# RIVERBED DEGRADATION IN MIXED ALLUVIAL-BEDROCK CURVING CHANNELS

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## 1. INTRODUCTION

Degradation of soft bedrock has been taking place in a number of rivers in Japan, posing serious problems to river management. For example, the rapid progress of degradation of soft bedrock in upstream reaches of Ishikari river, Hokkaido, may destabilize river structures such as bridges, bank revetment and groundsill. Among various processes, such as cavitation, plucking and dissolution, river bedrock degradation is often dominated by abrasion by bed load. The role of bed load on abrasion is twofold: it can function both as "tools" that collide with bedrock causing erosion, and as a "cover" that protects bedrock from erosion (Sklar & Dietrich, 2004, Howard, 1994). Where there is no sediment and the bedrock is completely exposed, no abrasion takes place. And where the bed is fully covered with sediment, no abrasion takes place as well. Abrasion is therefore active only in a portion moderately covered with sediment.

In the present work, we focus on the effect of secondary flow on bed incision and bed configuration in mixed alluvial-bedrock channels. Large secondary flow cells with a transverse and a vertical velocity component typically take place in meandering channels and channels with significant cross-sectional variation. In curved channels, secondary flow is generated by the difference between centrifugal forces exerted on flows near the water surface and the bottom. The secondary flow is spiral in the streamwise direction, and the flow direction near the bottom is from the outer to inner banks. When the amount of sediment on the bed is limited, bedrock is exposed on the bed near the outer bank, and sediment covers the bed near the inner bank completely. It is expected, therefore, that the bed near the outer and inner banks are not eroded due to abrasion, and abrasion takes place only around the boundary between.

## 2. METHODOLOGY

Experiments to simulate bed incision and bed configuration in curving channels were conducted in an acrylic annular flume installed in Hokkaido University (Fig. 1). The flume is 10cm wide, 11 cm deep and its mean radius is 45cm. The bedrock was simulated by a week mortar bed approximately 6cm deep. The mortar consisted on a mixture of Portland cement, sand (Tohoku Keisha N5, mean diameter 52mm) and water. The flume was filled with water. The water motion is generated by the rotation of an acrylic plate installed at the top of the flume in contact with the water surface. The angular velocity of the plate is electronically controlled. The water motion associated with the movement of sand particles resulted in changes in the bed configuration. The bed elevation was measured at regular times by a laser displacement sensor and velocity measurements were taken using a transducer.

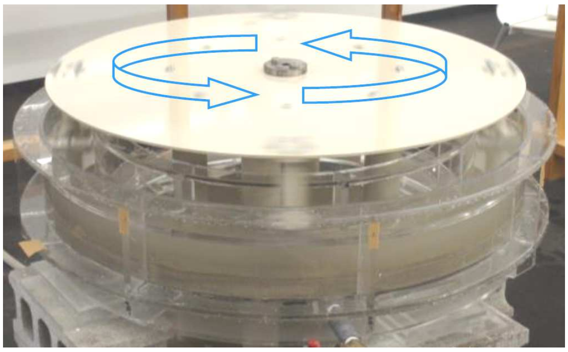

Fig. 1 Flume assembly

Fig. 2 Channel between adjacent point bars. The main flow is from left to right.

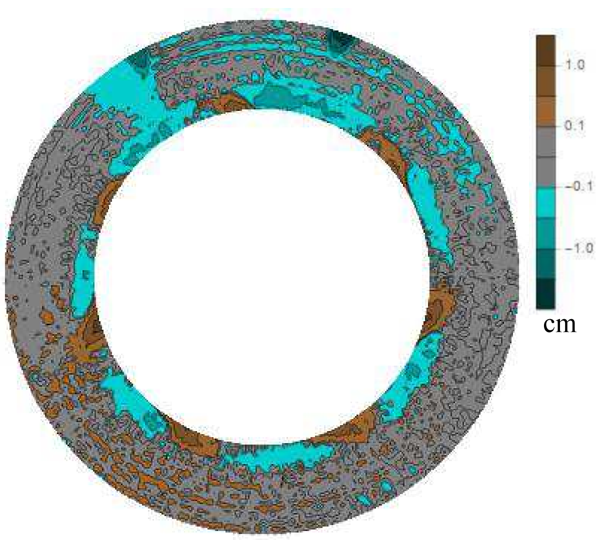


Fig. 3 Scheme of the upper view of the flume showing the bed elevation after 22h of rotation (difference from the initial condition) for Run 1. Positive values correspond to zones of sediment deposition.

Keywords: River morphology, Bedrock incision, Abrasion, Secondary flow.
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## 3. RESULTS

The mortar bed was initially completely exposed. With the motion of water induced by the rotation of the top cover, degradation of the mortar bed by plucking took place, especially at the vicinity of the outer wall of the flume. The plucking process released sand particles from the mortar, which became "tool" for abrasion. The released sand tended to accumulate in the vicinity of the inner wall, taking the form of a sand wave undulating along the circumferential direction (Fig. 2). A cyclic pattern of sand accumulation along the circumferential direction near the inner wall can be visualized in Fig. 3. The sand waves will be referred afterwards as point bars. The edge of the point bars, where the sediment cover bounded the exposed bed, were the zones where abrasion was maximized. Far from the outer wall, the bed suffered less erosion and exhibited insignificant accumulation of sediments, except for localized zones where the concrete was eroded due to plucking of localized cracks.

As the abrasion progressed, the volume of free sand increased, which increased the volume of the point bars. The wavelength of the point bars also increased, thus the number of bars decreased. The wavelength of the bars is closely related to the flow depth. As the flow depth decreases with increasing sediment deposition, downstream accelerations induced by shoaling over the point bars are enhanced and extend the downstream end of the bars. Furthermore, the downstream accelerations induced by shoaling have a strong component towards the outer wall (Dietrich and Smith, 1983). As a result alluvial channels which directed the flow outwards were formed between adjacent bars (Fig. 2). As the bars increased in volume and width, the zone of preferential incision by abrasion shifted towards the outer wall.

A cover factor is herein defined as the area or length covered by sediment divided by the total area or length. The cover factor of a certain area of length assumes the value of zero for a fully exposed mortar and the value of 1 for an area or length fully covered by sand. The cover factors and erosion rates of circumferential lengths for selected experimental runs are presented in Fig. 4. The ratio cement-sand-water was 1:150:50 in Run 1 and 1:14:50 in Run 2. The mortar base was weaker in Run 2 than in Run 1, resulting in larger incision rates being observed in Run 2.

In Run 1, for intervals surpassing 2h, the erosion rates (dashed lines) were maximized at cover factors 0.43 and 0.59, for the intervals 2h-10h and 10h-22h, respectively. Additionally, in Run 1 from 0 to 2h, large erosion rates are observed for cover factors equal to zero. This results from incision by plucking.

In Run 2, cover factors reaching 1 took place in the vicinity of the inner wall. In the end of experiment, the minimum cover factor was 0.26, as the sand domain reached up to the outer wall. The erosion rates were maximized at cover factors 0.98 and 0.84, for the intervals 2h-10h and 10h-18h, respectively. These values of cover factor are comparatively higher because plucking was also significant beyond the 0-2h interval due to the softer bedrock. However, a tendency of maximization of incision rates can be observed for moderate cover factors, and a tendency of minimization of incision rates can be observed for cover factors equal to 1. These tendencies reflect the occurrence of abrasion.

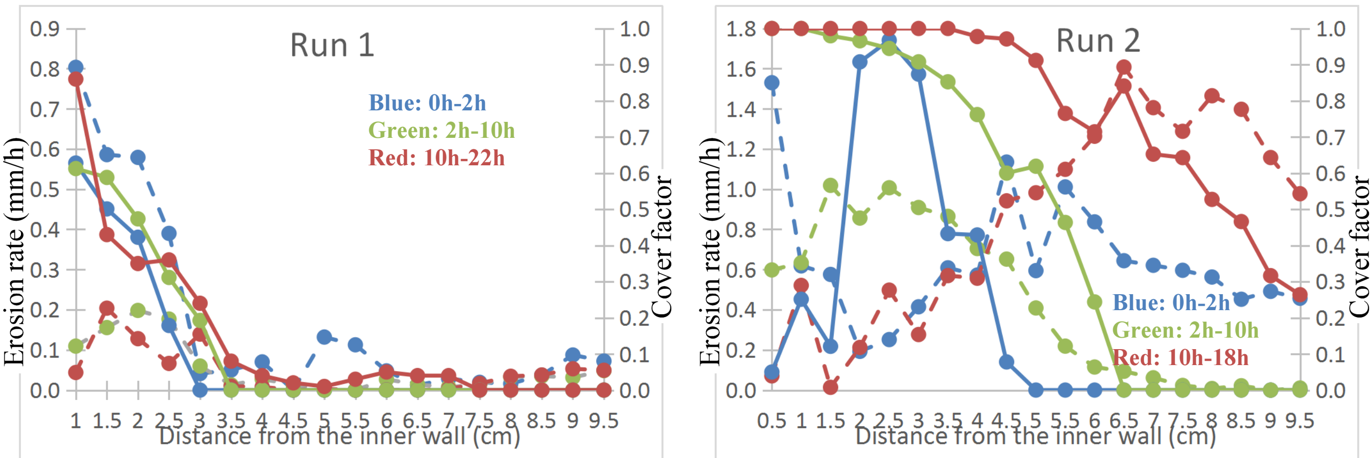


Fig. 4 Erosion rates (dashed lines) and cover factor (solid lines) for multiple rotation time intervals.

## 4. CONCLUSIONS

As expected, abrasion in the experiments tended to be more significant at moderate ratios of bed covered by sediment. The uniform radius of curvature and absence of inflow and outflow boundary conditions in the annular flume, although distinct from meanders in the field, allowed further clarifications over the formation of alluvial point bars and over patterns of bedrock incision in mixed alluvial-bedrock riverbeds.

## REFERENCES

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