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Development of New Coastal Erosion Countermeasure Using Wave Energy Control Method

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ABSTRACT

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Coastal erosion has become a social issue around the world, including Korea. A Considerable number of coastal erosions have occurred along the East Sea in Korea, primarily caused by port and harbor developments. Countermeasures have generally utilized wave breaks with wide–low–crest submerged breakwater (so-called artificial reefs), which are coastal constructions emulating the wave absorbing effect of natural reefs with good wave–protection performance. However, these result in secondary damages such as scouring near openings and erosion towards the rear because of strong currents generated by wave setups. This study suggests a new countermeasure for coastal erosion by controlling wave energy differentiated by incident wave, i.e., wave direction control method (WDCM) to prevent the critical coastal erosion expected from a massive harbor expansion project planned along the east coast of Korea. The WDCM attempts to balance disparities in wave energy caused by harbor expansion to restrain imbalanced wave energies that result in imbalanced littoral drift. To accomplish this purpose, low crest structures are obliquely deployed at 250–300 m from the coastline to manipulate the wave energy by modulating incident wave direction. This new deployment method avoids excessive interference with the incident waves, and prevents resilience by leaving cross-shore sediment transport unhindered. In order to determine the effectiveness of the proposed WDCM, numerical computations were conducted evaluating its performance regarding coastal erosion prevention.

ADDITIONAL INDEX WORDS: *Wave energy control, Countermeasure for coastal erosion, Imbalance of longshore sediment, Artificial reef*

INTRODUCTION

The onset of coastal erosion in Korea was comparatively later compared to other developed countries because coastal zone developments were legally restricted by political and military conditions. In the 1990s, coastal zone developments began in earnest in Korea, followed by local coastal erosions. In the 2000s, large-scale coastal developments were implemented, and consequentially erosions have also intensified.

Coastal erosion countermeasures were aggressively implemented in Korea starting in the 2000s to reduce and mitigate damages to beaches, most of which were superintended by the government as coastal improvement projects. Furthermore, aggressive monitoring has been conducted to systematically manage coastal erosion. The outcome of these efforts, however, has been unfavorable.

Wide–low–crest submerged breakwater wave absorbing structures (so-called local artificial reefs) have generally been employed for coastal erosion prevention. Artificial reefs have been recognized as a primary option to the extent of being employed in 90% of coastal erosion management projects in Korea (Kang *et al*., 2017). However, artificial reefs have not yet been proven to perform reliably in erosion prevention, whereas their flaws are well known from their development (Kang and Hong, 2016). Considerable numbers of studies have actively researched artificial reef performance improvements (Garcia *et al.*, 2004, Lamberti *et al.*, 2005, Kramer *et al.*, 2005, Sumer *et al.*, 2005, Uda *et al.*, 2009).

Kang (2017) investigated various coastal erosions cases along the east coast of Korea. According to his analyses, although the major reason for erosions in Korea were imbalances in longshore sediment transport (LST) due to harbor and port developments, the artificial reef, countermeasures targeted to high waves have persistently been used with unexpected side-effects contradicting their original purpose.

Kang and Hong (2016) studied coastal erosion outbreaks along the east coast of Korea and the advantages and disadvantages of artificial reefs. Their results indicated that artificial reefs are inappropriate for preventing coastal erosion in Korea. Most notably, they suggested a new coastal erosion management method using wave direction control and simply described its basic concepts and goal.

This paper is a follow-up of the research done by Kang and Hong (2016). The idea suggested by them is strengthened and materialized in this study. A method of countering coastal erosion by controlling wave energy differentiated by incident wave direction wave energy control method (WDCM) was developed based on ideas suggested by Kang and Hong (2016). The WDCM can control the imbalance of longshore sediment transport (ILST) caused by harbor and port developments. This

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paper elucidates the primary concepts of the WDCM. Additionally, the decision process for using the WDCM to prevent the coastal erosion expected with the massive expansions of Donghae harbor, Donghae-si, Gangwon-do, Korea, is simply explained.

The preliminary design for coastal erosion prevention in the expansions of Donghae harbor is currently being implemented using the WDCM. Construction will begin in the first half of 2018. Additionally, shoreline variations before and after construction are being consistently monitored, allowing the WDCM will to be improved via observational data analysis for shoreline variability. As such, the WDCM will be an interesting research topic.

METHODOLOGY

As described above, most coastal erosion countermeasures in Korea use artificial reefs. However, artificial reefs have various vulnerable features regarding coastal erosion countermeasures that have already been described published literature (National Association of Sea Coast, 2004, Guidebook of design for coastal management project, Ministry of Land, Transport and Maritime Affairs of Korea, 2010, Uda *et al.*, 2010, Yu and Cho, 2015, Kang and Hong, 2016). Their greatest vulnerabilities result in erosion and local scour at rear and opening areas, exacerbating erosion on the beach. This process is described in detail below.

The WDCM does not develop new structures preventing coastal erosion, instead proposing a new planar layout method to distinguish it from the traditional approach. The WDCM was suggested to relieve severe coastal erosions expected from the massive harbor expansion planned at Donghae harbor in Donghae-si, Korea. The first countermeasure plan used an artificial reef. However, after reexamination the eco-friendly WDCM was selected to complement the faults of the proposed artificial reef, in concurrence with local inhabitants. For this paper, the long-term shoreline variability of artificial reefs and the WDCM were computed and discussed.

Erosions at the Rear Area of Artificial Reefs

As described above, the rear and opening areas in artificial reefs are consistently eroded by strong currents. In Japan, erosion issues with artificial reefs have been perceived and studied via depth surveys around artificial reefs.

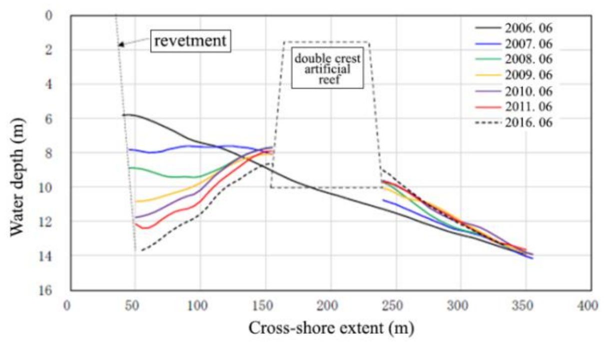


Figure 1. Surveyed water depths around double crest artificial reef (Sasa *et al*., 2017)

Sasa *et al.* (2017) investigated water depth variations around a double crested artificial reef installed at Fukui harbor, Fukui Prefecture, Japan, and reported the water depth behind the artificial reef increased by ~8 m in 10 years, as shown in Figure 1. It can be seen from Figure 1 that water depth increased by 6 m during the first 5 years, then by 2 m in the subsequent 5 years. As a result, the depths of beaches near artificial reefs become deeper than those of natural beaches; consequently, beach availability rapidly deteriorates after an artificial reef is installed.

Study Area

Figure 2 shows Donghae port, located in Donghae-si, Gangwon-do, Korea, overlaid with the three–phase Donghae harbor expansion project planned to enhance harbor infrastructure. As shown in Figure 2, the Donghae harbor expansion project builds 1,850 m of breakwaters (northern breakwater 1,700 m, eastern 150 m), a 2,288-m revetment, and more. Construction will continue until 2020 with a budget of 1.5 billion USD. The WDCM presented in this paper was developed and suggested to resolve the complaints posed by local residents relating to the severe coastal erosion this expansion is excepted to cause.

Countering Coastal Erosion in Donghae Harbor Expansion: the WDCM

As explained above, the WDCM idea as shown in Figure 3 was proposed by Kang and Hong (2016). Their idea was strengthened and applied as countermeasure to the coastal erosion expected from the Donghae harbor expansion.

In fact, an artificial reef was first planned to counter erosion in Donghae harbor. However, local residents required a more reliable proposition than the artificial reef. Thus, coastal erosion countermeasures were reconsidered (Donghea Regional Office of Ocean and Fisheries, 2016).

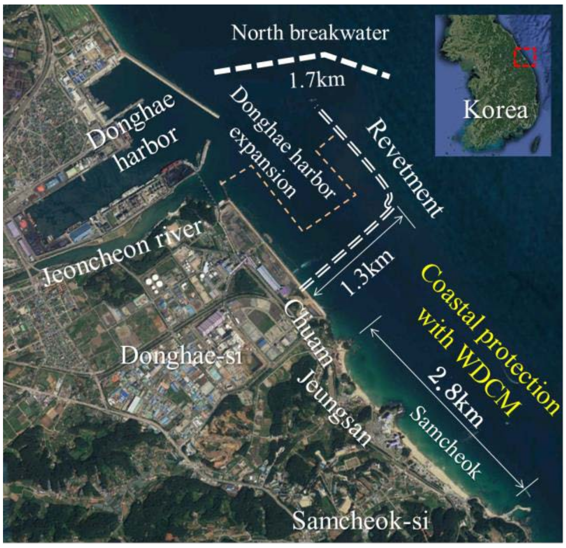


Figure 2. Schematic sketch of Donghae harbor three phase expansion project. Coastal protection with WDCM is planned to Chuam, Jeungsan, and Samcheok beaches located in the south of the harbor.

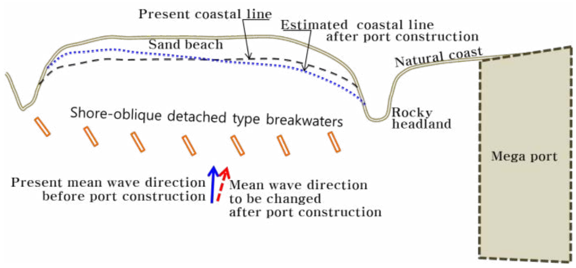


Figure 3. Schematic sketch of idea of the WDCM (Kang and Hong, 2016).

The reconsideration prioritized 1) efficiently control of the ILST resulting in coastal erosion, 2) preservation of natural resilience without damages, 3) preventing damage to beach utilization.

Numerical Computation of Shoreline Changes and Bathymetry

When their surroundings are changed, Chuam, Jeungsan, and Samcheok beaches may suffer severe coastal erosion from the ILST caused by harbor expansion. This was estimated using the depth contour model (DCOM) suggested by Lee and Hsu (2017), and is discussed below.

Furthermore, long term shoreline variabilities employing artificial reefs and the WDCM were computed, and are discussed in the Results section. The STWAVE and GenCade numerical models used in the comparisons were included in the SMS Package provided by US Army Corps of Engineering. The computational domains were 4.4 km in longshore direction and 2 km in the cross-shore direction, and waves given by an analysis of 34 years of long-term hindcast wave data (1979.01.01 ~ 2014.12.31) estimated by WaveWatch III operated by NOAA were used as input wave data.

RESULT

This section discusses the expected shoreline and bathymetry changes. Due to space limitations, primary results will be depicted and discussed, and sequel will contain other results.

To predict long term shoreline variations after the WDCM and artificial reef are applied, numerical computations were conducted and compared. Additionally, to determine a suitable wave transmission to balance wave energy, intensive numerical computations were performed at Samcheok beach.

Variations in Shoreline and Bathymetry

The harbor expansion will inevitably have a negative influence on shoreline stability. DCOM, suggested by Lee and Hus (2017), is a powerful tool for predicting the stabilized shoreline position and bathymetry.

Figure 4 shows the resulting computed shoreline and bathymetry changes related to the Donghae harbor expansion, and indicates the shoreline will retreat considerably and that bathymetry in the vicinity of the revetment will move seaward, implying the water depth at the revetment decreases due to sediment deposition, which may result from sediments migrating towards the harbor.

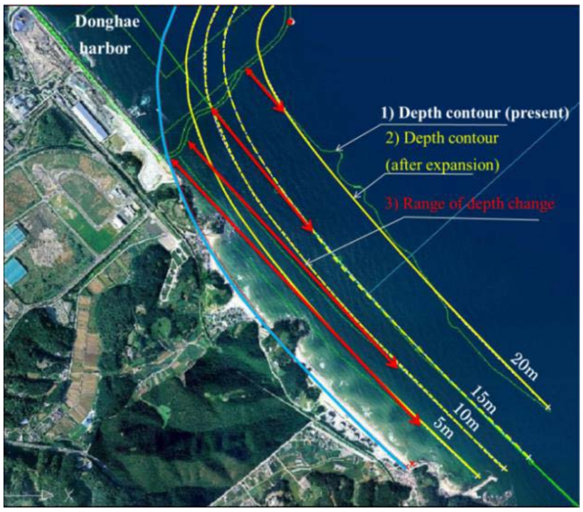


Figure 4. Shoreline and bathymetry variations estimated by DCOM, as proposed by Lee and Hsu (2017).

Application of the WDCM

As described above, the ILST inducing coastal erosion primarily results from alterations in wave direction caused by port and harbor construction or expansion. At the study area in Samcheok beach, as shown in panel (a) of Figure 5, the wave energy from the north decreases as harbor size increases, but the wave energy from the south is unchanged. Considering the concept of primary wave direction, the incident waves that propagated almost perpendicularly to the shore then change to incident waves traveling from the south. Accordingly, sediments gradually move northward. The basic concept of the WDCM, to maintain sediment movement equilibrium by balancing changes in wave energy caused by harbor expansion, is shown in panel (b) of Figure 5. This makes waves arriving from the north flow towards the shore as much as possible, simultaneously blocking waves coming from the south as needed.

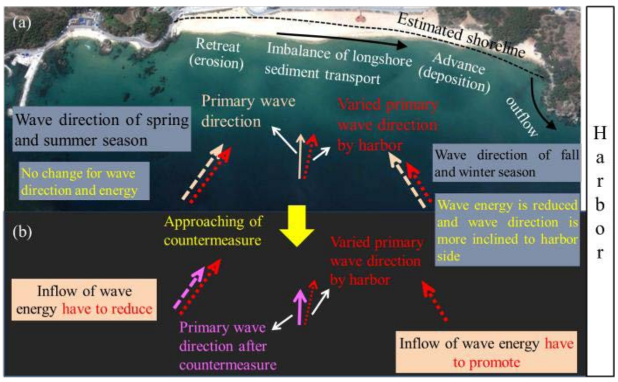


Figure 5. Schematic description of WDCM suggested in this study.

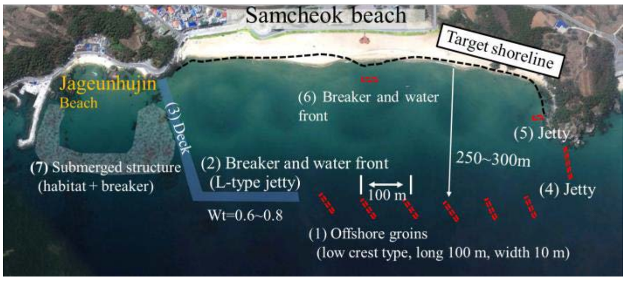


Figure 6. Schematic sketch of planar layout the WDCM at Samcheok beach.

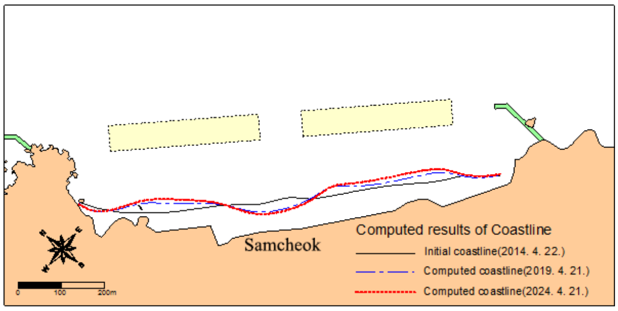
Constructing structures parallel to the shoreline will inevitably create variations in the shoreline caused by changing wave directions. To prevent shoreline variations due to changed wave directions, the WDCM places groins at a distance of 250–300 m from the shoreline at a southward slant (with respect to the shoreline) to control wave energy, as shown in the schematic sketch of the WDCM planar layout at Samcheok beach demonstrated in Figure 6. The L-type jetty marked (2) and (3) in Figure 6 is a combined waterfront and wave–breaking facility required by local inhabitants with a wave transmissivity (Wt) of approximately 0.6–0.8 with respect to the wave transmission coefficient.

In materializing the WDCM, the primary layout considerations were: 1) groins deployed obliquely to the shoreline to control wave energy enough to balance ILST, and 2) groins deployed far from the shoreline to preserve the natural resilience and ensure a sufficient space for wave propagation remains to smooth incident waves after they pass through the offshore groins.

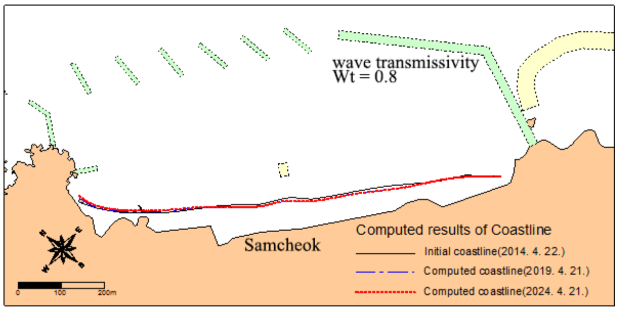
As described above, the WDCM is differentiated from previous coastal erosion countermeasures by its eco-friendly nature. The representative distinctions of the WDCM relative to other methods are as follows: 1) the WDCM attempts to control wave energy only as needed and permits incident wave inflows as much as possible, thus respecting the natural stance of the area; 2) most coastal erosion countermeasures are linear concepts installing structures parallel to the shoreline to block incident waves, whereas the WDCM manipulates the spatial distribution of wave energies through areal deployment of structures; 3) cross-shore sediments can migrate both on- and offshore during ordinary and abnormal times under the WDCM, better preserving natural resilience and more efficiently securing the dynamic stability of the sandy coast than artificial reefs; and 4) because the WDCM can provide an expanse of water when groins are deployed offshore, beach utilization and marine leisure conditions remain better than those seen with other countermeasures such as the artificial reef.

Computational Results of Long Term Shoreline Variations

Figure 7 depicts the computational results of long term shoreline variations given by STWAVE and GenCade (developed by the US Army Corps of Engineering). Panels (a) and (b) are the computational results for an artificial reef and the WDCM at Samcheok beach, respectively.



(a) Long term shoreline variaility after employment of the artificial reef



(b) Long term shoreline variaility after employment of the WDCM

Figure 7. Long term shoreline variation after employment of (a) the artificial reef and (b) the WDCM.

It is easy to demonstrate the shoreline positions are more stabilized in case of the WDCM relative to the artificial reef. In panel (a), a tortuous shoreline and erosions at the opening area are observed. Conversely, the shoreline in panel (b) is more stably preserved.

During several examinations for the Wt of an L-type jetty located east of the beach, the shoreline was most stably preserved when Wt=0.8, indicating the northward longshore wave energy was reduced by around 36% to counterbalance wave energy imbalances.

DISCUSSION

In order to prevent and relieve the coastal erosion expected with the grand scale of harbor expansion on the east coast of Korea, the WDCM suggested in this study was developed. The WDCM attempts to counterbalance ILSTs resulting in coastal erosion.

Long term shoreline variations were computed and compared for the cases of artificial reef and WDCM employment. The comparison indicated WDCM performance was convincingly effective for countering coastal erosion.

In order to widely employ the WDCM suggested in this study, multilateral considerations are required for structural specifications and planar layouts, and these are ongoing for the subject harbor expansion. In addition, field observations have been consistently implemented to check real-world validity. By analyzing this observational data, utilization of the WDCM will be strengthened in the future.

The WDCM can cope with long term changes in natural conditions such as rising sea levels more easily than previous countermeasures such as the artificial reef by adjusting structural specifications. Additionally, submerged structures such as the artificial reef are highly sensitive to crest elevation. Thus, precise construction is inevitably required. Conversely, the WDCM is relatively robust in such matters.

As described above, considerable evidence has been presented that wave breaking structures employed to alleviate coastal erosion have resulted in secondary damage. In these contexts, eco-friendly methods based on natural phenomena such as the WDCM are a positive direction for developing future coastal erosion countermeasures.

CONCLUSIONS

In this study, the WDCM was developed to prevent the severe coastal erosion expected from the Donghae harbor expansion in Donghae-si, Gangwond-do, Korea, acting as a countermeasure for coastal erosion by controlling wave energies differentiated by incident wave direction. Offshore groins were deployed at 250–300 m from the shoreline to counterbalance the imbalances in longshore wave energy caused by harbor expansion.

The preliminary design is currently being implemented, and construction will begin in March of 2018. Furthermore, field monitoring is being conducted and shoreline variations during construction will be observed, which will be utilized to improve the future availability of the WDCM. This series of process is a preventive countermeasure for the coastal erosion without a parallel case and an interesting research topic.

The performance of the WDCM was compared with that of the artificial reef using numerical computations, and demonstrated in regard to long-term shoreline stabilization. This can be understood with respect to the planar layout. Offshore groins positioned at a slant to the shoreline were deployed at 250–300 m from the shoreline to control longshore wave energies. Thus, wave energy can be manipulated as long as longshore wave energies remain counterbalanced.

The priorities of the WDCM are completely different from those of other methods, such as the artificial reef. The WDCM suggested in this study will consistently contribute to developing new coastal erosion countermeasures.

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