### CHAPTER 101

# FIELD EXPERIMENT ON BEACH GRAVEL TRANSPORT

by

Masataro Hattori\* and Takasuke Suzuki\*\*

\* Department of Civil Engineering \*\* Institute of Geoscience

> Chuo University Bunkyo-ku, Tokyo, Japan

# Abstract

To examine the longshore transport processes of beach gravels under wave action, a field experiment was performed by tracing the dacite blocks injected on Fuji Coast, Shizuoka Prefecture, Central Japan.

The mean dislocating velocity of the tracer was 2 to 3 m/day under normal sea conditions, while under storm conditions it reached about 400 m/day. This velocity was fairly proportional to the longshore component of incident wave energy flux.

The longshore variations of the size and shape of beach gravels were mainly resulted from the progressive attrition and impact breakage of beach gravels rather than from the selective transport.

#### INTRODUCTION

This paper describes a field experiment carried out to obtain a better understanding of the littoral transport of beach gravels under wave action.

The mechanism of littoral transport of sand by waves and wave-induced currents has been extensively investigated and the beach processes have also been discussed by many researchers (1)\*. On the other hand, our knowledge of the processes of beach gravel transport seems to be very limited in comparison with that of the sand transport, because it is very difficult to study the gravel transport by the laboratory experiments.

\* : The figure in parentheses represents the reference cited at the end of this paper.

The transport processes of beach gravels have been studied by the tracing experiment using marked beach materials (2,3,4). According to previous studies, the transport processes are controlled by the size of gravels and the location of the zone in which the transport occurs.

Some reseachers have inclined to the view that the longshore variation in beach gravel size can be produced by the selective transport processes. On the other hand, a number of field studies (5) demonstrates that beach gravels decrease in size, and change in shape due to the progressive attrition during their travel.

The present writers suggested in the previous paper(6) that the predominant direction and intensity of littoral sediment transport were more easily determined from longshore variations of beach gravel properties than from those of sand properties. More detailed informations on this subject are required to substantiate the writers' concept.

The principal purposes of this experiment were as follows:

- 1. To examine the longshore dislocating velocity of beach gravels,
- 2. To obtain the relation between the dislocating velocity and the longshore component of incident wave energy flux.
- 3. To elucidate the processes of the size and shape changes of beach gravels during their travel.

### OUTLINE OF THE STUDY AREA

The experiment was performed on Fuji Coast located at the head of Suruga Bay, Shizuoka Prefecture, Central Japan (Fig.1). The study beach is the eastern reach of Fuji Coast which extends about 15 km from Tagonoura Port on the west to Numazu Port on the east.

The beach is about 150 m in width and is composed of sand and gravels. They are derived mostly from Fuji River on the west and slightly from Kano River on the east.

Suruga Bay is extremely deep and faces the Pacific Ocean in the south-west direction. Since the head of a submarine canyon is located near the coastline, the nearshore slope is so steep, up to about 1 on 10, that breaking waves plunge and form an intense swash with a narrow surf zone. The longshore current is not strong under normal wave conditions.

According to the tide observation of Fuji Coast (7), the tidal range during a spring tide is about 1.5 m, and the greatest resultant velocity of tidal current in the east-west direction is about 9 cm/day.

The littoral drift is in the east direction, which is the dominant one along Fuji Coast, and it has been intercepted by a navigation channel at Tagonoura Port. This has



Location of the study area. Fig. 1

I: Tracer injection site, W: Hara Wave Observatory,

Q: Dacite block quarry, P.T.: Tagonoura Port, N: Numazu City, F: Fuji City, F1, F2 and F3: Outlet works.

resulted in severe beach erosion on the up-drift side of the study beach.

To prevent further beach erosion, wave defense works, a kind of offshore breakwater system, have been constructed along the shoreline in the vicinity of the Tagonoura Port. There are no other coastal structures on the beach, except for three diversion outlet works, whose locations are denoted by F1, F2 and F3 in Fig.1. Their effect on the shoreline configuration is not so large.

Figure 2 shows the two-dimensional bottom profile



along the study beach from the west to the east. Figures attached to the profile represent the bench mark number.

Due to the submarine topography of Suruga Bay, swells and huge waves generated by typhoons often attack the beach. The predominant wave direction is almost constant with respect to seasonal changes. The wave energy level along the study beach is considered to be almost constant, except for the vicinity of Numazu Port.

### METHODS OF FIELD EXPERIMENT

Various labelling techniques of beach materials for the tracing experiment have recently developed to examine the nature and dislocating velocity of sediment transport (8). In this experiment, dacite blocks from a quarry, Q in Fig. 1, were used as the tracer.

This dacite is whitish yellow in color and homogeneous in texture, and have the physical and mechanical properties as shown in Table 1. This type of dacite gravels are not found on the study beach and also on the bed of Fuji and Kano Rivers. Therefore, the dacite blocks could be easily distinguished from the indigenous beach gravels, most of which are sandstone, granite, slate and basalt. The tracer is slightly softer and lighter than these indigenous gravels.

Initial Tracer Properties	Water Condition	Number of Specimen	Mean	S.O.
apparent specific gravity		5	2.68	0.01
dry bulk weight ( gr/cm <sup>3</sup> )	dry	10	2.41	0.02
porosity (%)	dry	5	10.1	0.80
maximum water content (%)	wet	10	3.8	0.17
P-wave velocity (km/sec)	dry wet	5 5	3.2 3.3	0.06 0.07
S-wave velocity (km/sec)	dry wet	5 5	2.5 2.5	0.1 0.2
dynamic modulus of elasticity ( x10 <sup>5</sup> kg/cm <sup>2</sup> )	dry wet	5 5	3.5 3.1	0.6 0.7
compressive strength (kg/cm <sup>2</sup> )	dry wet	5 5	615 341	41 44
tensil strength (kg/cm <sup>2</sup> )	dry wet	5 5	70 29	4.5 3.8
weigth loss percentage by Los Angels test (%/500gr)	wet	1 -	18.3	

Table 1 Physical and mechanical properties of dacite blocks.

Some 7000 dacite blocks were injected on the beach face from the shoreline at low tide-level to the backshore berm line in the shape of a jetty 42 m long, 3 m wide and 0.3 m high. The injection site, I in Fig. 1, was about 1.5 COASTAL ENGINEERING-1978

km east of Tagonoura Port. The initial size and shape indices of the injected blocks are shown in Table 2. The injected blocks were larger in size and more angular in shape than the indigenous beach gravels.

Initial tracer parameters	maximum	minimum	mean
long diameter : a (cm)	85	10	26.0
intermediate diameter : b (cm)	40	7	19.2
short diameter : c (cm)	29	4	13.2
<pre>nominal volume : Vn(=axbxc)(cm<sup>3</sup>)</pre>	6.4x10 <sup>4</sup>	2.8x10 <sup>2</sup>	5.8x10 <sup>3</sup>
flatness : axb/c <sup>2</sup>	16.1	1.2	2.7
elongation : a/c	5.0	1.2	2.0
Krumbein's roundness	0.5	0.3	0.32

Table 2 Initial size and shape indices of the injected blocks

Surface sampling of the tracer was carried out across the entire beach profile along the beach every field survey. Every sampled block of tracer was measured for its long, intermediate and short diameters, and its sampling location on the beach was recorded in terms of the longshore distance from the injection site and the seaward distance from the bench mark. Its picture was also taken to determine the roundness on the basis of Krumbein chart of roundness. After measurement, the tracer was returned to its sampling point.

The tracer recovery rate was two or three percent for every field survey. In the discussion of the experimental results, it is assumed that the distribution of sampled tracer on the beach surface represents that of the whole transported tracer.

Wave data at Hara Wave Observatory, W in Fig. 1, were obtained from a pressure wave gage placed on the sea bottom at a depth of 20 m and lined to an analogue recorder on land. The measurements were made for twenty minutes every two hours.

Figure 3 shows a temporal change in wave height using the data for the first 70 days after injection. Two typhoons, Nos.5 and 6, attacked the beach 11 days and 17 days after injection. The greatest wave height of 11.6 m was recorded during Typhoon No.6.

Figure 4 shows the distributions of wave height and period. From these histograms, prepared using the data

during the experiment, the significant wave height and period are read as 0.5 m and 8 seconds, respectively.



Fig. 3 Temporal change of wave height during the first 70 days after injection.



Fig. 4 Distributions of wave height and period.

# DISLOCATING VELOCITY OF TRACER

Figure 5 shows the distribution of displaced blocks three days after injection. At that time, three quaters of the injected blocks still remained at the injection site. The drift piling zone, indicated by a thin dotted line, is considered to represent the upper limit of uprush at high tide-level.

Asymmetrical distribution indicates that the beach drift direction is eastward. Most of displaced blocks are distributed in the median zone between the top of foreshore and the upper limit of uprush.



Fig. 5 Distribution of displaced blocks three days after injection.

The mean longshore distance of transport was calculated from the longshore distribution of displaced blocks by taking the first moment of the tracer distribution in the longshore direction about the injection site.

The greatest or maximum distance was estimated from the sampling location of the furthest travelled block.

The mean longshore dislocating velocity was calculated by dividing the mean transport distance by the elapsed time during which the transport occured. The maximum velocity was also obtained in the same manner.

Experimental results of the longshore transport distance and the dislocating velocity are summerized in Table 3. Figure 6 shows the time changes of the greatest and mean longshore distances of tracer transport.

It is noticed from these results that the predominant direction of littoral transport was westward and the exceptional displacements occurred during the two typhoon attacks on the beach. The furthest blocks reached 14 km east of the injection site in about a half year after

Elapsed Time (days)	Deed The Number Longshore Distance from Injection Site (m) Sampled Tracer Xmax X		Longshore Oistance from Injection Site (m)				Dislocati (m/	Median Diameter	
(days)			Vmax	ν	(p-scale)				
0		(7000)		0		Q	147	67	~ 7.5
1	E	300	E	147	E	8.7		0.7	
		320					54	13.2	
3	W	320 15	E W	255	E	35		3 2	- 7.4
10	E	355	E	520	-		44	3.2	7.0
	W	12	W	5	E	54	345	326	- 7.0
11*	E	9	E	865	E	380	400		
12*	E	20	E	1265			217	44.4	
36	E	123	E	6250	E	1535			- 6.9
89	Е	148	E	5960	Ε	1640		2.0	- 6.9
174			E	14000			- 90	11.5	
364	E	138	E	14000	E	4800			- 6.6
7 30	E	240	E	14000					- 5.5
Mean Dislocating Vel. Ouring the Experiment						80	13.2		

Table 3 Transport distance and dislocating velocity.

Xmax and  $\overline{X}$ : the maximum and mean transport distances, Vmax and  $\overline{V}$ : the maximum and mean dislocating velocities, E: the eastward transport, W: the westward transport, \*: the storm conditions under Typhoon No.5.



Fig. 6 Temporal changes of the longshore distance of the tracer transport.

injection.

The dislocating velocities under various sea conditions are estimated from these results as follows: The mean dislocating velocity was between 2 and 3 m/day under normal sea conditions, while under storm conditions it reached about 400 m/day. The maximum velocity under normal sea conditions was estimated to be 50 to 60 m/day, and during Typhoon No.6 it produced about 1 km/day.

Table 4 shows that the mean velocity seems to increase with tracer-size decrease. Phillips (9) also reported a similar tendency, whereas, Evans (10) and Kindson and Carr (11) stated that the larger gravels were transported faster than the small. However, the problem is very complicated, because in the present experiment the tracer decreased in size due to the progressive attrition and impact breakage, as discussed later. Hence, the result shown in Table 4 does not necessary imply the size effect on the dislocating velocity.

Fable 4	Relation between	the tracer	size	and
	mean dislocating	velocity.		

Mean Diameter (ø-scale)	- 8	- 7	- 6	- 5	- 4
Mean Velocity V̄ (m/day)	6	14	19		23

The relation between the mean dislocating velocity and the longshore component of incident wave energy flux is shown by Fig. 7, which was prepared using the data collected during the first 89 days after injection.

This shows a fairly good linear relationship between the two quantities. A similar relationship between the rate of sand transport and wave energy flux has also been reported (12).

From Fig. 7, an empirical relation is obtained as

 $\overline{V} = 0.0025 \ \overline{E} - 3.75$ ,

where  $\overline{V}$  is the mean dislocating velocity in m/day, and  $\overline{E}$  is the longshore component of incident wave energy flux in ton·m/day·m.

Using this relation, the threshold wave height for the tracer movement is calculated to be about 0.2 m, for which the wave period is assumed to be 8 seconds.



Fig. 7 Relation between the mean dislocating velocity and the longshore component of wave energy flux.

# CHANGES IN TRACER SIZE AND SHAPE

Figure 8 shows the temporal changes of the mean long and short diameters and the mean nominal volume of the tracer. Figure 9 is the cumulative curves of the tracer nominal volume for each field survey.

- These figures indicate the following facts:
- 1. During the two typhoon attacks, there occurred considerable volumetric decreases, reaching about 70 percent of the initial mean volume (Fig.8), and all fraction of blocks seemed to lose volume uniformly (Fig.9).
- Over the 70 days after the typhoons, the tracer size seemed to be almost constant (Fig.8), because the sea conditions during this period were very calm.
   Over the 275 days between 89 days and 364 days after
- Over the 275 days between 89 days and 364 days after injection, only the small size fraction of the tracer decreased in volume (Fig.9).
- 4. The whole fraction of tracer decreased in volume in the next year (Fig.9).
- 5. The rates of decreases of the long and intermediate diameters were slightly greater than that of the short diameter (Fig.8).



Fig. 8 Temporal changes of the mean long and short diameters and the mean volume.



Fig. 9 Cumulative curves of tracer volume.

Figure 10 shows the longshore variations of the long and short diameters 36 days, 89 days and 364 days after injection. Abrupt decreases in diameters are found about 3 km east of the injection site. The location of the abrupt decrease moved progressively eastward with the elapsed time.



Figure 11 shows the longshore variations of the mean nominal volume of the ten largest blocks. In comparison with Fig. 10, it is found from this figure that the abrupt decrease in the tracer volume also occurs at almost the same location as the case of the long and shore diameters.

The temporal changes of the elongation and flatness of the tracer are shown in Fig. 12. These shape indices increased progressively with the elapsed time. After attaining their maximum values about 100 days after injection, they tend to decrease. The increases in these indices suggest also that the short diameter decreased faster than the long and intermediate diameters.



Fig. 11 Longshore variations of the ten largest tracer blocks.



The evidences deduced from the experimental results suggest that the large blocks tended to be displaced by sliding motion, and that as the blocks became smaller in size, they tended to be rolled and tossed by waves. Figure 13 shows the typical longshore distributions of the elongation and flatness of the tracer 36 days after injection. These distributions indicate that the two incices increase with longshore distance until a point about 2 km east of the injection site. Beyond this point they abruptly decrease, and then again increase gradually. Based on these longshore variations, it is concluded that the abrupt decreases in the shape incices of the tracer are caused by tracer breakage due to collisions with beach gravels.



Fig. 13 Longshore distributions of the elongation and flatness 36 days after injection.

Figure 14 shows the longshore variations of the tracer roundness. The upper figure indicates that the injected blocks having sharp edges were soon rounded due to the griding with the indigenous gravels and sand. As shown in the bottom figure, the roundness of about two thirds of the tracer 364 days after injection is more than 0.7.



Fig. 14 Longshore variations of the roundness.

In conclusion, a possible process of the size and shape changes of the tracer can be inferred from the results of the present experiment, as follows:

Over initial period after injection, the blocks are displaced through sliding motion due to wave action. Then, the blocks decrease in size and become rounder, flatter, and more slender through sliding abrasion.

When their shape indices attain certain values, for example, 4 to 5 for elongation and 10 to 15 for flatness, the block must be broken into two pieces by collisions with beach gravels. As a result, the elongation and flatness become about a half of these values before the impact breakage occurs.

As the blocks decrease in size due to both attrition and breakage, they are rolled and tossed by waves and thus they experience wearing on all sides.

Figure 15 is a comparison of the longshore variation of the mean nominal volume of the tracer with that of the main indigenous beach gravels. Abrupt changes in the indigenous gravel volume were observed at almost the same location as that giving abrupt decreases in tracer volume.

The tracer became smaller rapidly than the indigenous beach gravels. This fact depends on 1) the weaker resistance of the dacite blocks to the attrition and breakage, 2) the initial angularity of the tracer, and 3) the limited supply of the tracer.



Fig. 15 Longshore variations of the mean volume of tracer and beach gravels.

Ss: sandstone, Gr: granite, Sl: slate, Ba: basalt.

#### CONCLUSIONS

The mean dislocating velocity of the tracer was 2 to 3 m/day under normal sea conditions, while under storm conditions it reached about 400 m/day. This velocity was fairly proportional to the longshore component of incident wave energy flux.

The longshore variations of the size and shape of beach gravels were mainly resulted from the progressive attrition and impact breakage of beach gravels rather than from the selective transport.

#### REFERENCES

- 1) Horikawa, K.: Coastal Engineering An introduction to Ocean Engineering - , University of Tokyo Press, pp.269-274, 1978.
- 2) Zenkovich, V.P.: Processes of Coastal Development, edited by J.A.Steers, Oliver & Boyd, pp. 317-322, 1967. 3) King, C.A.M.: Beaches and Coasts, Edward Arnold, pp.290-
- 292, 1972.
- 4) Komar, P.D.: Beach Processes and Sedimentation, Prentice-Hall, pp. 351-363, 1976.
- 5) Komar, P.D.: loc. cit. 4).
  6) Hattori, M. and T. Suzuki: Concept for inferring the littoral drift trend, Proc. 15th Conf. on Coastal Engineering, pp. 1223-1239, 1976.
  7) Shuto, N., J. Taguchi and T. Endo: Field observation of sand drift at Engineering. Proc. 24th Conf. on Coastal
- sand drift at Fuji Coast, Proc. 24th Conf. on Coastal Engineering in Japan, pp. 211-215, 1977. (in Japanese)
  8) Kidson, C. and A.P. Carr: Marking beach materials for
- tracing experiment, Jour. of the Hydraulic Division, Proc. of ASCE, Vol. 88, No. HY 4, pp. 43-60, 1962.
  Phillips, A.W.: Tracer experiments at Spurn Head,
- Yorkshire, England, Shore and Beach, 31(2), pp.30-35, 1963.
- 10) Evans, O.F.: Sorting and transportation of material in the swash and backwash, Jour. of Sedim. Petrol., Vol. 9,
- No.1, pp. 28-31, 1939. 11) Kindson, C. and A.P. Carr: Beach drift experiments at Bridgewater Bay, Somerset, Proc. Bristol Nat. Soc., Vol. 30, No. 2, pp. 163-180, 1961.
- 12) Horikawa, K.: loc. cit. 1).