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学位論文題目	A study on the interaction of waves and turbulent currents （波と流れ共存場に関する研究）
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論文内容要旨

Experimental investigations and numerical computation are carried out to study the interaction between surface gravity waves and current. In particular, interactions among the time-mean, wave-induced, and turbulent flow fields are experimentally analyzed regarding to the effects of waves on the time-mean flow and the influence of current on the wave-induced motions.

In chapter 2, the measurements of velocities, tubulent quantities by an LDV, and bottom shear stress by the hot-film sensor are presented in datail. These two main instruments allow us to study distinguishably the flow characteristics under wave crest and wave trough.

In chapter 3, the experimental results are described. The experimental analysis in the present study indicates that there are interactions among the time-mean, wave-induced, and turbulent flow fields. These can cause significant changes in the magnitude and of the flow quantities from those of the original steady current or the original waves.

The time-mean flow quantities such as velocity, turbulent intensities are influenced by the superposition of waves. These are found to be depended upon the relative magnitude and direction of waves to current. The time-mean velocity is deviated from the normal log-current profile (especially near the water surface). This is caused not only by the Reynolds shear stress, but also by the wave-induced shear stress. The departure from the log-current profile of a steady current denoted by the "defect velocity" at the M.W.L. is obtained empirically. This is used in a new nonlinear wave-current model developed in chapter 7.

The vorticity generated within the current profile also affects directly the amplitude and the characteristic "overshooting" of the wave-induced velocity. This indicates that the use of an irrotational wave theory for the wave-current flows may not give good prediction of the flow kinematics.

One important findings in the present study is that the phase variation of the Reynolds shear stress is different from that of the velocity indicating a "non-local equilibrium" of the turbulent structure. This suggests that models employing the eddy viscosity hypothesis and the assumption of "local equilibrium" condition should be used with caution. In addition., the eddy viscosity felt by the current is found different from that felt by waves.

In chapter 4, several analytical models are reviewed for the predictions of the bottom shear stress as well as the enhanced apparent roughness. It is found that all models differ markedly in their quantitative predictions. Although, the eddy viscosity for the wave-current combined flows should be time-dependent, the assumption of a time-independent linear eddy viscosity (near the bottom) still give favorable predictions. This is as far as the ratio of the amplitude to roughness is high enough.

In chapter 5, a model for the wave-induced mass transport velocity in a turbulent wave boundary layer under wave-current combined flows is developed on assuming a time-invarient linear eddy viscosity. The solutions in the Eulerian description of the wave-induced mass transport velocity are obtained upto the second-order by a perturbation method. The present model is applicable for a large Reynolds number flow.

In chapter 6, four turbulence models are used to study the turbulent wave boundary layer flow and wave-current interactions within a rough bottom by the application of both finite difference and finite element methods. They are the Zero-equation, One-equation, Two-equation, and Reynolds stress models. Comparisons among these models suggest that for a time-dependent flow, at least a Two-equation model is neccessary. The distinct differences in the variation of velocity and turbulent intensities during the phase of acceleration and deceleration are favorably predicted by the Two-equation model.

As for the time-dependent flow, the "local equilibrium" condition is no longer completely satisfied. Therefore, deviation from the measured data is found in the very vicinity of the bottom where this condition is assumed applicable. Furthermore, the flow near the bottom always experiences the smooth bed near the phase of flow reversal. In order to obtain more reasonable results, the temporal variation of the roughness height as well as the effects of the moderate and low Reynolds number should be taken into consideration. In other words, the bottom boundary conditions for the turbulent kinetic energy and energy dissipation rate should be modified to account for this condition.

In chapter 7, a non-linesr model for the combined waves and current is developed to obtain the velocity as well as the shear stress. The new method employs the profile of a steady current modified by the introduction of an empirical defect velocity as described in chapter 3. On assuming a time-invarient linear eddy viscosity and making use of the application of the Fourier wave theory, the usual boundary value problem is formulated in term of the stream function. The study covers the flow regime from the laminar to smooth and rough turbulent flows.

Good agreements are, generally, obtained between the predicted results and measured data. The time histories of the particle velocities and the bottom shear stress are predicted reasonably well. The inclusion of the newly introduced empirical defect velocity is found to be effective, in particular, for a flow which experiences strong shear or vorticity distributions. The allowance of the change in the boundary layer of the time-mean velocity provides good physical insight.

In order to obtain more precise results in the vicinity of the bottom or near the overshooting zone, the more realistic models such as the K-ε or the Reynolds stress models with the effects of moderate and low Reynolds number are recommended. This, however, certainly will require a considerably time-consuming computation.

Finally, **chapter 8** sumarizes the general conclusions obtained from the present study.

審査結果の要旨

河口部や沿岸砕波帯は，激しい砂の移動による地形変化が著しく，洪水処理や海岸侵食対策の点から，国土保全上重要な場所である。砂移動は，非線形干渉の強い諸種の外力の下に生じており，未解決の問題が多く残されている。本論文は，波と流れが順行・逆行する場合について，実験・理論の両面から外力推定方法を求めるもので，全編8章からなる。

第1章は序論である。

第2章では実験方法と実験結果の処理方法が述べられている。測定出力の定常成分，波動成分，乱流成分への分離方法が詳細な検討に基づいて決定されている。

第3章は実験結果であり，理論との比較検討資料を豊富に揃えている。なかでも，波・流れ干渉の結果として定常成分に生ずる変化を定式化したことは，理論の簡略化に役立つ有用な成果である。また，底面粗度に起因する間歇的な乱れ強度の増加とその影響を明確にしたことは，将来のモデル化に対して重要な示唆を与えるものである。

第4章は底面剪断力に関する既存の7つの理論と実験値の比較である。諸理論は実験値を下回る値を与えることが明らかにされている。

第5章では，定常流と単一正弦波が共存する場合の質量輸送理論が展開され，二次近似解まで得られている。波の非線形性が強くなるほど，実験値との差が大きく，単一正弦波の想定に原因があることが示唆されている。

第6章では，4つの乱流モデルによる計算結果と実験で得られた乱流特性量の詳細な比較がなされ，少なくとも二方程式モデル以上でなくてはならないことが結論されている。なお，実験で得られた底面近くでの間歇的な乱流強度の増加は，粗度高さを時間的に変動させる手法などを導入しなくては再現できないことが確認されている。

第7章は，波と流れの干渉を取り入れた新しい流関数理論の展開であり，前章までの検討により明らかにされた欠点を解消しようとするものである。波は非線形性の強いものとし，波・流れの干渉には第3章の結果を導入している。時間的に不変な渦粘性モデルを採用しているため不十分なところも残るが，流速分布，底面剪断力を実用上必要な精度で得ることに成功した。これは重要な成果である。

第8章は結論である。

以上要するに本論文は，波・流れ共存場という強非線形現象を実験的に解明し，併せて新しい解析手法を提案したもので，流体力学及び海岸工学の発展に寄与するところが少なくない。

よって，本論文は博士（工学）の学位論文として合格と認める。