The European Research Programmes in Coastal Engineering

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The European Research Programmes in Coastal Engineering

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1. General Introduction

Since 1989, the European Union has established a number of scientific programmes to promote and coordinate a wide range of activities such as transport, fisheries, environment, tourism, etc. which also have an impact on the coastal zone.

The efforts of the European Commission to promote an overall concept of Integrated Coastal Zone Management (ICZM) encompass activities from the research carried out under the Marine Science and Technology programme (MAST) to the Environment and Climate programme (ENV).

2. The MAST-programme

The MAST-programme (Marine Science and Technology) has grown in three stages: first as a pilot programme (1989-92, budget ECU 50 million), then as MAST-II (1991-94, budget ECU 118 million), and finally as MAST-III (1994-98, 244 million ECU). From the start, coastal zone science and engineering has played an emportant part among the areas covered by the programme, absorbing about 20 % of the budget. In the on-going MAST-III, coastal zone research will receive about 50 million ECU.

According to the detailed contents of the first pilot programme, the objectives of coastal zone research were: "to strengthen European research in coastal processes, thereby allowing for better management of resources and for engineering designs; to provide the information and data required for application of modern tools in coastal management, such as mathematical numerical modelling; to advance and harmonise design of coastal engineering works and to help prepare for the consequences of the currently predicted rise in sea level in the next century" /1/.

Up to now, the MAST-programme has focussed on two areas of coastal zone research: morphodynamics and coastal structures.

Coastal morphodynamics refers to the fact that the state of a sandy coast is a manifestation of the dynamic system which is formed by the water motion (waves, currents), the sediment motion and the bed topography. These elements mutually interact in a highly dynamic, non-linear way. As a result, the behaviour of a coast is not a straightforward response to the inputs (storms, tides, etc.), but includes the effects of complex forms of autonomous

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behaviour at a variety of length and time scales. Examples of such autonomous behaviour are the formation of beach cusps, nearshore bars, sand waves, channel/shoal systems, etc. This makes the predictive modelling of coastal morphodynamics a complicated task /2/.

In coastal engineering, MAST supports work both on hard structures (rubble mound breakwaters, berm breakwaters, monolithic vertical walls, etc.) and on soft options (beach nourishment techniques, maintenance of intertidal flats, salt marshes and other defence mechanisms where Nature performs the actual work). The aim is to improve criteria and guidelines for the design of structures or schemes in a manner which ensures reliability, economy and environmental compatibility. Here, research again covers a wide range of issues, such as overtopping, scouring, wave impact forces on caissons, the role of biological factors in the consolidation of cohesive sediments, etc. /3/.

Under the MAST-umbrella, leading European hydraulic institutes have set up, for the first time, systematic cooperation projects on issues that are too complex to be tackled individually.

At the beginning, there were, of course, some difficulties in bringing the scientific ideas and basic approaches of University laboratories together with the more mission-oriented research aspects of commercial and governmental institutes. However, very soon an excellent cooperation was established between the partners from universities and government research institutes, with the common aim of promoting European research and knowledge in coastal engineering

Six European institutes participated In the project on coastal morphodynamics as the main contractors: Delft Hydraulics, HR Wallingford, Danish Hydraulic Institute, Sogreah, Electricité de France and the Technical University of Braunschweig. In addition, 26 associated contractors from European universities, state laboratories and consulting companies participated from Italy, Great Britain, Ireland, Spain, Denmark, France, The Netherlands, Belgium, Norway and Portugal.

Five European institutes participated as the main partners in the programme on coastal structures: the Franzius and Leichtweiss Institute, HR Wallingford, Delft Geotechnics, University of Sheffield and Delft University of Technology. The research work was in addition supported by 18 associated partners from Denmark, Great Britain, Spain, The Netherlands, Italy, Germany, France and Norway.

3. Scientific Results of the Morphodynamics-Project

The morphodynamics-project was subdivided into several sub-projects dealing with waves, currents, non-cohesive sediment transport, cohesive sediments and morphodynamics, respectively. The project also had a structure of working groups addressing cross-discipline problems such as wave-current-sediment interaction.

The morphodynamics-project had the following focal points:

(1) medium-term coastal profile modelling,
(2) medium-term coastal area modelling,
(3) rhythmic features ("bars and banks"), and
(4) long-term modelling.

Fundamentally different approaches were used: process-based simulation models for the medium-term applications, mathematical stability analyses for the rhythmic features and a range of more or less empirical large-scale modelling techniques for the long-term modelling.

3.1 Medium-term coastal profile models

The work on medium-term profile modelling concerned the evolution of the coastal profile in the case of longshore uniformity. These PC-based models are based on state-of-the-art knowledge of waves, current and sediment transport and their interactions with the changing bed topography.

Special attention was paid to bar formation, taking into account phenomena such as non-linear wave kinematics, low-frequency waves, the wave breaking process, undertow and induced streaming, bottom boundary layer effects, sloping-bed effects, sediment transport mechanisms and sediment sorting effects. A range of profile models was intercompared and tested against laboratory data, mainly from the Large-Wave-Flume-facility in Hannover. These models were extended, improved and validated against data from other laboratory and field experiments /4/. Figure 1 shows an example of measured and computed beach profile evolution /5/.

The availability of comprehensive datasets for validation of the profile evolution is a prerequisite for morphodynamic modelling. Therefore significant effort was spent on getting access to new data. For field data, a link was made with the MAST-project NOURTEC, which concerns the coastal response to underwater nourishment /5/. Other field data were obtained from the German coast and from El Saler Beach, near Valencia, Spain. A valuable

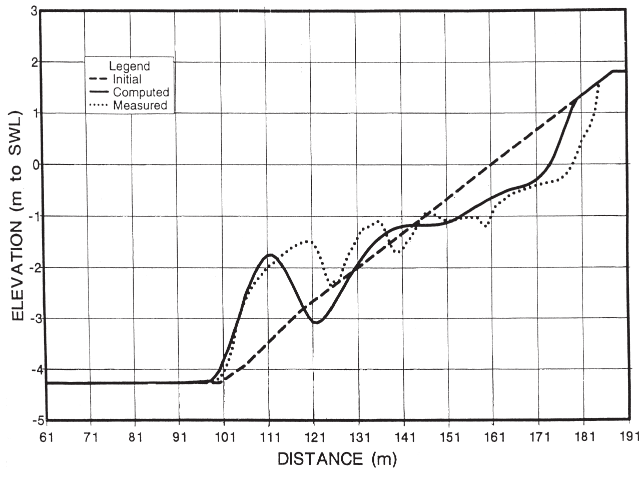


Figure 1: Measured and computed beach profile /5/.

set of laboratory data for model validation was obtained from a series of experiments in Delft Hydraulics' Delta Flume.

3.2 Medium-term coastal area models

There are many situations in which the assumption of longshore uniformity does not work and the coastal profile modelling approach is an over-simplification of reality. In such cases, a coastal area model is needed. Process-knowledge, modelling know-how and software implementation of this type of model are much less advanced than in the profile case, because of the extra complexity due to the second horizontal dimension. Also, there is a need for field and laboratory data to help develop and validate coastal area morphodynamic models. The effort which this requires is beyond the capacity of most research projects. This is why the validation of coastal area models was based, so far, on model intercomparisons for hypothetical cases and on comparisons with small-scale laboratory experiments /7,8/.

Although the necessity to include 3-D effects is obvious, morphodynamic modelling is still far from operational. Instead, some 2-D depth-integrated models have reached a level of operational use.

Figure 2 shows, as an example, the results of a coastal area model with the morphological response of the shore-line due to a shore-parallel breakwater for different angles of wave approach /5, 6/.

3.3 Rhythmic features

The main focus in the domain of rhythmic features was the analysis of free instabilities of the morphodynamic system. This involved non-linear analyses of wave-induced bed-ripple patterns, formed by turbulent boundary layers and effected by grain sorting and

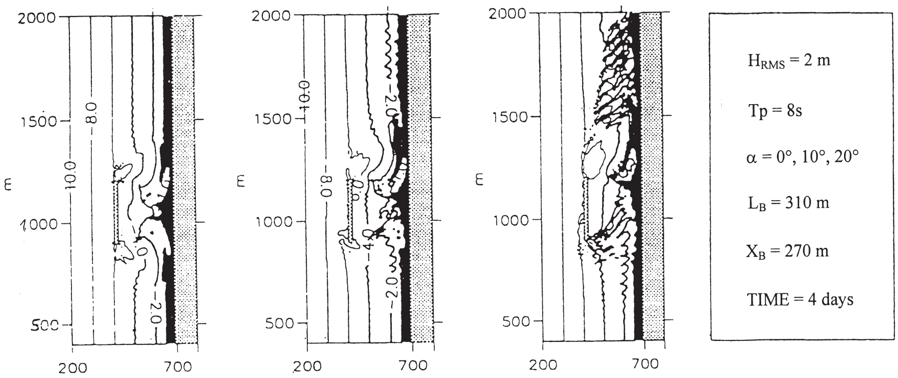


Figure 2: Morphological changes behind a shore parallel breakwater for different angles of wave approach. Results of a morphological model of DHI /5, 6/.

steady drift, but also much larger features, such as tidal sand banks, sand waves and shoreface ridges. Such an analysis, including the 3-D velocity field, revealed the essential mechanisms of the formation of large-scale rhythmic features on a horizontal seabed (sand banks, sand waves or tide-parallel ridges).

One example concerns sand waves on the seabed which can influence the effective depth of navigation channels. Here the deepening of the channel might lead to higher sand waves and to a smaller effective depth.

3.4 Long-term modelling

The driving factor behind the work on long-term modelling is the need for knowledge and model concepts with the scales of long-term/large-scale phenomena. There are practical as well as theoretical arguments for not relying exclusively on medium-term models to bridge the gap between the scales of the existing process knowledge and the scales of interest.

Large-scale modelling must be considered as being at an early stage of development. Only recently, new data-abundant monitoring techniques have been developed which enable us to study phenomena at time-scales up to a decade with a resolution of hours. These techniques are now being deployed all over the world, and they are producing results which offer perspectives for the use of advanced analysis techniques from other disciplines. For the time being, long-term modelling is still a matter of a number of ad-hoc models for specific applications /9, 10/.

3.5 Present and future projects on morphodynamic modelling

At present, research on morphodynamic modelling is being carried out in projects on large scale modelling (PACE), shore nourishment techniques (SAFE), tidal inlets (INDIA) and nearshore dynamics (SASME). Underlying processes are further investigated in several sub-projects /2/.

In a large field programme field data are gathered to support and validate the morphodynamic models

The results of the research work carried out so far in the MAST programme on morphodynamics have been published in over 460 papers, in reports, theses, congress proceedings and papers in journals. In addition, a special volume on the project was issued in 1993 in Coastal Engineering /9/, and the scientific results obtained are summarised in a book in preparation by De Vriend /10/.

Some of the software for the morphodynamics model concepts is commercially available through the big hydraulic laboratories which participated in the projects (Delft Hydraulics, Danish Hydraulic Institute, HR Wallingford, etc.).

4. Results of the MAST-project on coastal structures

The first large European project on Coastal Structures was coordinated by HR Wallingford in 1990 - 1992. This project created strong links between European research groups and formed the basis for the following MAST projects /11/:

- Monolithic coastal structures,
  coordinated by H. Oumeraci, Techn. Univ. of Braunschweig/Germany.
- Rubble mound breakwater failure modes,
  coordinated by H.F. Burcharth, Aalborg University/Denmark.
- Full-scale dynamic load monitoring of rubble mound breakwaters,
  coordinated by J. De Rouck, Univ. of Ghent/Belgium.
- Berm breakwater structures,
  coordinated by J. Juhl, Danish Hydraulic Institute/Denmark.
- Reflection of waves from natural man-made coastal structures,
  coordinated by M. Losada, Cantabria Univ./Spain.

The following MAST 3 projects are ongoing as a continuation of two of the above mentioned projects /12/:

- Probabilistic design tools for vertical breakwaters,
  coordinated by H. Oumeraci, Techn. Univ. of Braunschweig/Germany.
- The optimisation of crest level design of sloping coastal structures through prototype monitoring and modelling,
  coordinated by J. De Rouck, Univ. of Ghent/Belgium.

4.1 Monolithic coastal structures

For the stability calculation of monolithic structures the wave loading must be known. Although the front face geometry of a caisson is very simple, the wave pressures are very complicated functions of the sea state.

The character of the force histories and the pressure distributions due to breaking waves have therefore been intensively studied in the Hannover Large Wave Flume of the Universities of Hannover and Braunschweig /11/ (Figure 3).

In the tests, four principal breaker types could be distinguished (Figure 4) /13/. The highest wave impact as well as horizontal force at the structure occurs when waves are breaking against the breakwater.

Here, two cases must be distinguished: waves with an almost vertical front hit the breakwater (Figure 5), and breaking waves with an entrapped air pocket under the overturning tongue (Figure 6).

The first case has up to now been considered the most unfavourable condition with the highest impact force at the structure. Figure 7 shows the development of the dynamic pressure distribution at the structure during the wave impact. The maximum pressure occurs slightly above the mean water level. The impact duration, however, is very short ($t < 0{,}02$ s) and in general not long enough to displace the structure (Figure 8).

A theoretical distribution of the impact pressure is shown in Figure 9 /14/. However, this pressure distribution is only valid for a completely rigid structure without structural elasticity. In case of a displacement of the breakwater under the wave impact the resulting horizontal wave force will be considerably dampened.

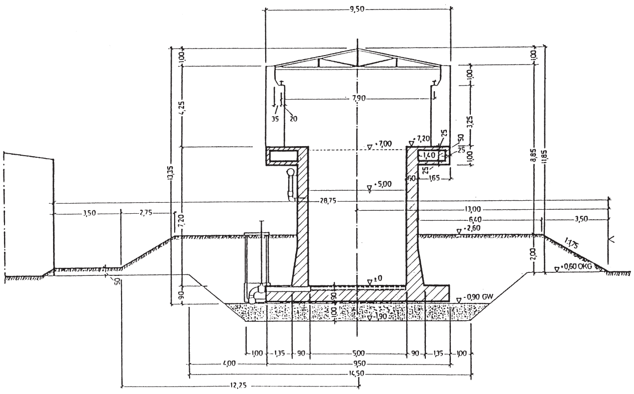


Figure 3: Cross-section of the Large Wave Channel in Hannover /11/.

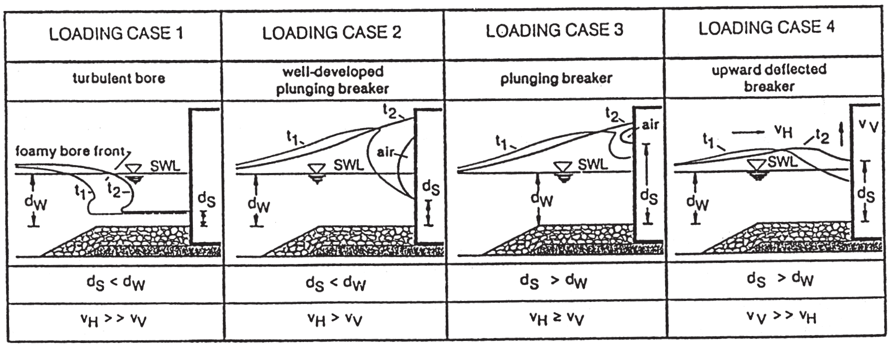


Figure 4: Classification of breaker types and loading cases /13/.

The displacement or reaction of a caisson-like structure under the wave impact is dependent on the kind of foundation, its structure and on the duration of the wave impact. Figure 10 shows some types of vertical and composite breakwaters.

In order to determine the reaction of a caisson under wave impact, some systematic tests were carried out in the Large Wave Flume in Hannover with an instrumentated caisson that has accelerometers for vertical and horizontal motions, pressure cells for impact and uplift pressures as well as pore pressure cells in the foundation (Figure 11) /14/. The tests showed only small displacements of the caisson due to the wave impact. However, depending on the breaker characteristics, the caisson oscillated with periods of 0.06 to 0.08 s, leading to structure oscillation amplitudes of 0.5 to 1.0 mm /13/.

In another series of tests, the second case of a breaking wave with an entrapped air volume was investigated. Here, the pressure and force diagramme generally showed two

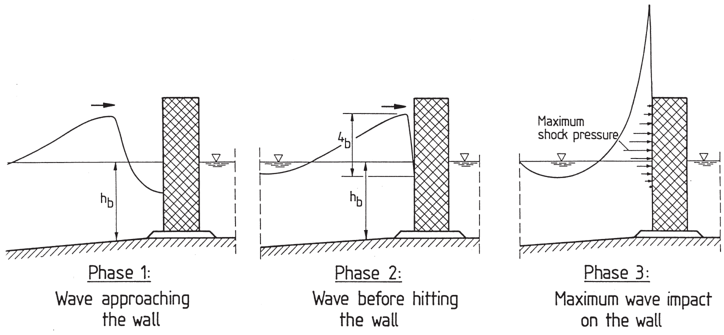


Figure 5: Breaking of wave without an enclosed air pocket /15/.

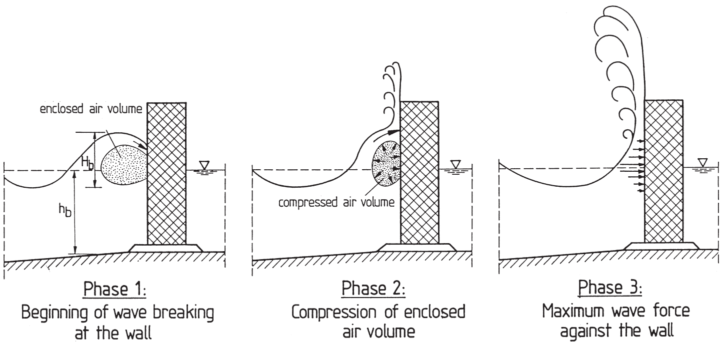


Figure 6: Breaking of wave with an enclosed air volume /15/.

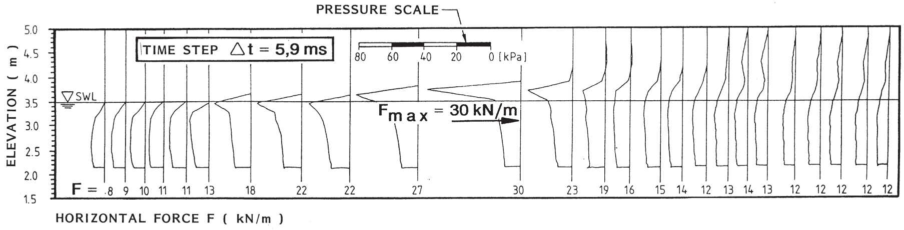


Figure 7: Development of the dynamic pressure distribution at the structure during the wave impact /15/.

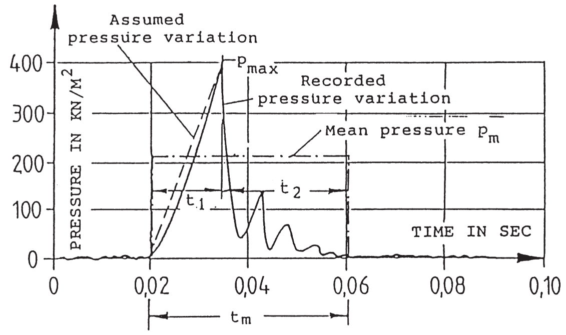


Figure 8: Duration of impact pressure /15/.

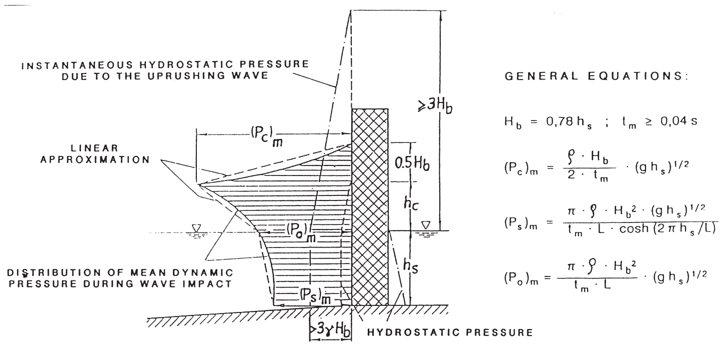


Figure 9: Dynamic pressure distribution at an unelastic rigid structure /15/.

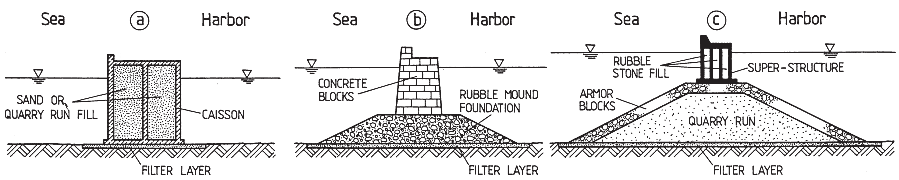


Figure 10: Types of vertical and composite breakwaters /15/.

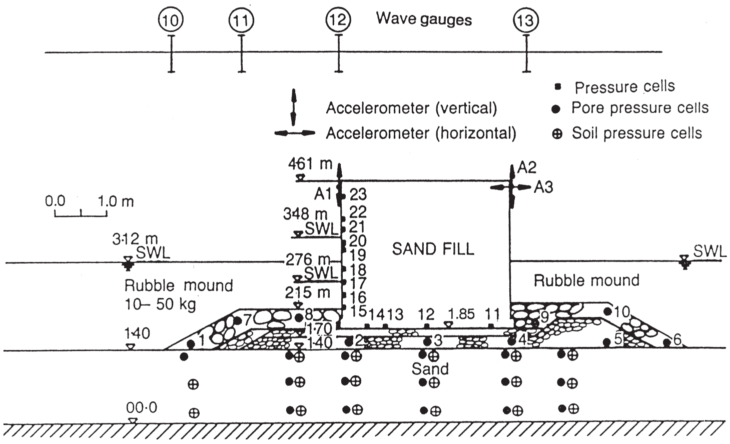


Figure 11: Cross-section of the caisson model with installed instrumentation /14/.

peaks with a time interval of approximately 0.02 to 0.03 s (Figure 12). The second peak was in this case caused by the compressed air volume. Depending upon the amount of air enclosed, the second peak pressure was in some cases higher than the first.

This means that the wave impact with an entrapped air volume can under certain conditions be the most unfavourable case for the structure. When the time lapse between the two peak forces is in the same order of magnitude as the natural period of the structure itself, the consecutive wave impact could initiate a structural oscillation. The same applies for the low frequency force oscillations following the peak values (Figure 12). The test results showed that the force oscillations have a period in the range of 0.3 to 0.7 s (Figure 13) /13, 14/.

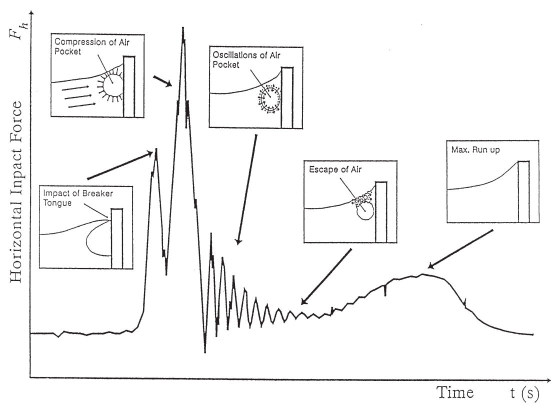


Figure 12: Horizontal impact force due to a breaking wave with an enclosed air pocket /11/.

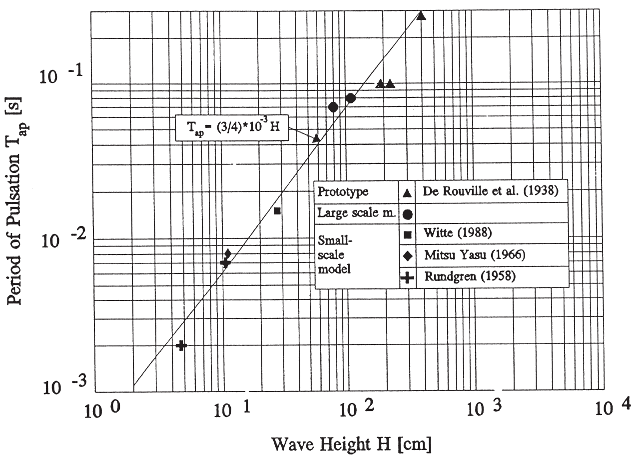
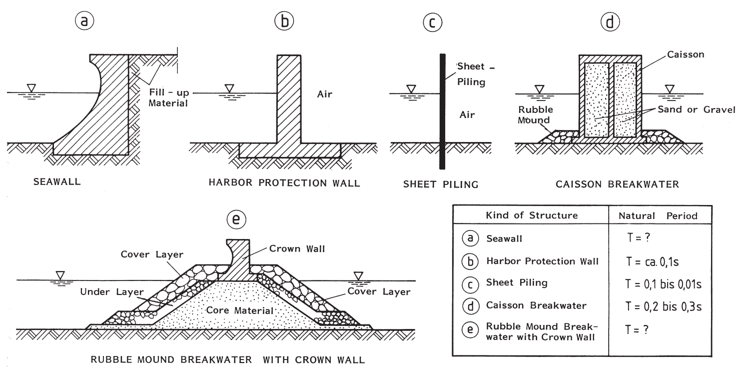


Figure 13: Pulsation Period of an entrapped air pocket versus height of breaking wave /14/.

Figure 14 shows the natural periods of some vertical structures which have been determined by means of a dying-out test /15/. As can be seen, the natural periods of vertical coastal structures lie partly in the same order of magnitude as the force oscillations due to the wave impact.

In addition, wave loads on crown walls were investigated. For the crown wall stability, the simultaneous wave induced pressures on the front face and the uplift pressures had to be analysed. A first systematic study of wave forces on crown walls of different heights including the influence of water level, berm height and width is presented by Pedersen /16/.

The results comprise the statistics of the horizontal force, the tilting moment and the wall base pressure, providing the basis for stability calculations of the crown wall.



Kind of Structure	Natural Period
a Seawall	T = ?
b Harbor Protection Wall	T = ca. 0,1s
c Sheet Piling	T = 0,1 bis 0,01s
d Caisson Breakwater	T = 0,2 bis 0,3s
e Rubble Mound Breakwater with Crown Wall	T = ?

Figure 14: Natural periods of some vertical structures /15/.

Based on experience from offshore platform designs and on extensive advanced laboratory soil tests, some guidelines for the design of foundation under caisson structures have been presented. The work continues and will probably result in sets of constitutive equations necessary for numerical stability calculations.

4.2 Rubble mound breakwaters

In a world-wide survey of existing breakwaters carried out in 1992 by an International Working Group of PIANC, some 150 rubble-mound and composite structures were investigated and the observed damage was analysed. The results showed that damage varied from slight to about 100 % and occurred to more than 25 % of all the breakwaters under investigation. The most spectacular cases within the last 15 years, with high damage or complete failure, were those at Sines/Portugal in 1978. Arzew/Algeria and San Ciprian and Bilbao/Spain /17/.

This damage and these failures show clearly that the existing design criteria for these structures are still inadequate and must be replaced by new approaches in which not only the hydraulic stability of the cover layer, which is generally composed of artificial armour units (Figure 15), is considered, but also the structural resistance of the individual armour unit against breaking due to rocking and displacement under wave impact as well as the geo-technical stability of the foundation. Figure 16 shows a typical cross-section of a rubble-mound breakwater with a crown wall.

The MAST projects of the European Union were closely coordinated with the activities of the PIANC working groups /12/. In particular, wave overtopping, wave run-up, wave

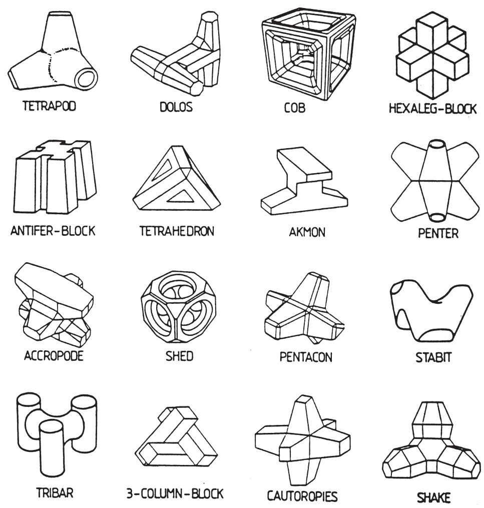


Figure 15: Artificial armour units for the cover layer of rubble-mound breakwaters.

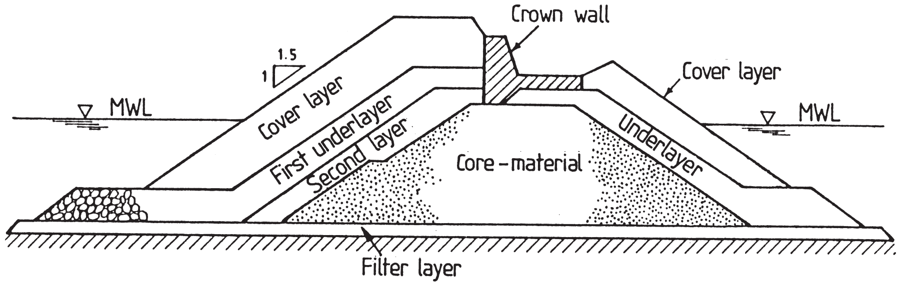


Figure 16: Typical Cross-section of a rubble-mound breakwater.

reflection, internal porous flow and pore pressure distributions have been tested in different laboratories. Special attention was paid to the displacement of armour units (Accropodes, Tetrapods, Cubes, hollowed Antifer cubes, etc.) and the breakage of slender concrete armour units (Dolosses, etc.). Coorporation between Aalborg University, Techn. University of Delft, Franzius-Institut and WES/USA resulted in formulae for a number of broken units /12/.

The breakage of slender armour units depends on the wave height, the interlocking effect between the unit blocs and on the strength of the concrete. For this reason prototype measurements of concrete strength in Tetrapods and Dolos units were carried out in Italy /18/. In addition, the effects of thermal stresses, solar stress and fatigue on the strength of the concrete in the armour units were investigated /12/.

The structural resistance of Tetrapod-blocs was investigated in the Franzius-Institute / University of Hannover. Static tests, pendulum tests and drop tests were carried out with Tetrapods of different sizes (Figures 17 and 18). Figure 19 shows a summary of the

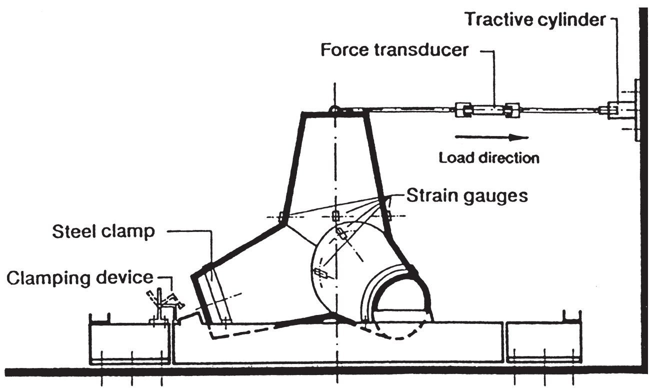


Figure 17: Set-up for static tests with tetrapods of 250 kg and 1.8 t.

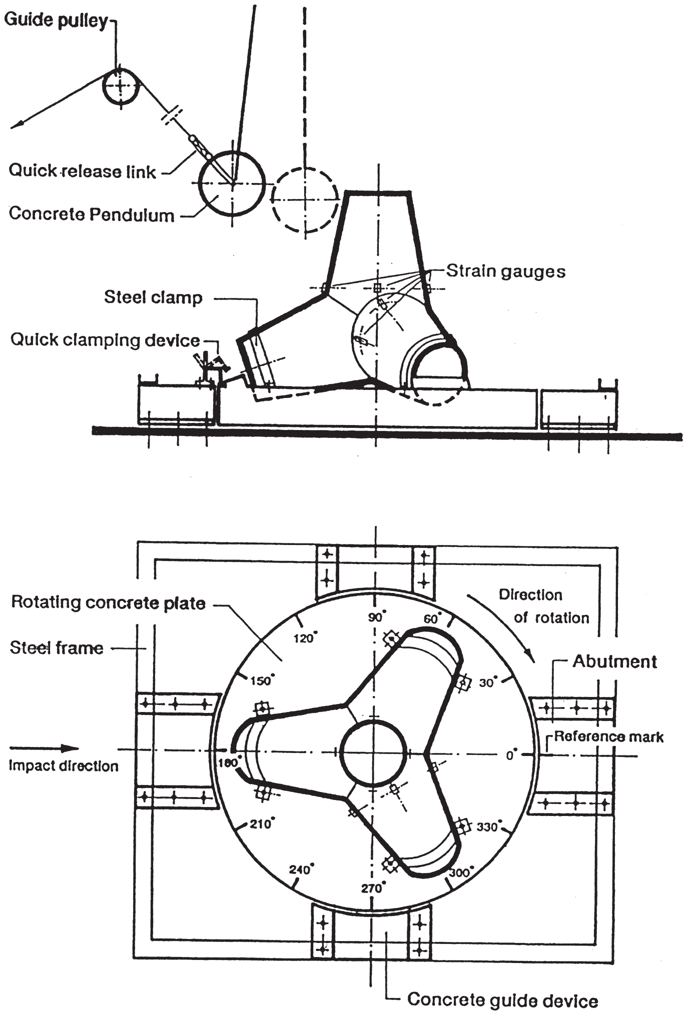


Figure 18: Set-up for pendulum tests with tetrapods of 250 kg and 1.8 t.

investigations performed. The results showed that for increasing wave heights the structural resistance of the armour units requires bloc weights higher than those determined by the HUDSON-formulae. These investigations must be continued for other kinds of slender armour units (Dolos, etc.).

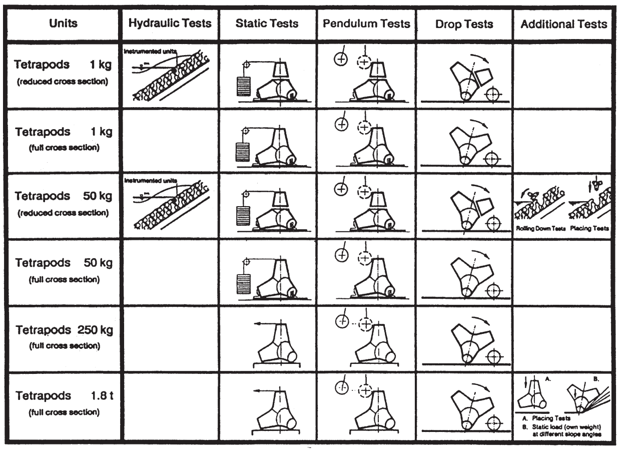


Figure 19: Summary of the laboratory tests performed with tetrapods.

4.3 Berm breakwaters

A berm breakwater is a rubble-mound breakwater with a berm above the still water level on the seaward side. During exposure to wave action of a certain intensity and duration, the berm reshapes until a final equilibrium profile on the seaward face of the breakwater is reached (Figure 20). The advantage of this type of breakwater is that the average armour rock size required for the structure is in general smaller than for a traditional rubble-mound breakwater /19/.

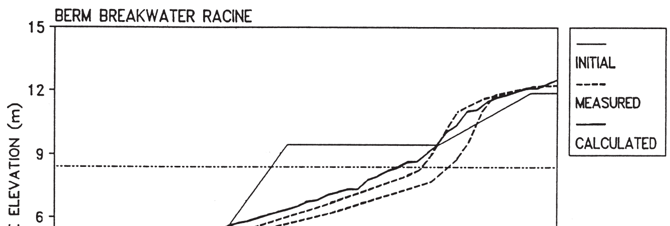


Figure 20: Comparison between measurd and computed reshaped profiles of a berm breakwater /19/.

In order to study the physics of berm breakwaters, their profile development as well as the stone transport at the trunk and the roundhead stability, eight European institutes from Denmark, The Netherlands, United Kingdom, Norway, Italy and Iceland participated in a joint research project co-sponsored by the European Commission under the second research and development programme of MAST II (1994-997). In addition, physical processes involved in the hydraulic and structural response of berm breakwaters under wave attack were examined, and a predictive numerical model for wave interaction with berm breakwaters developed. The results obtained were in good agreement with prototype measurements (Figure 20).

A summary of all the results obtained in the MAST-project can be found in the final report of JUHL, J. et al. on "Berm Breakwater Structures" of May 1997 /19/ as well as in a number of individual papers /12, 20, 21, 22, 23/.

4.4 Probabilistic failure mode analysis

The basic principle in reliability analyses is that the probability of damage is assessed for each failure mode. On this basis it is possible to estimate the safety or reliability of the whole structure by system analysis.

In each failure mode analysis all the load and resistance parameters are treated as stochastic variables. Consequently, it is necessary to introduce the uncertainty of these parameters, e.g. with the sea-state parameters (load) and the soil/strength parameters (resistance). The uncertainties with the parameters are given by their probability distributions. For most parameters a normal distribution with a certain standard deviation is used. The same holds for uncertainties concerning formulae. Most often a safety-index method is used for the estimation of the damage probability related to each failure mode /24/.

On the basis of extensive numerical simulations the PIANC working group developed a system of safety factors for most of the rubble mound breakwater failure modes and for the overall stability failure modes related to caisson breakwaters. Verification of the use of the coefficients in a fully dynamic analysis will be checked in a MAST-project and the system will be extended to include important local structure failure modes for caisson breakwaters.

4.5 Publications on breakwater research programmes

The results of the research work carried out in the MAST-projects on breakwaters and coastal structures have been published in a great number of papers in congress proceedings, scientific journals, internal reports and in theses. A summary of the findings on wave impact on vertical structures is found in the report of H. Oumeraci et al. on "Coastal structures - overview of MAST2-projects" /11/ and on rubble mound breakwaters in the book of H.F. Burchardt on "Reliability-based design of coastal structures" /24/.

5. Future research required in coastal engineering

The results of the different MAST-programmes have certainly essentially contributed to the solution and understanding of coastal problems and to the safer construction of coastal structures.

However, there are at least some main problems which must be dealt with in coastal engineering in the coming decades /25/:

1. The effect of the predicted rises of the sea water level on existing and future coast protection works as well as on the human community. (According to the latest predictions the water level rise in the next 100 years will be approximately 0.60 m/ 100 years, Figure 21).
2. The deposit of contaminated dredging material from harbours and navigation channels.
3. The increasing thermal and waste water pollution of tidal rivers, estuaries and near-shore coastal regions.

The predicted global sea level rises up to the year 2050 vary considerably; they have nevertheless sent alarming signals to all countries bordering the oceans /26/. Here more investigations are needed, based on reliable prototype data, in order to narrow the gap between the results of statistical approaches and interdisciplinary studies by means of mathematical models.

This opens a wide field of new activities for the coastal engineer in the future. All the problems to be solved are more or less linked to the adaptation of coast protection measures to the rising mean sea level. Examples in this respect are the development and construction of new harbours and access channels to them, the modification of existing jetties, the exploration and exploitation of marine resources as well as the reduction of pollution in estuaries and near shore regions, – to name a few.

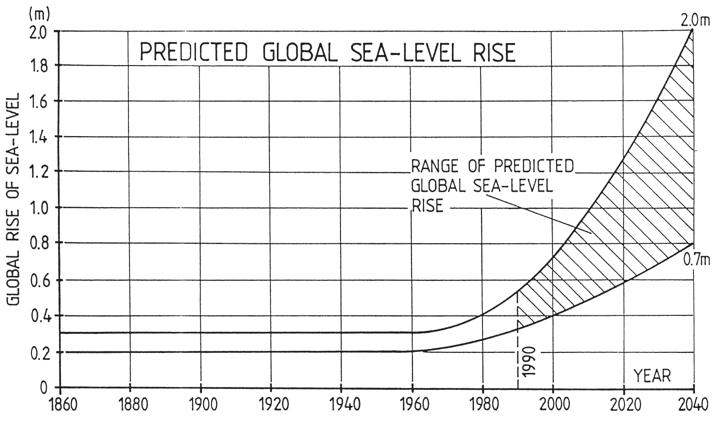


Figure 21: Predicted rise of mean sea level /25/.

The deposit of contaminated dredging material from navigation channels and harbours represents a world-wide problem for all countries bordering the sea. Here, methods must be developed to process the contaminated material in order to make it usable for reclamation purposes.

On the other hand, hydraulic measures must be investigated to reduce the annual maintenance dredging quantities in existing navigation channels as well as in the access channels to sea ports.

The tendency of new industrial plants to be constructed on the coast as well as on tidal rivers and estuaries leads to a steady increase of thermal and waste-water pollution in these areas. The cooling water systems of industrial factories and conventional as well as nuclear power plants, when designed as fresh water systems, cause increasing thermal pollution in these coastal regions due to the discharge of heated cooling water into the ambient bodies of fresh or sea water.

In addition, the continuous waste water discharge from communities, harbours and industrial factories into coastal waters must be considered a very serious problem in environmental engineering. Therefore, intensive further research on pollution problems must be carried out in estuaries as well as on the interaction of rivers and ocean regions /25, 26/.

In addition, international standards of permissible loads should be elaborated and measures to reduce the environmental impact must be developed.

However, there is still another problem in which coastal engineering and environmental engineering are closely related. Our present population on Earth amounts to approximately 6 billion, but shows a steady increase of some 300,000 people per day /27/. Our present population will therefore double in about 50 years, i.e. in the year 2050 a total of approximately 12 billion people must be expected on Earth (Figure 22).

This enormous increase in population in the near future has produced alarming signs for the whole of mankind, since the available food and water resources as well as the limited

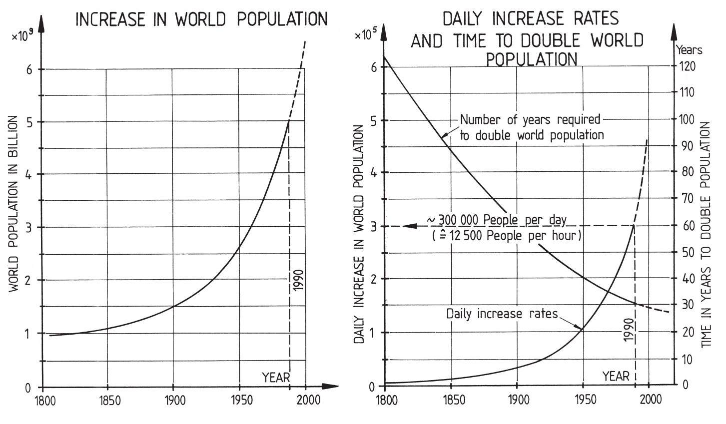


Figure 22: Increase in word population and rates of daily increase /25, 26, 27/.

resources for the production of energy are not sufficient and will be used up at a steadily increasing rate.

This certainly involves a great number of future problems in which the coastal engineer also has a world-wide task.

In addition, the increasing demand of our population for leisure and recreation (Figures 26, 27) requires the urgent preservation of existing natural beaches as well as the creation of new, artificial resorts. This means that new methods must be developed and tested to sustain and protect our sandy coasts from erosion by means of artificial beach nourishment, stabilisation of the bar-systems as well as by use of tombolo-effects (Figures 23, 24, 25).

Figure 23: Beach nourishment on the Island of Sylt / Germany / 25/.

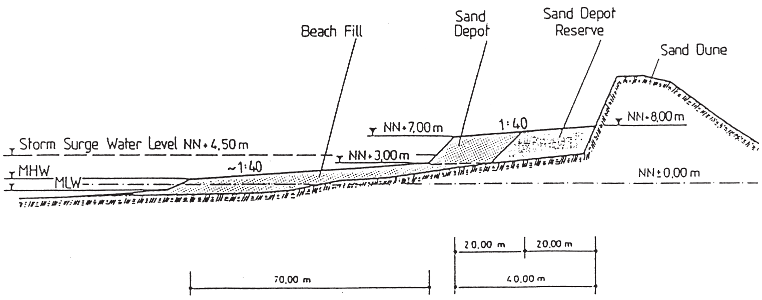


Figure 24: Principle of beach nourishment of the Island of Sylt /25/.

Figure 25: Effect of detached breakwater at the Spanish Meditarranian coast (tombolo effect) /25/.

Ladies and Gentlemen, the time is certainly not sufficient to discuss all the aspects of future research required in coastal engineering.

However, the presentation of the present European Research Programmes already shows that international cooperation is required to solve a few urgent problems in our field. It is hoped that the already existing connections of our European research laboratories with scientists of overseas countries such as Japan, USA, Canada, Australia, etc. will be intensified in the years to come because the solution of the world-wide problems I have mentioned need the international collaboration of all the scientists and research institutes in the world.

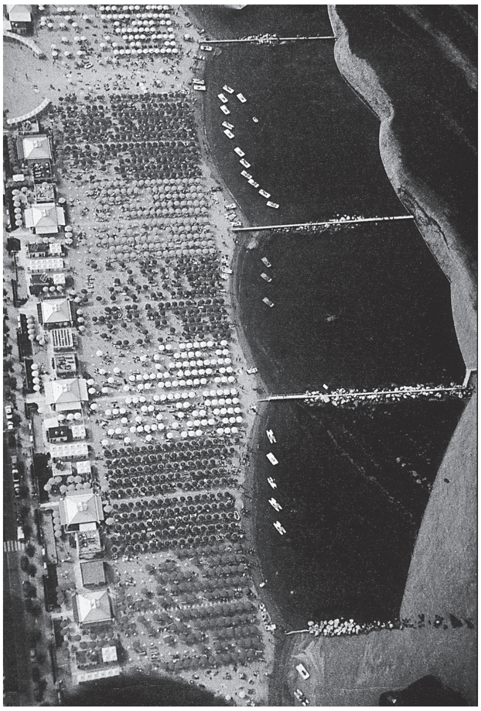


Figure 26: Densely occupied beach at Rimini /Italy

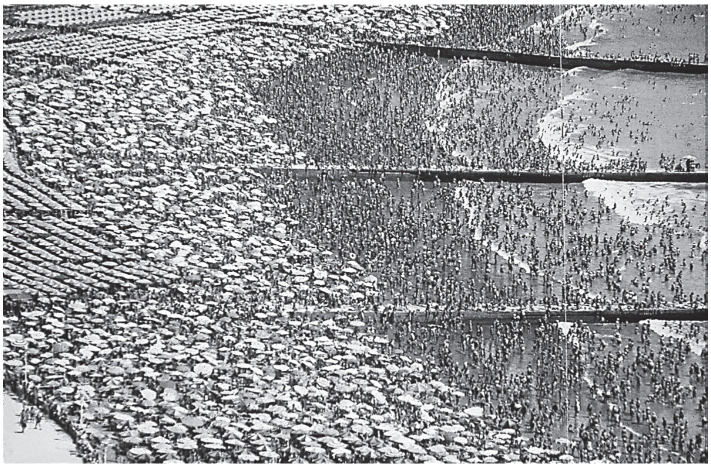


Figure 27: Overcrowded beach at Mar Del Plate (near Buenos Aires) Argentina.

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