RJS Whitehouse

# Sediment Transport by Combined Waves and Currents Contract Completion Report

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ABSTRACT

This report summarises the results of the development of improved methods for predicting sand transport in the coastal zone performed under MAFF Contract No.CSA1435.

A new sediment transport formula for combined wave and current conditions has been derived, incorporating results from linked work at University College North Wales. The formula has been successfully tested against field data.

A numerical model to predict wave and current distributions, sediment transport, and bed morphology changes on gently varying coastlines has been developed, and successfully tested against laboratory wave flume data.

CONTENTS



FIGURES

## 1. INTRODUCTION

Over much of the British coastline sediment transport takes place predominantly through the combined action of waves and currents (W+C). The currents may be tidal, wind-induced or wave-induced. Prediction of the resulting erosion or accretion rates at coastal and offshore sites requires a numerical model of the wave and current distributions, linked to a sediment transport formula designed for W+C conditions. This contract (CSA 1435) has the objective of making substantial improvements to the prediction capability through a combination of analytical, numerical, laboratory and field techniques.

The present work builds on that done in the previous MAFF contract CSA 992, and is closely linked with contract CSA 1434 with the University College of North Wales (UCNW). Only a summary of the main results are presented in this report, since detailed accounts have been presented in the publications arising from this contract which are listed in Section 8.

## 2. FIELD DATA

Field measurements of the hydrodynamics of W+C near the seabed were made successfully under contract CSA 992 at an immobile gravel bedded site near the Isle of Wight using the STABLE equipment developed at POL. It was planned to obtain further measurements with STABLE, this time over a sand bedded site, under the present contract, by linking with the NERC North Sea Programme which required similar data. However, possibly because of over-ambitious programming of the deployment schedule for STABLE in the North Sea Programme, no suitable data were obtained. To remedy this deficiency we instead put effort into re-analysing the very extensive field data-sets collected by HR some years ago at Maplin Sands and Boscombe Pier. These had undergone a preliminary analysis at the time, but considerably more effort was required to put them into a form suitable for testing a sediment transport formula. Important parameters, such as the vertical distribution of eddy diffusivity, were derived (Fig 1). Some of the results of this work were reported at a conference in Florence (Ref 1), and at a MAST Workshop (Ref 2). They are now available in data-base form.

## 3. LABORATORY DATA

A series of experiments has been performed in the Pulsating Water Tunnel at HR to measure both the hydrodynamic processes under W+C and the entrainment, suspension and transport of sand. These experiments demonstrated a 20-fold increase in the sediment transport rate as a result of adding waves to a current. They also shed valuable light on the more detailed processes, such as a large negative contribution to the sand transport from the so called wave-related term (Fig 2). Results were presented at a conference in Wallingford (Ref 3).

The work was undertaken primarily through a NERC grant by a student jointly supervised by UCNW and HR. Only the supervision time at HR was funded by MAFF, and this gave access to data of importance to the main part of the contract.

## 4. BOUNDARY LAYER MODEL

The turbulent-energy closure model of the W+C boundary layer developed at UCNW in an earlier contract was used as a test-bed to examine the dependence of the sediment transport on a number of key physical processes. These included the form in which the pick-up of sediment at the bed is specified, the effects of phase lags between sediment and water-motion, and the value of the ratio of eddy diffusivity to eddy viscosity. In addition, a thorough validation of the model was performed against the STABLE Isle of Wight data.

The following results have been obtained (Refs 4-6): (a) good agreement of the model with the field data, (b) the importance of the "wave-related" contribution to sediment transport was demonstrated, as confirmed by the laboratory measurements described above, (c) the magnitude and sign of the wave-related contribution depends strongly on the speed of response of the sediment to the flow, (d) the effect of different forms of sediment pick-up function is important but easily parameterised, (e) the effect of the eddy diffusivity/viscosity ratio is likewise important but easily parameterised. These results feed directly into the sediment transport formulation described next.

## 5. SEDIMENT TRANSPORT FORMULA

Numerical models to predict patterns of erosion and accretion in coastal waters resulting from engineering works require a sediment transport formula to translate the distributions of waves and currents into sediment transport rates. The UCNW model can provide this, but is far too expensive in computer time to run for engineering applications. In Phase I of this work (Contract CSA 992) a "Mark 1" version of a sediment transport formula for W+C was devised, but at that state only in a cumbersome and poorly tested form. In Phase II the formula has been modified to make it easier to apply, and it has been given more rigorous testing. A comparison with the UCNW model gave good agreement (Fig 3), showing that this formula can adequately reproduce the more detailed physics of the UCNW model (Ref 7). An algebraic model of the "wave-related" transport was devised (Ref 8), which reproduced the main findings of the laboratory experiments and also the UCNW model. As an improvement to the formula given in (Ref 7), a constraint has been applied to the bottom concentration of sediment to prevent it becoming impossibly large. Although exceedence of this condition does not arise under commonly encountered W+C values, it had been a recurring source of trouble with the use of other sediment transport formulae when modelling extreme events.

The sediment transport formula was tested against the Maplin Sands and Boscombe Pier data sets (more than 350 measured values), and found to give acceptable agreement (Fig 4). As is the case even for the relatively simple case of sediment transport in rivers, there is considerable random scatter between predictions and observations, but the important features are that the data points are reasonably evenly distributed about unity, and they do not show trends away from unity as the ratio of wave-to-current velocity increases. 70% of the ratios of predicted-to-observed values lie within a factor of 5 of agreement. Although this agreement is less good than for the simpler case of sediment transport in rivers (the best of which achieve about 70% of predictions within a factor 2 of observations), it is nevertheless a marked improvement on previous formulae for the coastal case.

Results were presented at conferences in Seattle and Florence (Refs 7,8) and at a MAST Workshop (Ref 9).

## 6. THE NEARSHORE PROFILE MODEL

An important element of HR's suite of numerical coastal and beach process models is the Nearshore Profile Model. This model aims to establish the beach profile response to storms and other relatively short-term events by modelling the detailed hydrodynamic and sediment processes driven (mainly) by wave breaking in the surf zone. The model can also determine longshore sediment transport rates, including the effects of tidal as well as wave-induced currents. It is applicable to sand-sized sediment.

During the present contract, the model has been developed to include a wide range of hydrodynamic and sediment processes, and extensive validation and sensitivity tests have been carried out. These developments and tests are outlined below.

## 6.1 Model Development

The main physical processes included in the model are:

(i) Wave transformation by refraction (by depth variations and currents), shoaling, Doppler shifting, bottom friction and wave breaking.

(ii) Wave set-up and driving forces for wave-induced currents, determined from values of wave radiation-stress gradients.

(iii) Longshore currents from pressure-driven tidal forces and wave radiation-stress forces, and the interaction between the two types of current.

(iv) Cross-shore undertow velocities using a three-layer model of the vertical distribution of cross-shore currents.

(v) Incorporation of transition zone effects (the transition zone is the distance between where a wave starts to break and where breaking-induced turbulence becomes fully developed).

(vi) Determination of wave bottom velocity 'moments' using the non-linear vocoidal wave theory. These 'moments' contribute to a net wave-driven sediment transport.

(vii) Cross-shore and longshore sediment transport rates using an 'energetics' approach. This takes account of sediment transport resulting from:
a) wave-driven and tidal currents
b) wave asymmetry effects (calculated from the bottom velocity moments) and
c) gravity in the downslope direction.

This will subsequently be replaced by the method described in Section 5.

(viii) Seabed level changes due to cross-shore sediment transport. The method uses a Lax-Wendroff solution to the sediment continuity equation. This ensures numerical stability and conservation of sand volume.

(ix) Cohesive Downcutting. Some stretches of UK coastline, particularly along the east coast between the Thames estuary and Flamborough Head, consist of glacial hard clay overlain by thin layers of sand. The underlying clay can erode (slowly but irreversibly) by a mechanism of sand abrasion when the sand layer is in motion.

## 6.2 Validation Tests

A very wide range of validation tests, against laboratory and field data, have been carried out to compare each element of the model against measured data and also the final model prediction of beach profile shape. These tests are described in the supplied references. The most recent series of validation tests have been carried out using flume data at prototype scale from the large wave flume in the University of Hannover, Germany. Regular wave tests were used in these comparisons in order to provide a more stringent test of the modelling of the surf zone processes than is possible with random waves. An example of the final model profile, compared with that measured in the flume, is shown in Figure 5.

### 6.3 Sensitivity Tests

Many sensitivity tests have been performed to establish how sensitive are the final results (profile shapes) to variations in the input parameters. Generally, it has been found that the most sensitive parameters are those directly related to the wave breaking process. By identifying the most critical processes, these sensitivity tests have enabled further improvements to the model to be concentrated on these processes.

Results were presented at conferences in Seattle and Delft (Refs 10,15), and at a MAST Workshop (Refs 11,12).

## 7. CONCLUSIONS

The objectives of the research have been satisfactorily accomplished, namely:

(a) the physical processes of sediment transport in the coastal zone have become better understood through a combination of laboratory and field experiments, and analytical and numerical simulation.

(b) the improved knowledge of these processes has been incorporated into a readily usable sediment transport formula for combined wave and current conditions, which was found to give satisfactory agreement with field measurements.

(c) a numerical model for predicting the evolution of sandy beaches on straight or slowly varying coastlines has been further developed, and proved to give accurate simulation when compared with large-scale wave flume tests.

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R L Soulsby. "Bottom turbulence and sand transport in coastal seas", presented at Institute of Ocean Sciences, B.C., Canada, 21 June 1991.

H N Southgate. "Wave and sediment transport modelling", presented at Instituto Superior Tecnico, Lisbon, Portugal, 28 November 1991.

# Figures

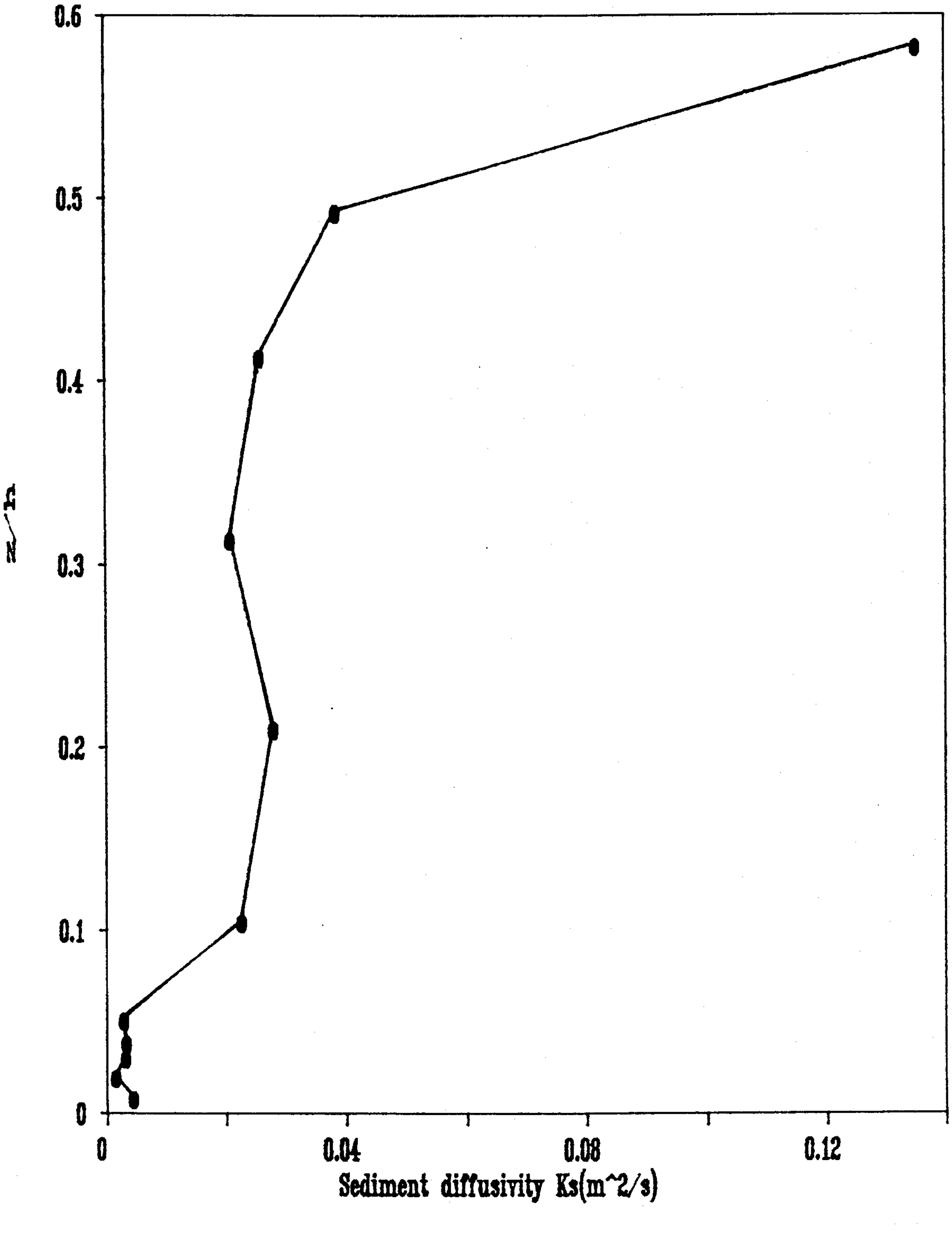


Figure 1 The vertical distribution of eddy diffusivity of sand derived from the Boscombe Pier field data-set. (Ref. 1).

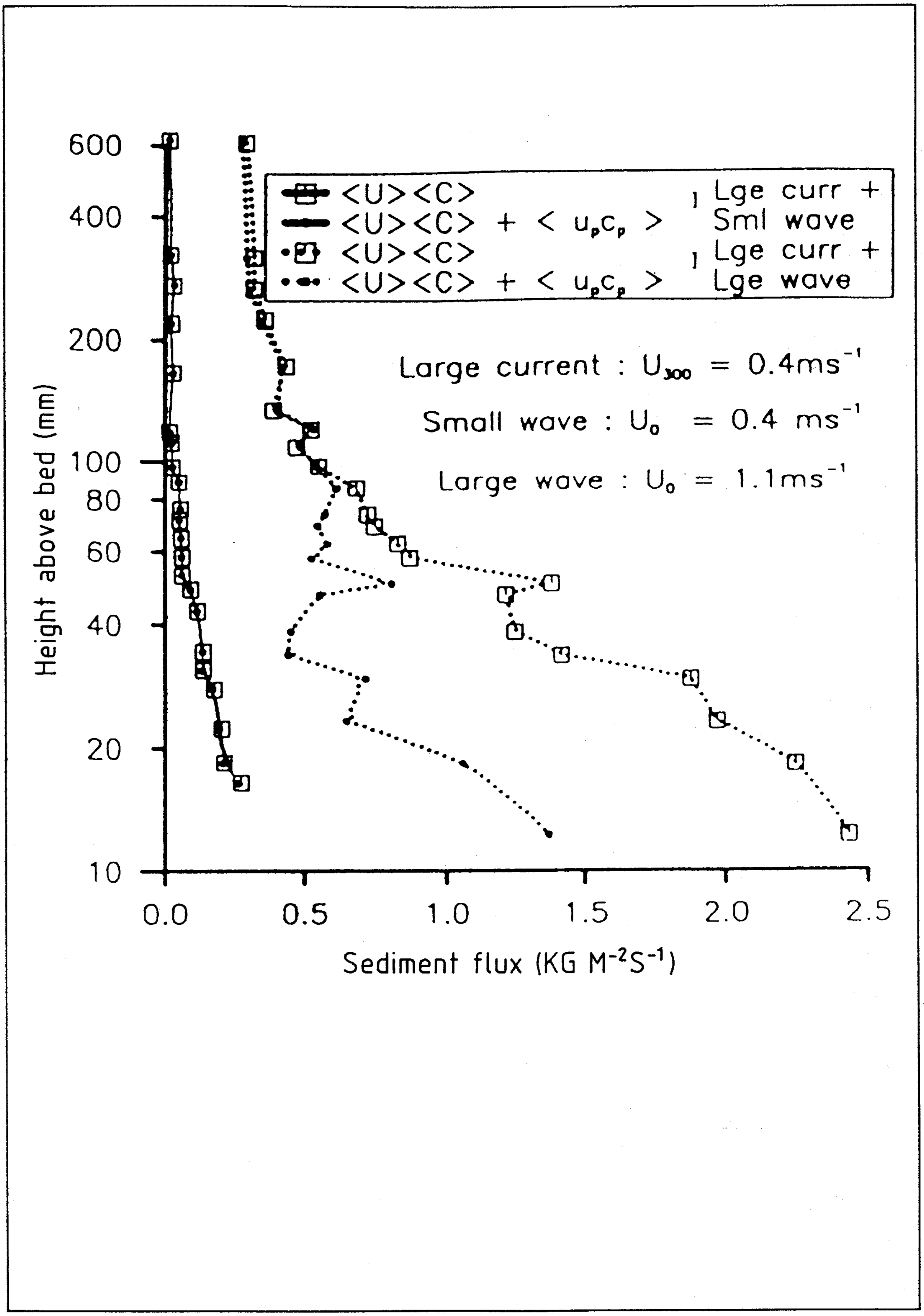


Figure 2 Vertical profiles of suspended sediment flux for combined waves and currents in the Pulsating Water Tunnel (Ref. 3).

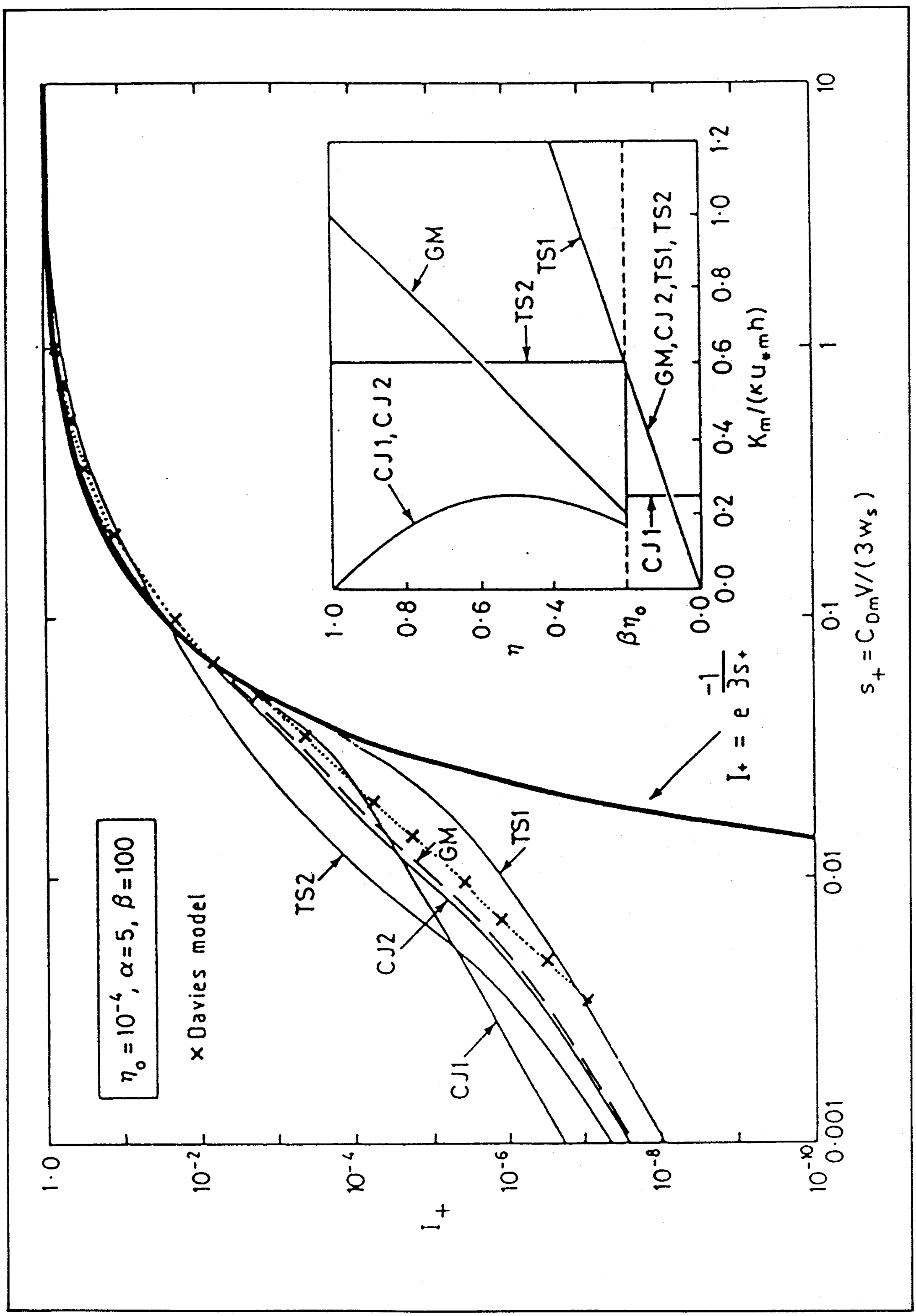


Figure 3 Comparison of sediment transport predictions using various proposed eddy-viscosity distributions (inset) from previous authors, the UCNW boundary layer model (x-x), and an exponential formula (bold line). (Ref 7)

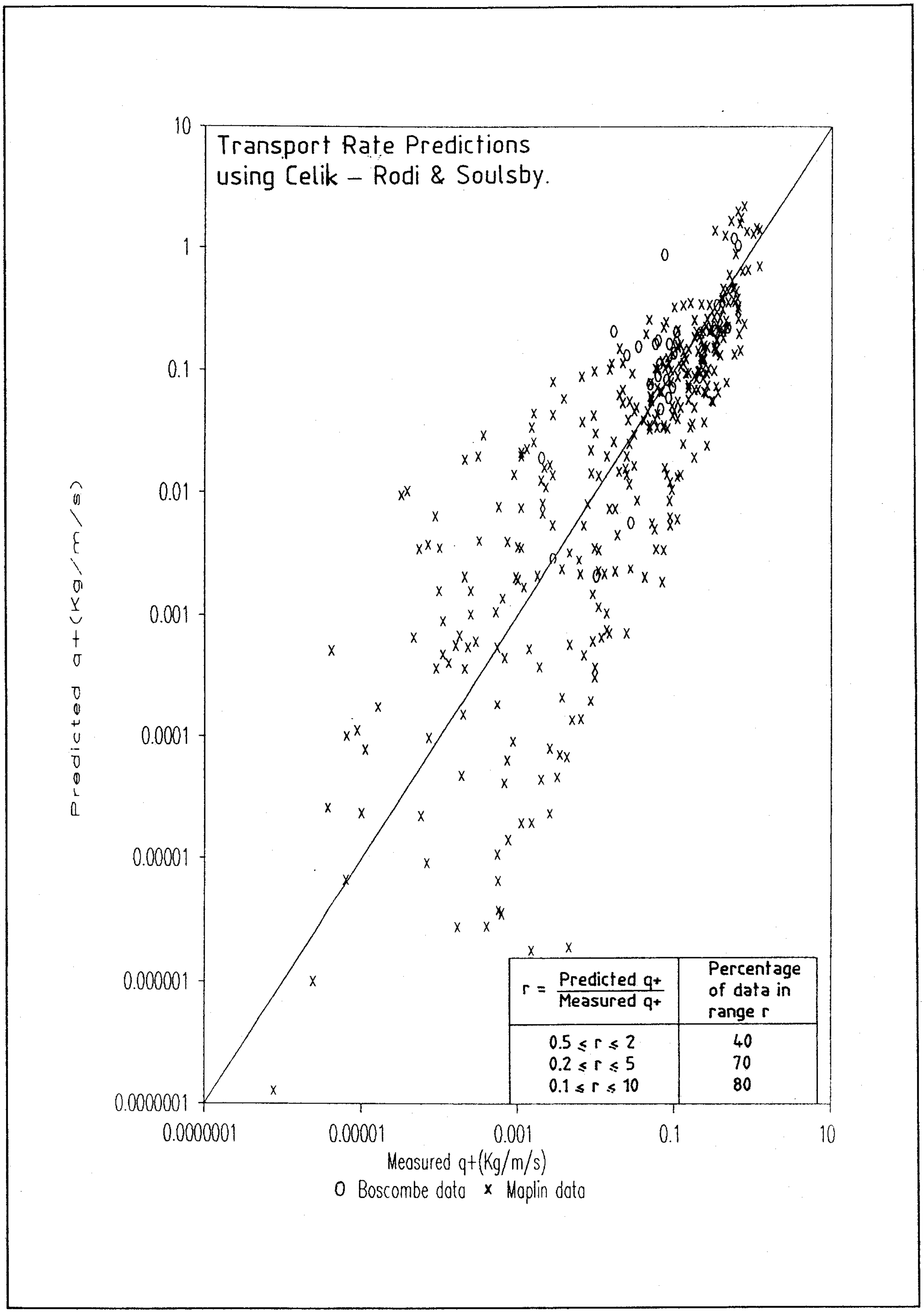


Figure 4 Comparison of predicted sediment transport rate using new formula with observed values at Maplin Sands and Boscombe Pier.

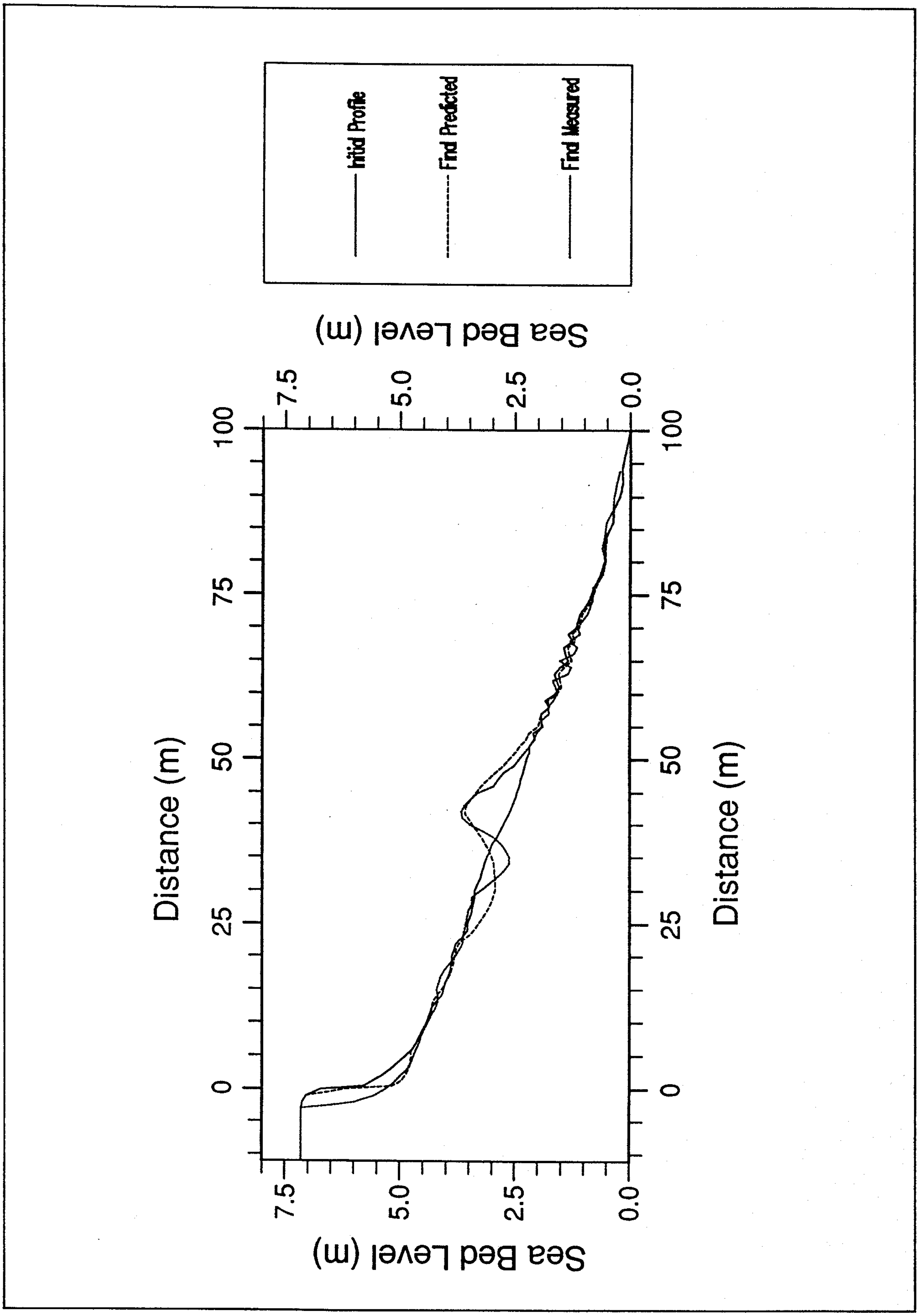


Figure 5 Comparison of predicted beach profile evolution using Nearshore Profile Model with measurements in Hannover Flume.