Small - Scale Morphology and Boundary Layer Processes: Measurement and Modeling

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LONG-TERM GOALS

The main goal of the research project was to contribute to a better understanding of the basic mechanisms controlling sediment transport in the near-shore region. In particular, the structure of flow in the bottom boundary layer was of interest along with its interaction with sediment dynamics and bottom morphology. Attention was also devoted to the steady streaming generated both in the bottom boundary layer and outside it up to the free surface.

OBJECTIVES

The dynamics of the coherent vortex structures beneath sea waves are examined, which are generated at the bottom by 1) the instability of the laminar boundary layer and the development of turbulence, 2) the nonlinear interaction of the oscillatory boundary layer with a wavy bed of small amplitude and with a sloping bottom, and 3) the separation of the boundary layer at the crests of 2-D ripples of large amplitude. Moreover, the steady streaming induced both close to the seabed and far from it is examined. The obtained results are useful in the study sediment dynamics and processes that lead to the formation of small and medium scale bed forms.

APPROACH

The investigation was based on analytical approaches, numerical simulations of momentum (Navier-Stokes) and continuity equations, and the analysis of field data. The numerical codes consider the full 3-D problem and simulate coherent vortex structures and turbulence. Field data are used to test the analytical results and the numerical findings. Analytical solutions describing the flow field generated by a propagating wave close to the sea bottom were obtained to understand certain field measurements and to study how the flow in the bottom boundary layer affects some small and large scale morphodynamic phenomena.

WORK COMPLETED

During the last year of the project the following work was completed:

a) A theoretical analysis of the flow generated by wind waves propagating over megaripples has been made. Both the oscillatory velocity component and the steady streaming have been determined.

b) Flow visualizations have been made in a numerical U-tube to investigate the dynamics of coherent vortex structures characterizing turbulence dynamics in oscillatory boundary layers. Simultaneously sediment trajectories have been determined to understand the basic mechanisms able to put into suspension sediment grains.

c) The study of mass transport generated by an oscillatory flow over asymmetric ripples has been started by numerical means. Preliminary results indicate that ripple asymmetry has a strong influence on the steady currents generated by waves at the sea bottom.

d) The analysis to investigate whether an appropriate rotation of the coordinate system exists such that the cross-correlation of the velocity components due to waves vanishes (allowing the time average of the product of the remaining velocity components to provide estimates of the turbulent Reynolds stresses) has been continued.

e) The cooperation between the Naval Postgraduate School and Genoa University has been continued and in particular Prof. Edward Thornton has visited Genoa University during February 2000 and Mr. Roos has visited N.P.S. for two months (July-August, 2000).

The personnel exchanges from the beginning of the project can be summarized as follows:

Person/Position	**From**	**to**	**Period**
Dr. Foti Senior Research	Univ. of Catania (I)	Naval Postgraduate School (USA)	15 Aug. 97-15 Jan. 98
Dr. Vittori Senior Research Temporary Professor	Univ. of Genova (I)	Naval Postgraduate School (USA)	1 July 98-30 Aug. 98
Prof. Blondeaux Full Professor	Univ. of Genova (I)	Naval Postgraduate School (USA)	1 July 98-30 Aug. 98
Dr. Vittori Senior Research Temporary Professor	Univ. of Genova (I)	Naval Postgraduate School (USA)	15 June 99-15 July 99
Prof. Blondeaux Full Professor	Univ. of Genova (I)	Naval Postgraduate School (USA)	15 June 99-15 July 99
Dr. P. Scandura Post Doctoral	Univ. of Genova (I)	Naval Postgraduate School (USA)	1 June 99-30 Aug. 99
Prof. Thornton Full Professor	Naval Postgraduate School (USA)	Univ. of Genova (I)	February 2000
Mr P. Roos Ph.D. Student	Univ. of Genova (I)	Naval Postgraduate School (USA)	1 July 00-30 Aug. 00

RESULTS

(a) The velocity field induced by a sea wave propagating on a sloping bottom has been determined to evaluate the cross-correlation of the velocity components away from the bed. The presence of megaripples has been taken into account. The wavelength of the bottom forms is assumed to be of the some order of magnitude as the local water depth h^* while their amplitude is much smaller than h^*. Waves of small amplitude propagating in shallow waters have been considered, but the results are felt to provide useful information also for finite depths and large amplitude waves. The analysis has been carried out to investigate whether an appropriate rotation of the coordinate system exists such that the cross-correlation of the velocity components due to waves vanishes allowing the time average of the product of the remaining velocity components to provide estimates of the turbulent Reynolds stresses. The obtained results show that turbulent Reynolds stresses can be evaluated from field measurements of velocity components, if an appropriate reference frame is chosen rotated with respect to the gravity oriented reference system. The tilting angle depends on the bottom profile, on the characteristics of the wavefield and on the geometrical characteristics of the megaripples. In particular, close to the bed the coordinate system turns out to be orthogonal to the bed and follows the bottom profile. However moving for away from the bed, the tilting angle changes. As suggested by Stanton & Thornton (1996) the angle can be computed by minimizing the measured covariance between horizontal and vertical velocity components. However, the present analysis suggests that the procedure should consider different wave components separately and should be applied sequentially at different heights from the bottom. An analysis of the field data seems to suggest the validity of the theoretical results.

(b) The unsteady boundary layer generated by a sea wave close to a flat bottom was considered with the aim of investigating the vortex structures that appear during transition form the laminar to the turbulent regime and those characterizing wall turbulence at moderate values of the Reynolds number. The obtained results provide a physical insight into the mechanism controlling momentum and mass (sediment) transfer close to the sea bottom. The flow is reproduced by means of

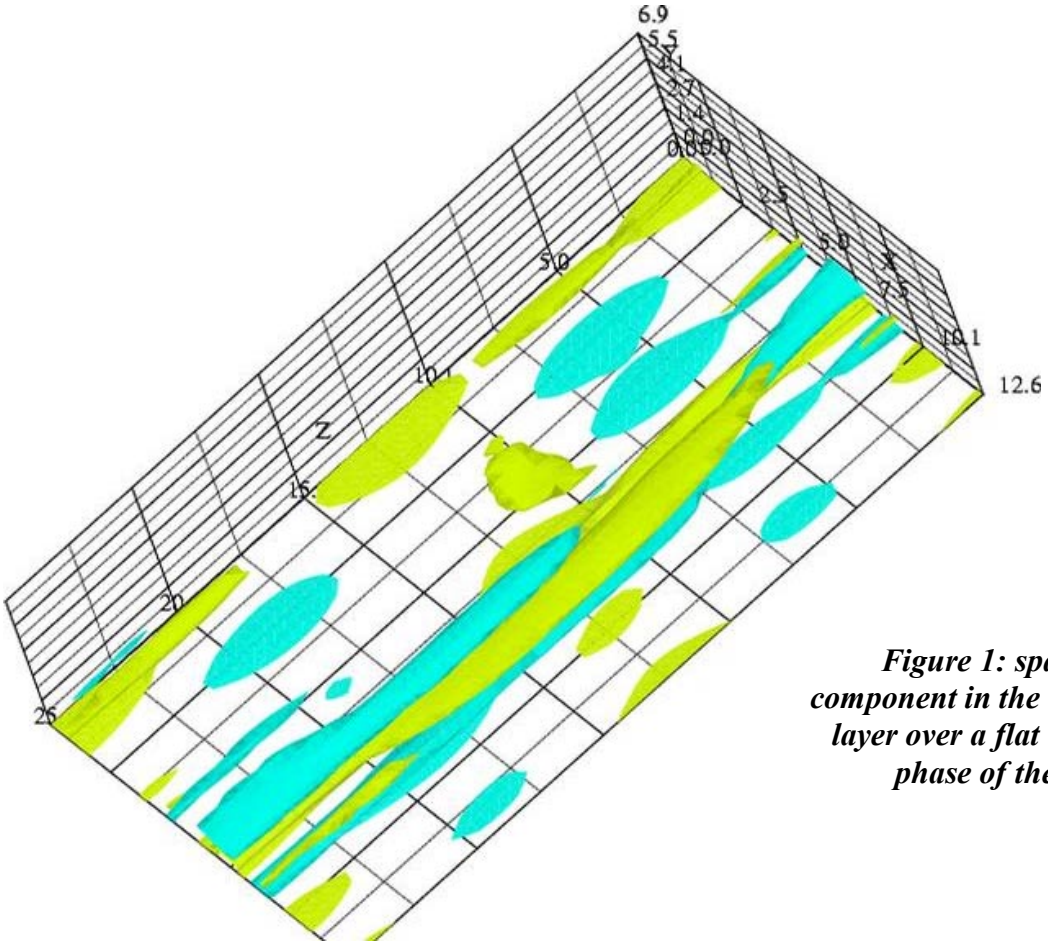

Figure 1: spanwise vorticity component in the oscillatory boundary layer over a flat wall (Re = 1.8 10^5, phase of the cycle = $\pi/4$) .

numerical simulations of Navier-Stokes and continuity equations with a numerical code partially developed within the framework of the present research project. The transitional regime is characterized by the presence of unevenly spaced low-speed streaks, which emerge toward the end of each decelerating phase. Then the streaks grow in amplitude, lift away from the wall, oscillate and then break down, i.e. they loose their coherence owing to an unstable interaction with the surrounding higher-speed fluid (see figure 1 where the spanwise vorticity component is plotted at the end of the accelerating phase of the cycle for a value of the Reynolds number equal to about 2 10^5). Preliminary results indicate that the mean spanwise spacing between low-speed streaks is about 100 ν/u_τ, ν/u_τ being the viscous length. This value is equal to that found in steady flows. (Lee, Eckelmann & Hanratty, 1974; Blackwelder & Eckelmann, 1979; Kreplin & Eckelmann, 1979; Nakagawa & Nezu, 1981). Similar vortex structures were observed by Sarpkaya (1993). However his laboratory visualization techniques did not allow a complete picture of vortex dynamics. Indeed, as pointed out by Sarpkaya (1993) himself, his results show coherent vortex structures along a particular plane, while it would have been desirable to have views of the structures in all planes. Up to now the flow has been investigated only for a few Reynolds numbers falling in the intermittently turbulent regime. Further simulations are being carried out.

(c) The generation of steady streaming by sea waves propagating over finite depth is a well know phenomena, first investigated by Longuet-Higgins (1953) and since then tackled by many researchers using various analytical, perturbative and numerical approaches. A steady velocity component is found at second order in the wave slope. The present research shows that steady streaming can be generated at the first order in the wave slope when the sea bottom is covered by asymmetric ripples. The results are obtained using a numerical approach based on the solution of the vorticity equation. The intensity of the steady current has been determined for different geometrical characteristics of the ripples and, in particular, for different asymmetry index. The investigation has been carried out also for different values of the Reynolds number. For low or moderate values the flow is periodic and the streaming can be computed averaging the flow over a wave cycle. Increasing the value of the Reynolds number, a sequence of bifurcations take place that leads the flow to become chaotic. In this case, to determine the steady velocity components, the flow should be simulated for a large number of periods. In all the cases investigated, the steady streaming is directed along the mild slope of the ripples towards the crest. Moreover its strength increases with the Reynolds number and with the asymmetry index of the ripples.

IMPACT/APPLICATIONS

RELATED PROJECTS

"Sediment Transport Modeling in Marine Coastal Environments" research project of European Union. MAS 3-CT97-0115 "Sedmoc".

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PUBLICATIONS

(List of papers acknowledging the support of NICOP Project appeared during the last year)

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- Blondeaux, P., Stanton, T., Thornton, E., Vittori, G. (2000). Shallow water waves propagating over megaripples. To be submitted to J. Geophys. Res.

- Blondeaux, P., Brocchini, M., Vittori, G. (2000). Sea waves and mass transport on a sloping beach. Submitted to J. Fluid Mech.

(The following paper, previously submitted, have been published)

- Scandura, P., Vittori, G., Blondeaux, P. (2000). Three dimensional oscillatory flow over steep ripples. J. Fluid Mech., 412, 355-378.

- Blondeaux, P., Foti, E., Vittori, G. (2000). Migrating sea ripples. Eur. J. Mech. B-Fluids, 19, 285-301.