Coastal and Estuarine Morphology Changes Induced by the 2011 Tsunami and Its Recovery Process

著者	VO CONG HOANG
号	61
学位授与機関	Tohoku University
学位授与番号	工博第5298号
URL	http://hdl.handle.net/10097/00122229

氏名	ヴオー　コン　ホワン Vo Cong Hoang
授与学位	博士（工学）
学位授与年月日	平成２８年９月２６日
学位授与の根拠法規	学位規則第４条第１項
研究科，専攻の名称	東北大学大学院工学研究科（博士課程）土木工学専攻
学位論文題目	Coastal and Estuarine Morphology Changes Induced by the 2011 Tsunami and Its Recovery Process (2011年東日本大震災津波による海浜・河口の地形変化と回復過程)
指導教員	東北大学教授　田中　仁
論文審査委員	主査　東北大学教授　田中　仁　東北大学教授　風間　聡 東北大学准教授　梅田　信　東北大学准教授　有働　恵子

論 文 内 容 要 旨

The 8.9 magnitude earthquake, which happened on March 11, 2011, triggered the huge tsunami approaching the northern coast of Japan. The tsunami, the maximum height of which was reported to be 40 m, caused significant changes to the coastal area in northeastern Japan. Tanaka et al. (2012) reported the significant changes of coastal and riverine morphology in Miyagi Prefecture such as erosion of sandy beaches, disappearance of sand barriers in front of lagoons, flushing of sandspits in front of river mouths and the breaching of sandy beaches at the locations of old river mouths. As a result, concave shorelines were observed at several places after the tsunami (Tanaka et al., 2012). One of the important factors leading to the fast or slow recovery of morphology in these areas is the sediment supply from adjacent sandy coasts. The recovery of morphology at the river mouths (Kitakami, Naruse, Natori, Abukuma), which have insufficient sediment supply from adjacent sandy coasts, was very slow. In contrast, concave shorelines at the Nanakita River mouth, at breaching of sandy coasts at Akaiko and Yamamoto, which have sufficient sediment supply from adjacent sandy coasts, recovered comparatively fast. However, the erosion of sandy coasts on both sides of the concave portion was also observed during the recovery process. Sediment from adjacent coasts was transported into the concave portion, and led to the accretion of shoreline in this area. The erosion firstly happened on the parts of the coasts which are next to the concave portion. Subsequently, it was propagating along the coast. Moreover, the intrusion of sandspit into the river mouth area was also observed during the recovery process. The above phenomenon reveals the sink effect at river mouth areas after the severe damages induced by the tsunami. Taken together, this study attempts to clarify the damages of morphology along Sendai Coast in Miyagi Prefecture and its recovery process through analyses of the aerial photographs,

the analytical solutions of one-line model, and the Empirical Orthogonal Function (EOF). In this dissertation, the recovery of morphology will be clarified in terms of temporal and spatial scales. On the temporal scale, there are recoveries in short-term and long-term, whereas on the spatial scale, there are small area and large area. Results of this study indicate that the tsunami caused severe damages of morphology, the coast was significantly eroded and the sand barriers in front of lagoons and the sandspits at the river mouths were swashed. The breaching of sandy coasts was observed at several places. Due to the existing of breaching, concave shorelines were observed commonly along the affected coast right after the tsunami. The recovery of morphology has different aspects, fast recovery at places with sufficient long adjacent sandy coasts, and very slow or no recovery at places without adjacent sandy coasts. At the fast recovery places, during the recovery process the sandy coasts adjacent to breaching were eroded. The erosion was propagating along the coast with the propagated distance proportional to the square root of elapsed time. A new approach for determining value of the diffusion coefficient from measured data and analytical solution of one-line model is introduced. Moreover, in the subsequent recovery, the intrusion into river mouths of sandspit was observed. That happened at all the river mouths in this study. The scouring deeper the river mouth, which caused the depth of water in the river mouth greater than the depth of closure, was the cause source leading to the sandspit intrusion into river mouth area. The depth of river mouth, D_R, and the depth of closure, D_C, are important physical quantities which express the representative depths of the drift-sand system of river and littoral drift system of ocean space, respectively. These two represented depths were treated separately; however by considering them together the sandspit intrusion into river mouth can be explained comprehensively. Results from EOF analysis on the short-term recovery of the sandy coast from Sendai Port to the Natori River mouth indicate that the first and third components reflect the recovery process of morphology at the severely damaged area such as lagoons, breaching of sandy coast. In addition, it also reflects the recovery of the shoreline at detached breakwaters. While, the second component reveals the variation of shoreline position on the cross-shore direction in corresponding to wave condition. The total contribution rate of the first and third components is about 75 % out of total. On the study of recovery of morphology in a large area and long-term period, a new analytical solution of one-line model describing the evolution of rectangular beach cut (concave shoreline) bounded by the rigid boundaries has been introduced. In addition, a new analytical solution of one-line model describing the proportional sediment filled area in the concave portion has been also given. These findings are very important for not only scientific interests but also for engineering application. The dimensionless recovery time of morphology, T^{*}_{ER}, which represents the recovery time when shoreline position at the central become 99 % of initial beach cut, Y_0, is depended on the total length of adjacent sandy coasts to the concave width, L_S^*. The larger value of L_S^* results in the smaller value of T_{ER}^*. With a certain value of B^* and large value of L^*, the relationship between t^* and y_C^* and t^* and P_A of the case with rigid boundaries are asymptotic with the ones of the case without rigid boundaries. The comparison between theoretical results and measured data has been made. Good agreement can be obtained for the cases of concave shorelines of the breaching of sandy coast at Yamamoto and Akaiko, however worse agreement was also obtained for the case of concave shoreline at the Nanakita River mouth which has complex concave shoreline and unclear rigid boundary. Results on the long-term recovery in a large area reveal that Shoreline position has not been reached the equilibrium state, although five years have been passed since the occurrence of the tsunami, and the more stable behavior can be observed. Shoreline change rates along the coast of the period five years after the tsunami have been changed significantly compared to the period before the tsunami and comparatively changed compared to the period three years after the tsunami. It means that the littoral system on this coast has been also changed. The first three dominant components of the long-term recovery reflect the same physical processes compared with what were found in the short-term recovery; however the contribution rates have been changed. The recommendations of the present study have been also given. The approach of classification small and large area, short-term and long-term in this study would be useful to apply in the areas which have similar characteristics. For engineering application, the fresh-sea water boundary moves upstream once happening the sandspit intrusion, hence the external wave forces need to be taken into account when implementing design of structures at river mouth area. In addition, the estimated values of diffusion coefficient would be useful for engineering application too. However, several things need to be improved in the future studies. Firstly, the introduced analytical solutions, which can deal with case of concave shoreline with symmetric rigid boundaries, need to be extensionally developed. So, they can be applied for the cases with asymmetric adjacent sandy coasts, or non-constant depth of closure, or non-uniform shape of concave portion. Moreover, the evolution shoreline position during the recovery process and the connections with bathymetry change and the sediment budget need to be evaluated. Last but not least, a numerical model is also necessary to be developed for predicting the evolution of shoreline evolution in the future.

論文審査結果の要旨

2011年東日本大震災津波により海浜部・河口部において大きな地形変化が生じた．特に多くのラグーン地形を有する仙台海岸においては大規模な凹型地形が生じた．その後の回復過程は箇所によって大きく異なり，迅速な回復から大幅な回復遅延まで多様である．そこで，本論文では東日本大震災津波がもたらした仙台海岸における地形変化を対象に，その回復過程の相違についてワンラインモデルの解析解，経験的固有関数展開などにより定量的な検討を行っている．

第１章では，本論文の目的と構成について述べている．

第２章においては，海浜部・河口部における地形変化について既往の研究を紹介している．

第３章においては，研究対象沿岸部の特性，使用データ，分析手法について述べている．

第４章においては，小領域における短期的な海岸線の回復過程について検討を行い，侵食域の拡大が経過時間の平方根に比例して拡大することを示した．これは，拡散方程式で記述される物理過程による地形の回復現象であることを示している．また，後述の時間スケール・空間スケールの長短の物理機構を明示しており，重要な成果である．

第５章においては，大領域での短期的な海岸線の回復過程について経験的固有関数展開を用いた検討を行い，第一，第三成分が大規模侵食の回復過程を示し，第二成分は波浪の増減に対応した岸沖漂砂による汀線変化であることを示した．これは海岸工学上重要な知見である．

第６章では小領域における長期的な海岸線の回復過程について山元海岸を対象としたワンラインモデルを構築している．特に，砂浜両端部の境界の影響を明らかにしており，津波後の海浜変形に及ぼす構造物の影響を明らかにした貴重な知見である．

第７章では大領域での長期的な海岸線の回復過程について示し，津波前後での短期的・長期的土砂収支の変化を明らかにしている．この成果は土砂水理学上有益な成果である．

第８章では総括及び今後の課題を述べたものである．

以上要するに，津波によりもたらされた海浜・河口地形変化の回復過程についてその物理的機構を現地データおよび理論により説明し，内在する物理過程を明らかにしており，今後予想される他所での類似現象に対して津波防災につながる実務的応用の可能性も有している．したがって，河川・海岸工学分野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．