Performance Design of Maritime Structures and Its Application to Armor Stones and Blocks of Breakwaters

Shigeo Takahashi[1], Minoru Hanzawa[2], Sunao Sugiura[2],
Ken-ichiro Shimosako[3] and Jentsje van der Meer[4]

1. INTRODUCTION

Reliability design considering probabilistic nature is quite suitable for coastal structures because waves are of irregular nature and wave actions fluctuate. However, solely considering the probability of failure is considered insufficient, as deformation (damage level) should also be taken into account.

This paper discusses performance design as an advanced design methodology for maritime structures, focusing on deformation-based reliability design of armor stones and blocks of breakwaters. The stability performance of breakwater armors is specifically considered by describing the design criteria (allowable limits) of damage level with respect to different design levels including probabilistic aspects. The accumulated damage during a lifetime is also discussed.

Fig. 1 Cross sections of breakwaters considered

Figure 1 shows the cross section of a rubble mound breakwaters and a caisson breakwater (horizontally composite breakwater), which are considered to discuss the performance design in this paper. The rubble mound breakwater has armor layers with stones while the caisson breakwater has concrete blocks to dissipate the wave energy. The stability of the armor stones and concrete blocks is the most important

[1] Port and Airport Research Institute, 3-1-1, Nagase , Yokosuka, Japan, 239-0826
Tel: +81-46-844-5013, Fax: +81-46-844-1274, E-mail: takahashi_s@pari.go.jp
[2] TETRA Co., Ltd., Japan
[2] TETRA Co., Ltd., Japan
[3] Port and Airport Research Institute, Japan
[4] INFRAM, Netherlands

aspect in the design of the respective breakwaters.

The necessary mass of the armor stones can be determined by the Van der Meer formula (1988), while the mass of wave-dissipating concrete blocks (tetra pods) by the Takahashi-Hanzawa formula (1998). It should be noted that the design formulas are for the evaluation of the stability number as a function of deformation (damage level S/relative damage No). Therefore, the deformation can be evaluated from the formulas if the mass is given.

2. PERFORMANCE DESIGN

2.1 Definition of Performance Design

While performance design started in Europe in 1960's, it became popular in the United States following the 1994 Northrige earthquake disaster. Stability performance of buildings and civil engineering structures is assessed in the performance design (SEACO,1995).

Intensive discussions on the performance design for coastal structures were made during the International Workshop on Advanced Design of Maritime Structures in the 21st century (Takahashi, 2001; Burcharth, 2001). Although the design technology for coastal structures has seen great advancements during the 20th century, it was concluded that the design technology should be integrated to meet higher level of society's demand in the 21st century.

The concept of performance design is new and fluid, which allows researchers and engineers to create an integrated design framework for its development. Performance design can be considered as a design process that systematically and clearly defines performance requirements and respective performance evaluation methods. In other words, performance design allows the performance of a structure to be explicitly and concretely described.

The performance design was started to describe the stability performance, and was easily extended to de-scribe the functional performance. In addition, the performance related to landscape, ecosystem, amenity, lifetime durability (deterioration/maintenance) etc. should be considered, although they are not discussed in this paper.

2.2 Performance Matrix for the Performance Design

The performance design is based on a performance matrix, as shown in Table 1. The horizontal axis is the performance level, while the vertical axis is the design level. Letters A, B, and C in the table denote the importance of the structure, ie., A is critical, B is ordinary and C lesser degree. Using the performance matrix, the demand performance of a structure corresponding to the respective design levels can be explicitly indicated in consideration of importance of the structure.

50-year lifetime. For the concrete blocks, those values are 4 times and 5000-year. This is due to the difference of the characteristics of the formulas.

5. CONCLUDING REMARKS

Nowadays it is crucial to obtain the understanding of the general public regarding the construction of coastal structures. Designs must incorporate accountability, and the performance of the facility must be explicitly and clearly explained. The best way for the citizens to understand the performance is to see what is actually happened when the storm attacks. To have better understanding from citizens, the performance should be described vividly like a scenario.

The actual failure is a prototype performance evaluation of the structure against the occurred storm, and the intensive investigation on the disaster usually done after the disaster is like a writing a scenario to describe what was happed by the storm. If such a scenario is made in the design stage, the stability performance can be understood very clearly by citizens. The performance design should include many scenarios for different occasions ie., different levels of storms. The design with many scenarios is actually the performance design, and therefore the performance design can be said as a scenario-based design.

In addition to having scenarios related to stability and functional performance, the future performance design should include the scenarios on durability and environmental aspects including amenity, landscape, and ecology.

Although the design technology for coastal structures has seen great advancements during the 20th century, the design frame is still unchanged. The design technology should be integrated to meet higher level of society's demand in the 21st century.

Sincere gratitude is extended to Professor Emeritus Y. Goda of Yokohama National Univ., Professor K. Tanimoto of Saitama Univ., and Professor T. Takayama of Kyoto Univ. for valuable comments on vertical breakwater studies. Discussions on the new design methodology with members of the working group within the Coastal Engineering Committee of JSCE were extremely beneficial in writing this paper; especially those with Professor T. Yasuda of Gifu Univ. and Professor S. Sato of Tokyo Univ.

DISCUSSIONS

After presenting the paper at Coastal Structures 2003 (Portland), I received a discussion letter from Prof. Hans Burcharth of Aalborg University, who is as all the coastal engineers knows one of the most experienced and distinguished coastal engineers in the world. Since it is very important for this paper, I like to include here the discussion with his comments and the reply from the first author.

Discussion from Prof. H. Burcharth:

I have studied your Portland Coastal Structures ´03 paper and have the following comments;

In section 2.1 you claim that "Discussion on the performance design for coastal structures were first made during the Int. Workshop on Advanced Design of Maritime Structures in the 21´st century" and you give the reference (Takahashi, 2001).

This is not correct and should be corrected. Performance based design has been used in coastal engineering like in other types of structural engineering for many – many years. For example it is very common to design a beam for a specific maximum deformation when exposed to service loading, and to design an armour layer for 5% displaced blocks for a given occurrence of waves within lifetime. Not always have the performance limits been defined on the basis of economic optimization and consequent probabilistic analyses, but design based on performance has been done for years.

The more advanced performance design has been discussed in many of my paper, f. ex. In my Keynote address in the Int. Workshop at PHRI in 2001 and in my Keynote Address for Coastal Structures ´99. In these papers I do not use the word Performance explicitly, simply because performance based design is a trivial term because design are normally based on performance. The important point is to determine the optimum probability of failures (defined as degrees of damage – i.e. the performance - for each failure mode and design limits state) within structure life time for each type of structure (f. ex. Classified as suggested in my Coastal Structures ´99 paper)

I hope this explanation can help clarifying the historic situation related to performance based design.

I have started the work in new PIANC working group on determination of optimum design safety levels for breakwaters following the Safety Class – Limit State – Failure Probability scheme outlined in my papers, and in fact already used in some standards for civil engineering structures as the basis for calibration of partial safety factors.

Discussion from S. Takahashi:

Thank you very much for your precious comments.

1) I do not intend to claim the first, and we intended to promote the performance design in the coastal engineering field by having the workshop. The aim of this paper is also the same, not to describe the historic situation. Therefore, I changed that part considering your suggestion.
2) The term of performance design is definitely **not trivial**. It represents the new direction of the coastal structure designs as frequently stated in my paper and the panel discussions in the workshop.
   @ The performance design is toward the citizens (not just toward professional engineers):
   Citizens need to clearly understand various performances of all the lifetime of the structure.
   @ The performance design is for young researchers and engineers to come:
   The coastal structure design had developed greatly in the 20th century. However, it is not enough for the demands from citizens in this century. Young researchers and engineers are encouraged to develop the new design not just by extending the existing old design but by cultivating an entirely new design scheme under the new name such as performance design.
3) The design based on the partial safety coefficients is a traditional design method and very convenient for engineers. However, it is like a black box for citizens impossible to understand and is therefore, not appropriate for the performance design.
4) Under the PIANC, I know a lot of innovative working groups being organized to cultivate new fields and new concepts. I feel we need a creative working group for coastal engineering to develop new design schemes for new century. We have to provide creative fields for

young researchers and engineers to be active and innovative.

5) If possible, I like to have a chance to discuss above more with engineers and researchers in the next coastal structure conference or in some other meetings.

REFERENCES

Burcharth, H. F. (1993): Development of a partial safety factor system for the design of rubble mound breakwaters, PIANC PTII working group 12, subgroup F, Final Report, published by PIANC.

Burcharth, H.F.(2001):Verification of overall safety factors in deterministic design of model tested breakwaters, Proceedings of International Workshop on Advanced Design of Maritime Structures in the 21st Century(ADMS21), Port and Harbour Research Institute, pp.15-27.

Goda, Y. (1973): A new method of wave pressure calculation for the design of composite breakwaters, Rept. of Port and Harbour Research Institute, Vol. 12, No. 3, pp. 31–70 (in Japanese).

Goda, Y. (1985): Random Seas and Design of Maritime Structures, Univ. of Tokyo Press, 323 p.

Goda, Y. (1988): On the methodology of selecting design wave height, Proc. 21st International Conference on Coastal Engineering, Spain, Malaga, pp. 899–913.

Goda, Y. and Takagi, H. (2000): A reliability design method for caisson breakwaters with optimal wave heights, Coastal Engineering Journal, 42(4), pp. 357–387.

Isobe, M, Takahashi, S., Yu, S. P., Sakakiyama, T., Fujima, K, Kawasaki, K., Jiang, Q., Akiyama, M., and Oyama, H. (1999): Interim report on development of numerical wave flume for maritime structure design, Proc. of Civil Engineering in the Ocean, Vol. 15, JSCE, pp. 321–326 .

Melby, J. A. and Kobayasi, N. (1998): Damage progression on breakwaters, Proc. 26th International Conference on Coastal Engineering, pp. 1884–1897.

Oumeraci, H., Allsop, N. W. H., De Groot, M. B., Crouch, R. S., and Vrijiling, J. K. (1999): Probabilistic design methods for vertical breakwaters, Proc. of Coastal Structures'99, pp. 585–594.

SEACO(1995): Vision 2000-Performance-based seismic engineering of bridges.

Shimosako, K. and Takahashi, S. (1999): Application of reliability design method for coastal structures-expected sliding distance method of composite breakwaters, Proc. of Coastal Structures '99, pp. 363–371.

Shimosako, K, Masuda, S., and Takahashi, S. (2000): Effect of breakwater alignment on reliability design of composite breakwater using expected sliding distance, Proc. of Coastal Engineering, JSCE, pp. 821–825.

Takahashi, S. (1996): Design of vertical breakwaters, Reference Document No. 34, Port and Harbour Research Institute, 85 p.

Takahashi, S., Hanzawa, M., Sato, K., Gomyo, M., Shimosako, K., Terauchi, K., Takayama, T., and Tanimoto, K. (1998): Lifetime damage estimation with a new stability formula for concrete blocks, Rpt. of Port and Harbour Research Institute, Vol. 37, No. 1, pp. 3–32 (in Japanese).

Takahashi, S., Mizuguchi, M., and Goda, Y. (1999): Japanese technical standards for maritime facilities, Proc. of Coastal Structures '99, pp. 1049–1058.

Takahashi, S., Shimosako, K., Kimura, K., and Suzuki, K. (2000): Typical failures of composite breakwaters in Japan, Proc. 27th International Conference on Coastal Engineering. ASCE.

Takahashi, S, Shimosako, K., and M. Hanzawa(2001): Performance design for maritime structures and its application to vertical breakwaters, Proceedings of International Workshop on Advanced Design of Maritime Structures in the 21st Century(ADMS21), PHRI, pp.63-75.

Takayama, T., Suzuki, Y., Kawai, H., and Fujisaku, H. (1994): Approach to probabilistic design for a breakwater, Tech. Note Port and Harbour Research Institute, No. 785:1–36 (in Japanese).

Tanimoto, K, Furukawa, K., and Hiroaki, N. (1996): Fluid resistant forces during sliding of breakwater upright section and estimation model of sliding under wave forces, Proc. of Coastal Engineering, JSCE, pp. 846–850.

Tanimoto, K. and Takahashi, S. (1994): Design and construction of caisson breakwaters—The Japanese experience, Coastal Engineering, Vol. 22, pp. 57–77.

Van der Meer, J. W. (1987): Stability of breakwater armor layers—Design formulae, Coastal Eng, 11, pp. 219–239.

Van der Meer, J. W. (1988): Deterministic and probabilistic design of breakwater armor layers, Proc. American Society of Civil Engineers, J. of Waterways, Coastal and Ocean Engineering Division, 114, No. 1, pp. 66–80.

Vrijling, J. K., Vorrtman, H. G., Burcharth, H. F., and Sorensen, J. D. (1999): Design philosophy for a vertical breakwater, Proc. of Coastal Structures '99, pp. 631–635.