

EFFECT OF ABRASION ON DOWNSTREAM GRAVEL-SIZE REDUCTION IN THE WATARASE RIVER, JAPAN: FIELD WORK AND LABORATORY EXPERIMENT*

By Yoshinori KODAMA**

(Manuscript received 30 October, 1991)

ABSTRACT

Two processes have been considered to explain downstream grain-size reduction in gravel-bed rivers. One is sorting which results in finer grains being transported downstream faster and further than the larger ones. The other is abrasion by which individual particles are diminished in size.

Previous experimental studies on abrasion of gravels showed much lower diminution rates than those of gravels in natural rivers. Therefore most studies on the cause of downstream fining in rivers stress the downstream reduction of grain size by sorting. However, broken boulders are often observed among river-bed materials in Japan and sometimes grain-size changes have a great deal to do with the difference in resistance to breakdown among lithologies. The purpose of this study is to examine the effect of abrasion on downstream fining in the field and then compare this effect with laboratory results to determine if abrasion is responsible for longitudinal changes in gravel size.

The lower part of the Watarase River in eastern Japan was selected for the study reach. In the lower reach, the Watarase River flows on a dissected alluvial fan, which means that the river is no longer aggrading. In addition, the study reach is only slightly influenced by the input of gravel from tributaries. Bed gravel in the study reach consists of several different lithologies: andesite, quartz-porphry, sandstone, hornfels, and chert. The grain size distribution and the lithologic compositions of the river-bed material were examined at nine sites.

There are two principal results from these analyses. **i)** Size distribution of gravel is strongly related to lithologic composition. Andesite boulders or large cobbles make up the framework sizes in the upstream part, while chert pebbles make up the framework sizes in the downstream part of the study reach. There are few andesite pebbles or chert boulders in the river-bed. **ii)** Longitudinal changes in the composition of each grain size class show that selective transport by lithology occurs in every gravel size. Since the mobility of gravel depends mainly on its size, hydraulic sorting by lithology does not occur within the same size class. These results clearly indicate that particle abrasion does occur in the Watarase River and is responsible, at least in part, for the downstream decrease in particle size of bed material.

Previous experimental studies on abrasion do not replicate well the grain-to-grain impact between bedload gravels and bed gravels in a natural river during large floods. This study used a rotating drum with three vanes inside, called the "ERC abrasion mixer", as an experimental

* A dissertation submitted in partial fulfilment of the requirements for the degree of Doctor of Science in Doctoral Program in the University of Tsukuba

** Environmental Research Center, University of Tsukuba, Tsukuba 305, Japan

apparatus to produce repeated collisions among test gravel particles and to simulate closely the impact velocity of collision (3m/sec at maximum) occurring in the Watarase River during a flood. Test gravels of slightly weathered andesite and chert were obtained from the bed of the Watarase. Uniform materials of three sizes (L: $-7.0\phi \sim -6.5\phi$, M: $-5.5\phi \sim -5.0\phi$, S: $-4.0\phi \sim -3.5\phi$) and mixtures of two of the three sizes were used to evaluate abrasion properties under vigorous impact conditions.

There are five principal results from the experiment. **i)** Test gravels break frequently and decrease in weight rapidly. **ii)** Abrasion of chert produces mostly gravel while andesite produces mostly sand and silt. **iii)** L-size chert cobbles decrease in weight rapidly as a result of being broken into smaller pieces, while andesite cobbles break so rarely that their weight decreases very slowly. **iv)** S-size andesite pebbles decrease in weight more rapidly than chert. **v)** Size mixture affects abrasion strongly, with smaller fragments being crushed by the larger gravel particles.

Lithologic grain-size reduction and some characteristics of lithologic composition of the river-bed material in the Watarase River can be explained by the results of the ERC abrasion mixer experiment. Diminution coefficients of andesite and chert obtained from the ERC abrasion mixer experiment are in the range of $10^{-3} \sim 10^{-1} \text{ km}^{-1}$. These are larger by one to two orders of magnitude than those from previous experiments on abrasion. This results mainly because the ERC abrasion mixer experiment closely simulates particle to particle collisions during floods in the Watarase River. In addition, diminution coefficients from the ERC abrasion mixer experiment are consistent with those obtained from many Japanese rivers on alluvial fans ($10^{-2} \sim 10^{-1} \text{ km}^{-1}$). This result shows that a downstream reduction of size of river-bed gravels can be explained by abrasion alone.