

## CHAPTER TWENTY TWO

### IRREGULAR WAVE OVERTOPPING RATES

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**ABSTRACT:** Methods for estimating wave overtopping of coastal structures are reviewed and compared with the very limited available data and with each other. The different methods yield results which can vary more than an order-of-magnitude. For vertical seawalls, the U. S. Army Engineer Shore Protection Manual method estimates more overtopping than Goda's method except in very shallow water. For sloped structures, the Shore Protection Manual method usually estimates less overtopping than Battjes' method and Owen's method. However, data for adequately evaluating how well these methods predict overtopping has not been published.

#### INTRODUCTION

Accurately estimating the amount of water which will wash over a coastal structure can be vital to design engineers. Building seawalls high enough to completely prevent overtopping is often unacceptable because of aesthetics and costs. For example, at Roughan's Point, Massachusetts, a coastal suburb of Boston, overtopping of the existing seawall causes flooding. A moderately higher seawall with improved backside drainage will reduce the flooding. In such situations, a reliable method for estimating overtopping rates for proposed seawall designs is imperative. Kobayashi and Reece (9) have pointed out that overtopping is also important in the design of arctic, gravel islands.

Overtopping is an extremely complex coastal phenomenon. Variables include structure characteristics (shape, height, slope, roughness, porosity, berm width, offshore slope, etc.) wave characteristics (height, period, direction, and the statistical descriptions of the wave field such as spectral widths and the correlation between height and period), water depth, wind speed and direction, air and water densities and viscosities, etc. Most overtopping

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investigations have ignored the effects of local winds and wave direction in order to concentrate on the relationship between overtopping and the other variables.

#### METHODS FOR ESTIMATING OVERTOPPING

The US Army Corps of Engineers Coastal Engineering Research Center's (CERC) Shore Protection Manual (SPM) (17) presents a method for estimating overtopping due to irregular waves. The method uses results from three separate CERC investigations. Weggel (18) used Saville's (13) monochromatic wave overtopping data to derive an equation for overtopping due to monochromatic waves. Ahrens (2) extrapolates Weggel's equation to irregular waves by assuming that runup is Rayleigh distributed and by holding Weggel's empirical coefficients constant. These assumptions allow Ahrens to sum the overtopping contributions from each runup in an irregular sea.

Tsuruta and Goda (16) and Goda (7) use Saville's data and some Japanese data to generate dimensionless curves for monochromatic wave overtopping. The monochromatic wave curves are extrapolated to irregular seas by assuming that wave height is Rayleigh distributed and summing the overtopping contributions of each wave in the irregular sea. This method is called Goda's method in this paper.

Battjes (3) uses Saville's data to derive a different equation for monochromatic wave overtopping. Battjes then accounts for the irregularity of the seas by assuming deepwater wave height and length are jointly Rayleigh distributed. The overtopping contribution from each wave in the irregular sea is summed to estimate the overtopping rate.

All three of the methods use a form of what Tsuruta and Goda (16) call a "linear summation" procedure. They use an overtopping relationship derived for monochromatic waves and assume that the relationship holds for each component (wave or runup) in the irregular sea.

Recently, versions of the "summation" procedure have been presented which are computationally less direct. Kobayashi and Reece (9) and Gadd, et. al. (6) begin with assumed joint probability distributions of wave height and period. Then, a monochromatic runup formula is used to calculate the runup associated with each probability cell (H-T group). Thirdly, some form of Weggel's equation is used to calculate the overtopping contribution associated with each probability cell. And finally, all of these overtopping contributions are summed.

A different approach to estimating overtopping due to irregular waves has been taken by Owen (10, 11). He has related overtopping to irregular wave field parameters by conducting small-scale laboratory tests with irregular waves. However, Owen does not discuss scale effects in his 1:25 scale laboratory data. Aaen (1) found scale

effects at a 1:8 scale to be 60-150% and at a 1:10 to be 50-200%. Jensen and Sorensen (8) also suggest small-scale laboratory tests with irregular waves for estimating overtopping.

The rest of this paper focuses on four of the above mentioned methods:

SPM  
Goda  
Battjes  
Owen

The three basic questions which are addressed are:

- For what situations are the methods most applicable?
- How do estimates from the different methods compare?
- How good are the methods at estimating overtopping?

#### APPLICABILITY OF METHODS

Each of the four methods for estimating overtopping is applicable to specific design situations. The SPM method is limited by the range of situations which Saville tested: vertical and curved structures, smooth-slope structures, stepped structures, and a 1:1.5 slope impermeable quarrystone structure. While it may be necessary to extrapolate from these situations, particularly for composite walls and quarrystone structures at other slopes, Weggel derived his empirical coefficients only for those situations tested by Saville.

Goda's method is for vertical seawalls. He duplicated his work with seawalls covered with concrete blocks, but does not clearly define the situation.

Battjes' method is applicable to gently-sloped smooth structures. He did not attempt to apply the method to rough slopes.

Owen's method is for structures with slope between 1:1 and 1:4. Owen does not recommend using the method for situations outside of the range of wave and structure variables he tested. However, he does suggest an unverified way to apply his smooth-slope results to rough slopes.

These general regions of applicability are schematically represented in Figure 1.  $H_s$  is the offshore significant wave height and  $d$  is the water depth at the toe of the structure. The dashed portion of Battjes region represents the breaking wave limit, which will vary with wave steepness. Battjes' method is based on the assumption that the waves break on the structure.

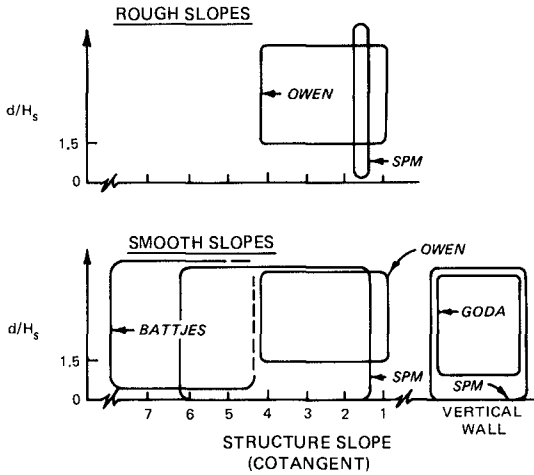


Figure 1. General regions of applicability of methods for estimating overtopping.

COMPARISON BETWEEN METHODS

The method's estimates can be compared in design situations for which more than one method is applicable. Figure 1 shows that both Goda's method and the SPM method can be used for estimating overtopping over a vertical wall. The methods can be compared in dimensionless form as in Figure 2.  $F$  is the freeboard (the height of the structure above the still water level),  $g$  is the acceleration due to gravity, and,  $Q$  is the volume rate of overtopping per unit length of structure. The four  $d/H_s$  ratios correspond to situations tested by Saville. The vertical spread of the SPM method is the effect of the variability of peak wave period, which Goda ignores.

The relationship between SPM and Goda estimates is dependent on the relative depth,  $d/H_s$ . For relative depths of 3 and 1.5, the SPM method estimates more overtopping than Goda's method. For a relative depth of 0.75, the two methods yield similar results. For a relative depth of 0.4, i.e. very shallow water, the SPM method estimates less overtopping than Goda's method. This dependence on relative depth implies a dependence on wave breaking and appears to be a result of

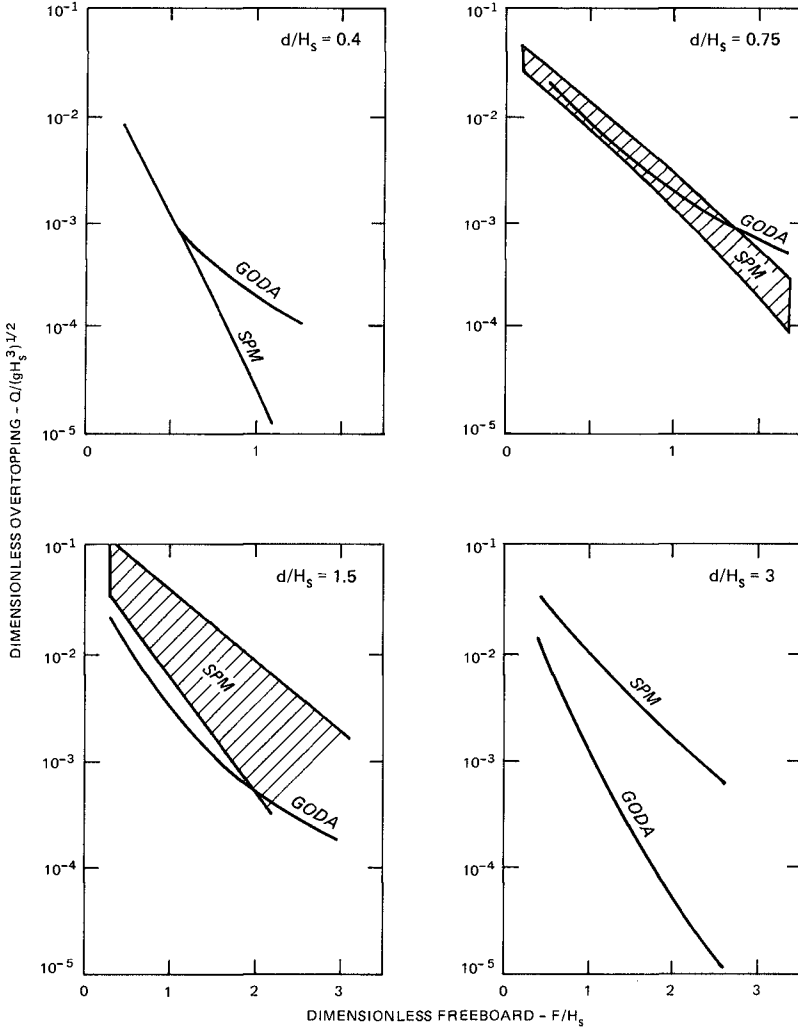


Figure 2. Goda's method and SPM method. Overtopping of a vertical wall.

the different approaches used to extrapolate monochromatic wave overtopping results to irregular seas.

Figure 2 clearly shows the sensitivity of overtopping to the freeboard. Since the freeboard is merely the difference between the structure height and the water level, overtopping is extremely sensitive to changes in either parameter. A varying water level, such as a tide or storm surge, will cause the overtopping rate to vary significantly with time.

Similar dimensionless plots can be generated to compare the SPM method with Battjes method for mildly-sloped, smooth structures. Figure 3 shows that Battjes method estimates more overtopping than the SPM method.  $\bar{T}$  is the average wave period. The spread of Battjes method is due to  $\kappa$ , a parameter which varies from 0 to 1 and is a function of the correlation between wave height and lengths.

Figure 1 shows that Owen's method can be compared with the SPM method. Figure 4 shows the comparison for 1:3 smooth slopes. Owen's method estimates more overtopping than the SPM method. The same result is found for both rough and smooth 1:1.5 slopes.

#### COMPARISON WITH DATA

The four overtopping methods should be evaluated by seeing how they agree with laboratory and field overtopping data. Unfortunately, no conclusive, comprehensive set of overtopping rates due to irregular waves has been published. Paape (12), Sibul and Tickner (14), and Tsuruta and Goda (16) conducted laboratory experiments before the present generation of irregular wave generators was developed. They could not generate a controlled, realistic irregular sea. Neither Owen (10, 11) nor Jensen and Sorensen (8) published their data. However, two studies provide rough "spot checks" of three of the overtopping methods.

Aaen (1) measured actual overtopping rates at a breakwater in Denmark. He then reproduced the structure and storm conditions in the laboratory at two scales, 1:8 and 1:10. The breakwater had a 1:2 slope of rounded sea stones. Figure 1 shows that Owen's method for rough slopes is applicable. The SPM method will be used for the sake of comparison by ignoring the difference in slope (1:2, not 1:1.5) and the difference in armor (rounded sea stone, not angular quarrystone). Aaen's data for these storms are plotted with the method's estimates in Figure 5.

The SPM method underpredicts Aaen's data and Owen's method overpredicts Aaen's data. Note that the relationship between the two estimates agrees with the trend in Figure 4; that is, for low overtopping rates, Owen's method estimates much more overtopping than the SPM method.

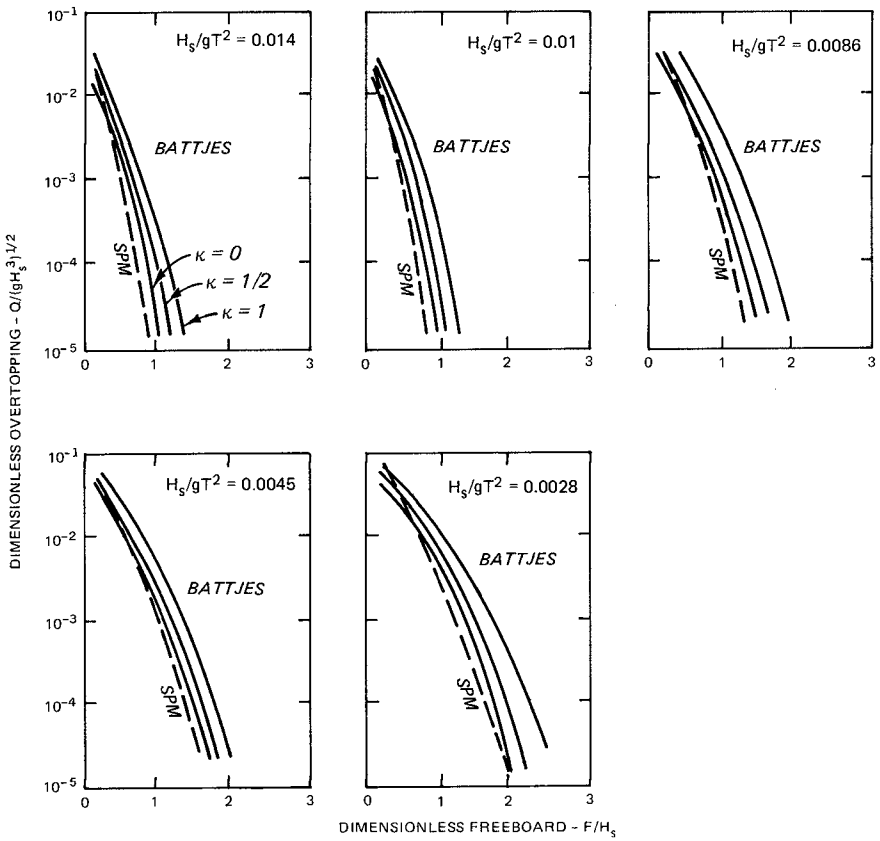


Figure 3. Battjes method and SPM method. Overtopping of a 1:6 smooth-slope structure.

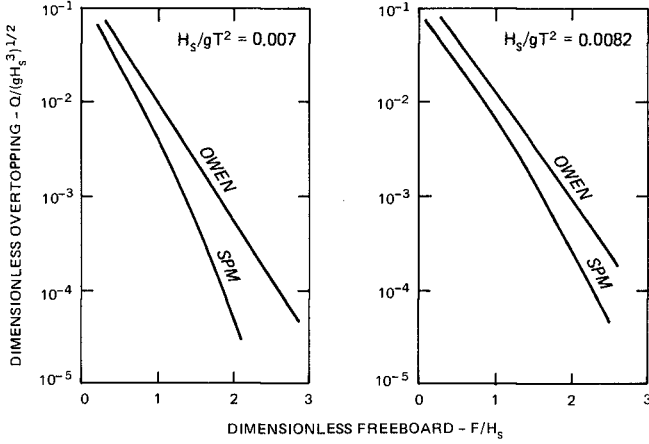


Figure 4. Owen method and SPM method. Overtopping of a 1:3 smooth-slope structure.

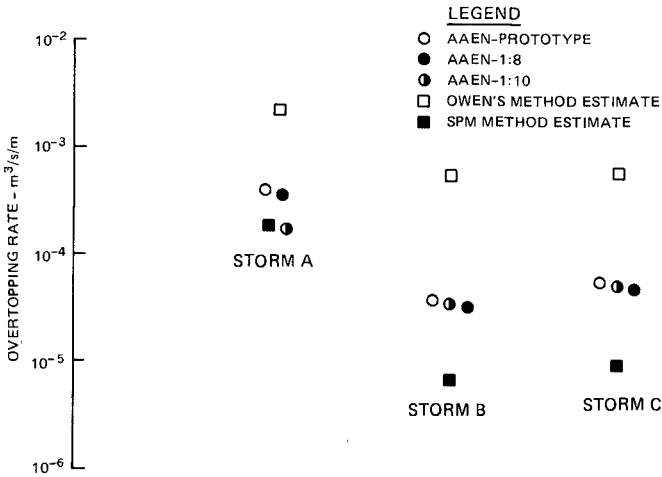


Figure 5. Aaen's overtopping data with estimates by Owen's method and the SPM method.



There are several possible explanations for the discrepancies shown in figure 5. Considering the inherent assumptions in the method, the unverified wind correction factor, and the ignored differences in slope and stone, the difference between the SPM estimate and the data is not discouraging. The difference between Owen's estimate and the data could be due to the unverified wind and roughness corrections and to scale effects. It must be strongly pointed out that Aaen measured only small rates of overtopping. Conclusions from Aaen's data apply to overtopping rates which may be less than the design engineer is considering.

Fukuda, Uno, and Irie (5) measured actual overtopping rates at a seawall fronted by artificial concrete blocks. They found that Goda's curves for seawalls covered with artificial blocks overpredicted their data by between one and two orders of magnitude. Fukuda, et. al. believe this drastic difference is due to energy dissipation across their offshore slope (1:80), which was much flatter than Goda's offshore slope (1:10 to 1:30).

#### OTHER PARAMETERS WHICH EFFECT OVERTOPPING

Several parameters which effect overtopping are ignored in the four methods. Onshore winds should increase the overtopping rate at a seawall. The SPM recommends an unverified wind correction factor which varies from 1 to 3.2. Owen uses the SPM wind correction factor and the other two methods do not address the problem. It must be realized, however, that the SPM correction is merely an engineering judgement approximation of a very complex phenomenon. Gadd et. al. (6) discuss some qualitative trends in the wind effect and conclude that more data is needed to improve upon the SPM correction.

Very little information exists concerning the effect that angle of wave attack has on overtopping. In the absence of data, engineers have usually assumed that overtopping is maximum when waves hit the structure head on, i.e. perpendicularly, and tapers off to zero as the angle of attack lessens. However, Owen found that overtopping is maximum not when waves approach the structure perpendicularly, but at an angle of 15°. Owen (10, 11) has no explanation for his results. Similar results have been seen for monochromatic wave runup by Tautenhain, Kohlhas, and Partensky (15). Until data is available to better define this phenomenon, care should be taken to not assume too much overtopping reduction for oblique angles of wave attack.

#### CONCLUSIONS

There are a number of methods for estimating wave overtopping rates. Some of the methods are based on "summation" extrapolations of monochromatic wave overtopping theory. Some of the methods are based on small-scale overtopping tests with irregular waves. For vertical walls, the SPM method estimates more overtopping than Goda's

method except in very shallow water. For sloped structures, the SPM method generally estimates less overtopping than Battjes' method and Owen's method.

Better data is sorely needed. The US Army Engineer Coastal Engineering Research Center (CERC) plans to conduct site-specific and general research overtopping tests. The tests will begin this fall in CERC's two-dimensional flumes with irregular waves. Also, prototype data is needed to determine scale effects in overtopping modelling, and data is needed to better understand the effects of wind and angle of attack.

The question, "how well do the available methods estimate overtopping?," cannot be conclusively answered at this time. The methods discussed in this paper provide the best available estimate. Until better data is available, these estimates should be considered to be within, at best, a factor-of-three, and conservatively, an order-of-magnitude of the actual overtopping rate. This final conclusion is made considering:

- a. The lack of comprehensive, conclusive data and the discrepancies between the methods' estimates and the very limited published data
- b. The assumptions made in the derivations of the methods
- c. The factor-of-three confidence band that Owen claims for his method, which is the only method of the four based on irregular wave overtopping data
- d. The scale effects found by Aaen, and
- e. The order-of-magnitude difference between estimates from different methods

#### ACKNOWLEDGEMENTS

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## APPENDIX - REFERENCES

1. Aaen, S., Oversprojt (Overtopping), Bachelor Thesis, Danish Academy, Department of Civil Engineering, Copenhagen (in Danish), June 1977.
2. Ahrens, J., "Prediction of Irregular Wave Overtopping," CETA 77-7, US Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Virginia, December 1977.
3. Battjes, J.A., "Computation of Set-up, Longshore Currents, Runup and Overtopping Due to Wind-Generated Waves," Report No. 74-2, Delft University of Technology, Department of Civil Engineering, 1974.
4. Douglass, S.L., "Methods for Estimating Overtopping Rates," Technical Report (in publication), US Army Engineering Waterways Experiment Station, Vicksburg, Mississippi, 1984.
5. Fukuda, N., Uno, F., and Irie, S., "Field Observations of Wave Absorbing Revetment," Coastal Engineering in Japan, Vol. 17, 1974.
6. Gadd, P.E., Potter, R.E., Safaie, B., and Resio, D., "Wave Runup and Overtopping: A Review and Recommendations," Proceedings of the 1984 Offshore Technology Conference, Houston, Texas, May 1984.
7. Goda, Y., "Expected Rate of Irregular Wave Overtopping of Seawalls," Coastal Engineering in Japan, Vol. 14, 1971.
8. Jensen, O.J., and Sorensen, F., "Overspilling/Overtopping of Rubble-Mound Breakwaters," Coastal Engineering, Vol. 3, No. 1, 1979.
9. Kobayashi, N., and Reece, A.M., "Irregular Wave Overtopping on Gravel Islands," ASCE Journal of Waterway, Port, Coastal and Ocean Engineering, WW4, Vol. 109, pp. 429-444, November 1983.
10. Owen, M.W., "Design of Seawalls Allowing for Wave Overtopping," Report No. EX924, Hydraulics Research Station, Wallingford, Oxfordshire, England, June 1980.
11. Owen, M.W., "Overtopping of Sea Defences," International Conference on the Hydraulic Modelling of Civil Engineering Structures, Coventry, England, pp. 469-480, September 1982.
12. Paape, A., "Experimental Data on the Overtopping of Seawalls by Waves," 7th Conference on Coastal Engineering, The Hague, Netherlands, pp. 674-681, 1960.

13. Saville, T., Jr., "Laboratory Data on Wave Runup and Overtopping on Shore Structures," TM-64, Beach Erosion Board, US Army, Corps of Engineers, 1955.
14. Sibul, O.W., and Tickner, E.G., "Model Study of Overtopping of Wind-Generated Waves on Levees with Slopes of 1:3 and 1:6," TM-80, Beach Erosion Board, US Army Corps of Engineers, 1956.
15. Tautenhain, E., Kohlhase, S., and Partenscky, H.W., "Wave Runup at Sea Dikes Under Oblique Wave Approach," 18th International Conference on Coastal Engineering, Capetown, South Africa, pp. 804-810, 1982.
16. Tsuruta, S., and Goda, T., "Expected Discharge of Irregular Wave Overtopping," 11th Conference on Coastal Engineering, London, England, pp. 833-852, 1968.
17. US Army Corps of Engineers, Coastal Engineering Research Center, Shore Protection Manual, 3rd ed., US Government Printing Office, Washington, D.C., 1977.
18. Weggel, J.R., "Wave Overtopping Equation," Proceedings of the 15th Coastal Engineering Conference, Honolulu, Hawaii, pp. 2737-2755, 1976.