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Review of the field-data base for longshore sediment transport

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ABSTRACT

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A literature search was undertaken to collect field data on longshore sediment transport. This yielded a large number of data sets (273 points for bulk transport rates) from a variety of sites around the world. Data are especially lacking for transport rates exceeding 0.2×10^6 m^3/year, significant wave heights higher than 1.8 m, sediment grain sizes coarser than 0.6 mm and beach slopes steeper than 0.06 ($=1/14$). A point rating system was devised whereby the quality of the data could be assessed. The recording method and the accuracy thereof as well as the representativeness of the data were taken into account. It was found that the evaluation was done reasonably objectively and consistently. The data were divided into three categories. The highest score achieved in the evaluation was only 71% thus reflecting the difficulty of measuring longshore transport accurately. It is recommended that longshore transport formulae be calibrated against the data in the higher category (60% and better) and then be tested against all the other data. This will ensure that the formulae will be tested in as many different conditions and sites as possible without the lower quality data contributing to the calibration constants.

INTRODUCTION

General

Knowledge of longshore sediment transport is essential for the design of breakwaters at harbour entrances, navigation channels and dredging requirements, beach improvement schemes incorporating groynes, detached breakwaters and beach fill as well as for the determination of the stability of inlets and estuaries.

Formulae for the prediction of longshore transport rates can only be as good

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as the data on which they are based. Although this is especially true for empirical methods, even the most sophisticated formula requires verification. It is therefore of utmost importance to realise the limitations of the data.

Another important consideration is that, in order for a formula to be universally applicable, it should be verified under as many as possible different conditions and at different sites. The aim of this paper is therefore, firstly, to compile such a longshore sediment transport data base by listing all the relevant references and, secondly, to evaluate the quality of the data contained in these publications.

The data considered in this paper are only for particulate (non-cohesive) sediment (including sand, gravel and shingle) being transported alongshore from the swash zone across the surf zone to deep water. Both bulk (total rate across the shore) and local transport rates are considered. However, cases where only bedload or suspended load was measured are only included if the measurements were used to determine the total transport rate (for example Downing, 1984). Data sets are excluded where simultaneous wave and transport data are not available as in the case of Johnson (1957). Only field data are evaluated because of possible scale effects in laboratory investigations and/or because regular waves were used. Furthermore, the ultimate aim is to be able to predict longshore transport accurately in the field (Komar, 1988).

The data are not meant to provide average long-term data at (a) specific site(s). It is rather assumed that if a longshore transport formula is capable of accurately predicting transport rates for the data sets given herein, it can be used with reasonable confidence at similar sites to determine the long-term longshore sediment budget if representative wave and other input parameters are available. It would of course be even better to have site-specific calibration data before calculating average long-term transport rates.

It is well known that it is extremely difficult to measure sediment transport rates and the associated wave and current parameters accurately, especially in the surf zone. This will be illustrated in the evaluation of the data.

Previous studies

Das (1971) compiled laboratory and field data. He also summarized, among others, the site characteristics and the measuring techniques used by the earlier American investigators Watts (1953), Caldwell (1956), Moore and Cole (1960) and Komar (1969). Dean (1978) not only compiled but also evaluated the longshore transport data considering the measuring techniques used and investigating the variation of the dimensionless coefficient K in the SPM longshore transport formula (Komar, 1988):

$$I = KP_{ls}$$

where I is the immersed-weight transport rate and P_{ls} is the longshore energy flux factor.

One of Dean's conclusions was that the variability in the K values is quite large and that it is not known whether this is due to recording errors or to true variation in the factor K. In the present evaluation, only recording errors are addressed so as not to assume in effect a theoretical basis for any longshore transport formula.

Greer and Madsen (1978) provide a detailed critical review of the data sets collected by Watts (1953), Caldwell (1956) and Komar (1969). After giving a set of criteria to be adhered to, they concluded that the data "by Watts (1953) and Caldwell (1956) are of questionable quality" (the values of P_{ls} could be off by factors of 5 and 10 respectively). To darken the picture further, they found "that several of the basic assumptions underlying the use of tracers in sediment transport studies appear to have been violated" by Komar (1969).

Walton and Chiu (1979) and Bruno et al. (1981) list the methods of obtaining the data in the earlier studies. Bruno et al. also commented (mostly) on the accuracy of the sand tracer tests by Komar (1969), stating that the transport rate was probably overestimated due to the way the shore-parallel tracer displacement was determined from sediment samples taken close to the top of the seabed and because the thickness of the moving sediment layer was expected to increase in time.

More recently, Kamphuis et al. (1986) tabulated data from 9 field studies and Morfett (1990) briefly reviewed the longshore transport data base (including a number of newer studies such as Inman et al., 1980, and Kraus et al., 1982) concentrating on how accurately the variables were determined. Although deficiencies were noted, no firm conclusions were drawn in these studies regarding the overall accuracy of the data sets.

To conclude then, only Greer and Madsen (1978) provide an in-depth analysis of the accuracy of the data. Unfortunately, they could only review a few of the earlier studies.

FIELD-DATA BASE

Sources

Tables 1 (bulk transport rates) and 2 (local transport rates) summarize the field data available to the authors. As can be seen from these tables, the data were collected at a wide variety of sites around the world, yielding a large number of points of which 273 points give bulk transport rates. This is considerably more than the 41 data points used in the Shore Protection Manual by US Army, Corps of Engineers (1984).

A number of other field studies were also carried out where the longshore

TABLE 1

Field data sources (bulk transport rates)

Data set No.	Reference(s)	Location	No. of points	Transport measured by	Wave height and period measured by	Wave angle measured by	Survey method
1	Caldwell (1956)	Anaheim Bay California	5	beach fill	hindcasting & step, float gauge	hindcasting & visual observed	hydro + topo echo sounder
2	Watts (1952)	South Lake Worth	3	deposition in trap & sand bypassing	staff gauge	visual observed	not described
3	Ishihara et al. (1958)	North Akashi Miyazu	10 7	accretion at temporary groyne	wind analysis (verified)	wind analysis (verified)	soundings
4	Adachi et al. (1959)	Miyazu Japan	8	accretion at off-shore breakwater	estimated wind analysis	not described	not described
5	Moore and Cole (1960)	Cape Thompson Alaska	1	growth of a spit	visual estimate	visual estimate	plane table survey
6	Delorme (1981)	North & Central Africa	5	not described (measured and estimated)	not described	not described	not described
7	Sato (1962)	Fukue, Atsumi Japan	5	accretion at breakwater	pressure gauge	wind analysis	not described
8	Sireyjol (1964)	Cotonou Benin	1	accretion at breakwater	not described	visual estimate	air photo analysis
9	Castanho (1966)	Lobito Angola	2	accretion at breakwater & spit	not described	calculated	not described
10	Fairchild (1977)	Ventnor (NJ) Nags Head (NC)	2	pump sampler	pressure gauge & staff gauge	not described	profiles + lead lines
11	Sato and Tanaka (1966)	Port Kashima Japan	2	accretion at breakwater	pressure gauge	visual observed	echo-sounder + rod & level
12	Bijker (1968)	Ivory Coast Abidjan	1	estimated	assumed estim.	not described	not described
13	Komar and Inman (1970)	El Moreno & Silver Strand	11	tracer	pressure gauges & dig. wave staffs	visual observed sensor array	not described
14	Duane and James (1980)	Point Mugu California	1	tracer	visual observed	visual observed	not described
15	Hou et al. (1980)	Taichung Harbour Taiwan	4	accretion at breakwater	ultrasonic gauge	wind analysis	profile & bathymetric
16	Lee (1975)	Lake Michigan	8	sampler	poles, posts	visual observed & photos	transit & stadia
17	Kana (1977)	Price Inlet South Carolina	25	sampler	visual observed staff	visual observed	not described

18	Bruno et al. (1981)	Channel Islands Harbor	18	accretion at off-shore breakwater	pressure gauge & LEO observations	pressure gauge & LEO observations	topo + bathy (fathometer)
19	Chang and Wang (1978), Wang and Chang (1978)	Santa Rosa I. (Bayside)	35	tracer	not described	not described	not described
20	Knoth and Nummedal (1977)	North Bull Island	5	tracer	not described	not described	not described
21	Inman et al. (1980)	Torrey Pines California	2	tracer & sampler	pressure gauges array & wave staffs	electromagnetic current meter	not described
22	Kana and Ward (1980)	Duck North Carolina	2	sampler	pressure gauge	radar & LEO observations	not described
23	Gable (1981) Dean et al. (1982)	Leadbetter, Santa Barbara	9	accretion at breakwater	pressure gauges array	pressure gauge array	rod & level + (fathometer)
24	Dean et al. (1987)	Rudee inlet Virginia	3	deposition in trap (weir)	pressure gauges array	pressure gauge array	rod & level + soundings
25	Nicholls and Wright (1991)	Southern England H.Bury Long Beach HurstCastle Spit	6	tracer (aluminium)	visual observed	visual observed	beach profiles
26	Kraus et al. (1982)	Shi, Hir, Aji, Oar Japan	12	tracer	pressure gauge & photo poles	electromagnetic current meter	not described
27	Mangor et al. (1984)	Danish North Sea	6	deposition in trap & trench-backfill	Waverider & wind analysis	wind analysis	profiles & echosounder
28	Kooistra and Kamphuis (1984)	Pointe Sapin Canada	2	accretion at offsh. breakwater tracer	pressure gauge	electromagnetic current meter	beach + bathymetric
29	Bodge (1986)	Duck North Carolina	8	accretion at mobile groyne	pressure gauge & visual observed	radar imagery & visual observed	rod & level + transit
30	Laubscher et al. (1989)	Richards Bay South Africa	5	deposition in trap & dredging	Waverider	clinometer & VOS	survey beach + hydro
31	Kraus et al. (1982, 1988, 1989) Rosati et al. (1991)	Duck North Carolina	8	sampler (streamer)	photo poles & movie camera	not measured	infrared survey + transit
32	Voitsekhovich (1986)	Ros., Pri., Kin. Black Sea	39	samples (siphon)	string gauge & poles	not described	not described
33	Chadwick (1989)	Shoreham Sussex, England	7	gravel trap	mes.SEM & visual, pole array	visual, pole array	tache survey & hydrographic
34	Hou (1988)	Lin-Kou Northwest Taiwan	1	accretion at breakwater	measured	wind analysis	profile & echo-sounder
35	Caviglia et al. (1991)	Mar del Plata Argentine	4	accretion at break-water, dredge	pressure gauge	visual observed	hydrographic
35	Total		273				

TABLE 2

Field data sources (local transport rates)

Data set No.	Reference(s)	Location	No. of points	Transport measured by	Wave height and period measured by	Wave angle measured by	Survey method
1	Sawaragi and Deguchi (1978)	Isonoura, Matsuho (Japan)	18	bedtrap	pressure gauge	not given	not described
2	Downing (1984)	Twin Harbor Beach (Wash.)	20	back-scatter-rometer	resistance gauge	not given	rod & level
3	Kraus et al. (1982)	Aji, Shi, Hir, Oar (Japan)	26	tracer	pressure gauge & photopoles	electromagnetic current meter	not described
4	Mangor et al. (1984)	Danish North Sea	32	deposition in trench, backfill	waverider & wind analysis	wind analysis	echo-sounder
5	White (1987)	Torrey Pines & Scripps	25	tracer	pressure gauge	not measured	fathometer + rod & level
6	Bodge (1986)	Duck North Carolina	8	buildup against mobile groyne	pressure gauge & observed	radar imagery & visual observ.	rod & level + transit
7	Kraus et al. (1988, 1989)	Duck North Carolina	55	sampler (streamer trap)	photopoles & movie camera	not measured	infrared survey & transit
7	Total		184				

transport rate was determined together with wave and beach characteristics; unfortunately, most of the values of the variables are not given in the references. These studies include Iwagaki and Sawaragi (1962), Bonnefille and Pernecker (1967), Walton (1978), Swart and Fleming (1980), Maruyama et al. (1982) and Katoh et al. (1985). Although the data collected by Rosati et al. (1991) were discussed in their paper the report listing the complete data was not yet published and was therefore not evaluated.

Measuring techniques

Various methods were used to measure both the sediment transport rates and the wave characteristics (Tables 1 and 2). Sediment transport rates were obtained by measuring:

- accretion at a breakwater/groyne
- accretion plus bypassing
- erosion downdrift of a barrier
- growth of a spit;

and by the use of:

- tracers
- samplers
- gravel traps.

It is important to note whether the transport rate was determined over the long term (monthly and longer) or the short term (hourly or daily). The advantage of long-term data (typically accretion at a breakwater) is that the measured transport rates should be less variable (Dean, 1978), most probably because of natural smoothing of the data. The disadvantage is, however, that wave conditions change during a longer recording period. Furthermore, because this type of data usually is accretion or erosion adjacent to a breakwater, the structure influences the wave and current fields in its vicinity (Greer and Madsen, 1978 and Komar, 1988). On the other hand, wave conditions are usually more constant during shorter recording periods (Dean, 1978).

Another important consideration is the accuracy of the survey methods (Table 1) used to obtain the data for the calculation of volume differences. The seaward limit of the profiles, spacing of profiles, accuracy of the datum level, etc. are all factors to be taken into account.

Wave conditions were determined by a variety of methods ranging in sophistication from visual estimates, to wave hindcasting to the use of recorders such as pressure transducers (Table 1). Because of the sensitivity of longshore transport formulae to the wave incidence angle, the technique used to measure it is of particular interest; unfortunately, it is also one of the most difficult variables to measure accurately. Typical methods include visual estimates, the use of radar, aerial photography, hindcasting and an array of wave recorders (Table 1).

Additional factors influencing the accuracy of the data include, among others, the determination of the sediment grain sizes and the measurement of the nearshore currents.

Range of the data

When verifying the general validity of longshore transport formulae, it is important to know the range of the data used. For this reason, the distributions of the measured transport rates (S), significant breaker wave heights (H_{bs}), peak wave periods (T_p), wave incidence angles at the breaker line (θ_b), median grain sizes (D_{50}) and the beach slope in the surf zone ($\tan \alpha$) are plotted in Figs. 1a and b, and 2 to 6. In the case of the bulk transport rates, the units are m^3/year (1 m^3/year = 3.15576×10^7 m^3/s). If the recording period was less than one year, it was assumed that the conditions persisted for a year thus making large rates possible. For data collected over the long term (monthly and longer), the maximum H_{bs}, T_p and θ_b were selected.

From Figs. 1a and b it is immediately apparent that almost all measured transport rates are less than 2×10^6 m^3/year (0.0634 m^3/s) and of these, most are less than 0.1×10^6 m^3/year (0.0317 m^3/s). The reason for this is obvious: predominantly lower waves occur and it is easier to measure during these conditions.

This trend can also be seen for the breaker height in Fig. 2 where few waves higher than 1.8 m were recorded. Here a larger variation in T_p values can be seen in Fig. 3. A bimodal distribution is evident with peaks at about 5 s and 12 s, which most probably is indicative of wind waves and swell. Despite this, wave periods lower than 8 s occur more frequently. Few data sets contain θ_b values exceeding 16° (Fig. 4). Typically the most common situation is small angles (5°or 10°). Angles were apparently often reported to the nearest 5°. If the intervals in Fig. 4 are reduced to 1°, pronounced local maxima are shown at 5°, 10°, 15°, 20° and 30° thus substantiating the above conclusion.

Most measurements were done on beaches with fine sand and especially in the range 0.20 mm to 0.25 mm (Fig. 5). Virtually no data were collected on beaches with sediment grain sizes between 0.6 mm and 15 mm. Realising the relation between grain size and beach slope, it is logical to expect that most of the data were collected on beaches with flat slopes; as is evident from Fig. 6, almost all the slopes fall between 0.01 ($=1/100$) and 0.07 ($=1/14$).

Bearing in mind that usually a few storms contribute to almost all the longshore transport at a site, it is critical that longshore transport formulae be verified against such conditions. In most cases this was not done except per-

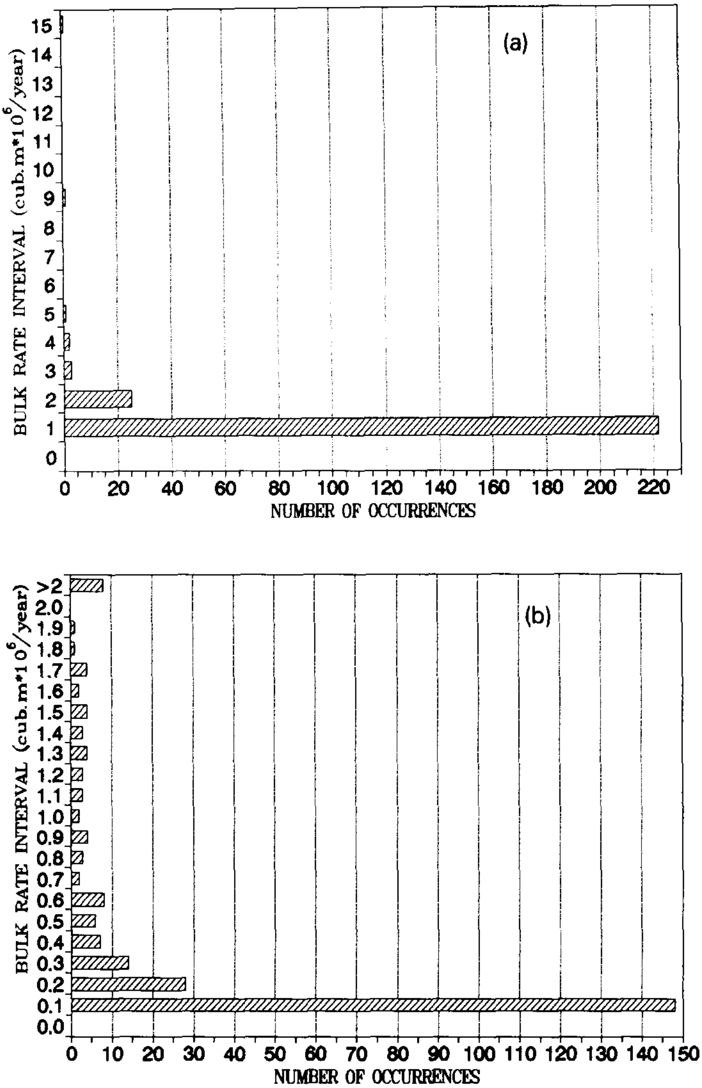

Fig. 1. Bulk rate histograms.

haps where the long-term accretion adjacent to a structure was monitored. Data are especially lacking for

$S > 0.2 \times 10^6\ \mathrm{m^3/year}\ (0.0634\ \mathrm{m^3/s})$

$H_{bs} > 1.8\ \mathrm{m}$

$D_{50} > 0.6\ \mathrm{mm}$

$\tan\alpha > 0.06\ (= 1/14)$

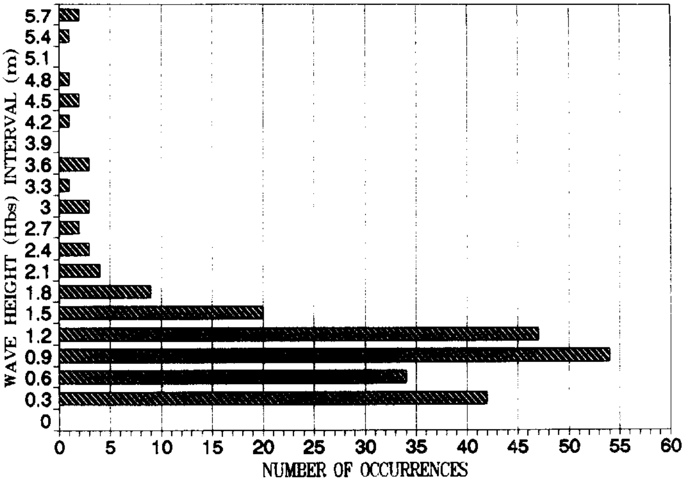

Fig. 2. Wave height histogram.

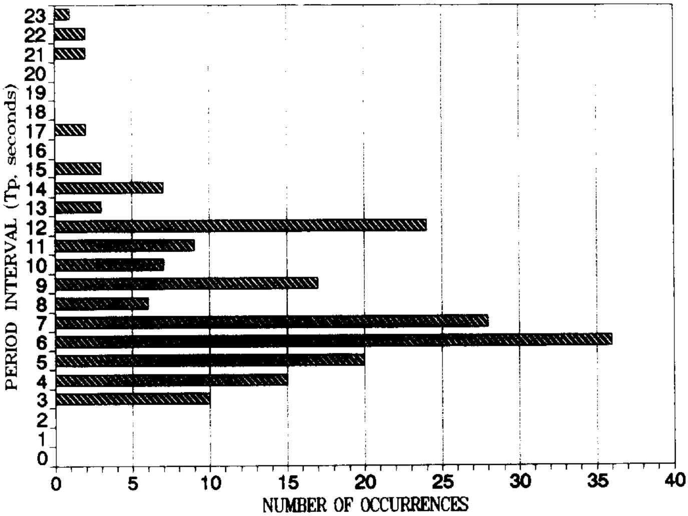

Fig. 3. Wave period histogram.

DATA EVALUATION

Method

A point-rating system was devised so that data sets could be compared with respect to overall quality of the data and suitability for testing longshore transport formulae. Keeping in mind the interdependence of the various physical factors that influence longshore transport rates, as well as the relative

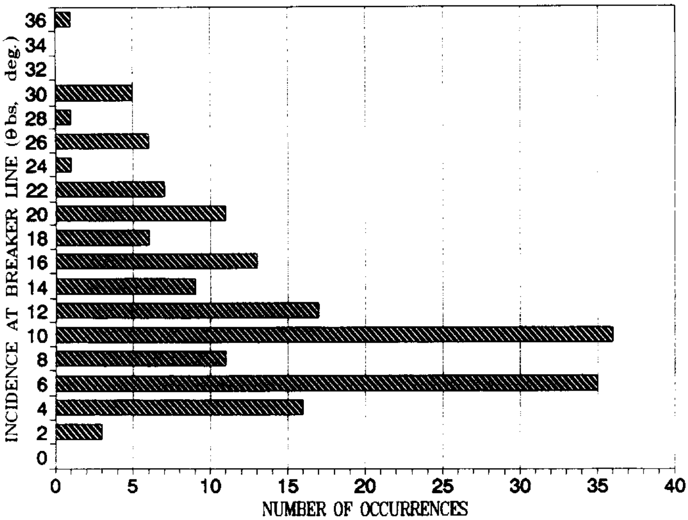

Fig. 4. Wave incidence angle histogram.

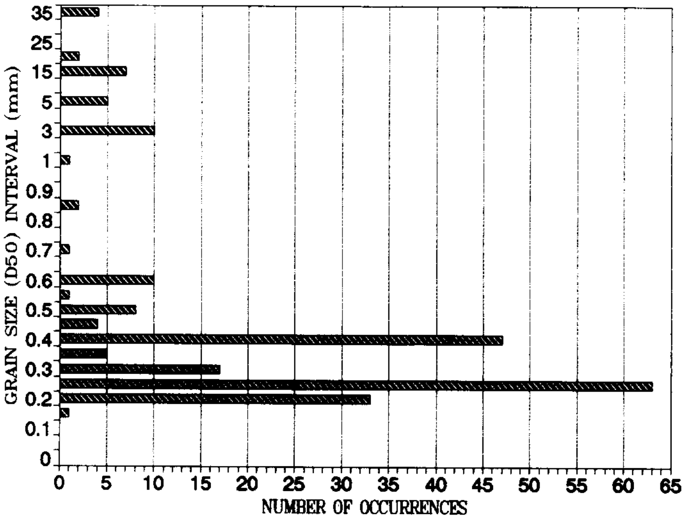

Fig. 5. Sediment grain size histogram.

importance of these factors, a point-rating system was compiled for the evaluation of the data sets relative to each other. This system is based on the point-rating systems developed previously for the comparative evaluation of the beach suitability of different beaches (CSIR, 1976, 1987; Schoonees and Bartels, 1991). Points were allocated to a data set according to the quality of the data of the six physical parameters deemed most appropriate (impor-

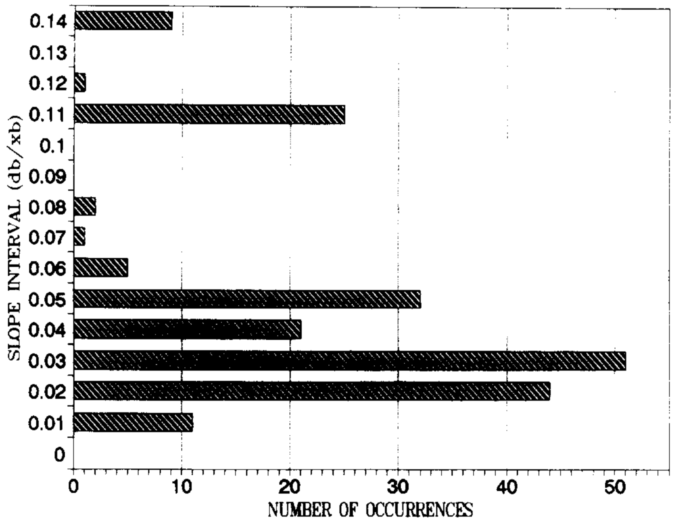

Fig. 6. Beach slope histogram.

tant) in determining longshore transport rates. These parameters and the relative importance ("weighting") allocated to the parameters were:

*	longshore transport rate	40
*	wave height	20
*	wave period	10
*	wave direction (angle of incidence)	20
*	beach profile (bottom) slope	5
*	sediment size	5
	Total	100

The data sets were further evaluated with respect to each parameter in terms of three sub-divisions namely:

- method by which the data were determined for a specific parameter
- accuracy with which the data were determined or measured
- representativeness of the data

The data sets were each given a score out of a total of 10 points in terms of each of these sub-divisions with respect to each specific parameter.

The scores for the sub-divisions were added and after the relative weighting of the parameters had been applied, the total points were converted to give a total score out of 100.

Table 3 gives a hypothetical example of how this method was used to assess the quality of the data. Both authors did the evaluation independently in order to be able to judge the objectivity and consistency of the method.

It must be noted that full descriptions of how data were measured or deter-

TABLE 3

Longshore transport data evaluation

Parameter	Weighting	Sub-division	Max. points		Points of hyp. ref.	
				total		total
Transport rate	40	method	10	40	6	23
		accuracy	10		5	
		representativeness	10		6	
Wave height	20	method	10	20	6	12
		accuracy	10		6	
		representativeness	10		6	
Wave period	10	method	10	10	6	6
		accuracy	10		6	
		representativeness	10		6	
Wave angle	20	method	10	20	5	10
		accuracy	10		5	
		representativeness	10		5	
Beach slope	5	method	10	5	7	4
		accuracy	10		8	
		representativeness	10		7	
Grain size	5	method	10	5	6	4
		accuracy	10		8	
		representativeness	10		7	
Total score				100		58

mined are not given in all the references. If the data for a specific parameter were given without description of how the data were obtained, the data set was given a score of 5 for that parameter. Although this may seem a bit arbitrary, it is felt that this is the most "fair" score that can be given under the circumstances. If a specific parameter was not measured or the data could not be determined from the information given in the reference, the data set was given a score of 0 for that parameter.

It must be stressed that this system primarily rates data sets relative to each other and with respect to longshore transport data, and that data sets receiving a lower score than the rest of the data sets, may nevertheless be quite usable, especially in respect of other parameters.

The parameters chosen and the relative weighting applied to these parameters will of course influence the evaluation and are debatable, but nevertheless the authors believe that based on current knowledge, the system gives a fair method of evaluating longshore transport data as objectively as possible. A limited sensitivity analysis (described in the section "Discussion" below) has also been done to evaluate the effect of different weightings. It must, however, be kept in mind that the data are evaluated with regard to their suitability to predict total longshore transport rates. For example, if measured suspended sediment concentrations were extrapolated up to the sea bottom and then integrated through the water column to estimate the local longshore transport rate, the total score could be low. However, that does not necessarily mean that the accuracy of the measured sediment concentrations is poor.

Criteria

The most basic question concerning the measurements is: What exactly (transport rate or wave characteristic, etc.) was measured? (Nielsen, 1984), or alternatively, Was the total (real) transport rate (or wave characteristic, etc.) measured?

Based on the criteria set by Greer and Madsen (1978), Duane and James (1980), Bruno et al. (1981) and Madsen (1987) among others, points were allocated for each technique for measuring the transport rate to be given under the sub-division Method. To evaluate how representative the measured transport rate was, aspects such as the following were taken into account:

- Was it a total trap?
- Was only bedload or suspended load measured?
- Was the transport determined over the long term?
- Was the coverage considered to be adequate if samplers or traps were used?
- Did an offshore breakwater possibly contribute to overtrapping of sediment?

Similarly, the acquisition of the wave characteristics was evaluated giving, firstly, points for the method (lowest for assumed data, then hindcasted data and highest for accurately measured data). Secondly, aspects pertaining to the representativeness of the data included:

- Was it measured directly opposite the site?
- Was it recorded in deep water and then refracted in towards the shoreline?
- Were distributions or spectra of the wave characteristics given?
- Were the recordings done over the short or long term?

For beach slope, the following were taken into account: the spacing of survey lines, their seaward limit, their datum level and whether both beach and nearshore surveys were done and if so, whether they overlapped.

Adequate spatial and temporal coverage of the beach and nearshore zone

TABLE 4

Longshore transport data evaluation

No.	reference	location & data set	total
Bulk transport rates			
12	Bijker (1968)	Abidjan	19
4	Adachi et al. (1959)	Miyazu	24
10	Fairchild (1977)	Ventnor	36
3	Ishihara et al. (1958)	North Akashi, Miyazu	37
10	Fairchild (1977)	Nags Head	37
2	Watts (1953)	South Lake Worth	42
1	Caldwell (1956)	Anaheim Bay	46
17	Kana (1977)	Price Inlet	48
25	Nicholls and Wright (1991)	South England	48
6	Delorme (1981)	North Africa	49
5	Moore and Cole (1960)	Cape Thompson	50
8	Sireyjol (1964)	Cotonou	51
9	Castanho (1966)	Aveiro	52
9	Castanho (1966)	Lobito	52
20	Knoth and Nummedal (1977)	Bull Island	52
30	Laubscher et al. (1989, 1991)	Richards Bay	54
18	Bruno et al. (1981)	Channel Islands Harbor, 1	55
19	Chang and Wang (1978)	Santa Rosa Island	55
27	Mangor et al. (1984)	Danish North Sea	55
31	Kraus et al. (1989)	Duck	55
14	Duane and James (1980)	Point Mugu	56
29	Bodge (1986)	Duck, 2	56
15	Hou et al. (1980)	Taichung Harbour	57
16	Lee (1975)	Lake Michigan	57
22	Kana and Ward (1980)	Duck	57
29	Bodge (1986)	Duck, 3	57
33	Chadwick (1989)	Shoreham, M6, M7	57
11	Sato and Tanaka (1966)	Port Kashima	58
32	Viotsekhovich (1986)	Black Sea	58
34	Hou (1988)	North West Taiwan	58
35	Caviglia et al. (1991)	Mar del Plata	58
28	Kooistra and Kamphuis (1984)	Pointe Sapin NOV4	60
33	Chadwick (1989)	Shoreham, M1-M5	60
7	Sato (1962)	Fukue, Atsumi	61
29	Bodge (1986)	Duck, 4	61
13	Komar and Inman (1970)	El Moreno, Silver Strand	62
24	Dean et al. (1982, 1987)	Rudee Inlet	63
26	Kraus et al. (1982)	Japan	63
21	Inman et al. (1980)	Torrey Pines	64
18	Bruno et al. (1081)	Channel Islands Harbor, 2	67
23	Gable (1981)	Leadbetter Beach	68
28	Kooistra and Kamphuis (1984)	Pointe Sapin, OCT25	71
Local transport rates			
2	Downing	Twin Harbors Beach	44
1	Sawaragi and Deguchi	Isonoura	47
1	Sawaragi and Deguchi	Matsubo	49
6	White et al.	Torrey Pines, SIO	50
7	Kraus et al.	Duck	55
4	Mangor et al.	Danish North Sea	56
5	Bodge	Duck, 2	56
5	Bodge	Duck, 3	57
5	Bodge	Duck, 4	61
3	Kraus et al.	Japan	63

by sediment sampling were the primary factors for evaluating the sediment characteristics.

For all the Accuracy sub-divisions, a subjective rating out of 10 was given.

Results

The results of evaluating the overall quality of the longshore transport data are presented in Table 4 and Fig. 7. (Some references are listed more than once because the specific data sets contained in that reference differ in quality.) The data were sorted according to the final point rating (that is, the mean of the total score given by the two authors).

DISCUSSION

From Fig. 7, three categories of data can be distinguished for the bulk transport rates. Cut-off points were essentially arbitrarily chosen to be scores of 50% and 60%. It is clear from this graph that the majority of data sets fall in the middle category and that there is a very gradual increase in the point rating (accuracy) in this category. The largest gradients occur in the lower category and right at the top end of the higher category. The transition between the categories at both cut-off points is also gradual. From Table 4 and Fig. 7 it is clear that fewer studies yielding local transport rates were conducted. In addition, the range in the total scores are much less for the local rates (from a lowest score of 44% to a maximum score of 63%, being 19 percentage points) compared with 52 percentage points for the bulk rates (Table 4).

Inspection of Table 4 reveals that the poorer data sets are generally from the older references or from those where the purpose of the exercise was not necessarily to obtain good longshore transport data (for example, Nicholls

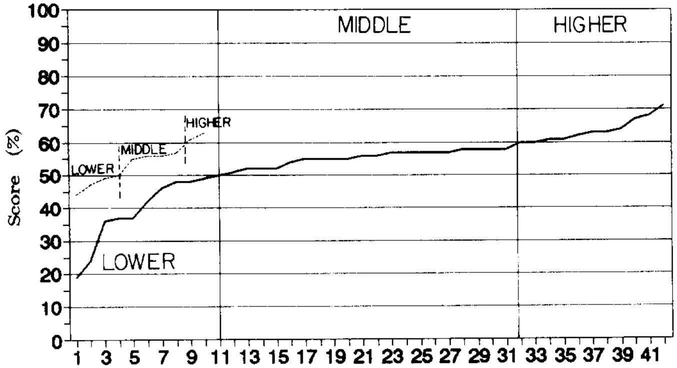

Fig. 7. Longshore transport data evaluation. (——) Bulk, (·····) local transport.

and Wright, 1991). However, this does not necessarily mean that older data sets are of poorer quality as can be seen from the Komar (1969) data falling in the higher category. With the development of better measurement techniques and equipment it is not surprising that most of the data sets in the higher category originated in recent years.

In interpreting the results, it must be borne in mind that a score of 0 points was given if a particular parameter was not measured or reported. For example, Kraus et al. (1989) did not measure the wave incidence angle because they conducted their exercise in the feeder current of a rip current. However, they measured the longshore current velocity. It can therefore be argued that their data are accurate because the incidence angle is usually only applied to predict the longshore current velocity. Table 5 lists the studies where one or more of the parameters were either not measured or not reported.

Greer and Madsen (1978) recommended that the data by Watts (1953) and Caldwell (1956) should be "excluded from establishing empirical sediment transport relationships" and that the data by Komar (1969) should not be "too heavily relied upon". The results of this review agree reasonably well with the former recommendation (because both the earlier studies fall in the lower category). Greer and Madsen based their recommendation concerning Komar's data mainly on the following arguments: (1) The lack of stationarity of the transporting system during the experiments at El Moreno beach; (2) The uncertainty about whether or not sufficient time was allowed between injection and sampling to ensure that equilibrium transport of tracer was reached during the exercise at Silver Strand Beach; and (3) the ambiquity in determining the thickness of the moving layer of sediment. Considering the extensive procedure followed by Kraus (1985) and Kraus et al. (1982) and the direct influence of this thickness on the transport rate, the third reason can be regarded as being the most important. Despite the fact that the proposed evaluation procedure is primarily comparative in nature, it is believed

TABLE 5

Studies with incomplete data listings

Reference	Parameter(s) either not measured or not reported
Watts (1953)	$\tan\alpha$
Adachi et al. (1959)	D_{50} and wave height
Delorme (1981)	$\tan\alpha$
Castanho (1966)	D_{50}
Fairchild (1977)	θ_b
Kraus et al. (1989)	θ_b*
Sawaragi and Deguchi (1978)	θ_b
Downing (1984)	θ_b*
White (1987)	θ_b*

*do contain detailed current measurements.

that some importance can be attached to the absolute value of the scores (the Komar, 1969 data got a score of 62%; Table 4). Normally, a score of 80% or higher is regarded as being good. It can therefore be argued that the cut-off point for the higher cateogry should be 80% or rather another category say, an excellent category should be established. That would mean that no data points fall in this category (Table 4). It can thus be concluded that the data of Komar (1969) have deficiences (which corresponds to the conclusion by Greer and Madsen, 1978) but still are amongst the best data sets available.

The individual scores allocated by the two authors were analyzed in order to assess the consistency and objectivity of the method. The mean difference in the total scores was +0.6 (out of 100) and the standard deviation 2.6 (out of 100). It can therefore be provisionally concluded that there was very little systematic difference between the scores given by the two authors. At the same time, the objectivity of the method is acceptable taking into account the subjectivity of estimating the accuracy of measurements.

As the weightings allocated to the different parameters are somewhat arbitrary, a limited sensitivity analysis was carried out. The weighting given to the longshore transport rate and to the wave direction were changed by plus or minus 10 points in both cases in order to assess what effect this would have on the data evaluation. These two parameters were chosen because the transport rate is the single most important parameter; and the wave direction was selected because it is also relatively important and because it is usually the most difficult parameter to measure accurately. Changing the weighting of the other parameters would have less effect on the data evaluation. The results of the sensitivity analysis are shown in Table 6. From the table it can be seen that the average changes in total scores are relatively small. Furthermore, the changes in category are all due to data sets moving from just below (or above) to just above (or below) the arbitarily chosen category cut-off points. The

TABLE 6

Sensitivity analysis (on weighting of parameters)

Parameter	Change in weighting	Absolute change in total score of particular sets*			No. of data sets moving from one category** to the next
		max.	ave.	std. dev.	
Longshore transport rate (S)	+10	2	0.69	0.89	2
	−10	2	0.76	1.02	1
Wave direction (θ)	+10	5	1.19	1.34	3
	−10	6	1.60	1.61	4

*The absolute change is given out of 100; that is, for an absolute change of 2, the total score moved, for example, from 54% to 56% or from 54% to 52%.

**Category refers to either the lower, middle or higher category (Figs. 7 and 8).

conclusion is that the data evaluation is not overly sensitive to the weightings allocated to the different parameters. Keeping in mind that the data evaluation is of a comparative nature and that the aim is mainly to place the data sets in one of three main categories, the evaluation procedure is considered to be valid and meets the objective.

The data were evaluated only with regard to what was considered to be the most important parameters for longshore transport. Others factors like breaker type, the variation in the composition and grading of the bed material (and thus in settling velocity; see Nielsen, 1979, for example), porosity and specific gravity of the bed material, the effect of nearshore cell circulation (except for rip currents), tidal influence, the effect of cross-shore sediment transport, etc. were not included in the evaluation.

Separating the short- from the long-term bulk transport rates yielded Table 7 and Fig. 8. The trend in the accuracy of the data is very similar for both types of bulk rates, except that more short-term data sets have a ranking in the higher categories while more of the long-term data sets are in the lower category.

It is important that the random error in the measurement of the transport rates and therefore the consistency of the data, be determined. This can be done by using two or more samplers at essentially the same recording position (Kraus et al., 1989), by using different colours of sand tracer and/or different sampling strategies (spatial or temporal) (Chang and Wang, 1978; Inman et al., 1980; White, 1987), using more than one temporary groyne along a long straight beach or by combining more than one method; for example, a sand tracer test (using one or more colours of sand tracer) and/or using streamer traps combined with measuring the accretion next to a temporary groyne.

In the latter case, it could of course also be argued that the difference between two estimates will be due to the methods used as well as because of the random nature of the transport processes.

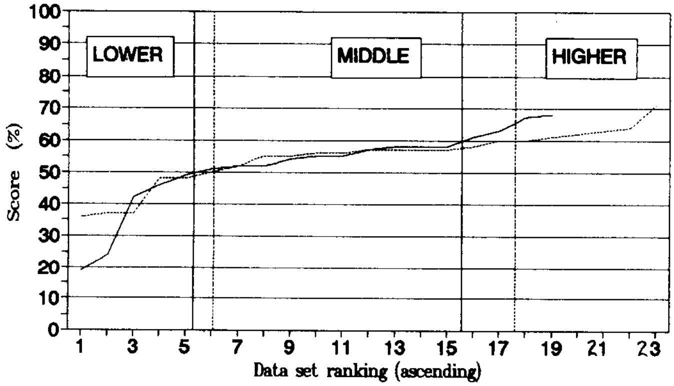

Fig. 8. (——) Long- and (·····) short-term bulk transport rates.

TABLE 7

Evaluation of short- and long-term bulk transport data

No.	reference	location & data set	total %
Long-term rates			
12	Bijker (1968)	Abidjan	19
4	Adachi et al. (1959)	Miyazu	24
2	Watts (1953)	South Lake Worth	42
1	Caldwell (1956)	Anaheim Bay	46
6	Delorme (1981)	North Africa	49
8	Sireyjol (1964)	Cotonou	51
9	Castanho (1966)	Aveiro	52
9	Castanho (1966)	Lobito	52
30	Laubscher et al. (1989, 1991)	Richards Bay	54
18	Bruno et al. (1981)	Channel Islands Harbor, 1	55
27	Mangor et al. (1984)	Danish North Sea	55
15	Hou et al. (1980)	Taichung Harbour	57
11	Sato and Tanaka (1966)	Port Kashima	58
34	Hou (1988)	North West Taiwan	58
35	Caviglia et al. (1991)	Mar del Plata	58
7	Sato (1962)	Fukue, Atsumi	61
24	Dean et al. (1982, 1987)	Rudee Inlet	63
18	Bruno et al. (1081)	Channel Islands Harbor, 2	67
23	Gable (1981)	Leadbetter Beach	68
Short-term rates			
10	Fairchild (1977)	Ventnor	36
3	Ishihara et al. (1958)	North Akashi, Miyazu	37
10	Fairchild (1977)	Nags Head	37
17	Kana (1977)	Price Inlet	48
25	Nicholls and Wright (1991)	South England	48
5	Moore and Cole (1960)	Cape Thompson	50
20	Knoth and Nummedal (1977)	Bull Island	52
19	Chang and Wang (1978)	Santa Rosa Island	55
31	Kraus et al. (1989)	Duck	55
14	Duane and James (1980)	Point Mugu	56
29	Bodge (1986)	Duck, 2	56
16	Lee (1975)	Lake Michigan	57
22	Kana and Ward (1980)	Duck	57
29	Bodge (1986)	Duck, 3	57
33	Chadwick (1989)	Shoreham, M6, M7	57
32	Viotsekhovich (1986)	Black Sea	58
28	Kooistra and Kamphuis (1984)	Pointe Sapin NOV4	60
33	Chadwick (1989)	Shoreham, M1–M5	60
29	Bodge (1986)	Duck, 4	61
13	Komar and Inman (1970)	El Moreno, Silver Strand	62
26	Kraus et al. (1982)	Japan	63
21	Inman et al. (1980)	Torrey Pines	64
28	Kooistra and Kamphuis (1984)	Pointe Sapin, OCT25	71

CONCLUSIONS AND RECOMMENDATIONS

A literature search was undertaken to collect field data on longshore transport. This yielded a large number of data sets for both bulk and local transport rates, far in excess of the 41 data points used by US Army, Corps of Engineers (1984). Altogether 273 data sets were collected for bulk transport rates. The data originated from a large variety of sites from around the world.

The transport rates were determined by measuring accretion and erosion rates adjacent to coastal structures and at sand spits, by using sand tracers and by different kinds of samplers and traps.

Most of the data were obtained during mild wave conditions for fine to medium sand. Data are especially lacking for:

$S > 0.2 \times 10^6 \mathrm{m}^3/\mathrm{year}$ ($0.0634\ \mathrm{m}^3/\mathrm{s}$)

$H_{\mathrm{bs}} > 1.8$ m

$D_{50} > 0.6$ mm

$\tan\alpha > 0.06$ $(= 1/14)$

A serious consequence of this lack of data is that longshore transport formulae are calibrated almost exclusively against data for mild conditions while, in the case of an average annual longshore transport budget, a few storms usually contribute by far the most to the total sediment transport. In other words, the most important predictions for which the formulae are used, are for conditions outside their calibration range. It is therefore strongly recommended that data be collected in these ranges.

A point rating system was devised to compare different data sets with regard to the most important parameters for longshore transport. It was found that the evaluation was done reasonably objectively and consistently within the limitations of evaluating the accuracy of measurements. A limited sensitivity study indicated that the data evaluation was not overly sensitive to the weightings allocated to the different parameters.

The data sets were divided, based on the evaluation, into three categories, namely, the lower, middle and higher categories. Most of the data sets fall in the middle category which exhibits a very gradual increase in the overall accuracy of the data. Distinguishing between short- and long-term bulk transport data yielded similar trends in the accuracy of the data. It is recommended that longshore transport formulae first be calibrated against the data in the higher category only and then be tested against all the other data. This will ensure that the formulae will be tested under as many different conditions and at different sites as possible without the lower quality data contributing to the calibration constants. Preferably only data having a score of 80% or more should be used for calibration. However, until such data are available, the data sets in the higher category will have to suffice. The goodness of fit to the data should then be interpreted with due cognisance of the accuracy rating of the data sets, taking Table 5 into account. This table shows what parameter(s) in some references are either not measured or not reported which could have influenced the rating.

It is already known that it is difficult to measure longshore transport rates, and the parameters that influence them, accurately. This is supported by the fact that the highest score achieved in the evaluation was only 71%. It is recommended that multiple measurements of the transport rate be made simultaneously in order to be able to estimate the random error involved in the data and to demonstrate the consistency of the measurements.

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