of the USACE equation

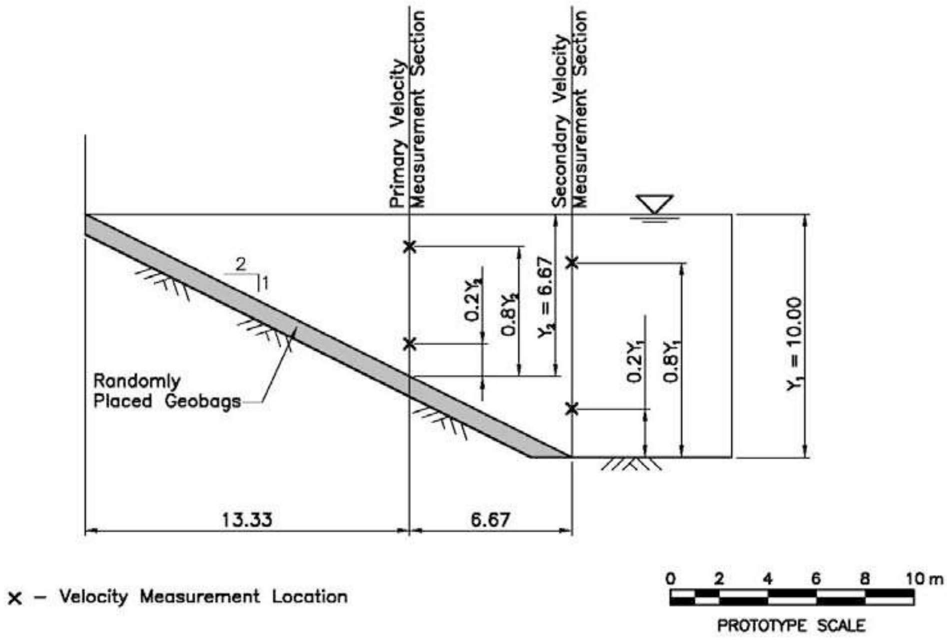

Fig. 2 Incipient-motion test section.

can be written:

$$V = K_1^{0.5} g^{0.5} (s-1)^{0.5} D_{30}^{0.4} Y^{0.1}/(C_s C_V)^{0.4} \quad ....(1)$$

Where:

V = local vertically-averaged velocity
K_1 = side slope factor = $(1- \sin^2\theta/\sin^2\Phi)^{0.5}$
Where:
θ = slope angle to horizontal and
Φ = angle of repose
g = gravitational acceleration
s = dry density of stone relative to water, normally about 2.6
D_{30} = 30% passing size of stone
Y = depth of flow
C_s = shape factor = 0.3 for angular rock and 0.36 for rounded
C_v = coefficient for vertical velocity distribution, ranging from 1.0 for straight channels to 1.28 for abrupt bends

In this simplified version, two coefficients in the USACE equation – safety factor and thickness coefficient – have been set equal to 1.0.

a) Rock riprap

The model riprap results were analyzed first, as a check on their fit to Eqn. 1. Measured incipient-motion velocities were about 25% less than predicted for the steeper 1V:1.5H slope, and about 10% less than predicted for the flatter 1V:2H slope. These discrepancies were not investigated in detail, but are thought to be related to different visual criteria: a few displaced stones in these tests, against a criterion close to revetment failure in the USACE tests.

b) Geobags

To analyze the geobag results in terms of Eqn. 1, the following definitions were adopted for key parameters:

V = vertically averaged-velocity at 1/3 bank length inshore from toe
Y = flow depth at same point
$D_{50} = (abc)^{1/3}$, where a, b and c are length, width and thickness of the bags after filling.

The value of D_{50} so calculated was substituted for D_{30} in Eqn.1, and other test values were inserted to derive experimental values of the shape coefficient C_s. For the various geobag sizes, C_s ranged from 0.74 to 0.82 with an average of 0.77. Corresponding USACE values are 0.30 for angular and 0.36 for rounded riprap. In terms of Eqn.1, this result therefore shows that due to their flattish shape, geobags are displaced at lower velocities than roughly equi-dimensional riprap stones of similar volume and density. Also, saturated geobags have lower densities than riprap stones. Taking those two factors together, the result is that for equivalent stability under a given velocity, geobags must be considerably larger than riprap stones.

Slope revetments composed of mixtures of geobag sizes showed little advantage over single sizes. For various practical reasons, single sizes are preferred in the field. Most of the mixture tests are therefore not reported here. A comment about mixtures is included in the Summary of Conclusions.

4. LAUNCHING TESTS

"Launching" or "falling" aprons of riprap to prevent undermining by scour at the toe of protected river banks were first used on the Indian subcontinent towards the end of the 19th century (Inglis 1949). As undermining begins at the outer end of the apron and works back towards the bank, the apron riprap gradually "launches" over the newly scoured bed slope (see **Fig. 1**) and prevents undermining of the bank. Enough material is normally provided to cover the extended slope to the estimated maximum depth of scour, at a thickness of at least one average stone.

The model tests of launching aprons were designed to compare geobags with rock riprap and to assess the suitability of geobag aprons in conjunction with geobag slope protection. Tests were conducted on angular and rounded riprap, single-size geobags and geobag size mixtures, in several initial cross-sectional configurations as illustrated in **Fig. 3**. Test velocities were selected low enough for first displacement of material to occur due to undermining by scour, rather than due to displacement by hydraulic forces.

Fig. 4 shows photographs of a riprap slope revetment and apron before and after toe undermining and apron launching. **Fig. 5** shows similar situations with single-size geobags. The launched coverage with the geobags is less even and complete than with riprap, but nevertheless appears fairly acceptable. The lesser flexibility of model bags compared to full-size ones may have had some influence on this result. Systematic diving observations of launched geobags in the field indicate closer spacing and fewer gaps, possibly because the plasticity of the sand fill allows shape adjustment between adjacent bags.

Principal conclusions from the launching tests are included in the following Summary of Conclusions.

5. SUMMARY OF CONCLUSIONS

(1) Incipient motion

1. The USACE (1991) equation for riprap stability can be adapted for application to geobags, using a shape factor of 0.77 and a characteristic bag size defined as the cube root of (length x width x thickness).
2. Because of their higher shape factor and lower submerged density, geobags are displaced at significantly lower velocities than equivalent riprap sizes.
3. A slope revetment consisting of a single large size is more resistant to displacement or failure than a mixture containing smaller sizes. (This could be expected, since the mixture has a smaller average or effective size.)

(2) Launching

4. Riprap toe aprons launch as the underlying bed is scoured, starting at the outer end, to form a uniform layer of thickness 1 to 1.5 D_{50}. Similar results have been reported by other investigators.
5. Geobags upon launching tend to form a less uniform layer than riprap, with some overlapping and unprotected patches. Mixtures perform slightly better than single sizes in this respect. However, scale effects associated with the flexibility of filled bags may have influenced these results.
6. The best cross-sectional configuration for an apron appears to be a relatively thin, wide apron with a small heap of bags at its outer edge, similar to Configuration 3 in **Fig. 3**. Thicker narrower aprons (Configuration 1), or a heap of bags at the toe (Configuration 2), have a tendency to form vertical faces followed by slumps. A heap of bags placed on the upper bank (Configuration 4) is liable to slide down as a mass.

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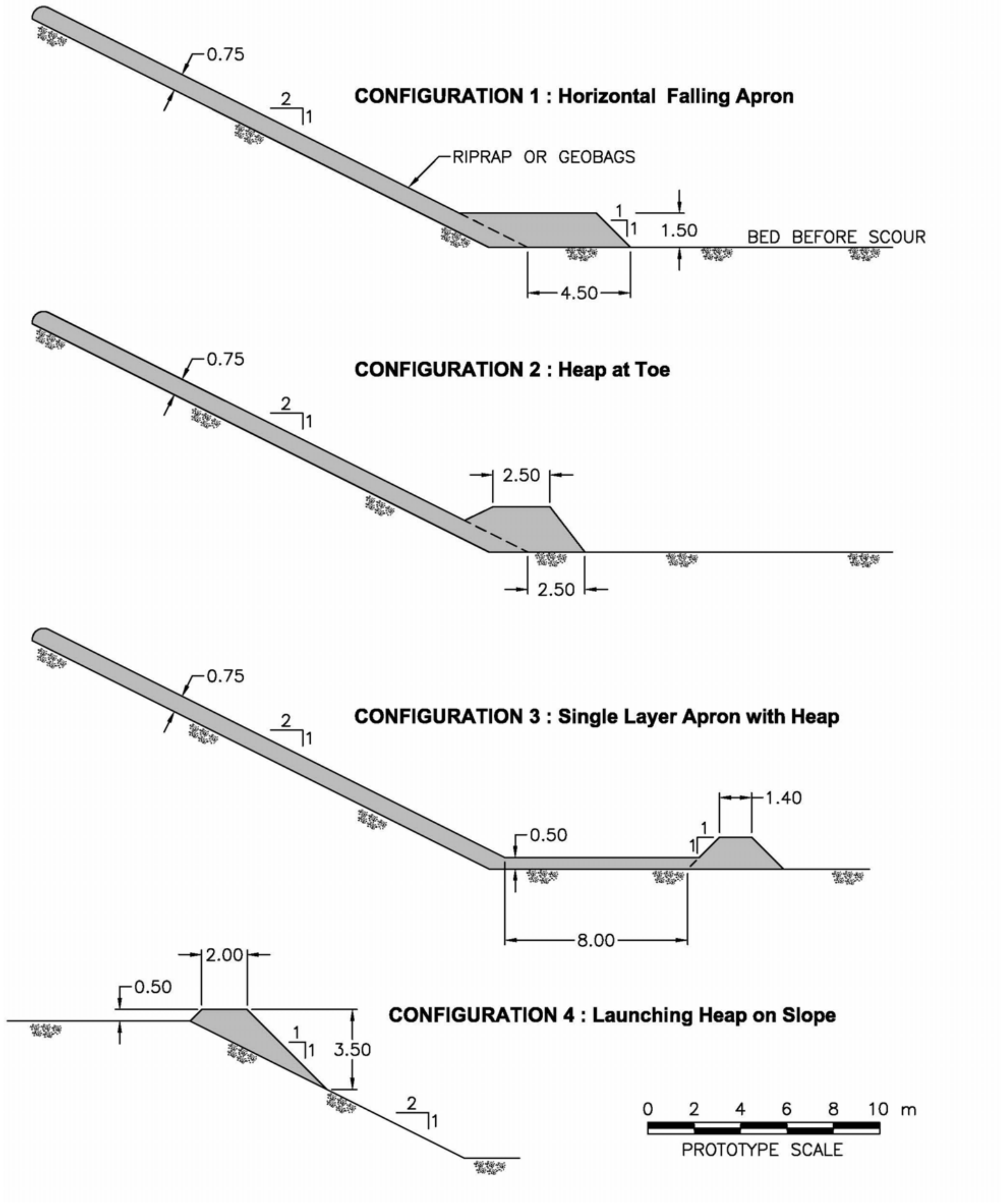

Fig. 3 Tested cofigurations of revetments and fallingaprons.

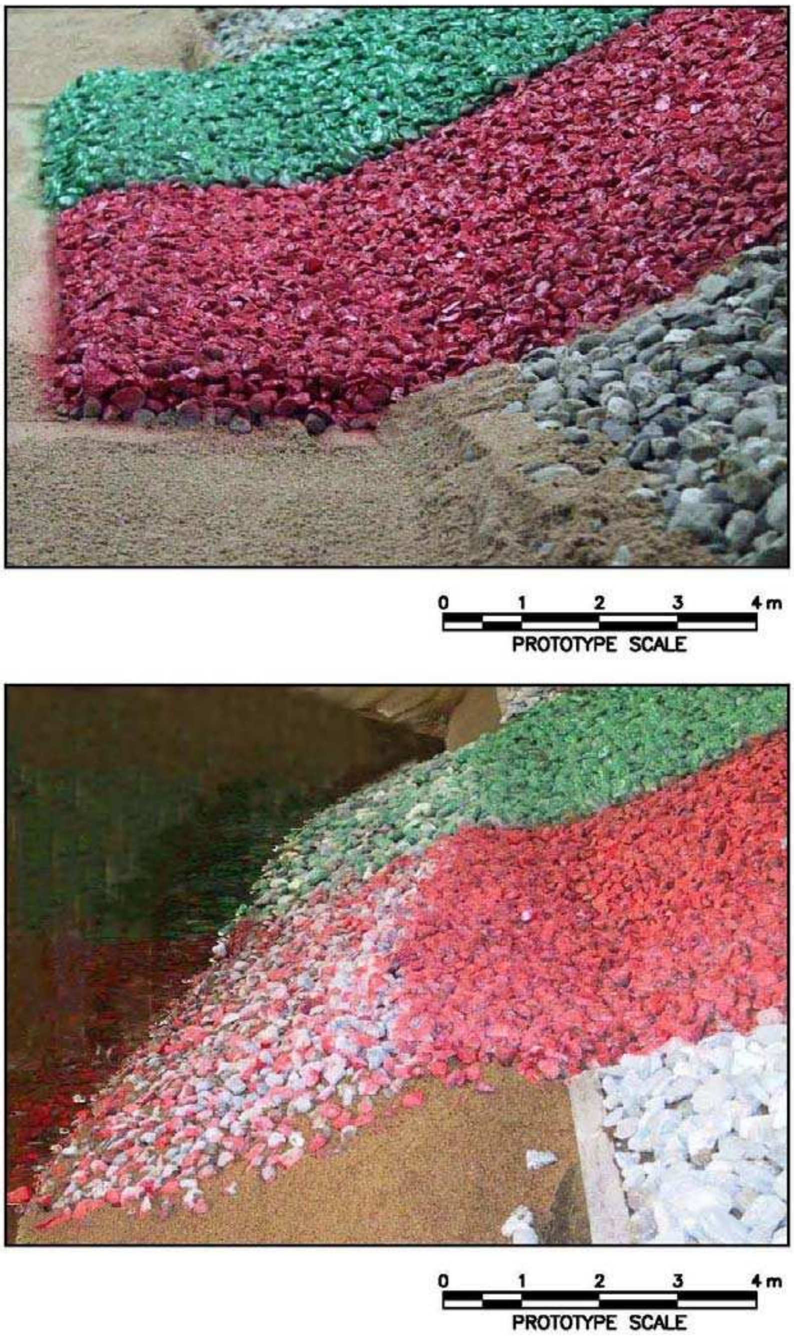

Fig. 4 Model rock riprap before and after launching.

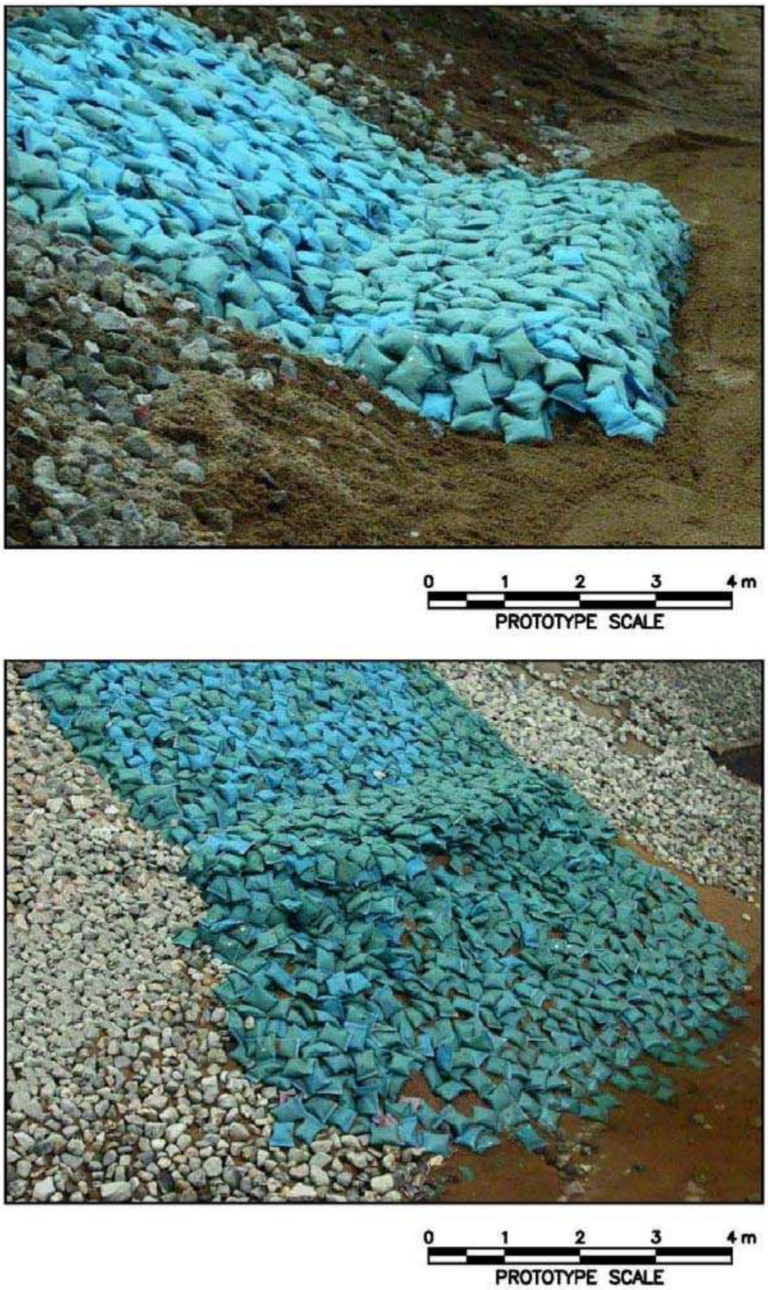

Fig. 5 Model geobags before and after launching.

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