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CALCULATION OF SEDIMENT TRANSPORT WITH A SECOND MOMENT TURBULENCE CLOSURE

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РАСЧЕТ ОСАЖДЕНИЯ ЧАСТИЦ С ПОМОЩЬЮ ЗАМЫКАНИЯ ВТОРЫХ МОМЕНТОВ ТУРБУЛЕНТНОСТИ. Майкл Дж. О'Д. ЛОУГЛИН, Майкл М. ГИБСОН

Key words: the transport and deposition of fine sediment, turbulence kinetic energy, buoyancy effect, Reynolds-stress closure.

The problem of determining accurately the transport and deposition of fine sediment held in suspension in turbulent flow is one of considerable practical importance which is reflected in the considerable literature on the subject. When the sediment particles are small enough to move with the turbulent motion they may be considered as part of the continuum contributing to the mean density. Established methods of calculation use eddy-viscosity and eddy-diffusivity ideas, the transport coefficients being computed from specified mixing lengths, or calculated from transport equations for primary turbulence quantities such as the turbulence kinetic energy and its dissipation rate. The drawback to mean-field closures of this type is that important buoyancy effects are neglected or, at best only included through ad-hoc functions of local Richardson numbers. The lowest level of turbulence closure in which buoyancy effects are formally accounted for is that in which modelled transport equations are solved for components of the Reynolds stress tensor, the scalar fluxes, and the scalar variance, the scalar in this instance being the concentration of sediment. The development of Reynolds-stress closures has proceeded apace since the pioneer of Rotta [1] and Daly and Harlow [2], the main principles of turbulence modelling at this level are established, and adequate results for engineering purposes are obtainable from several different schemes. The problems of closing the scalar flux equations have received much less attention, at least partly in view of the difficulties discussed by Launder [3]. Nevertheless, the relatively uncomplicated method of Gibson and Launder [4, 5] accounts reasonably well for the effects of density stratification in the atmospheric surface layer and other two-dimensional turbulent shear layers. In a more recent study Gibson and Rodi [6] have shown how the model might be adapted to predict the nature of the highly anisotropic turbulence in the weakly-sheared layers near a free surface. But it is in the immediate vicinity of the bed that the real problems lie. These are twofold: first there is the difficulty of specifying boundary conditions for the turbulence variables at a loose bed, or even of specifying the effective level of the bed. The literature of sediment transport contains a number of proposals for loose-bed modelling; in the course of the present study it has been found that they may give inconsistent, even contradictory, results. At any rate there appears to be no physical description of conditions at a loose bed which can be used with confidence as the input to a practical calculation method. The second difficulty is that of modelling turbulence in the near-wall layers where the Reynolds number is insufficiently high for the energy-containing and dissipative eddies to be separated in wave-number space, and viscous transport assumes a dominant role in the energy balance. This difficulty is avoided in the present calculations where, as a temporary expedient, a one-equation eddy-viscosity model is used for the near-wall regions. The results from the near-wall calculations from the boundary conditions for the second-order closure at a convenient level in the logarithmic region. The turbulence length scale (the mixing length) is specified across the channel flow: exponentially damped in the viscous layers near the wall, and modified for buoyancy effects as in atmospheric turbulence [7]. Calculations for fully-developed sediment-laden channel flow are to be compared with the measurements reported in [8, 9, 10], each calculation repeated for different bed conditions obtained from the loose-bed models presented in [11–14]. The experimental conditions are summarised in the table which shows channel height (H), Reynolds number (Re_H), mean sediment diameter (d_S), settling velocity (v_S), friction velocity at the bed ($u_\tau = \sqrt{(\tau/\rho)}$), and the bulk Richardson number (Ri). The values of the Richardson number suggest that buoyancy is never likely to be more than a secondary effect in these flows, a surmise fully borne out by the calculations. The most remarkable and somewhat dismaying result to emerge from these studies is the extremely wide disparity of these bed conditions calculated according to the several theories. These conditions dominate the calculations and this disparity overwhelms any differences in the detailed modelling of the turbulence including sediment pick up and dispersion. It is evident that the first priority must be to rationalise the input to the turbulence calculations by correlating the bed calculations, perhaps by extension of the Clauser profile-fitting technique. This work is in hand with, so far, encouraging results.

Experimental conditions

References	H mm	Re_H $x10^{-3}$	d_S mm	v_S m/s	u_τ m/s	Ri
[9]	64.5	48.83	0.15	0.016	0.0358	0.0076
[9]	65.1	50.58	0.19	0.023	0.0375	0.0041
[9]	65.4	56.18	0.24	0.031	0.0425	0.0022
[8]	170.0	183.70	0.105	0.0085	0.041	0.0317
[8]	172.0	181.77	0.21	0.0277	0.041	0.0194
[8]	171.0	187.17	0.42	0.0620	0.045	0.0029
[10]	28.0	16.80	0.2	0.024	0.0384	0.0113

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