파랑하중과 지진하중하의 방파제 구조해석

Structural Analysis of a Breakwater in Wave and Seismic Loads

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요 지

본 논문에서는 파랑하중과 지진하중 하에서의 방파제 설계와 관련한 해석에 대한 하나의 설계지침을 제시하였다. 이를 위해서 파랑하중 중 쇄파대내에서 일어날 수 있는 충격파랑하중을 정량적으로 하나의 모델에 대해 제안된 식에 의해 산출해 보았다. 널리 사용되는 모리슨 방정식에 의한 파력과 쇄파력으로 야기되는 충격하중을 산술적으로 합하는 방식으로 계산해보았다. 결과적으로 충격하중이 크지 않아, 일반적으로 쇄파파력산정에 있어서 오차범위가 큰 불규칙파의 쇄파대내의 파력공식인 고다식을 사용하는 것은 큰 문제가 없다는 가정을 할 수 있었다. 이에 파랑하중의 경우 항만구조물에 사용되는 고다식을 이용하여 방파제 구조물의 거동을 해석해 보았다. 지진하중의 경우 단주기, 장주기, 인공지진파에 의한 수치해석을 수행하여 방파제의 거동을 해석하였다. 방파제의 설계에 있어서 중요한 것은 설치해역에 적합한 방파제를 선택하는 문제이며 다음으로는 파랑하중과 지진하중의 중요도를 판단하는 것이라 판단된다. 모델을 선정하여 계산해본 결과 파랑하중에 의한 구조물의 거동과 지진하중에 의한 거동이 같은 정도의 구조적인 변화를 나타내는 것으로 판단되어 방파제 설계 시 두 하중을 같은 비중으로 다루어야 할 것으로 판단되어 진다. 방파제 설계의 주요 항목으로 파랑하중과 지진하중이 동시에 중요하다는 점을 제시하였다.

핵심용어 : 파랑하중, 충격하중, 지진하중, 방파제설계, 구조해석

Abstract

In this paper, a guideline for designing breakwater in wave loads and in seismic loads is proposed. A simple model structure in breaking wave zone is examined using Morison equation in consideration with the effect of an impact load, for evaluation of the wave loads. As the impact load effect is not significant, pressure distributions according to Goda are applied for evaluation of wave loads on breakwater. Structural behavior of breakwater in wave loads can be obtained using the Goda method, as well. For seismic analysis, Ofunato and Hachinohe models, as well as an artificial seismic acceleration loads model, are adopted. Soil-structure interaction analysis is carried out to find the seismic load effect. It is found that, in certain cases, structural deformation in wave loads is in the same level as deformation that in seismic loads. Thus, it is our recommendation that these two loads are considered at the same level in breakwater design.

Keywords : *wave loads, seismic loads, breakwater, structural analysis, design guideline*

1. Introduction

The purpose of wave control is to maintain the level of wave energy in the object sea area within a safe level, and also to make use of the associated wave energy by proper control devices. For the optimum design of wave control structures, design factors, such as stability, economy, scenery, and eco-control, are to be considered with a priority within these factors. Breakwater is one of the best ways to protect the associated structures, and to control the object sea area. In breakwater design, main points of consideration are wave control ability, optimum type selection, and proper cross section design of the structure that can

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withstand wave loads. Among several design guidelines, Goda proposed a model for calculating the wave force in wave breaking and wave irregularity(Goda, 1991). This equation can be used if the breaking wave force is in a moderate change range with respect to wave elevation to the wall. Experimental verification of the impact loads due to the wave using the ocean basin showed results that were in agreement with the theoretical approach(Choi, 1999).

Once the breakwater type is chosen, another aspect to be considered in designing is the seismic loads. The Korean peninsula no longer remains an earthquake-safe zone; earthquakes that exceed the level of MMI IV have frequently been reported since 1990(Do et al., 2004). Therefore, proper procedure of earthquake analysis for the breakwater is needed. Since response to earthquake at the basis of the structure can be amplified through response propagation after passing the soft soil foundation, soil-structure interaction problems with regards to safety need to be evaluated thoroughly(Yun, 2002). However, until now, seismic loads have been considered a minor factor, as shown in recent breakwater design cases in Ulsan and Busan harbors. Environmental loads, such as wave and seismic acceleration due to the earthquake, are main sources of study in this paper. A typical breakwater is chosen as objective structure, and relevant wave-related structural analysis, as well as soil-structure interaction analysis, are carried out to provide guideline for breakwater design(Park, 2001).

For evaluation of wave loads, a concise form of pressure distributions by Goda is employed after making pre-calculations to figure out the effects of impact load. For seismic analysis, Ofunato and Hachinohe models, artificial seismic acceleration load models, are used. It is purpose of this paper to provide a guideline for design and analysis for breakwater in wave loads in seismic loads using the above-mentioned methods.

2. Influence of the impact wave loads

2.1 Formulation of wave loads

Morison Equation was developed for calculating the surrounding inertia force and the drag force that act on the vertical pile in the water. The equation can is as shown below. However, the equation (1) cannot account for the impact force due to breaking wave, which is important in designing offshore structures in the surf zone.

$$F = \frac{1}{2}\rho\, C_D D |u|\, u + \rho\, C_I \frac{\pi D^2}{4} a_x \tag{1}$$

Where ρ = water density

C_D = drag coefficient

D = diameter of the pile

u = water particle velocity

C_I = inertia coefficient

a_x = water particle acceleration

2.2 Morison equation with impact term

Impact force on vertical offshore circular structure in the surf zone due to breaking wave can be incorporated into calculation by modifying Morison Equation, as shown below, and as described in Figure 1(Cho, 2006)

$$F' = F + F_I \tag{2}$$

Impact term can be expressed as shown below.

$$F_I = \frac{1}{2}\rho C_S D u^2 \tag{3}$$

Where C_S= slamming coefficient

Maximum theoretical value of π for slamming

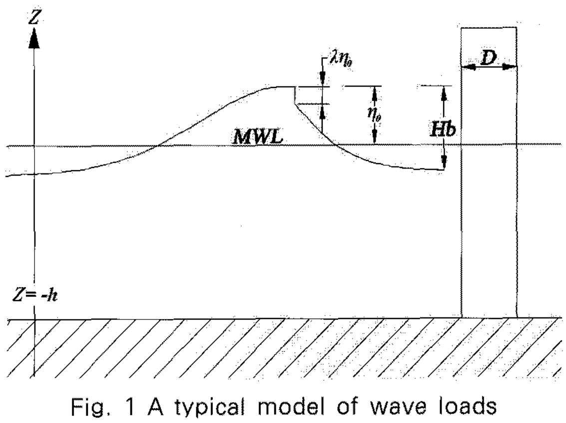


Fig. 1 A typical model of wave loads

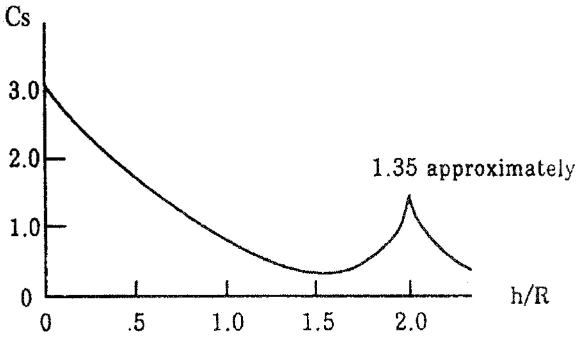


Fig. 2 C_S as a function of relative submergence

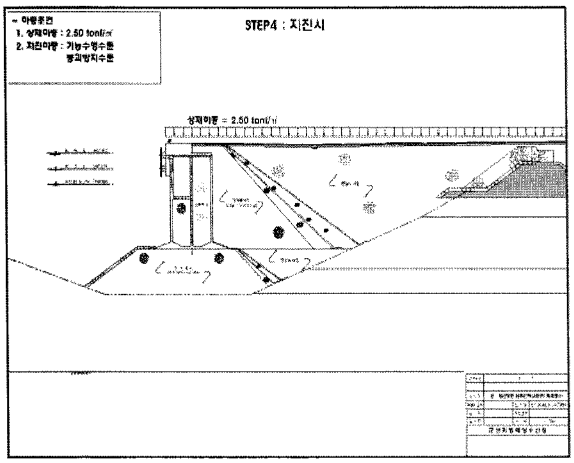


Fig. 3 A real breakwater structure

coefficient for the conservative calculation of the impact force(Cho, 2002), may be used, as shown in Figure 2. Ratio h/R is the submerged water depth of the circular member into the water divided by the radius of the member. Figure 3 shows a real breakwater structure to be used for relevant structural analysis.

2.3 Numerical approach for impact loads

Figure 4 shows basic modeling of the given breakwater with circular piles. Figure 5 shows altered modeling that has fewer piles, compared to the basic one. Figure 6 shows a changed configuration that has inclined piles in the front and back side of the pier. These different model structures are used find the qualitative structural behavior in wave loads.

Wave loads are calculated with Morison equation first, and with modified Morison equation second, which includes the impact load. This is shown in equation (3).

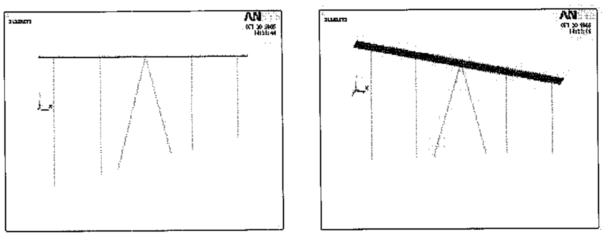


Fig. 4 Standard plan(2D Structure modeling)

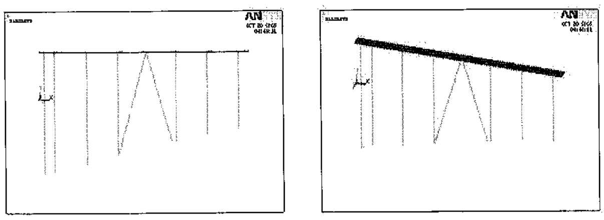


Fig. 5 Alternative plan-1(2D Structure modeling)

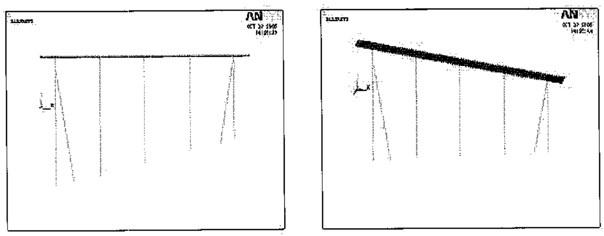


Fig. 6 Alternative plan-2(2D Structure modeling)

For verification of the impact loads effects, the given structure is modeled using typical circular pile members attached to the pier. Diameter of the pile is 1.016m, and the wavelength is 84.7m, with period of 8 sec. Water at the first pile location is 16.82m deep. Drag force term and the inertia force term for piles are calculated using Morison equation (1), and the impact load is calculated using equation (3). Calculated wave loads are applied to the piles, as shown in Figure 4. Several models are adopted for various design configurations. FEM analysis is used for the calculations. Analysis results show that the effects of impact loads are within a tolerable range, as shown in Table 1. Although through a model, this approach provides the qualitative critetia necessary for finding the impact term, a variable in the Goda equations. Range of the impact load effect lies between 30% to 54% in terms of stress, and 24% to 54% in terms of deformation, compared with baseline deformation without impact load. Influence of the impact load due to the breaking wave is considerably moderate,

Table 1 Impact loads analysis result

Analysis Result(2D)				
		standard	alt-1	alt-2
wave loads	stress (N/m^2)	5.13×10^6	3.45×10^6	3.26×10^6
	Def. (mm)	1.186	0.609	1.04
wave load + impact loads	stress (N/m^2)	6.68×10^6	4.70×10^6	5.03×10^6
	Def. (mm)	1.48	0.910	1.603

i. e. within 54%, at maximum. This implies that error bound by the Goda equation in association with breaking wave is not substantial. Table 1 shows the qualitative analysis results.

3. Criteria on wave loads and seismic loads

3.1 Wave load and related analysis

Structural behavior in wave loads is of primary concern in designing. A concise form of the Goda pressure distributions due to design wave and current can be employed. A typical breakwater as shown in Figure 3 and load for the structure by applying Goda method is chosen for the finite element modeling and analysis to obtain deformation and stress values for the given structure. The analysis results show that the maximum structural deformation is 7.187cm, and the maximum stress is 15.736kgf/㎠(1.54MPa), with 5.4m design wave height.

3.2 Seismic load and related analysis

For verification of structural safety in earthquake circumstances, soil-structure interaction analysis is needed(Kwon et al, 2006). A major point of consideration is proper selection of the analysis scheme and realistic modeling technique of the given structure. We employed 3-dimensional substructure method for the method's simplicity and the efficiency, compared with the direct method. Finite element modeling of the structure is also an important factor for successful analysis. Figure 7 shows modeling of breakwater based on different soil types properties. Soil properties used in the analysis are shown in Table 2.

Figure 8 shows an analysis procedure here used in seismic loads.

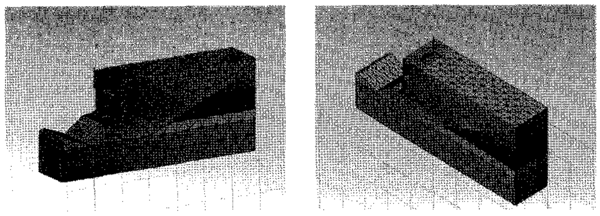


Fig. 7 Modeling of structure with diff. soil properties

Ofunato, Hachinohe and Artificial model
- operational level criteria,
- collapse level criteria

↓

Input foundation properties

↓

Response analysis of caisson(Dynamic analysis)
-Seismic Analysis(MIDAS/GTS)

↓

Diagram of stress of the sections

↓

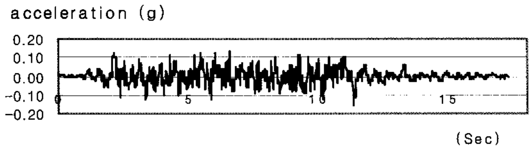
Evaluation of resistance level of the caisson section

Fig. 8 Hierarchical chart of a seismic analysis

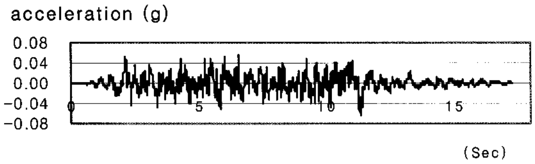
Table 2 Soil property used in the analysis

Soil & Rock type	Vp (m/sec)	Vs (m/sec)	Dynamic Modulus of Elasticity (tf/m^2)	Dynamic Shear Modulus (tf/m^2)	Dynamic Bulk Modulus (tf/m^2)	Unit Weight (tf/m3)	Poisson's Ratio (υ)	Damping Ratio (%)	Angle of Internal Friction
Silt and	1,153	597	153,090	58,130	139,710	1.6	0.317	2.0	30
Silt mud	1,217	621	166,890	63,050	157,890	1.6	0.324	-	-
Weathered Soil	1,450	743	257,010	97,260	240,090	1.7	0.321	-	37
Weathered Rock	1,640	857	393,150	149,790	349,220	2.0	0.312	-	40
Dredged Fills	-	-	2,000	741	2,222	1.8	0.35	-	26

In the modeling that takes interaction effects into account, foundation of the structure is modeled by semi-infinite horizontal layer level, and the rest of the structure by proper Finite elements. Boundary condition in y-axis(vertical direction) is modeled by connecting the spring element with the foundation.

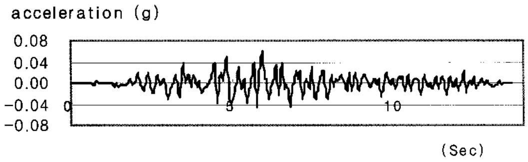


Operational level Criteria(Amax=0.0627g)

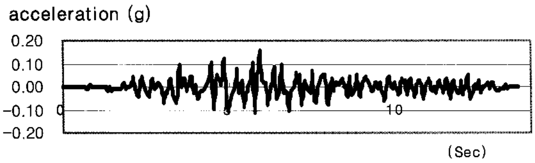


Collapse level Criteria(Amax=0.154g)

(a) Artificial model

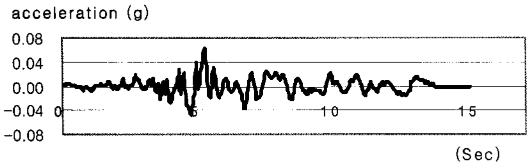


Operational level Criteria(Amax=0.0627g)

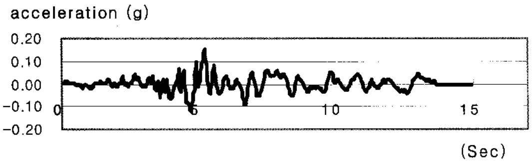


Collapse level Criteria(Amax=0.154g)

(b) Ofunato model



Operational level Criteria(Amax=0.0627g)



Collapse level Criteria(Amax=0.154g)

(c) Hachinohe model

Fig. 9 Acceleration data from Ofunato, Hachinohe and Artificial model

Table 3 Summary of soil-structure interaction analysis

(a) Artificial model

Step		Performance level	Collapse level
Dynamic def.(cm)	Basis level	2.173	5.338
	Side level	2.174	5.339
	Caisson bottom	2.174	5.338
	Caisson top	2.174	5.339
Dynamic stress(kgf/cm²)		3.680×10^{-4}	9.039×10^{-4}

(b) Ofunato modelz

Step		Performance level	Collapse level
Dynamic def.(cm)	Basis level	8.495	20.86
	Side level	8.496	20.87
	Caisson bottom	8.496	20.87
	Caisson top	8.497	20.87
Dynamic stress(kgf/cm²)		8.523×10^{-4}	20.93×10^{-4}

(c) Hachinohe model

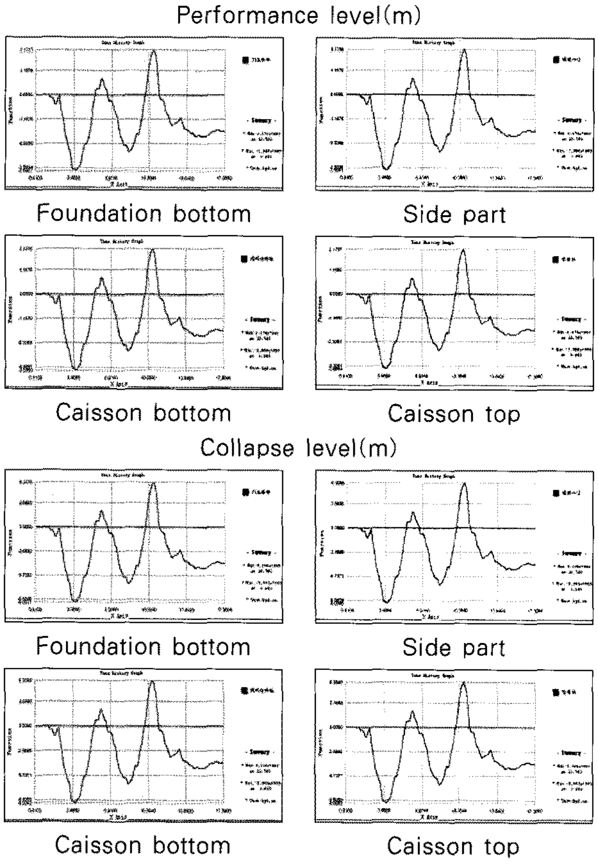
Step		Performance level	Collapse level
Dynamic def.(cm)	Basis level	4.270	10.48
	Side level	4.270	10.48
	Caisson bottom	4.270	10.48
	Caisson top	4.271	10.48
Dynamic stress(kgf/cm²)		4.365×10^{-4}	10.71×10^{-4}

Other boundaries are set free to move. Water pressure in facing caisson is calculated from relevant mass. This analysis is done by MIDAS/GTS(Park. I., 2005) using acceleration data from Ofunato, Hachinohe and artificial models. Ofunato model is adopted for short-period earthquake wave characteristics, and Hachinohe model for long-period earthquake wave characteristics(MOMAF, 1999). Characteristics of the relevant soil properties are also used in analysis, as shown in the following figures(Park, S., 2001, ISSC, 2006).

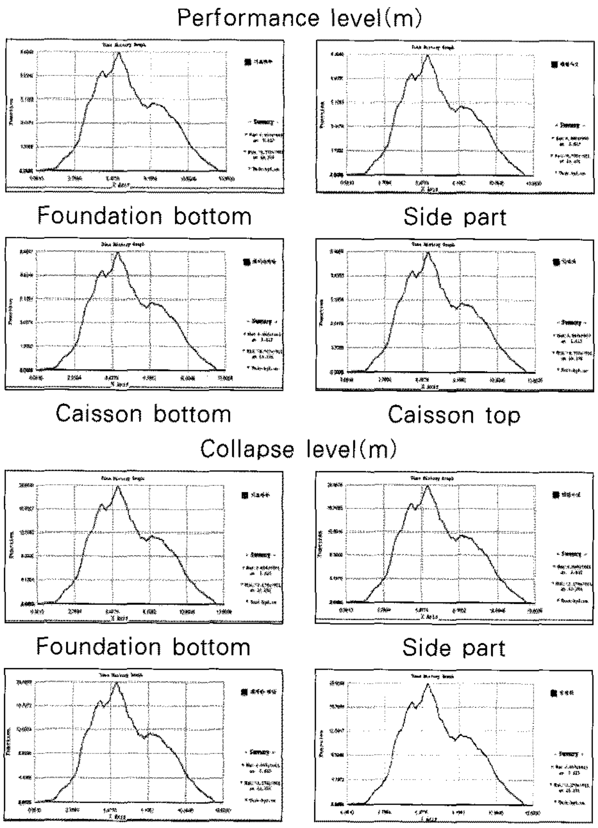
Based on Region I, which includes most of the Korean peninsular, except for Kangwon province and Jeju Island, and the area's risk factor based on regional occurrence(Do and Ko, 2004), maximum acceleration of A=0.154g, 0.0627g is used.

Figure 9 shows acceleration data from Ofunato, Hachinohe and the artificial models.

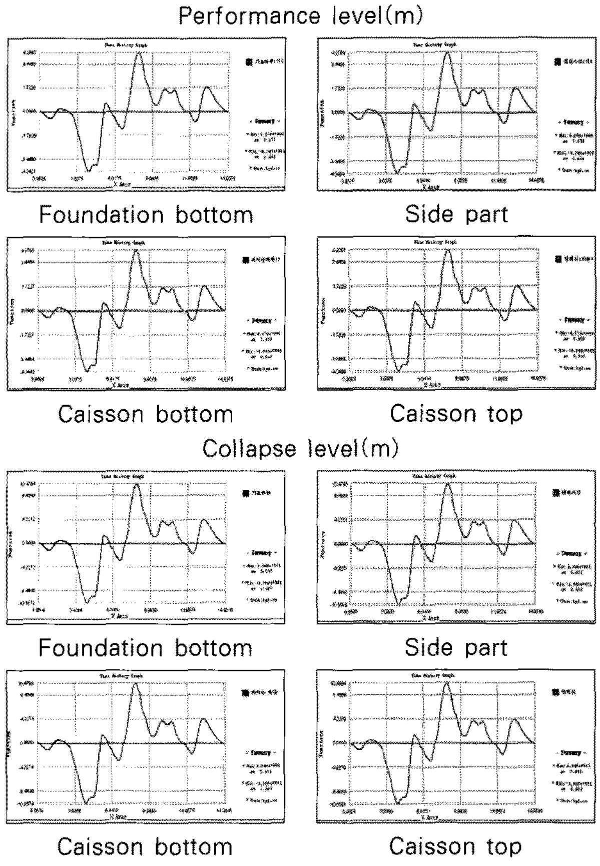
The x-axis, Dx., in the following figures shows



(a) Artificial model



(b) Ofunato model



(c) Hachinohe model

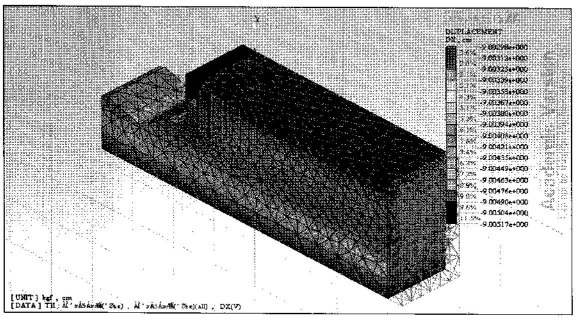
Fig. 10 Time history of relevant deformation

maximum displacement of a structural point in seismic analysis. Table 3 shows summary of the soil-structure interaction analysis.

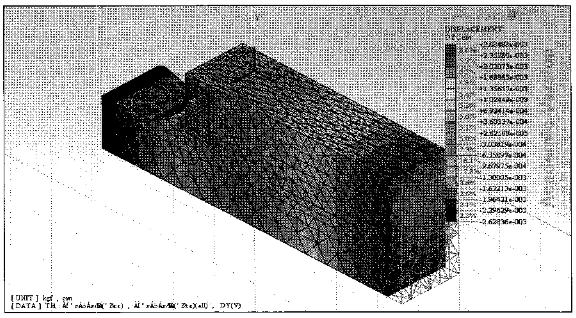
Figure 10 shows time history of relevant deformation of the structure. Figure 11 shows the model and analysis results in seismic loads, in which deformations in x and y directions are thought to be significant.

4. Discussions and Conclusion

For evaluation of wave loads on breakwater, pressure distributions due to wave loads proposed by Goda can be employed, as the impact load effect is not influential. The Goda method can also be applied for finding structural behavior of a breakwater without inherent difficulties. In this paper, analysis was based on the condition of 5.40m design wave height, 10sec. of period, and current velocity of 0.69m/sec. Maximum wave-related analysis results show the resulting

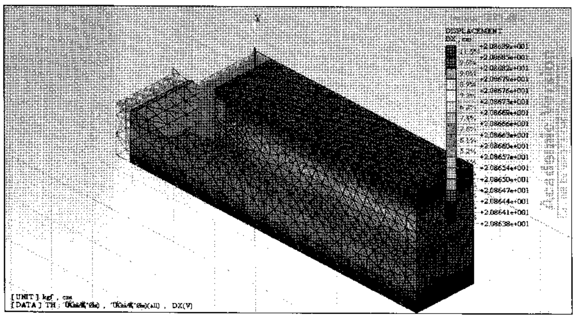


Collapse level Dx

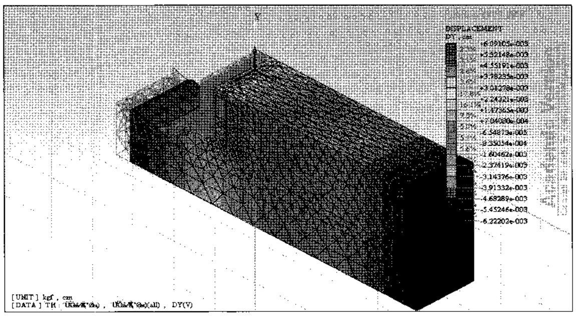


Collapse level Dy

(a)Artificial model

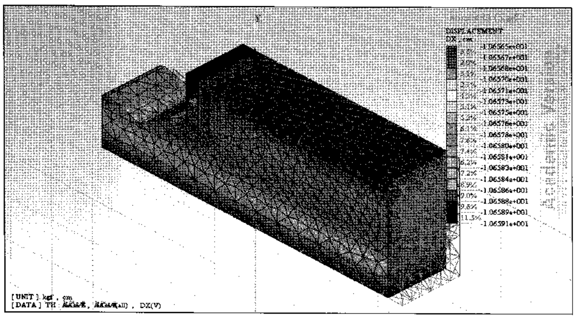


Collapse level Dx

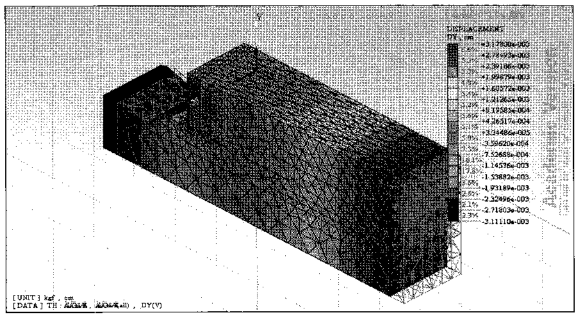


Collapse level Dy

(b) Ofunato model



Collapse level Dx



Collapse level Dy

(c) Hachinohe model

Fig. 11 Structural model and analysis results

deformation of the structure to be 7.18㎝.

For seismic analysis, several important points need to be considered in analysis, which were obtained through relevant modeling and analysis. They are: (1) engineering characteristic of the soil in z-axis, including the soil property variations, (2) structural characteristics of caisson, including the condition of the connections between the caisson and the upper structure, (3) the caisson itself, as well as the mechanical behavior of the surrounding foundation, (4) configuration, stiffness and mass of the structure, and (5) dynamic characteristics of the given seismic loads.

For evaluation of the seismic loads effects for breakwater, Ofunato and Hachinohe models can be adopted, as well as an artificial seismic acceleration loads model. Typical soil-structure interaction analysis is carried out here to find the seismic load effect. Based on analysis using maximum seismic loads, maximum deformation was 8.497㎝. As analysis results in Table 3 show, deformation values in the Ofunato acceleration are much greater than those in the Hachinohe acceleration. The reason for this is that the Ofunato acceleration has a shorter period-based acceleration and more intensive impact compared to the long period-based Hachinohe acceleration model. Thus, for the initial designing purpose, analysis using Ofunato acceleration is sufficient for calculating maximum deformation due to the earthquake.

In the typical model, wave load by non-breaking wave and impact load by breaking wave are determined using a modified version of Morison equation. Credibility of the model is improved by applying boundary conditions figured from a sample spring element in association with the foundation soil properties. Based on the obtained analysis results, we took the seismic load effects into account, which generally has been considered insignificant, compared to wave load effects. We conclude that the seismic analysis, as well as the wave-related analysis, both play an important role in determining criteria for the breakwater design.

It is found that, in certain cases, structural deformation of the structure in wave loads and seismic loads are the same order. This supports considering these two loads at the same importance level in breakwater design.

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References

Cho, K.N. (2006) A study on the Dolphin mooring system for floating offshore structure, *Journal of Computation structural engineering*, 19(1).

Choi, Y.C., Cho, K.N., Lee, K.M. (1999) A Study on the Determination of Wave Load Acting on Offshore Structures, *Journal of Ocean engineering*, 14(1).

Do, D.H., Ko, J.M. (2004) *Earthquake Engineering*, Gunsulbook Co., Korea.

Goda (1991) *Randon waves and coastal structures*, Chungmungak.

ISSC (2006) Proceedings of the 16th International Ship and Offshore Structures Congress, Elsevier.

Kwon, Y.R., Kim, J.W., Choi, K.K. (2006) Pounding Mechanism and Mitigation Effect of Pounding between Adjacent Decks during Strong Earthquake, *Journal of Ocean Engineering and Technology*, 20(5), pp.63~69.

MOMAF (1999) *Design guidelines of earthquake proof for Harbour and Marinas*, Ministry of Marine Affairs and Fisheries.

Park, I.J. (2005) *MIDAS Technical Lecture Series in Geotechnical Engineering*, Korea.

Park, S.K. (2001) *Coastal Structures Design*, Moonwoondang, Korea.

Yun, C.B., Chang, S.H., Kim, J.M. (2002) Fluid-Structure-Soil Interaction Analysis of Cylindrical Liquid Storage Tanks Using Mixed-Fluid-Element and Infinite-Element, *Advances in Structural Engineering and Mechanics*, Korea.