Barrier Spit Morphology Changes Caused by Storms

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論文内容要旨

Barrier spits are organized surface-piercing accumulations of sediment that grow by transport directed from landmass or sediment source toward a water body. Barrier spit growth refers to the elongation and curvature of these features. Barrier spits can form at the ocean, bay sides of inlets and river mouth. These spit processes are of interest both for understanding inlet and river mouth morphodynamics and for managing navigation channels and inlets. Inlet and river mouth closure through spit development has implications for water quality, as well as for commercial and recreational navigation.

Each year, several hurricanes and severe storms impact the coastlines around the world in general and in Japan in particular. Large wave height together with the increase of storm surge level during these extremely events create high likelihoods for wave overtopping or overflow the barrier crest height as we called coastal overwash. Coastal overwash results from complex geologic and oceanographic processes, such as extreme storms or hurricanes, changes in sediment supply at the coast, and sea-level rise. Coastal overwash is the flow of water including sediment over the crest of the beach that does not directly return to the water body, such as ocean, sea, bay, or lake, where it originated and washover is the sediment deposited inland by overwash processes. Overwash occurs when wave runup level or water level including storm surge exceeds the beach crest height. Overwash may also occur during non-storm conditions caused by extreme tide levels or seiches in lakes which exceed the beach crest or due to severe floods from lagoon to ocean as observed in Hoa Duan coast in the Thua Thien Hue province, Vietnam during a large flood in 1999. There are two different phases of overwash, runup overwash and inundation overwash. Runup overwash occurs when the wave runup height is higher than the dune or barrier island crest. Inundation overwash occurs when the water level exceeds the beach crest. Inundation overwash may cause the destruction of dunes and man-made structures on barrier islands.

The occurrence of overwash is expected to increase because of sea level rise and diminished sediment supply along many coasts. The capability to quantitatively predict and simulate overwash and washover deposits is just beginning to emerge. Prediction of overwash occurrence can provide valuable planning information for local authorities, emergency services, and coastal residents. The information of maximum water level rise, including the wave setup height at the entrance, is very important in terms of river mouth morphology change, navigation transportation, and saline water intrusion into the river or lagoon. In addition, a barrier spit is often located at river mouth or tidal inlet; the morphology of barrier is, therefore, can be affected by wave setup height and when the sand spit was inundated by storm surge level the wave setup is additional force causing barrier crest evolution. Thus the wave setup study, especially in the prototype scale, is necessary to investigate for this study.

The overall aims of this study are to increasing the physical understanding of how a barrier spit morphology changes caused by storm and modeling improvement of the whole processes. There are three different types of coastal overwash modeling: empirical, analytical and numerical models.

In this study, a new empirical model was developed for estimating washover volumes by modifying previous empirical models (Williams 1978 and Tanaka et al. 2002) but using new assumptions based on the governing physical processes. It was assumed that the excess runup is transporting the sediment landward for duration of excess runup. Moreover, the ratio of beach crest height over wave runup height was added in the model to consider the effects of a limited dune height on the mobilization of material from the dune. The model was calibrated against huge full field data sets within the United States to obtain a proper value on the main empirical coefficient. Verification of the model with a further fourteen field data points, which collected from the United States and from the Yokosuka Coast of Japan, showed satisfactory results, indicating the generality and robustness of the calibrated coefficient, with the modeled volumes within a factor of two of the measured volumes. The model also predicted well cases for which inundation overwash occurred a part of the time, in spite of the assumption that runup overwash prevails.

In connection with the wave setup at the river mouth in this study, an investigation of the wave setup height at ten various river entrance geomorphologies in Japan was conducted. The results have been shown that the wave setup height is not only depending on wave breaking at the entrance but also affected by the river discharge and river mouth morphology. The wave setup height is attained to from 2 to 14 percent of offshore wave height for the cases of average water depth at entrance range from 1.1m to 6.5m. A new analytical model for predicting the wave setup at a river entrance was proposed and its results overall compare to observed wave setup height. The final result was obtained as a technical diagram for estimating the wave setup height at the river entrance. This study is useful for river management and engineers to find out the best solution in controlling the river mouth morphology change and environment.

A laboratory experiment in 2-dimentional wave flume was carried out to in-depth investigate a sand barrier island cross-shore profile responses and to increase understanding of physical insight sediment transport mechanisms in different zones of barrier profile under the storm hydrodynamics. The storm surge level and wave height were allowed to continuously increase and decrease as same as in a reality storm dynamics. The deposited sediment in the bay area was measured for each run by a sand trap. Barrier crest accumulation was shown to occur due to the runup overwash, and barrier lowering caused by the inundation overwash. The eroded sediment volume appeared equal to 1.48 times larger than the washover sediment volume. On the back of barrier island, overwash hydrodynamics and sediment transport were shown to be affected by the bay water level, friction, infiltration and lateral spreading. The amount of sediment deposition in the bayside was higher as excess flow increases. The landward sediment transport rates appeared to be equal to offshore sediment transport rates during the states of runup overwash and inundation overwash.

An analytical model for predicting profile response caused by wave impact and overwash was first developed by Donnelly 2008. However, this model can only reproduce order-of-magnitude the sub-aerial barrier profile responses but in fact the eroded part is often at some distance seaward direction. Hence, a further development of this model to take into account of the submerge area until the water depth is one half of the offshore wave height (a lesson from the laboratory experiment). The results of validating new algorithm against the current laboratory data sets indicate that the model was quite satisfactory captured the volumetric response of profile but the barrier crest height and location were underestimated.

The numerical model used in this study, SBEACH (Storm-induced BEAch CHange), was developed by Larson and Kraus (1989) to calculate profile change resulting from erosive storm conditions. Overwash was initially added to the model by Kraus and Wise (1993). This algorithm was updated by Larson et al. (2003) to provide a more physically based description of overwash processes and the model was able to successfully indicate the depth and inland penetration of sediment as well as beach face recession and beach crest height reduction; however, these algorithms only considered runup overwash. Recently, a new algorithm has been added to the SBEACH overwash model to calculate inundation overwash, and the algorithm to calculate the hydrodynamics on the backslope for both runup and inundation overwash has also been improved. This new model is then applied for the current new field data sets as well as laboratory experiments data. It was shown that the simulated barrier profile evolution was in good agreement with measured post-storm profiles.

Engineers must be able to predict where and how much coastal change will occur in order to locate new construction landward of coastal change hazards or to develop evacuation plans. Developing this predictive capability requires quantifying how coasts respond to extreme storms. The outcome of this study provides the answer for this kind of questions.

論文審査結果の要旨

砂浜背後にラグーンなどの閉鎖性水域を控えるバリアー地形や、河口部に形成された砂州地形においては、高波浪時に越波による土砂移動が生じる。ラグーン内や河口感潮域には豊かな生物環境が形成されている場合が多く、この様な環境の保全のためにはバリアー上の越波による砂移動に関して、土砂移動のダイナミックスに立脚した検討が必要である。本論文では越波に伴う土砂堆積現象について現地資料・室内実験をもとにその実態を明らかにするとともに、堆積土砂量を推定するための手法について検討を行っている。

第１章では、本研究の背景・目的およびその意義について述べている。

第２章では、越波に伴う海浜地形変化に関するレビューを行い、これまで多くの研究がなされている水面下に生じる漂砂移動との相違について、砂移動現象・水理特性の両面から概説している。

第３章では、暴浪時の越波により顕著な土砂堆積が生じた現地データとして、米国と宮城県横須賀海岸における資料を収集し、これをもとに、既存の越波流量式を応用し、土砂堆積量の定式化および検証を行っている。得られた算定式は既往の算定式に比べてばらつきが小さく、高い精度を有している。同式を用いることにより、海面上昇が生じた場合の越波による堆積土砂量を算定することも可能である。これは海岸工学上、有用な成果である。

第４章では、高波浪時の河口部土砂移動に関わる水理特性として、wave set-up を定量的に評価している。複数の河川の現地資料より、河川の規模に応じてその発現に相違が見られた。特に、wave set-up 高さと沖波波高との間の比例定数がほぼ河口水深に反比例することを示している。河道計画における出発水位に関わる水位上昇機構についての研究成果であり、河川工学上、有用な知見である。

第５章では、室内実験により越波による砂移動に関する検討を行っている。条件を制御された実験により、土砂移動量を計測し、第３章の現地データとの関係について検討を行った。その結果、第３章で得られた式とほぼ同様な式形を得た。これは，土砂の相似性の観点から、有用な成果である。

第６章では、越波に伴う海浜地形変化を予測するためのモデルを提案し、上記の実測データ・実験データを良好に再現することを確認した。同モデルにより、気候変動に伴う将来の波浪条件変化や海面上昇の効果を加味した地形予測を行うことも可能であり、将来予測に不可欠な知見である。

第７章は、結論と今後の課題について述べている。

以上本研究は、越波に伴う海浜の土砂輸送・地形変化現象を解明し、さらに、海面上昇などの影響を加味した海浜地形の変化を予測する手法を提案しており、土木工学の発展に多大な貢献したものである。

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。