Chapter 19

ATTRITION TESTS OF NATURAL AND REDEPOSITED SHINGLE BEACHES

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SUMMARY

Administrative difficulties sometimes inhibit the transfer of beach shingle from areas where there is a surplus to areas where there is a shortage and it may be necessary to form an artificial beach of ballast dug from an inland pit or of quarried stone to reinforce the defence works or as a substitute for them.

Coast erosion may be caused by a seasonal reversal of the prevailing drift, or by the protection of a previously eroding frontage up-drift, or by building harbour works, or by attrition of beach material, and the recharging of a beach with imported stone may be a cheaper and more satisfactory all round solution than the progressive underpinning of sea walls.

Nevertheless it can be a costly expedient and it is necessary to be able to compare the resistance of the imported material to loss by attrition with the behaviour of the natural beach material.

The paper describes some simple tests which were carried out in an attempt to evaluate the relative resistance of various quarried stones and natural beaches to attrition.

INTRODUCTION

There is no better protection to a coast against sea erosion than a natural beach of hard shingle or sand, and at places where there is a steady inflow of fresh material to compensate for material that is lost by outward drift or by other causes erosion problems do not exist.

Where the average rate of inflow by littoral drift is on balance less than the outflow it may be necessary to have recourse to coast protection works such as sea walls and groynes, or to artificial beach nourishment, or a combination of the two in order to preserve the status-quo.

Artificial nourishment may involve merely transferring shingle or sand from parts of the coast where there is a surplus to places where there is a shortage; if there is no surplus available within an economical hauling distance, the material for recharging must be quarried, excavated or dredged

from an inland or offshore source and transported and dumped on the shore.

There are difficulties about transferring shingle from one part of a populated coast line to another, even when both places are within the administrative area of one Authority, as people who own properties bordering on the sea usually object to the transfer of what they consider to be their beach to other parts of the coast for the protection of other people's properties.

The outflow of shingle from a beach by littoral drift, and the resulting exposure of the underlying strata to erosion by the sea, is sometimes an intermittent or a seasonal occurrence. For example, the dominant winds and the resultant drift on the Durham Coast are on balance from north, to south but during the three successive winters of 1958, 1959 and 1960 the dominant wind was from south to north with the result that much of the shingle below the cliffs to the north of the harbour was moved northward towards Sunderland and fresh material was unable to move in from the south due to the obstruction caused by the harbour breakwaters.

A state of accretion or of stability may be changed to a state of erosion by the construction of sea defences up-drift. For example, the stabilisation of the coast in front of the town of Aldeburgh, Suffolk, by means of groynes and a sea wall has given rise to an erosion problem to the south which is causing the River Board some concern. The stabilisation of the North Shore of Bathurst, Gambia, by groynes and laterite revetments between 1957 and 1960 has given rise to a state of erosion at the eastern end of the sandspit on which the town was built.

The denudation of a shingle beach may give rise to foundation problems in cases where the exposed substratum consists of soft and easily eroded material such as silty sandy clay.

A few years ago the clay substratum at Hayling Island (Hampshire) and Fleetwood (Lancashire) was eroded during the course of a single storm to depths of 6 to 7 feet and the sea walls at these places were breached.

Even rock can be a deceptive foundation for a sea wall. The new Seaham wall was founded on Magnesian Limestone, yet the limestone seaward of the wall was eroded to such a depth during the period of exposure referred to in an earlier paragraph that it was subsequently necessary to extend the wall foundations down to a substantially lower level by means of sloping concrete aprons and the groynes also had to be underpinned.

However, the long-term solution to a problem of

this nature is not to be found in the progressive underpinning of a sea wall to an ever increasing depth. Apart from the difficulty and expense of building sea defence works under tidal conditions in exposed situations and the difficulty and expense of maintaining them, a narrow beach which is submerged except at low tide is of little use to the public, the strain and wear and tear on the defences is greatly increased, sea front property is drenched with spray and continuous expense is incurred in clearing shingle and weed from promenades and roadways after storms.

A possible solution to such problems is to recharge the beach with imported stone, to contain as much as possible of the recharged material against lateral displacement by means of groynes and to import fresh material from time to time under a maintenance programme to replace shingle that escapes over the groynes, or round their outer ends, or that is ground away and lost by attrition.

An artificial flint beach 6 feet high and 90 feet wide with a slope of 1 in 15 may cost up to £10 per foot of frontage to create. Groynes to contain it would cost about another £12 to £15 a foot.

Artificial replenishment can therefore be a costly expedient and it is necessary to weigh the cost against the probable life of the material which must be tough, chemically inert and of a suitable size for placing on beaches which may be used by the public.

The rate at which shingle is wasted by attrition depends upon the hardness of the material, its size and the extent to which wastage occurs by the impact and attrition of one wave-driven stone upon another, or by the impact of the shingle upon a concrete or granite faced sea wall.

To restore and maintain a shingle beach to its original form by recharging with imported stone it is necessary to compare the properties of the imported material with those of the natural material. If the rate of wastage of the natural beach is known, it is possible to form a rough estimate of the quantity of recharge material that will be required provided the comparative properties of the two materials are known.

Usually the rate at which a shingle beach wears away by attrition is not known although it could probably be determined by a suitable full scale experiment extending over a number of years. However, it is not usually possible to wait upon long-term experiments before prescribing a remedy to a sea defence problem.

In certain cases where the beach as a whole is and has been for many years confined laterally between clearly defined limits (e.g. Aberystwyth, North Shore) and record sections have been taken at intervals for a number of years, the rate of loss by attrition, i.e., the rate at which shingle is reduced to fine sand and silt can be roughly estimated.

Tests were carried out by the author's firm recently to compare the relative rate of wastage of various types of material comprising samples of quarried stone, mine waste and natural beach shingles from various parts of the coast.

Samples were taken from four sites, one on the east coast, two on the west and one on the south coast.

At Site 1, Selsey, Sussex, the beach consists of rounded flint pebbles of varying size from about 3 inches down; the pebbles were derived originally by attrition from large angular flints eroded from the chalk but the recent beaches consist of pebbles eroded from glacial period deposit in the cliffs. Selected samples were tested for comparison with the less durable shingle and stone available elsewhere.

At Site 2, Seaham, Co. Durham, the beach material consists of a mixture of siltstone, limestone and Dolerite pebbles, derived partly from erosion of the Magnesian Limestone of which the cliffs are composed and of the Boulder Clay which overlies them. The Magnesian Limestone pebbles have a short life compared with the Lower Carboniferous Limestone and other stones. Large quantities of shingle were removed several years ago for the construction of breakwaters at Seaham Harbour. Much of the remaining material has been lost by attrition.

The only stone that is available in sufficient quantities at an economical price for recharging the beach consists of Coal-Measure shales and sandstone from local collieries, two of which are situated at a short distance from the coast.

The material from the collieries naturally varies in composition and quality; the best material, known locally as "Post-Stone", is a fairly hard light grey sandstone and is found mainly when cutting drifts from one level to another. The supply of this material is consequently uncertain and the quantity available at the pit heads is small.

Very large quantities of shale, with varying amounts of Post Stone are, however, available from the coal seams and this was found to be the only material which could be obtained at an economic cost. Some of the larger material is sorted below ground before being sent to the surface and is known as "Pit Stone", but the bulk of the waste

material is brought out mixed with the coal and is sorted on the surface, the larger pieces of stone being removed by hand on the picking belts and the remainder in the washing plant.

For nearly a century the mine waste has been tipped indiscriminately on to the shore south of Seaham Harbour and an appreciable area has been reclaimed from the sea by this method, the rate of tipping having been in excess of the rate of loss by attrition which, in the case of shale, is considerable.

At Site 3, Aberystwyth, West Wales, the beach consists of flat elongated fine-grained sandstone pebbles of various sizes from 6" down to sand, together with small quantities of shale. For several years the rate of beach regeneration by littoral drift has been substantially less than the loss by attrition and the sea wall at the north end of the town has had to be reinforced by means of a low level sheet piled granite-paved apron which has been costly to maintain.

Material for replenishing the beach is obtainable in unlimited quantities from the cliffs north of the town and from outcrops situated within the town itself, and consists of alternating bands of fine grained sandstone and shale.

The shale has a short life compared with the sandstone and in calculating the amount of recharge material it is necessary to make allowance for their relative resistance to attrition and to the relative proportions of the two materials at the quarry face.

At Site 4, Fleetwood, Lancashire, the shingle contains a high proportion of hard igneous pebbles derived partly by erosion of the underlying Boulder Clay and partly by erosion of the cliffs north of Blackpool. The latter are now protected by sea walls over the whole of this seven mile stretch of coast and the loss by attrition has in recent years exceeded the rate of regeneration by littoral drift, and erosion of the Boulder Clay and gravel deposits and the quantity of residual material has been insufficient to cover and protect the underlying soft silty sandy clay against erosion. As a result the foreshore has been progressively lowered and it has been necessary to extend the sea wall foundations downward and seaward by stages by building sloping granite aprons in order to prevent the walls from being undermined. Beach loss by attrition has been accelerated since these aprons were built and the aprons themselves have been costly to maintain.

Large quantities of shingle were excavated from places where there was a surplus and redeposited at places where there was nothing but a shifting layer of sand over the underlying clay.

THE TESTS

The tests were carried out by placing weighed and graded samples of each material (between 40 and 50 lbs. of each) in a revolving steel drum and re-weighing and re-sieving the residue at 3, 6 and 9 hour intervals.

A 14/10 Stothert and Pitt concrete mixer was used for the tests. All except two opposite blades were removed and the filling skip and discharge spout were replaced by steel cover plates. A drain plug for washing out fine residue was welded into the perimeter of the drum.

Each sample was weighed, graded and placed in the drum with two gallons of water and the machine was then run for 3 hours at a constant speed of 19 r.p.m. The sample was then removed from the drum, all fine sand and silt below No.14 sieve discarded and the residue weighed and regraded.

The residue above No.14 sieve was then replaced in the drum and the procedure repeated for two further three hour tests. The reason for removing all but two of the blades was to simulate both the rolling and impact forces to which beach shingle is subjected by waves.

The results of the tests are shown in Fig. 1. The percentage weight of the residue above No. 14 sieve is plotted against duration of test in hours.

In each test the samples containing the largest stones showed greater percentage losses than samples of similar materials of smaller size. Presumably the heavy stones fracture more readily than the small ones and the sharp fractured edges are worn away rapidly until the stones acquire the characteristic rounded shape of beach pebbles.

The softer materials which arrived as large broken lumps broke down very quickly into lozenge shaped pebbles up to about 2" long. Until this stage was reached fractured faces could still be seen.

The most resistant of all samples were the fine flint pebbles from Selsey C2. This material which initially was graded from $\frac{3}{4}$" down to 3/16" produced only 10% of fines below No.14 sieve after 9 hours wear. Coarse flint pebbles C1 with an initial grading from $1\frac{1}{2}$" down to $\frac{3}{8}$" produced 45% of fines. The rate of wear of sample C1 was greatest in the first 3 hours. It continued to wear at a faster rate than C2 for the remainder of the test. The behaviour of mixed flint pebbles (sample C3) was intermediate between C1 and C2.

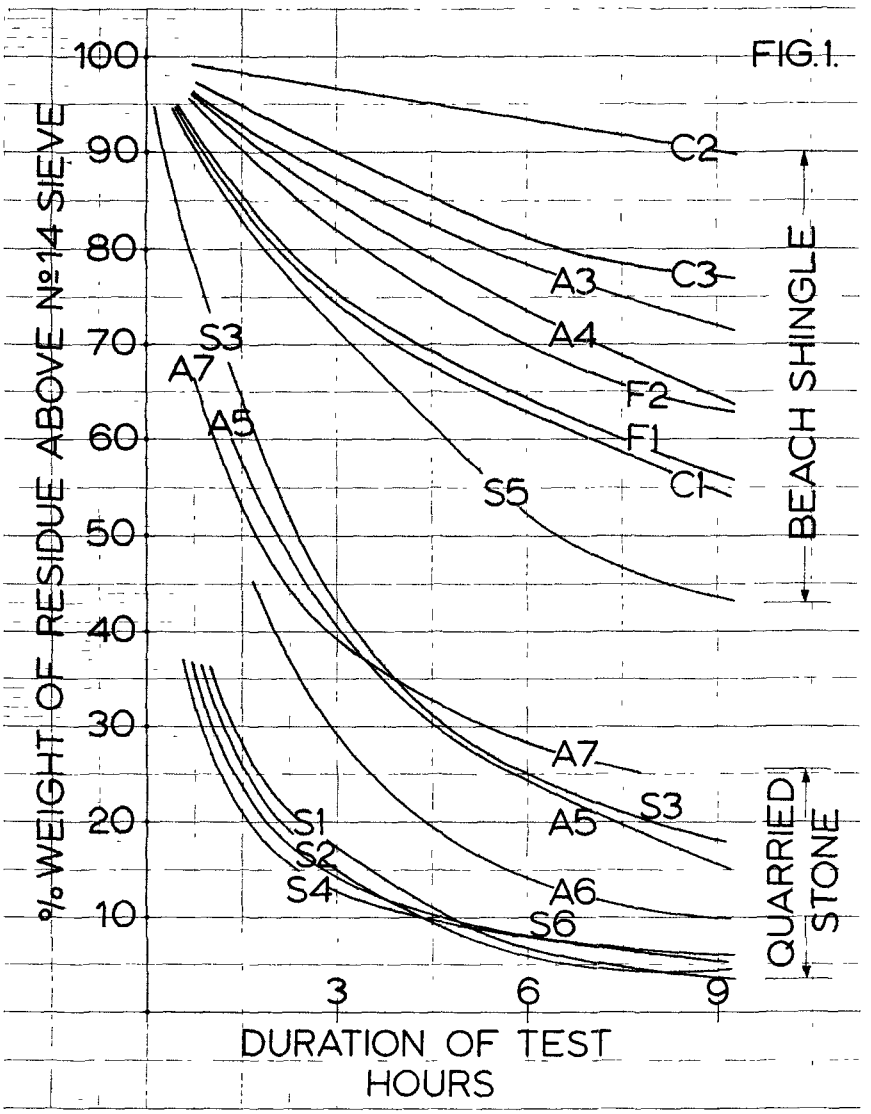
FIG. 1.
% WEIGHT OF RESIDUE ABOVE Nº14 SIEVE
100
90
80
70
60
50
40
30
20
10
3
6
9
DURATION OF TEST
HOURS
C2
C3
A3
A4
F2
F1
C1
S5
S3
A7
A5
A7
S3
A5
A6
S6
S1
S2
S4
BEACH SHINGLE
QUARRIED STONE

The highest percentage losses occurred with samples of mine waste from the collieries at Seaham and a hand-picked sample of Magnesian Limestone pebbles from the beach north of Seaham Harbour. The results of the Seaham tests were as follows:-

Serial No.	Origin	Description	Composition	Size	% loss after 9 hours
S1	Vane Tempest Colliery	Pit Stone	Mainly grey shale but with some siltstone (Post Stone) fairly clean.	8" down to $1\frac{1}{2}$"	96
S2	"	Picking belt chippings	As above but not so clean	6" down to $1\frac{1}{2}$"	97
S3	"	Wet Shale	Mainly grey oily shale with some coal	3" down to $1\frac{1}{2}$"	82
S4	Dawdon Beach Tip	Pit Stone	As S1 but picked by hand from the Coal Board tip at Dawdon	4" down to $\frac{3}{4}$"	95
S5	Seaham	Average natural shingle	Siltstone, limestone and Dolerite	3" down to $\frac{3}{4}$"	56
S6	Seaham Beach	Selected pebbles	Limestone	6" down to $1\frac{1}{2}$"	94

It will be seen that by comparison with the natural shingle of Seaham Beach (S5), the mine refuse from Vane Tempest and Dawdon has a short life and that some 11,000 tons of this material would have to be placed on the beach to replace every 1000 tons of natural beach shingle worn away by attrition. The limestone pebbles (S6) are seen to be useless as a beach material and as mine refuse is the only material available in large quantities and it costs only 3/- a ton to dig, transport and dump it on the beach,

the local authority was advised to carry out a massive initial recharge of the beach, to contain the tipped material between massive groynes so that it is retained at places on the Seaham coast line where concentrated erosion of the underlying bed rock had occurred and to maintain the beach in a healthy condition by recharging month by month at a rate in excess of the rate at which the material wears away.

Sample (S3), showed 13% less loss than the other mine waste samples, due presumably to the fact that it was composed of finer material than the other Seaham samples.

Somewhat similar results were experienced with comparative tests between natural beach shingle in two sizes and quarry stone and quarry waste from Aberystwyth (Samples A3, A4, A5, A6 and A7).

The natural shingle is flat and rounded and varies from 6" to 8" dia. down to $\frac{1}{4}$" material and sand. Samples A3 and A4 were respectively fine ($1\frac{1}{2}$" down to $\frac{3}{8}$") and coarse (3" down to $\frac{3}{8}$"). Both gave good results under test, the finer material showing less wear than the coarser. The percentage loss after 9 hours testing (28% with A3 and 36% with A4) was of the same order as with mixed flint shingle from Selsey C3 and the finer of the two samples of natural beach shingle from Fleetwood.

Three samples of quarried stone and quarry waste were tested.

A5, selected hard material from one of the tips from 4" down, lost 84% of its bulk. A6, similar to A5 but containing rather more shale and graded from 6" down to sand lost 90%. The third sample A7 consisting exclusively of hard sandstone rubble and containing seven hand-picked stones measuring 11" x 8" x 5" down to 5" x 3" x 3" lost 74% by weight after $7\frac{1}{2}$ hours when the test was discontinued due to the fracture of the drum.

APPLICATION OF THE TEST RESULTS

It hardly needs emphasising that the treatment to which shingle on an open foreshore is subjected by wave action is much more complicated than the treatment given to the samples in the revolving drum. In nature the beach profile is continually changing, being drawn down by short steep waves and built up again by long low waves. Further, in the revolving drum the amount of material above No.14

sieve size was continually being reduced, whereas on an open beach only a relatively thin surface layer is being attacked at any one time and as material is worn away it is replaced in the surface layer by new material from below, i.e., the amount of material being subjected to attrition does not vary in the same way as the material in the experiments although it obviously must vary from time to time with changes in tide level and the severity of wave action. Consequently there is no simple correlation between the scales of the experimental work and the natural scale on an open beach. Nevertheless, it has been found possible to use the results of the experiments to give a comparison of the durability of different types of material and, consequently, to determine the amount of imported material that is needed to maintain the required beach levels relative to the amount that would have been needed if material equal to the natural beach had been available.