CHAPTER 119

EXPERIMENTS ON COASTAL PROTECTION SUBMERGED BREAKWATERS: A WAY TO LOOK AT THE RESULTS

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1. ABSTRACT

In this paper, various damping action on submerged breakwater test results will be analyzed, in order to improve the methodology for future analysis. Experimental data from the authors an other researchers will be analized.

2. INTRODUCTION

The use of submerged detached breakwaters has become very attractive in beach restoration projects. The knowledge of how these breakwaters can affect coastal dynamics is necessary for almost any study.

Even though two-dimensional experiments on wave transmission on submerged breakwaters have been carried out by several authors, the application of the results to particular coastal protection projects is difficult and inapplicable in many cases.

Very often, relatively highly sophisticated wave propagation or coastal evolution models consider the influence of the submerged breakwater in a rather simplistic way: by a particular value of the transmission coefficient (Kt).

Furthermore, the application of the coefficient might not respond to realistic situations, depending on model test conditions, data analysis, wave evolution characteristics in the area between the submerged breakwater and the beach, etc.

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3. OBJECTIVE OF THIS STUDY

The purpose of this study is to analyze various damping action on submerged breakwater test results, in order to improve the methodology for future analysis. Due to the breadth of this topic as well as the space limitation, the two following aspects are emphasized in this paper: A) Why it is too simplistic to model all processes by the parameter Kt (normally measured in one position behind the breakwater). B) The potential for mis-interpreting data when analyzing Kt.

4. ANALYSIS OF PHENOMENA INDUCED BY A SUBMERGED BREAKWATER

4.1. Characteristic zones of study

For analyzing hydrodynamic phenomena induced by a submerged breakwater or barrier, five characteristic zones are considered by the authors. This zones are schematized in Fig. 1.

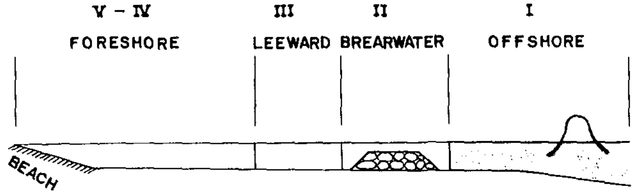


Fig. 1.- Scheme of Characteristic Zones of Study.

Fig. 2 tries to emphasize the two following concepts (which are sometimes ignored or not considered relevant):

- A) Most of experimental data are measured in zone III (near the breakwater) while practical application is needed in zone IV-V (near the beach).

- B) Some hydrodynamic phenomena induced in zones IV-V (difficult to be separated for practical applications) can affect data acquisition in zone III (i.e. wave reflection at the beach).

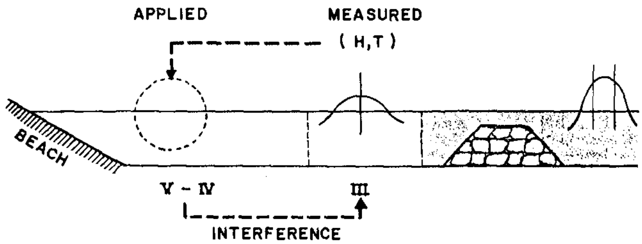


Fig.2.- Interrelation between Characteristic Zones.

4.2. Summary of Hydrodynamic Phenomena

In the authors' opinion, an attempt to show the complexity of the hydrodynamic phenomena induced by a submerged breakwater would help in understanding the existing shortcomings in data acquisition and application. Some of this hydrodynamic phenomena found in the area between the breakwater and the beach were corroborated from some of the experimental results carried out at CEPYC (CEDEX) by the authors (Ref.6, 7, 8 and 15). This will be shown in a very simple, schematic and "descriptive" way (including a few "liberties" with the drawings).

ZONE I

Phenomena: shoaling; wave reflection; breaking (or not) in front of breakwater.

Dimensionless Parameters

$Kr = Hr/Hi$

$Ir = tg\alpha/\sqrt{Hi/Li}$

X_B/Li

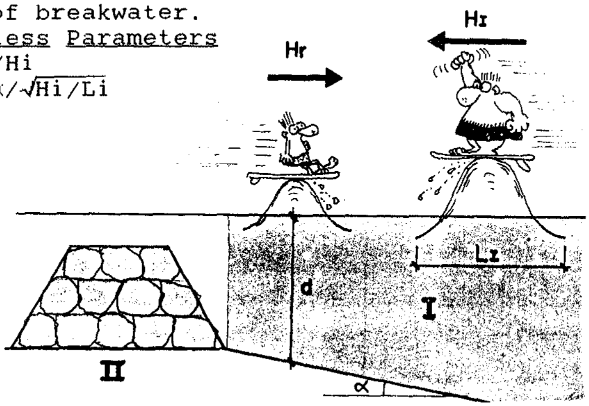


Fig. 3.- Zone I

ZONE II

Phenomena: wave breaking (possible); wave energy losses; long wave pulsative amplification; on/off-shore flow.

Dimensionless Parameters

C_L (breaking, friction, turbulence, percolation)

B/Li (or B/gT^2, B/Hi, B/d)

F/Li (or F/gT^2, F/Hi, F/d)

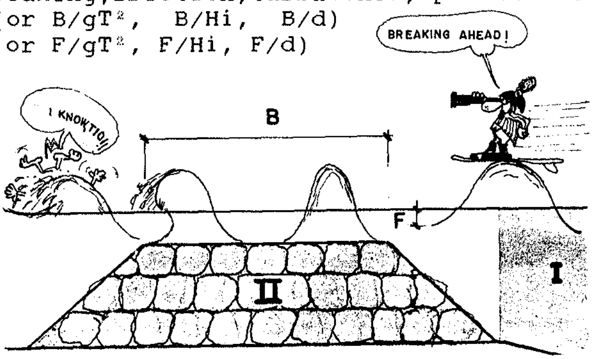


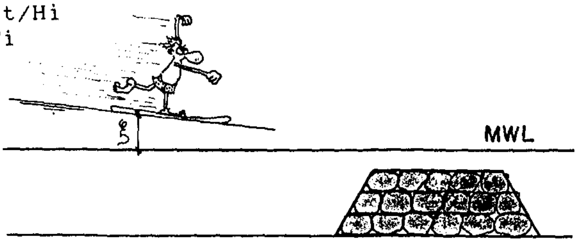
Fig. 4.- Zone II

ZONE III

Phenomena: wave transmission and damping; shifting of transmitted wave periods; wave set-up; periodic on/off-shore flow; possible standing wave patterns; possible longwave oscillations.

Dimensionless Parameters

Kt=Ht/Hi
Tt/Ti
ξ/Hi



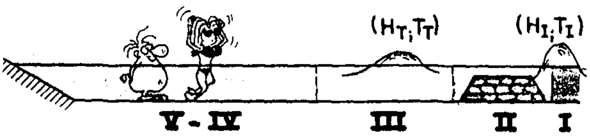


Fig. 5.- Zone III

ZONE IV-V

Phenomena: wave height and period evolution; wave reshaping and possible wave breaking, interference with waves reflected from the beach.

Dimensionless Parameters

Evolution of Kt, Tt/Ti, ξ/Hi
Influence of (Kr) beach.

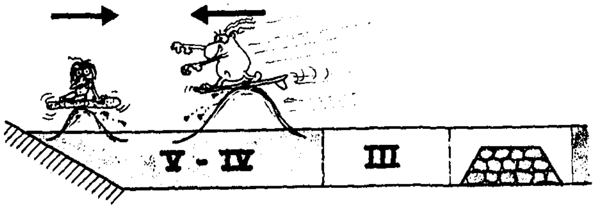


Fig. 6.- Zone IV-V

5. LOOKING AT THE RESULTS IN CHARACTERISTIC ZONES

The two aforementioned concepts (A and B) derived from Fig. 2, should be kept in mind by Coastal Engineers when analyzing experimental data on wave damping action on submerged breakwaters as well as for future model tests. Model tests carried out at CEPYC (CEDEX) (Ref.6, 7 and 8) have shown that in certain cases, it is not so simple to draw conclusions on wave damping by only analyzing Kt (generally in zone III). In other words: submerged breakwaters could (under certain conditions) be not as "efficient" as one might think, when the evolution of the transmitted wave parameters are compared in the characteristic zones (especially in zone IV-V).

Fig. 7 schematizes the CEPYC model set-up and parameters of study. Notice that waves were measured in 13 points past the breakwater. Also, breaking wave conditions (induced or not by the submerged breakwater) were investigated.

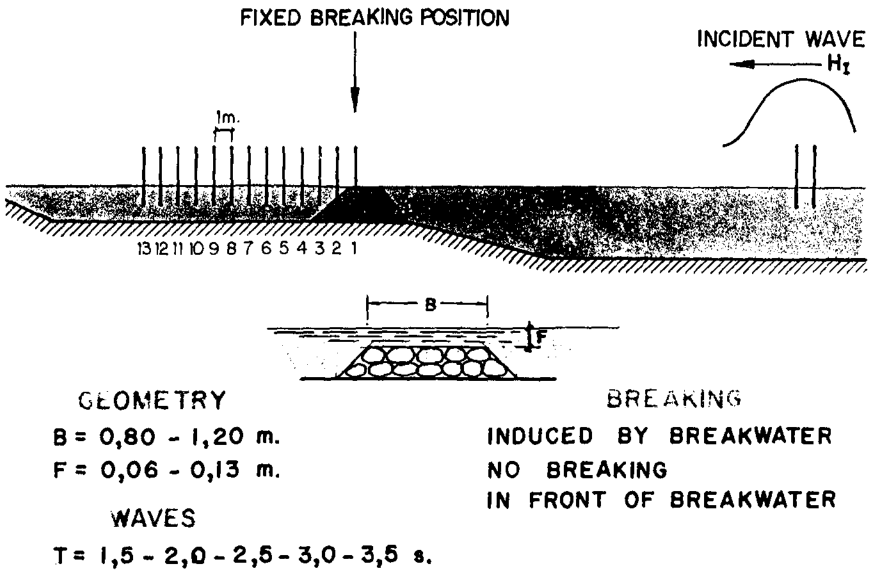


Fig. 7.- Scheme of Transmitted Wave Evolution Model Set-Up.

The two following figures, from the above mentioned model tests, have been chosen as a "reflexion" on the importance of measuring wave characteristics (H, T, ξ) in more than one or two points behind the breakwater.

The first figure is an example of the "relative efficiency" in crest width increment: in zone III (where most of measurements were taken) the increment seems to be very favorable in decreasing transmitted wave height (Ht) while the efficiency is not as clear for zone IV-V (close to the beach).

The second figure remarks the importance of wave reshaping and possible new breaking once the submerged breakwater has induced waves breaking on the breakwater (notice also the set-down points outlined on this figure).

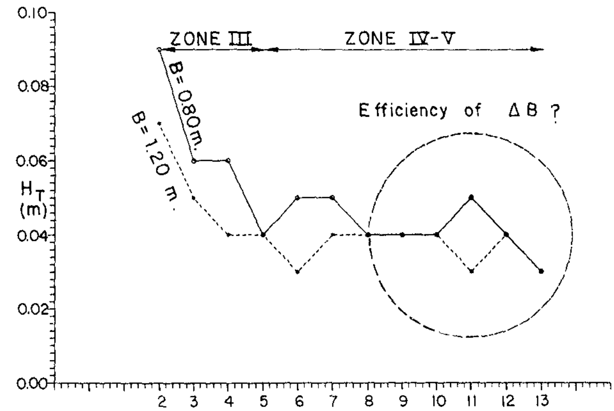


Fig.8.- Example of Wave Transmitted Height (Ht) Evolution

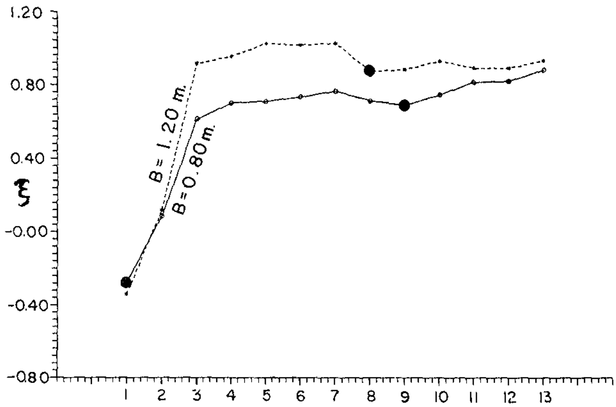


Fig.9.- Example of Wave Set-Up (ξ) Evolution

For a thorough understanding of the main hydrodynamic phenomena induced after wave breaking, including undertow, the authors would like to point out the elegant work carried out by Prof. Svendsen (i.e. Refer.14). New studies trying to "link" the main submerged breakwater parameters and wave evolution in characteristic zones would be very beneficial for coastal engineering applications.

6. LOOKING AT THE RESULTS OF Kt IN ZONE III

The potential for mis-interpreting data, even in the simplest cases of analyzing Kt in zone III will be discussed.

6.1. Transmission Coefficient (Kt) versus relative crest width (B/L)

For coastal engineering applications it is important to know which is the optimum breakwater crest width (B) which gives the minimum transmission coefficient (Kt). From dimensional analysis, the following expression can be derived as one possibility:

$$Kt = f(B/L, Hi/d) \qquad (1)$$

To accurately plot the results it is important to note the fact that a change of crest width will also alter the reflection coefficient (Kr) and thus the incident wave height (Hi), according, for instance, to the method of Goda and Suzuki (Ref.5). Therefore, it is not so easy to get the exact values of the term Hi/d unless a large number of model tests are performed. In other words: the plot of Kt versus B/L (Eq. 1) should include the mean value and also the standard deviation of the relative incident wave height term (Hi/d), due to the difficulties in obtaining "exact values" of (Hi/d). This fact, in the authors' opinion, has not been considered in the existing literature.

Even though different authors (Ref.3, 4, 10 and 13) have shown the existence of distinctive maximum and minimum values of Kt in Eq. 1, it has not been remarked whether these curves respond to the spreading characteristics of the results themselves or to the real hydrodynamic problem, according to the equations involved in that modelling.

This fact is important when analyzing experimental results, since one could think (at first) that the obtained results, for instance, might not be valuable due to the large data spread, even when this spread is inherent to the mathematics involved in modelling (i.e. matching conditions).

6.2. Poble Nou Wave Transmission Study

This study, carried out at the CEPYC (Ref.6 and 7), was part of a large project to greatly improve the sea front in Poble Nou, in Barcelona (Spain), for the '92 Olympic Games. Basically, the aim of the model tests was to investigate the efficiency of increasing crest width on wave damping action.

For that, three crest widths (B = 34.50 m. and ± 15% on this value), and three wave periods (T=7, 9 and 11 secs) were tested, for a crest freeboard F=0.00 m. Also a mean water elevation of 0.50 m., associated to the largest wave period was considered.

There were 108 model tests (a relatively large number, in our opinion), in order to get well defined maximum and minimum values in the curves Kt versus B/L, as explained in 6.1. Fig 10 is a typical example of a curve representing Eq. (1):

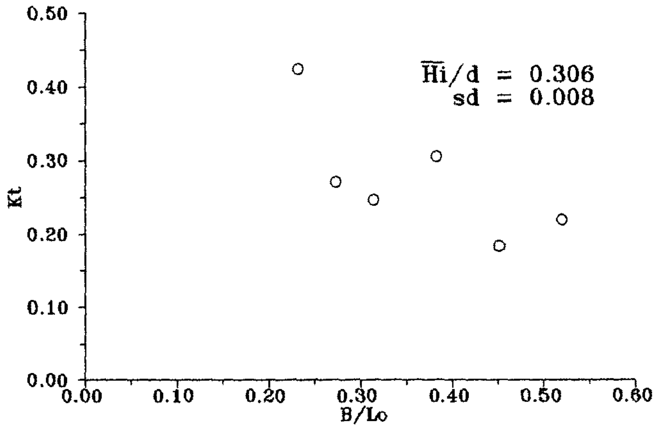


Fig. 10.- A Typical Example of Kt versus B/Lo, for $\overline{Hi}/d=0.306$ (Crest Freeboard F=0.00 m.).

From Fig. 10 one could ask the following reasonable questions:

A) Are the results valuable due to the apparently large data spreading shown in Fig. 10 ?

B) Should a fitting curve be used ?

C) Could a figure obtained by connecting all points, and showing distinctive maximum and minimum points, be a real response of the wave transmission phenomenum ?

D) Supposing the above mentioned questions were known, which should be the design value for the relative crest width B/L ?

And, before giving any answer to all these questions, one could also make the following logical reasoning: Which is really the most simple mathematical answer to these questions?

In Fig. 11, the geometric parameters and also the reflected (R and D) and transmitted (C and T) waves are shown for the three regions in an impervious submerged obstacle. The four variables R, C, D and T are calculated using the four known matching conditions related to velocities and pressure.

A graphic solution is shown in Fig. 12, using the most simple case of short waves, linear theory and no dissipation. Also a crest freeboard of 0.50 m. is adopted, to greatly simplify the problem.

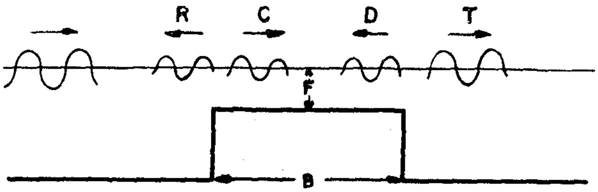


Fig. 11.- Geometric and Wave Parameters for a Submerged Obstacle.

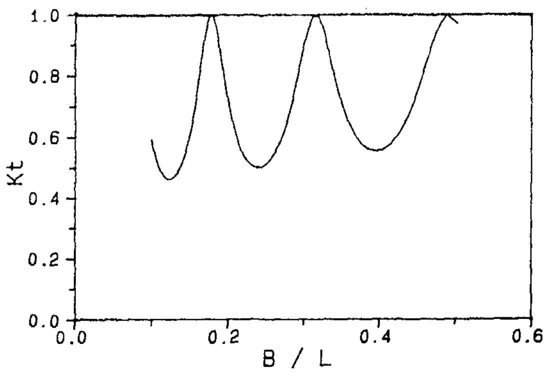


Fig. 12.- A Typical Solution of Kt versus B/Lo for an Impervious Submerged Obstacle (F=0.50 m) Using Linear Theory and Short Waves.

In Fig. 12 it can be seen that in the analysis for the most simple case of short waves, linear theory, and no wave dissipation, the solution for Kt (and also for Kr) shows distinctive maximum and minimum values, as found in other works on submerged obstacles.

However, the theoretical transmission coefficient of linear waves propagating over a submerged porous step decays monotonously with the relative crest width (B/L), but reflection coefficient does oscillate (Losada, personal communication, 1990). This distinct behaviour is worthy of further research.

Fig. 13 summarizes the results obtained in Ref.6, related to wave transmission (Kt) versus relative crest width (B/Lo) for different relative incident wave height (Hi/d) and zero freeboard (F=0) values.

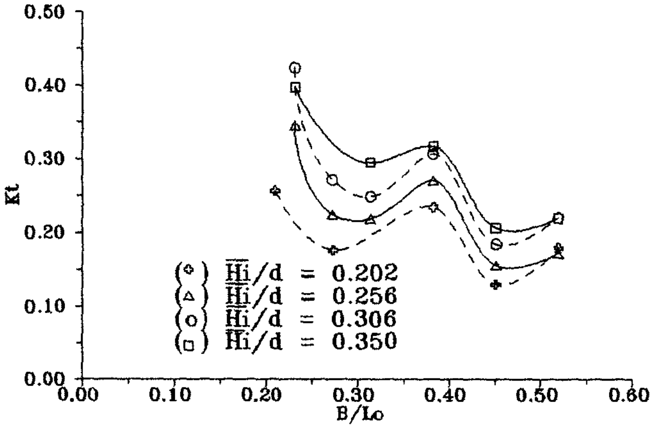


Fig. 13.- Kt versus B/Lo for Different (Hi/d) and Zero Freeboard (F=0).

The following conclusions could be drawn from Fig.13:

- The wave transmission coefficient shows a decreasing oscillatory trend when plotted against the relative crest width (B/Lo) with distinctive maximum and minimum values.

- The relative incident wave height (Hi/d) seems to have influence only on the amplitude of Kt, but not in the values of (B/Lo) corresponding to the maximum and minimum values of Kt.

- Small variations of B/Lo, corresponding to the minimum values of Kt, gives rise to relatively high values of Kt. Thus, design criteria based on minimum Kt values might be too risky due to the joint appearence of all the complex hydrodynamic phenomena involved and model scale effects in two-dimensional tests.

Unfortunately, the relative small number of model tests considering a freeboard F=0.50 m. make the authors unable to compare the results with those obtained applying the most simple theoretical cases of impervious and porous submerged steps, as obtained in Losada's work (Ref.11).

6.3. Influence of Breaking Conditions

The influence of taking into account different breaking conditions (i.e. breaking in front of the breakwater, breaking induced by the breakwater or not breaking) on wave transmission is investigated.

6.3.1. Plotting of Results

The plotting of different dimensionless coefficients versus a new parameter Ir*(B/F), provided a reasonably good fitting in general, as well as a good physical understanding of the results, including the influence of breaking (Ir = the known Iribarren's parameter = $tg\alpha/\sqrt{H/gT^2}$; $tg\alpha$ = bottom slope in front of the breakwater; B = crest width; F = crest freeboard).

Space limitations have prevented the authors from presenting some of the results obtained in References 1, 2, 9, 13 and 15, using the above mentioned parameter. However, figure below is the result of analyzing some specific data from Dattatri et al (Ref.3) using the condition of breaking over the breakwater, presented in Nakamura et al (Ref.12).

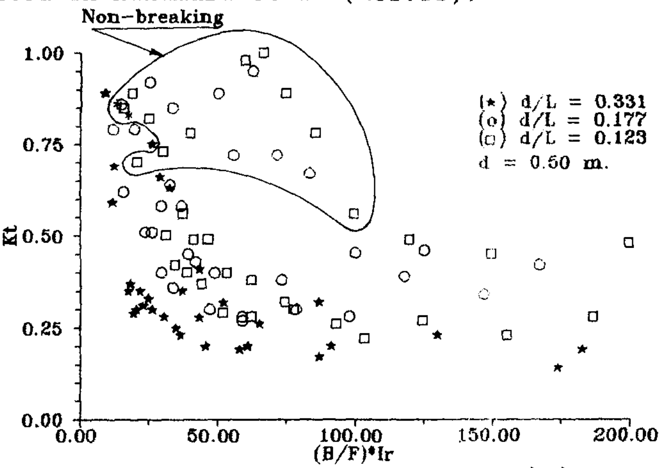


Fig. 14.- Influence of Breaking Conditions on Kt

The following conclusions could be drawn from Fig.14:

- Large data spreading occurs if breaking conditions are not separated adequately.

- The fitting of Kt versus the parameter Ir*(B/F), both for breaking and non-breaking conditions (using Nakamura's criteria), seems to be quite reasonable: the fitting for breaking condition should show a quasi-asymptotic decreasing curve as expected ($Kt \rightarrow 1$ for relatively small values of B/F and $Kt \rightarrow 0$ for large values of B/F). On the other hand, the pattern for non-breaking condition shows a definitely different shape. This could be also expected since values of $Kt>1$ are reported for non-breaking conditions (i.e. Ref.12 and 15).

7.-CONCLUSIONS

1) Most of the practical data obtained by different authors is measured in zone III. Thus, one should be aware of this when they are used in zone IV-V for beach application.

2) Since various transmitted wave parameters evolve in different zones as wave propagates landwards, more detailed information should be provided in model tests. In particular, several wave gauges, appropriately separated, should be used for measurements of wave transmitted parameters. Also, reflective beach characteristics and distance from the beach to the breakwater should be reproduced as reliably as possible.

3) When analyzing data in one particular zone, the different processes affecting that zone should, if possible, be separated, for a proper interpretation and application of this data. In particular, breaking conditions (such as breaking induced by the breakwater, breaking in front of the breakwater, or not breaking at all) should be adequately distinguished. This observation should be kept in mind when simple formulae for combined wave transmission data are tried for general design purposes.

4) The use of the parameter (B/F)*Ir versus the other dimensionless parameters (transmission, reflection and losses coefficients, ratio between transmitted and incident wave period and relative wave set-up) seems to improve the fitting of results, especially if the above-mentioned breaking conditions are separated.

5) Experimental studies on wave transmission on submerged breakwaters and zero crest freeboard, as the one explained about Poble Nou, have shown that curves representing transmission coefficients (Kt) versus relative crest width (B/L), for various relative incident wave heights (Hi/d) show, in general, distinctive maximum and minimum values.

Since theoretical studies, with negative crest freeboard, also show in general oscillatory patterns, experimental data should not at first be treated as though they were presenting a large spreading (as is sometimes reported).

6) Even though the above mentioned experimental curves show in general, distinctive maximum and minimum values, the joint appearence of all the complex hydrodynamic phenomena, explained at the beginning of this paper, together with possible model scale effects, make design criteria based on minimum Kt values too risky.

8.-ACKNOWLEDGEMENTS

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