EXPERIMENTAL ABRASION OF PEBBLES

I. WET SANDBLASTING

by

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Abstract

Pebbles of various kinds were subjected to abrasion by a sand-laden current of water. The loss in weight resulting from the action of coarse and fine sand at different velocities was measured. There proved to be no abrasion below a velocity of 70 cm per second.

At a bottom velocity of this amount medium to large pebbles are already rolled along. This causes much severer loss of weight. Hence wet sandblasting is not important for particles under cobble size either in streams or on beaches.

Introduction

It is a well known fact that boulders and the rocky bed of streams subjected to the action of sand-laden water are fluted and abraded. The writer has pointed out that aquafacts are sometimes modelled in this manner both by torrents and by waves on the beach (1947). Several authors have suggested that the same action is an important factor in the abrasion and rounding of pebbles in rivers (BARRELL, 1925; RUBEY, 1933, p. 21; TRICART and SCHAEFFER, 1950). However, actual demonstration of the latter contention does not appear to have been given. A series of experiments was therefore undertaken in an attempt to obtain quantitative data.

Acknowledgements. The writer wishes to thank Dr. W. G. PERDOK, who suggested a method for carrying out the delicate weighings required and for helpful discussions. The Netherlands Organization for Pure Research (Z. W. O.) provided a grant for equipment.

Experiments

The apparatus used consisted of a round concrete basin with a churn (= revolving paddle) in the centre to give the water a swift revolving motion. The pebbles were suspended at various levels but more or less in the heart of the current. They were held in place against a metal loop covered with rubber tubing by a thin rubber band. To ensure a violent bombardment with sand, flanges ("turbulence ridges") were fixed against the side of the tank running up obliquely with the current from the floor to near the surface of the water. Some of the sand tending to collect on the bottom was thus continuously scooped up and scattered at higher levels. Also the turbulence was increased. In this manner an ample amount of sand was held in suspension even at moderate current velocities. Fig. 1 shows the arrangement on the left hand side of II and in the upper half of I; the other halves refer to experiments on rolling which will be described elsewhere.

The main technical difficulty was to obtain sufficiently accurate weighings. Dr. W. G. PERDOK, who kindly undertook to carry out these time

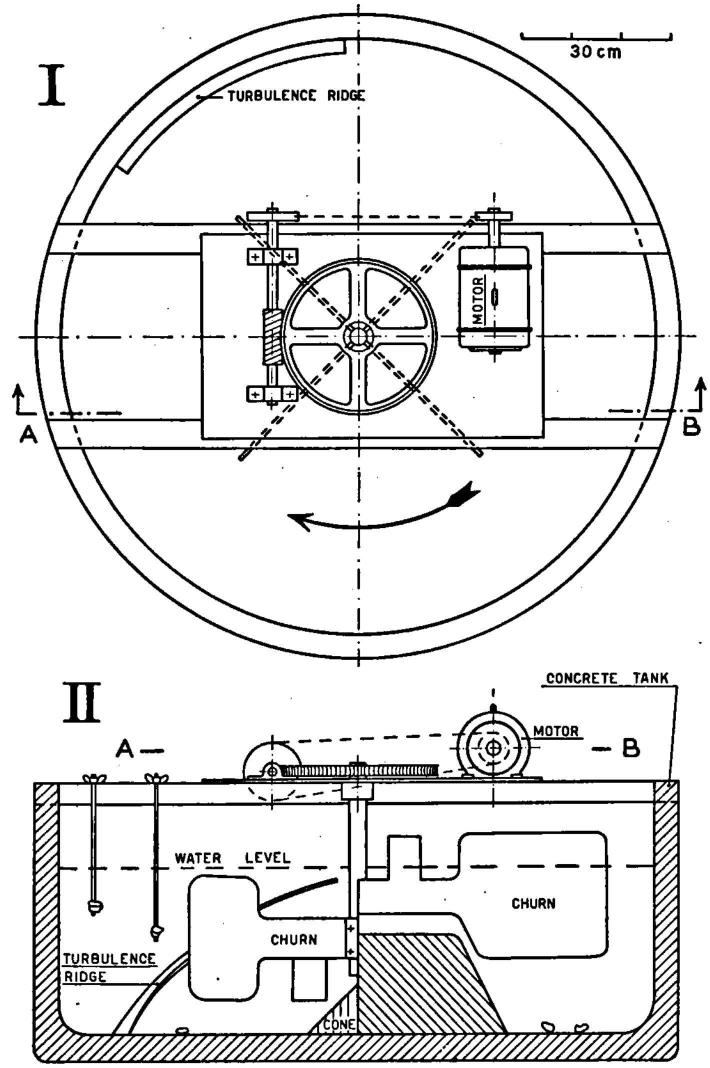

Fig. 1. Concrete tank with churn. Upper half of I and left half of II show experiments on wet sandblasting. The remainder refers to experiments on rolling.

consuming determinations, found that it is practically impossible to ascertain a fixed value for a given pebble. No matter whether a compact limestone, radiolarite or vein quartz are weighed on successive days the results continually change. For the sizes used, of 25 to 50 grams, variations of 10 milligrams are not unusual. If dried in a desiccator the weight changes while the weighing is in progress. Yet, as will be shown, it is the milligrams which are significant in these experiments.

Finally Dr. PERDOK hit on the method of weighing the pebbles under water. This proved entirely satisfactory and had the additional advantage of saving time. The pebbles were, of course, wetted during the blasting tests and they could be weighed under water without undergoing any further treatment. And they were then immediately ready for the next test. The only requisite was to soak them for two or three weeks in advance. Not until then has the under-water weight become constant by the expulsion of all air. As the balance did not allow greater weights than 50 grams the pebbles were restricted to dry weights less than that amount [1].

For the tests a representative set of small pebbles was selected, divided over soft, medium, and hard (tough). Two kinds of sand were employed: a fine well rounded sand with median diameter of 0.125 mm and a coarse sub-angular sand with a median diameter of 0.650 mm. Each run lasted a full week.

The current velocity was measured with a current meter at various points in the cross-section of the circular current. Each of the values shown in Table I is the average of the velocities thus ascertained at a certain speed of the paddle. These velocities did not vary more than about ten per cent from point to point in the stream.

Experimental results

The results of the experiments are brought together in Table I.

Certain irregularities are apparent such as the relations between the limestone and shale. These are no doubt partly due to the variations in velocity within the cross-section of the current combined with the fact that the stones were placed in different positions for each new test.

The following rules can be deduced. Noticeable abrasion begins at the same velocity between 60 and 80 cm per second both for coarse and fine sand. It seems that below this critical velocity the grains are unable to pierce the capillary film around the pebbles and hit the surface with sufficient force to cause abrasion.

The three most resistant rock types, vein quartz, flint and radiolarite do not even show abrasion when the velocity is 120 centimeters per second as long as fine sand is used. This is the bottom velocity of a torrent. With coarse sand the radiolarite is slightly attacked. It would take about one year for a loss of one per cent in weight to occur.

The pebbles of intermediate resistance: the quartz porphyry, obsidian, dolerite and graywacke show an unmistakable loss at 80 cm/sec. Curiously enough abrasion begins at about the same current velocity for both fine and coarse sand. However, the amount of loss is four times as large with the heavier grains. This ratio is maintained at the highest speed tested and the values found are proportional to the increase in velocity.

For the less resistant rock types there are not only irregularities, but the coarse sand and the higher velocity both have a more marked influence than with the former group.

[1] The suspending thread should be greased, otherwise surface tension causes irregularities up to 5 milligrams.

TABLE I

EXPERIMENTAL ABRASION OF PEBBLES BY WET SANDBLASTING

Loss in weight under water in milligrams per week

Current velocity		40 cm/sec	60 cm/sec	80 cm/sec		120 cm/sec	
Rock type	Weight under water in grams	coarse sand	coarse sand	fine sand	coarse sand/	fine sand	coarse sand
Quartzite	27	0	0	0	0	0	0
Flint	26	0	0 } 0	0 } 0	0 } 0	0 } 0	0 } 3
Radiolarite	16	0	0	0	0	—	3
Quartz porphyry	33	0	0	3	10	3	18
Obsidian	16	0	0 } 0	2 } 14	12 } 57	4 } 19	15 } 74
Dolerite	26	0	0	4	19	4	26
Graywacke	17	0	0	5	16	8	15
Compact limestone	8	0	0	18	307	28	706
Carbonif. shale	14	0	0	4	321	21	1673
Sum		0	0	36	685	68	2456

Fine sand, median diameter 0.125 mm

Coarse sand, median diameter 0.650 mm

Averaging all losses the coarse sand causes 19 times as much abrasion at 80 cm/sec as fine sand and 36 times as much at 120 cm/sec.

Stream action. The most important of these results is that wet sandblasting does not begin until the current velocity is 70 to 80 cm per second. At this speed as bottom velocity small and medium sized pebbles are rolled along, except if firmly wedged between boulders, an exceptional condition that has no quantitative significance.

Even if travelling at no more than 50 cm per second in a current sandblasting at 70 to 80 cm/sec a pebble would have gone 300 km in a week. During that week a soft pebble would have lost about 2 to 3 per cent by the sandblasting but ten or twenty times that amount by abrasion caused by rolling (ascertained in a different set of experiments). For medium hard pebbles these values are 0.05 against 15 per cent and for the resistant pebbles zero against 3 per cent.

From these results the conclusion is warranted that for pebbles of medium size sandblasting is: 1) a minor factor with soft rocks, 2) negligible with normal material, 3) absent with flint, hard quartzites, etc.

Pebbles above a size of about 5 cm occurring in a pebble bed can theoretically remain stationary in a sandblasting current with sufficient velocity to cause abrasion of the part sticking out. But on account of the natural variations in velocity in a torrent the current will tend at one time to be too slow for effective wet blasting and then during the next increase to surpass the 70 cm/sec limit thus becoming so fast as to roll even large pebbles along. Hence these larger ones like the smaller ones suffer little sandblast abrasion as they gradually travel down stream.

It is mainly in the cobble and boulder sizes that the sandblasting can cause attack, because there is a wide range of velocities, in themselves nothing out of the ordinary in mountain streams, great enough to cause abrasion but not to dislodge the stone. However, compared to the large volume of such cobbles and boulders the loss must be extremely slow except for soft rocks. Doubtless this accounts for the comparative scarcity of aquafacts. For usually a boulder will be dislodged by an exceptionally violent flood before the sandblasting of preceeding years has succeeded in changing the shape significantly.

Surf action. A final point to be considered is whether sandblasting can play a more important part in abrasion of beach pebbles. Aquafacts are not very rare on open coasts where sandy beaches with a few large boulders occur. Small stacks piercing through sandy beaches tend to be smoothed and deeply fluted. The conclusion may therefore be drawn that the velocity of the swash is sufficient to sandblast objects over which it sweeps. Numerically this is borne out because it is common knowledge that swash can exceed the minimum velocity required for sandblasting, namely 70 cm per second (a leisurely walking velocity).

It is normal for pebbles to remain permanently on a certain stretch of the beach however much they are moved about. It is therefore reasonable to suppose that they are subjected at intervals during their lifetime to an amount of severe sandblasting that will cause abrasion. But they will also be rolled about and lose weight by this process. It is difficult to answer the question whether the loss by sandblasting can attain a significant fraction of the loss caused by rolling. If pebbles or cobbles were held in a fixed position, for instance on the front of a steep pebble beach, wet blasting might cause distinct fluting. The writer has never observed this to have occurred and he is therefore of opinion that the process of wet sandblasting is of quite minor importance on beaches, being entirely overshadowed by the loss due to rolling. Only in the case of great boulders too large or too firmly wedged to be shifted by waves does fluting and aquafacting become apparent, especially on soft rocks.

Conclusion

Sandblasting by currents and swash is of some importance for cobbles, boulders and country rock, especially those of soft materials. Pebbles, however, lose weight by rolling so much faster than by wet blasting that the latter process is negligible.

The experimental results of abrasion by rolling carried out in the same tank with revolving current will be published elsewhere (KUENEN, in press).

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APPENDIX

Measurement of the relative loss in weight of pebbles

by

W. G. PERDOK

Experimental determination of abrasion by sandblasting on submerged pebbles requires weighings with an accuracy of at least one milligram. At the request of Dr. PH. H. KUENEN the writer of this note undertook to carry out these weighings.

A rapid and accurate method was developed that is entirely repetitive (and that could have given even tenths of milligrams under conditions of constant temperature). This special method was needed because it turned out, that determining the weight of "dry" pebbles by normal weighing is an unsatisfactory procedure from several points of view.

A "dry" pebble is a poorly defined object, quite different from, say, a piece of glass, because it is more or less porous and able to absorb water, so that its weight depends strongly on the way in which it has been dried. Considerable differences are obtained, when a wet pebble is dried (1) by wiping with a cloth, (2) by leaving it in the open air for some days, (3) by drying it at 110° C in an oven or in a desiccator with a water-binding agent.

In the first case the pebble is quickly loosing weight while on the balance, in the second the final weight depends on the relative humidity of the air, and in the third case the pebble slowly gains weight on the balance. Some typical figures are given in Table 1.

TABLE 1.

Treatment	Quartzite	Sandstone
Air dry	37.6353 g	30.8593 g
18 hours in water and dried with a cloth	37.6780 g	31.1380 g
After 1 minute in the air	37.6761 g	31.1332 g
After 1 hour in the air	37.6646 g	31.0084 g
After 7 hours in the air	37.6481 g	30.9151 g
Dried at 110° C for 16 hours	37.6052 g	30.7950 g
After 1 hour in the air	37.6060 g	30.7985 g
After two days in the air	37.6123 g	30.8267 g
After two weeks in the air	37.6300 g	30.8502 g

Moreover, the two latter methods have the great disadvantage, that it takes a long time, before the pebble is in equilibrium with its surrounding atmosphere, so that the abrasion experiments carried out under water could not follow each other with a shorter interval than several days.

A satisfactory procedure to determine the relative loss of weight in wet abrasion was found by keeping the pebbles constantly under water, also during the weighing in the balance.

Indeed in this case not the true weight is found, but a lower value, depending on the hydrostatic upward force that acts on the immersed pebble. Though it is generally not necessary to consider the true loss of weight G, it can be easily calculated from the formula:

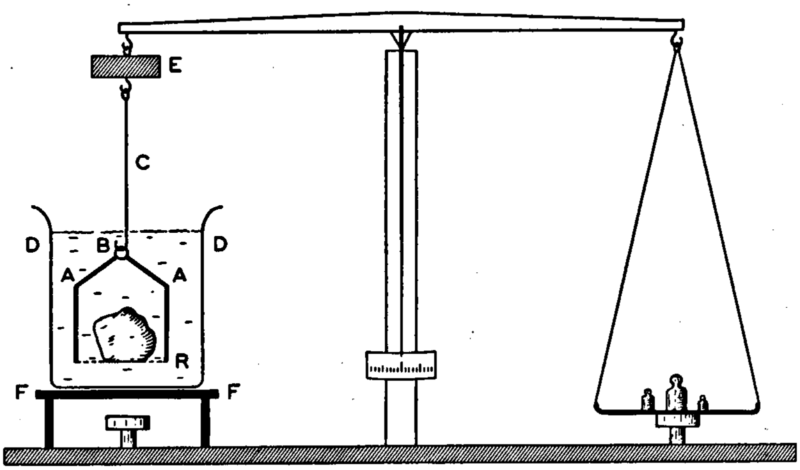
$$G = R \frac{d_p}{d_p - d_w}$$

in which R is the relative loss of weight as found by weighing under water, d_p the density of the pebble and d_w the density of the water.

When the pebbles have been kept under water for two or three weeks, they are in equilibrium and their relative weight remains constant within some tenths of a milligram (Table 2). This high constancy is required specially for the "sandblasting" experiments, where the pebbles are suspended in a stream of sandy water and in which the abrasion is of the order of some milligrams.

The weighing must of course be done on an analytical balance, preferably of the direct reading type. The weight, under water, of the pebbles should not exceed the maximum capacity of the instrument, which is in general 200 g.

To adapt the balance for these hydrostatic weighings (see schematic drawing in Fig. 1), the left scale must be replaced by a suspended ring *R*, in which a piece of wide-mesh, non-corroding wire netting has been soldered. This ring is carried by four thick nickel-plated brass wires *A*, coming together exactly above its center in an eye *B*. This device is hung up at the left arm of the balance by means of a very thing platinum wire *C*. During the weighing of the pebble, which rests under water on the wire netting in a beaker *D*, the device must remain completely immersed, so that only the thin wire penetrates the water surface. To avoid surface tension effects which



attain values of a few milligrams, the wire is greased very slightly, or a little amount of a detergent like sodium lauryl sulphonate is added to the water.

TABLE 2. RELATIVE WEIGHT UNDER WATER AT 20° C.
(balance not adjusted to zero)

	Quartzite	Sandstone
Initial weight	23.2606 g	19.7460 g
After 6 days	24.3024 g	20.0300 g
After 9 days	24.3088 g	20.0382 g
After 12 days	24.3086 g	20.0424 g
After 14 days	24.3086 g	20.0442 g

To prevent any damage to the mechanism of the balance, all handling of the pebbles should be done outside the case. When they are immersed, the beaker is place carefully on a bridge *F* in the balance after which the eye of the thin wire it slipped over the hook of the left arm, so that the device can move freely up and down without touching the walls of the container. The beaker with water must be kept outside the balance when not in use.

When the pebbles are lowered into the water, any adherence of air bubbles to their surface or to the device must be carefully avoided, as this is the main source of errors in hydrostatic weighing. For the same reason the water in the beaker should be boiled previously to drive out dissolved air.

If a great number of pebbles has to be investigated in many experiments it is worthwhile to adjust the device in such a way, that the balance will read exactly zero when the ring is immersed unloaded. This is conveniently done by hanging a flat brass disc *E*, with a hook and an eye on the left arm of the balance. Its weight should tip the scales just to the left, after which the overweight is taken away roughly with a fine file, the exact adjustment being done by single strokes with fine emery paper.