# **CHAPTER 197**

# A CRITICAL REVIEW OF AVAILABLE DATA FOR CALIBRATION AND/OR VERIFICATION OF SEDIMENT TRANSPORT MODELS

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#### Abstract

A survey and a critical review of existing sediment transport data in waves and/or currents has been performed. Special emphasis has been given to the applicability of the data sets for the calibration and/or verification of sediment transport models. Only data sets dealing with non-cohesive sediment have been considered in this review. The eventual need for further experimental research is discussed under the light of the results from the present study.

# Introduction

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The increased understanding achieved in recent years of the phenomena involved in the processes of sediment suspension and transport by streams and by the combined action of waves and currents in the marine environment has lead to the formulation of increasingly more detailed (and complex) sediment transport models.

In spite of this improved understanding, the intricacy of the phenomena being described and an incomplete comprehension of all mechanisms involved frequently result in the introduction of crude hypotheses into the models, assumptions that have to be validated against experimental data. Some models are based on calibration factors that can only be determined from experimental results. In other cases, an empirical approach based on measured data is the only feasible way of describing phenomena that are either too complex or poorly understood to allow for a theoretical or semi-empirical description.

The preceding discussion points out the permanent need for sediment transport data of good quality. A critical data review has therefore been performed in order to identify potentially useful data sets for the calibration and/or verification of transport models.

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# General Requirements to Experimental Data

The flow chart of a generic sediment transport model is shown in figure 1. Most sediment transport models that are provided with adequate input data (hydrodynamic, sediment, bed form and miscellaneous data), will yield the sediment transport rates as output. More advanced models may be constituted by different modules; each module aiming to describe of one or several of the phenomena involved: for example, a module to determine the vertical structure of the flow, another to calculate the turbulence levels along the water column, a third one to determine the concentration profiles of suspended sediment, etc. Output of such advanced models may therefore include information such as velocity profiles (time-mean or instantaneous), concentration profiles (time-mean or instantaneous), etc. Other models may calculate the characteristics of bed forms based on the input data provided, so bed form data can in some cases be found as output from the model.



Figure 1. Flow chart of a generic sediment transport model.

It appears from the figure that the model/data interaction takes place at least at two levels, namely at the input and the output levels of the model. In the case of more complex models, the interaction could also occur at the output level of each constituent module. In order to be suitable for the purposes of calibration and/or verification of mathematical models, the data used should fulfill general and specific requirements. The general requirements will be addressed in what follows, whereas the specific ones will be discussed in the next section.

The amount of sediment transported by streams or by the combined action of waves and current in the coastal environment is determined by the complex interaction between the flow conditions and the bed material. Enough information about all the relevant physical parameters involved should be provided to the transport model in a format suited to its particular formulation, in order to obtain an accurate characterization of the phenomena that the model intends to simulate.

Generally speaking, it can be said that the quantity of the data should be sufficient to ensure that the degree of agreement or discrepancy found between the calculated and the observed transport rates can only be attributed to the assumptions inherent to the model and not to scarce or missing information about the conditions in which the reported transport rates were determined. The data should also be of good quality, obtained under well-defined conditions and using instruments suited for the measurement of the desired magnitudes.

Another general requisite refers to the way in which the measured data is reported. Tabulated form is preferable to graphic form, since it avoids the possible inaccuracies associated with collecting values from a figure, and facilitates the process of handling the data and the supply of information to the transport model. In this connection, data on magnetic media is highly favoured, especially if they have been stored in a database, with the related advantages regarding data retrieval and search for selected ranges of one or several of the physical variables involved.

# Specific Requirements and Classification of Experimental Data Sets

The amount and degree of detail of the data required for the calibration and/or validation of a given model depends not only on the assumptions and physical principles involved in its derivation but also on the situation the model aims to describe (transport by streams, or under combined current and waves, etc.). More complex models will require in general larger amounts of more detailed input data in order to allow for an adequate description of the phenomena under consideration. More parameters will be required in order to characterize intricate hydrodynamic conditions such as in the case of breaking waves propagating at arbitrary angles with respect to a current than in the relatively simpler situation of a steady current flowing along a laboratory flume.

One out of many possible classifications for the sediment transport data sets consists of separating between those obtained under pure-current situations and those measured in presence of waves or, eventually, in combined waves and current situations. This classification is based not only in the inherent differences between the hydrodynamic conditions but also reflects the trend usually followed when developing sediment transport models. In turn, each case can be split up into data obtained in the laboratory and data acquired in the field. Another item in the classification corresponds to the data collected in oscillating wave tunnels. These laboratory facilities are able to reproduce full-scale flow conditions (although lacking phase-differences along the tunnel and the vertical component of the wave-induced motion) under the controlled conditions of a laboratory.

The number of physical parameters required for a complete characterization of each situation depends not only on the flow condition but also on the particular sediment transport model considered. Instead of addressing a particular model formulation, it was chosen to pose requirements to the experimental data sets that were strict enough so as to ensure their suitability for the calibration and/or validation of the most advanced transport models that

are normally used, namely the deterministic-type model for sediment transport in coastal areas (see for example Zyserman et al. (1991 a) for a classification of models) and models calculating separately bed-load and suspended-load transport in the case of streams.

The requisites regarding the description of the experimental conditions and the measured transport rates vary for the different items in the classification, the major differences being, however, restricted to the characterisation of the hydrodynamic data.

The geometrical properties of the sediment can be appropriately described in any case through its median size  $\mathbf{d}_{so}$ , other percentiles  $\mathbf{d}_i$ , gradation  $\sigma_g$ , or, conversely, through its grading curve G.C. Another important parameter is the settling velocity w. If not specified, it can be determined if the sediment density  $\rho_a$  and the kinematic viscosity  $\nu$  or the temperature T of the water are known. The kinematic viscosity of water has been explicitly included because it is not always a function of the water temperature alone, as in the case when suspended particles of a clay-size fraction are present.

Bed forms are suitably described by means of their type, height h, length l and celerity a under all cases.

The rates of bed-load transport  $\mathbf{q}_{\mathbf{h}}$ , suspended-load transport  $\mathbf{q}_{\mathbf{a}}$  and total-load transport  $\mathbf{q}_{\mathbf{t}}$  are of course of basic interest. Concentration profiles  $\mathbf{c}(\mathbf{y})$  are also important, where y is the elevation about the bottom. For measurements in water tunnels, or under combined waves and currents, the time-mean values of the transport rates  $\mathbf{\bar{q}}_{\mathbf{b}}$ ,  $\mathbf{\bar{q}}_{\mathbf{a}}$  and  $\mathbf{\bar{q}}_{\mathbf{t}}$  are of interest. Vertical profiles of time-mean concentration  $\mathbf{\bar{c}}(\mathbf{y})$  and time series of the instantaneous concentration at different elevations (time series of ensemble-average concentration in the case of wave-tunnel data)  $\mathbf{c}(\mathbf{y}, \mathbf{t})$  are also relevant parameters.

In the case of pure-current flow conditions in the laboratory, the flow is adequately described if information about the dimensions of the flume (length L, width W and height H), about the water depth D, discharge Q and/or mean velocity V and water surface slope I is provided. Additionally, vertical profiles of the horizontal velocity component  $\mathbf{u}(\mathbf{y})$  could be used to check the hydrodynamic module (if any) of the model considered. The same parameters are valid to describe the flow conditions in the case of currents measured in the field, but information about the orientation O of the study reach and the cross-section A of the measuring section should be provided.

Appropriate parameters to describe the flow when considering measurements in water tunnels are the amplitude of the oscillatory motion  $\mathbf{a}_0$  or its maximum velocity  $\mathbf{u}_0$ , together with the period **T**, the discharge of the net current **Q** or its mean velocity **V**. Useful additional parameters are the vertical profiles of the ensemble-averaged velocity  $\bar{\mathbf{u}}(\mathbf{y})$  and time series of the instantaneous velocity recorded at different elevation above the bed  $\mathbf{u}(\mathbf{y}, \mathbf{t})$ .

Waves plus current conditions in the laboratory can be characterized by means of the water depth **D**, the wave height (root-mean-square, significant, etc.)  $H_i$ , the period (peak, zero-up-crossing, etc.)  $T_i$ , the type of breaking wave (if any) and the distance to the point of breaking  $x_8$ . Information about the breaker type and the distance from the measuring position in the surf zone to the breaker line is relevant because the production of turbulence by breaking waves is usually taken equal to that of a bore or hydraulic jump. This assump-

tion may be valid in the case of spilling breakers or of breaking waves of other type in the inner surf zone, but not close to the breaking point in the case of plunging breakers. Important additional parameters are the local bed slope S, the discharge Q or the mean velocity V (when relevant), a time series of the instantaneous elevation of the water surface from which the spectrum can be determined in the case of irregular waves or, conversely, information about the spectral parameters  $\eta(t)$ . Useful additional information for the calibration/validation of the hydrodynamic module of the model (if any) is provided by  $\bar{u}(y)$  and u(y,t).

In the case of combined waves and current in the field, the same parameters used to describe the waves and the spectrum in the laboratory can be applied. Due to the twodimensional (in plan) nature of the problem, it is now necessary to speak about the longshore and cross-shore components of the bed slope  $S_j$ , of the time- and depth-averaged velocity  $V_j$ , of the time-mean velocity profile  $\bar{u}_j(y)$ , and of the instantaneous velocity  $u_j(y,t)$ . Another important parameter is the angle  $\gamma$  between the current and the direction of wave propagation. Information about the beach profile **P** and orientation **O** may also be useful.

#### Data Sets Reviewed

A list of the 40 data sets reviewed, arranged according to the classification discussed, is listed below. This list is by no means exhaustive, but it has been deemed that the results of their review will provide an overview of the type of data available. A more detailed description of most of the data sets can be found in Zyserman et al. (1991 b).

## Pure Current, Laboratory

Barton and Lin (1955) Laursen (1957) Meyer-Peter and Müller (1948) Stein (1965) Williams (1970)

#### Pure Current, Field

Anderson (1942) Culbertson et al. (1972) Scott and Stephens (1966)

#### Wave Tunnel

Hayakawa et al. (1983) Murray et al. (1991) Ribberink and Al Salem (1989) Sawamoto and Yamashita (1986) Staub et al. (1984) Van der Velden (1987)

Waves (+ Current), Laboratory Bosman and Steetzel (1986) Nap and van Kampen (1988) Skafel and Krishnapan (1984) Vellinga (1984) Guy et al. (1966) Lyn (1986) Nomicos (1956) Vanoni and Brooks (1957) Wang and Qian (1992)

Colby and Hembree (1982) Nordin and Dempster (1963)

Horikawa et al. (1982) Nakato et al. (1977) Sato and Horikawa (1986) Sleath (1982) Steetzel (1984)

Dette and Uliczka (1986) Nieuwjaar and van der Kaaij (1987) Steetzel (1987) Waves (+ Current), Field Downing (1984) Jaffe et al. (1984) Kos'yan (1985) Owen and Thorn (1978)

Fairchild (1977) Kana and Ward (1980) Nielsen (1984)

It is important to keep in mind that most of the data sets reviewed were obtained under tests not specifically aimed to the calibration and/or verification of sediment transport models, so the results of the present review must be interpreted under the light of this restriction. On the other hand, the obtention of many of the parameters required to characterize the test conditions from the point of view of sediment transport models could be done without great efforts or additional costs, and would render the data sets useful for more application that those devised when the tests were designed.

Only data sets dealing with non-cohesive sediment of sand-fraction size have been considered in the present review, with the sole exception of the bed-load transport data of Meyer-Peter and Müller, which was obtained using bed materials in the range from coarse sand to gravel.

All data sets reviewed regarding wave-tunnel measurements were obtained under simulated regular wave conditions. Only the tests of Murray et al. included a net current superimposed to the oscillatory motion.

In some cases, the experimental results were not included in the reference reviewed, but a description of the tests, the measuring techniques and the results obtained was included. The review is based on the information provided in the reference, especially in the case of data collected under large field measurement programmes. More detailed information could be possibly found in the original data sets.

# Results of Data Review

It has been chosen to present the review in tabulated form, in order to allow for a quick interpretation of the results obtained. Tables 1 and 2 include the results for the pure current case in laboratory and the field, respectively. Table 3 refers to wave tunnel data, whereas Tables 4 and 5 deal with the waves plus current cases in laboratory and in the field.

The variables selected for the description of each case have been placed in the columns of the tables and collected in groups for hydrodynamic data, miscellaneous data, sediment data, bed form data and transport data. Information about the format in which the data is presented in the reference (tabulated (T) or graphic (G)) is also provided. Different types of bed material (both with regard to size and/or density) were used in some of the tests performed in the laboratory. This has also been indicated in the corresponding tables.

An open triangle has been used to indicate that the relevant parameter was reported for each data record of the data set, whereas a dot indicates that such information is available only for some data records. A cross means that information about the corresponding variable was not provided in the reference reviewed, but that it can be obtained from other sources, typically related papers. Finally, an empty circle indicates that no information at all was reported on the parameter.

It can be observed upon examination of the results that, in general, data sets collected in flume experiments in the laboratory are well-documented, with good information about the hydrodynamic conditions (including velocity profiles), and satisfactory details about the sediment and bed form data. Most of those references reporting transport data do so with the total-load transport rates. The Meyer-Peter and Müller data set was intended for the collection of bed-transport data. Laursen (1957) and Guy et al. (1966) also report the suspended transport, although the manner in which it was separated from the bed-load transport differs between both references.

All the data sets reviewed under the classification of pure current in the field except that of Anderson (1942) were collected by the U.S. Geological Survey, and present therefore similar characteristics with regard to the amount and format of the information reported. All five sets provide very good details about the hydrodynamic data, although information about the discharge is missing in Anderson's data set. The bed material is defined mainly through its grading curve, and vertical profiles of velocity and concentration of suspended sediment are reported in all cases, with vertical profiles of the median grain size of suspended sediment indicated in four of them. The information about bed forms is scarce (only the type of the observed bed forms is listed) and no transport rates of any kind are reported at all, probably because of the difficulties related to the effective trapping of the sediment in the field.

The wave-tunnel data reviewed is mainly reported in graphical form. The hydrodynamic conditions of the tests are well described, but measurements of velocity profiles (both ensemble-averaged and instantaneous) are scarce. The water temperature is only reported in two cases, even though its determination is an easy task. The same applies to the grading curve of the bed material, which is mainly defined through its median size  $d_{50}$ . Measurements of the concentration of suspended sediment are also rather scarce. With regard to  $\bar{c}(y)$ , Ribberink and Al Salem, Steetzel and van der Velden measured time-averaged concentration profiles, while the other authors determined ensemble averages. Bed form data may be termed as satisfactory, whereas transport data is very scarce.

The experimental data under combined waves and current considered in the present review were obtained either from profile-evolution tests (Dette and Uliczka, Steetzel, Vellinga) or from experiments with a horizontal or sloping bed. Data is well-documented, in the sense that it is usually presented both in tabulated and in graphic form. The wave conditions and the water depth at the measuring position are well-defined, although the type of breaking waves and the distance to the breaking line are reported only in a few cases. Time-averaged velocity profiles were measured in most data sets. The sediments are described mainly through the median grain size and/or other percentiles. No grading curves are presented. All the data sets reviewed include measured profiles of time-mean concentration of suspended sediment. Neither instantaneous values of concentration nor transport rates were directly determined in any case, although the magnitude of the transport could be estimated from the time sequence of observed profile changes. Bed form data is well defined in all tests with horizontal or uniformly sloping bottom, with exclusion of the rate of migration of bed forms. When data obtained under waves and current conditions in the field is considered, it appears that the overall quantity of information is scarce. Data are mainly presented in graphical form, with a reasonable amount of details about the local wave conditions, but are rather poor regarding the miscellaneous, sediment and bed form data. Transport data is completely missing. The lack of detailed information can of course be understood if the difficulties related to collecting data in the marine environment are recalled, especially so in the case of measurements within the surf zone.

## Conclusions

The general conclusions presented here are biased by the choice of the transport models selected when describing the particular requirements to be fulfilled by the data. Quite different conclusions may of course be reached if the results of the review are seen under the light of the requirements of transport models based on simpler principles.

It appears that information about sediment transport rates collected in pure current situations in the field is missing. This type of data is important for the verification of models developed using only laboratory data. Similar considerations apply to the characteristics of bed forms.

The total transport rate in combined wave and current motion on a plane or uniformly sloping bottom should also be determined from laboratory tests and compared to the results of similar experiments under pure current situations, in order to evaluate the influence of the waves on the time-mean transport rates.

Vertical profiles of time-mean concentration of suspended sediment were determined in most of the data sets reviewed that were obtained from wave tunnels or under combined current and waves, both in laboratory and in the field. Time-mean transport rates are missing in most cases.

The time-averaged rates of suspended transport can not be accurately evaluated by integration along the vertical of the product of time-mean concentration and velocity, due to the so-called wave-related component of the transport, which is defined as the time-average of the product of the periodic oscillatory components of the velocity and the concentration, see Murray et al (1991) and Zyserman et al. (1991 a) for a discussion. The influence of the wave-related component on the rate of suspended transport becomes more important for wave-dominated or weak-current cases.

Transport data collected from wave tunnels provide a unique possibility of evaluating the vertical structure of the wave-related component of the suspended sediment transport in reallife conditions through the measurement of the ensemble-averaged values of both the velocity and the concentration at the same position at different elevations above the bed under wellcontrolled test conditions. The influence of this component should therefore be evaluated for different relative magnitudes of the current-related and wave-induced velocities.

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Doto set	Data set	Barton–Lin	Guy et al.	Laursen	Lyn	Mayer-Peter	Nomicos	Stein	Vanoni-Brooks	Williams	Wang-Qian

# LEGENDS:

- Available
- O Not available
- Incomplete/some records only
- Can be obtained from other sources

Table 1. Pure Current Situation. Laboratory Data.

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Culbertson et al.	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nordin-Dempster	26	۲	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scott-Stephens	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2. Pure Current Situation. Field Data.

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Table 3. Wave Tunnel Data.

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Nieuwjaar-van der Kaaij	29	1	45	0.8	-	0	0	٥	0	٥	0	0	٥	0	0	0	٩	0	Ø	0	0	0	0	0	õ	0	0	6	0	0	0	0	0	0	0	
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Table 4. Waves (+ Current) Situation. Laboratory Data.

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Table 5. Waves (+ Current) Situation. Field Data.

# SEDIMENT TRANSPORT MODELS

It appears that the obtention of suitable data under the combined action of waves and current in the field will require the careful planning of comprehensive survey campaigns, most probably involving the participation of a large number of researchers with interest in the different aspects related to the phenomena of sediment transport in the marine environment. In this connection, and whenever new experiments aiming to the collection of sediment transport data are being planned, the interaction between researchers and modellers can only be of mutual benefit, and would render the data sets useful for a larger number of potential users.

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