CHAPTER 102

SHINGLE[1] TRACING BY A NEW TECHNIQUE

Peter Wright, J.S. Cross and N. B. Webber
Department of Civil Engineering
University of Southampton, England

Abstract

A major drawback of all existing tracer techniques for monitoring shingle movement, except that of labelling with radioactive isotopes, is that tracer recovery rates are invariably low, (commonly less than 15% of the total injected) because recovery is limited to the beach surface. Investigations were made into the possibilities of developing a new tracer that might overcome this problem.

The paper describes the results of, and the conclusions drawn from two trial field experiments carried out using metal tracer pebbles. These had specific gravities, size and shape similar to the indigenous beach pebbles, and were recovered both on and beneath the beach surface using metal detectors. By assessing the relative merits and drawbacks of the technique it was concluded that the use of metal pebbles as tracers for shingle beaches is more practical than other methods for most tracing purposes. At present the technique is best suited to investigations ranging in length from a few days to a few months and requiring small to medium-scale injections of 5000 tracer pebbles or less. The considerable scope for the further development and application of the technique is discussed.

Introduction

Most techniques for investigating shingle transport on beaches depend either on some method of marking the indigenous beach material, on the introduction of beach pebbles and cobbles of a different petrological type or pebble and cobble substitutes and monitoring their movement after injection. The relative merits and drawbacks of existing tracer techniques are well documented in the literature by Kidson and Carr (1962). A more recent but less comprehensive review of shingle tracing is contained in Hails (1974).

A major drawback of all existing tracer techniques except that of labelling with radioactive isotopes, is that tracer recovery is limited to the beach surface. Consequently tracer recovery rates are seldom

---

SHINGLE[1] - used here in the context defined by Carr (1971), that is as encompassing all sediment particles whose long diameter, 'a', lies within the range 4-256mm, and as such includes the pebble and cobble categories of the Wentworth Scale.

greater than 30% and commonly less than 15% of the total quantity of tracer injected. This situation in which tracer recovery rates are low and little, if anything, is known of the tracer distribution beneath the beach surface is clearly unsatisfactory for seeking a detailed understanding of the behavioural patterns of shingle beaches.

Investigations were made into the possibilities of developing a new tracer for shingle beach studies that might overcome these difficulties.

Metal Pebbles: A New Type of Tracer for Shingle Beaches

The potential merits of using metal pebbles as a new type of tracer for shingle beaches were considered to be:

1. With the use of metal detectors it would be possible to detect the tracer pebbles beneath the beach surface which would not only increase tracer recovery rates but also provide information on the vertical distribution of the tracer.

2. Metal tracer pebbles could be manufactured to reproduce the specific gravity, size and shape of the indigenous beach pebbles.

3. Of importance when investigating beaches which are popular with the general public, they would be unobtrusive and present no health risk.

The specific gravity of the indigenous pebble-sized material found on the beaches to be investigated directly governed the metal used for the manufacture of the tracer pebbles. The pebble and cobble fractions of these beaches are composed of 90+% of flint and chert, both have specific gravities of 2.7. Aluminium was chosen as the metal most suitable for the purpose, not only because it has a specific gravity of 2.7, but also because it is easy to work with. The tracer pebbles used in the first trial field experiment were manufactured using the "full mould" or "cavityless" method of casting (Waring, 1965). Those used in the second trial field experiment were manufactured using a "sand-casting" technique (Fig.1).

Full details of the manufacturing procedures and the methods of tracer pebble detection and recovery in the field, including a discussion of the relative merits of the various types of metal detectors and search procedures, are contained in Wright, et al (1978).

Field Trials of the New Tracer

Aims of the field trials

1. To establish estimates of "expected" tracer recovery rates when using aluminium tracer pebbles.

Fig.1. Aluminium tracer pebbles manufactured using a "sand-casting" technique (first and third columns). Indigenous beach pebbles used as patterns (second and fourth columns).

2. To gain a clearer insight into the practicalities of undertaking a larger-scale field investigation using this tracer technique.
3. To ascertain the purpose and scale of tracer experiments to which this new tracing technique would be best suited.
4. To assess the corrasive and corrosive qualities of the aluminium tracer pebbles under field conditions.

It was hoped to assess whether or not the behaviour of the aluminium pebbles differs significantly from that of the indigenous beach pebbles by releasing simultaneously with the aluminium tracers, and at the same site, marine-painted or flourescent-coated beach pebbles. However, due to financial restrictions this was not possible.

Conduct and results of the field trials

Field trials were undertaken at Hengistbury Long Beach, Poole Bay, Dorset (Fig.2), during the periods 9/5/77 - 25/5/77 and 20/2/78 - 11/3/78.

In both experiments the tracer pebbles were injected at one-pebble depth (40-50mm) on the upper foreshore at the seaward foot of the shingle scarp face of the backshore zone. The background indigenous pebble population incorporated the full size range of the artificial aluminium pebbles. The dimensions of the tracer pebbles injected in the two experiments are given in Table I.

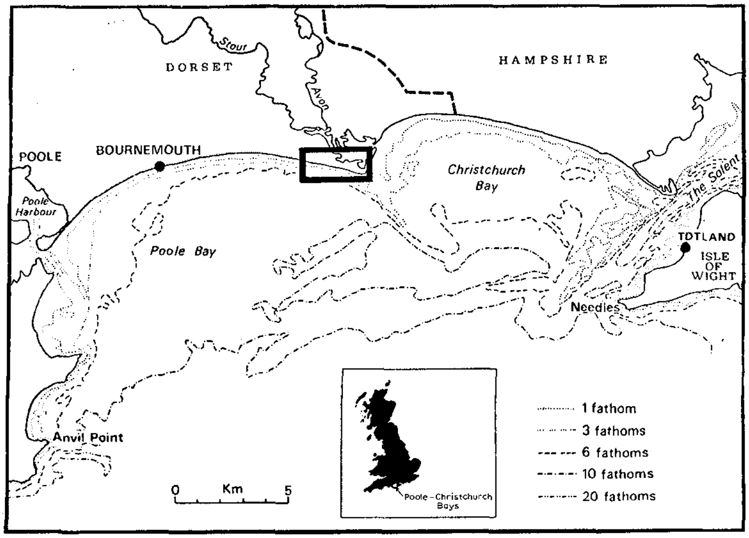

Fig.2. Location of field trial site.

TABLE 1

Size and shape parameters of the tracer pebbles used in the field trials (measurements in millimetres).

Pebble batch	Quantity injected	Length of 'a', 'b', and 'c' axes a	b	c	Sphericity index value ($c/\sqrt{ab}$)
Field Trial 1					
L	25	60	50	45	0.82
M	25	45	40	30	0.71
S	25	40	35	25	0.67
Field Trial 2					
LA	70	70	55	35	0.56
MA	70	67	38	25	0.50
SA	90	58	45	24	0.47
LR	70	57	49	44	0.83
MR	70	61	34	30	0.66
SR	90	44	34	31	0.80

TABLE II

Classification of wind and wave conditions during the field trials (all observations were made at the field site).

No. of tides after injection	Wind states direction	force (Beaufort)	Wave states breaker height (m)	period (sec)	orientation
Field Trial 1					
0-4	SW-W	4-5↑7-8	0.6↑1.5	4-6	+5° to +12°
5-6	NW	4	2.0↓0.8	8-10	+7° to +14°
7-29	N-NE	4-5	0.3-0.5	5	-17° to -27°
Field Trial 2					
0-8	E-SE	6↓2-3	1.1↓0.9	4-6	-17° to -29°
9-14	SW	4-5	1.5↓1.2	12	-18° to -20°
15-20	SE	3-4	1.0	4-6	-23° to -29°
21-25	NE-N	4↓2-3	0.4	6-8	+1° to -6°
26-27	SSE	2	2.0	18	0° to +4°
28-33	S↷WNW	2	0.7	6	+10° to +12°
34-37	WNW↶SE	2	0.8	6	+1° to +8°

Key
↑ - increasing
↓ - decreasing
↶ - wind backing
↷ - wind veering

Wave orientation is expressed as the angle which the orthogonals of waves approaching the shore make with an imaginary line drawn at right-angles to the same shoreline. Angles measured to the west of the line are prefixed +, and those measured to the east, prefixed -.

During the first field trial the tracer pebbles were subjected to movement under three distinct sets of wave conditions. During the second experiment however conditions were much more varied. Wind and wave conditions during the two field trials are summarized in Table II. During the first field trial tracer recoveries of 41% (no lower foreshore search), 63%, 59% and 61% were made on the four days of full sweeping of the tracer-spread area. During the second trial tracer recoveries of 38%, 27%, 28%, 30%, 34% and 43% were made. Tracer recovery rates for both field trials are fully tabulated in Table III.

TABLE III

Tracer recovery rates during the field trials (values are expressed as percentages of the total number of tracer pebbles injected).

No. of tides after injection	Tracer recoveries: Total	Pebble Batches					
Field Trial 1		L	M	S			
6	41*	45	64	12			
12	63	72	84	32			
14	59	76	72	28			
29	61	80	58	40			
Field Trial 2		LA	MA	SA	LR	MR	SR
2	38*	49	31	34	44	39	31
6	27*	27	39	32	20	22	21
8	28*	27	30	36	22	29	22
17	30*	34	37	26	31	26	23
27	34*	42	44	30	34	34	22
37	43	54	54	32	43	41	33

* - No lower foreshore search possible

The lower rates of tracer recovery made during the second field trial were attributed to three main causes. Firstly, only on the occasion of the final full sweep of the backshore and foreshore zones was the lower foreshore sufficiently exposed for an adequate search to be made. Secondly, the area of beach through which the tracer spread was $18510 m^2$, four times greater than that during the first field trial (Table IV). Consequently, with the limited personnel available, searches of the beach were insufficiently thorough. Finally, the depth of beach through which the tracer spread was 1.3m, 2.5 times greater than that during the first field trial (Table IV). Consequently, a high proportion of the tracer pebbles were buried at depths exceeding the maximum penetration depth of 0.4m of the metal detectors. The validity of the latter explanation is illustrated by the data presented in Table V. Although tracer recoveries during any one search of the beach averaged only 30-35% of the total quantity injected, the majority of the remaining tracer pebbles had not been "lost" either longitudinally or transversely beyond the search area. After only two tides the tracer pebbles were thoroughly distributed through the backshore and foreshore zones. Subsequent reworking of the beach material by wave action successively returned tracer pebbles to within 0.4m of the beach surface, where they could be readily detected. Table V shows that in this way an overall average of 72% of the tracer pebbles injected had been recovered at least once since injection (The tracer pebbles were number stamped so that the movement of individual pebbles could be monitored).

TABLE IV

Comparison of tracer recovery rates with the volume of beach through which the tracer had spread.

No. of tides after injection	Total tracer recoveries	Tracer spread area (m^2)	Depth of beach through which tracer spread (m)
Field Trial 1			
6	41	2620	0.50
12	63	2960	0.45
14	59	3080	0.45
29	61	4800	0.45
Field Trial 2			
2	38	4080	0.8
6	27	7040	0.8
8	28	9850	0.8
17	30	14210	0.7
27	34	16680	1.3
37	43	18510	1.2

TABLE V

Cumulative percentage of tracer pebbles within each batch recovered at least once since injection.

No. of tides after injection	Tracer recoveries						
Field Trial 2	Total	Pebble Batches					
		LA	MA	SA	LR	MR	SR
2	28.1	39	21	24	34	29	21
6	40.8	46	46	44	43	36	30
8	49.6	61	54	56	46	43	38
17	55.3	67	61	59	51	49	44
27	59.0	73	64	61	59	51	46
37	66.8	74	77	69	67	60	53
57	69.3	77	79	72	67	64	57
97	71.7	80	80	76	69	66	60

During both field trials recovery rates for the larger size tracer pebbles were, for the most part, greater than that for the smaller pebbles because the former have a greater surface area than the latter and are consequently detectable at greater depths. Further discrepancies in the recovery rates of tracer pebbles of differing size and shape were attributable to pebble sorting by wave action. For example, angular tracer pebbles, irrespective of size, tended to be carried up on to, and remain on, the upper foreshore and backshore zones, whereas rounded tracer pebbles under the same wave action were more likely to be returned with the backwash to the lower foreshore.

The use of metal detectors better suited to the conditions of operation should result in higher recovery rates.

Conclusions

From our investigations carried out to-date the application of metal pebbles as a tracer for shingle beaches offers the following merits:

1. The most valuable capability of the new technique is the ease of detection of the tracer beneath the beach surface. This provides:
   a) a direct, and consequently more reliable means of studying beaches as three-dimensional features.
   b) a higher rate of tracer recovery upon which to base statistical inferences.

2. The ability to manufacture tracer pebbles with similar specific gravity, size and shape to that of the indigenous beach pebbles is a considerable advantage over many previously devised artificial tracers.

3. Number stamping the tracer pebbles can provide a means of tracking the movement of individual pebbles.

4. Of prime importance when investigating beaches which receive use by the general public are the considerations that:
   a) aluminium pebbles present no health risk. Whilst the use of radioactive isotopes provide a means of tracer pebble detection and recovery from beneath the beach surface they should not be used on popular public beaches.
   b) they are also unobtrusive, and as such are unlikely to arouse public interest in the same way that painted pebbles might. Therefore losses and redistribution due to interference should be minimal.

5. The new technique provides a means of pebble detection, although not necessarily recovery, in the unexposed swash zone.

6. Tracer contamination of the beach is no particular problem because pebbles used in successive experiments can be colour-coded with small resin plugs poured into holes, either cast or drilled, in the individual pebbles. Tracer contamination

is a problem when using mass injection of "foreign" beach pebbles, because the range of pebbles of different petrological types which have similar specific gravity, size and shape characteristics to that of the indigenous beach pebbles is normally very limited.

7. Tracer pebbles recovered at the end of an experiment are reusable in subsequent investigations.

Four possible drawbacks of the technique can be identified:

1. Cost. At current British prices 1000 tracer pebbles 50x40x35mm in size can be manufactured, using a "sand-casting" technique, at a cost of £200 sterling (380 U.S. dollars). This cost may be considered high by researchers working on a low budget. However, the cost of using aluminium tracer pebbles compares favourably with that of other tracer techniques when one considers that:
   a) in order to achieve comparable results, the number of tracer pebbles required using the new technique is less than that by any other method because of the higher recovery rates one can normally expect
   b) the tracer pebbles are reusable on recovery.

2. Tracer pebbles not recovered at the end of an experiment are liable to be unnecessarily detected in subsequent experiments carried out on the same length of beach. However, in the normal sequence of events the longer the tracer pebbles remain on the beach the more diffused they become, i.e. spread longitudinally beyond the limits of later experiments and buried to depths exceeding the maximum penetration depth of the metal detectors.

3. The background metal content of the beach can be a problem if the beach being investigated is highly contaminated with metal objects.

4. Losses and redistribution of the tracer during field experiments due to public interference arising from the fact that treasure hunting using metal detectors has become a popular minority pastime in Britain in recent years. The majority of these treasure hunters are members of regional clubs, which when approached, are very pleased to co-operate and even give assistance during field experiments.

Summary

By assessing the relative merits and drawbacks of the technique, we have concluded that the use of metal pebbles as tracers for shingle beaches is more practical than other methods for most tracing purposes. At present the technique is best suited to investigations ranging in length from a few days to a few months and requiring small to medium-scale injections of 5000 tracer pebbles or less. It is of particular value when a knowledge of the movements of individual pebbles is required.

Refinements to the efficiency of the technique would greatly increase its value. The efficiency to be gained from improvements to the field application of the technique are small compared to that attainable by improvement to the detection equipment. Two such improvements to the latter are of prime importance and both are within the bounds of present technology. There is a need to increase the depth of sensitivity of the search heads, and to increase the reliability of metal discrimination devices that are currently built into detectors. There is a future need for a detector capable of differentiating between various grades of tracer pebbles on the basis of size and/or shape differences. This might be achieved in one of two ways, either with a programmable detector in which the differentiation could be carried out internally or with a detector with an inbuilt display panel upon which it could display an outline of the detected metal object which could then be classified by the operator.

There is considerable scope for the further development and application of the technique both for use on beaches and in the nearshore and offshore zones.

Acknowledgements

The authors are grateful to N. H. Babbedge for his innovations, to Messrs. J. Blizzard, A. L. Clarke and S. Horrill of Southampton College of Technology and to Haworth Castings Ltd. of Romsey for advice and practical assistance in the manufacture of the aluminium pebbles, and to Messrs. J. and R. Compton for the kind loan of metal detectors.

The research was undertaken as part of a large coastal-engineering research project sponsored by the Department of the Environment and co-ordinated by Sir. W. Halcrow and Partners in which the Hydraulics Research Station, and Bournemouth, Christchurch, and New Forest District Councils are participating. The authors gratefully acknowledge the assistance given by the engineering staff of Bournemouth Corporation in connection with the field trials.

References

Carr, A.P., 1971. Experiments on longshore transport and sorting of pebbles: Chesil Beach, England. J. Sedim. Petrol., 41: 1084-1104.

Hails, J.R., 1974. A review of some current trends in nearshore research. Earth-Sci. Rev., 10: 171-202.

Kidson, C. and Carr, A.P., 1962. Marking beach materials for tracing experiments. J. Hydraulic Div., Proc. Am. Soc. Civ. Eng., 3189: HY4: 43-60.

Waring, J., 1965. The development of the full mould casting process. J. Aust. Inst. Met., 10(4): 313-322.

Wright,P., Cross,J.S. and Webber,N.B., 1978. Aluminium pebbles: a new type of tracer for flint and chert pebble beaches. Mar. Geol., 27: M9-M17.