Recent Experience with Non-Conventional Rubblemound Breakwater Designs

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INTRODUCTION

Baird & Associates has been involved in the modeling, design and construction of numerous conventional, non-conventional and innovative breakwater designs over the past 25 years. This paper provides a discussion of the design process utilized by Baird & Associates for the design of breakwaters and other coastal structures. This is followed by brief summaries of four recent projects that required the development of unique rubblemound breakwater designs to meet project specific constraints, criteria and requirements.

DISCUSSION OF OVERALL DESIGN PROCESS

For the purpose of this paper, it is assumed that the project type (i.e. port, marina, etc.), location and layout have been previously defined. In other words, the investigations leading to site selection and overall project layout have already been completed.

The breakwater design process, which is generally applicable to other types of coastal structures as well, includes a logical sequence of activities that facilitates the consideration of numerous and complex issues as they relate to various stages in the design process. The design process is summarized below.

Phase I - Review and Assessment of Design Alternatives

Task I-1 - Review Relevant Background Information
This task involves a detailed review and assessment of background information of relevance to the project, including:

- Project objectives/functions/purpose/performance criteria;
- Structure objectives/functions/purpose/performance criteria;
- Site conditions (in particular, water depths and bottom conditions);
- Environmental design conditions (wind, waves, water levels, ice);
- Coastal processes (currents/circulation, sediment transport/budget);
- Available materials - alternative sources, characteristics and unit costs for quarried stone, concrete, steel and other structural materials;
- Construction issues - access, available equipment/expertise.

It is noted that a significant level of effort may be required in order to define the site conditions, environmental design conditions, coastal processes and available materials. This may include field investigations (topographic and hydrographic surveys, geophysical and geotechnical investigations, deployment of met-ocean equipment, etc.), numerical modeling of waves and coastal processes, etc. In addition, discussions with quarry operators and contractors may be required to define available materials and construction issues. The requirement for and scope of these investigations will be dependent upon the scope of the project, the characteristics and complexity of the site and coastal environment, and available data.

Task I-2 - Identify Alternative Design Concepts
This task involves the identification and preliminary assessment of alternative design concepts. Initially, a "long list" of structural concepts should be developed, potentially including:

- Rubblemound structures (conventional and non-conventional design concepts);
- Vertical wall structures (conventional and non-conventional caissons, steel sheet pile cells, parallel sheet pile walls, etc.);
- Composite structures (vertically or horizontally composite)
- Other structural concepts (i.e. curtain walls, floating breakwaters, etc).

It is important to note that not all concepts will be appropriate for every project. In particular, the water depths, bottom conditions and wave climate may preclude certain concepts. In addition, the availability/cost of suitable construction materials and equipment will be an important factor. Review and assessment of these issues by the design team will lead to the identification of a "short list" of breakwater design concepts that warrant more detailed consideration.

Task I-3 - Concept Design Development and Assessment
This task involves conceptual design development for selected design alternatives, including:

- Preliminary design cross-sections for representative locations along the length of the breakwater;
- Preliminary quantity and cost estimates;
- Comparison of alternatives under key categories, including:
  - Cost (capital and maintenance),
  - Conventional vs. non-conventional design concept (design scope/risk),
  - Performance under design conditions relative to design criteria,
  - Risk/implications of non-performance (operational and structural),
  - Available materials,
  - Construction logistics,
  - Environmental impacts.

A comparative assessment is then undertaken in order to identify preferred alternative(s) for detailed design development. This may be facilitated through the application of a matrix method, with each alternative ranked within each category, including appropriate weighting factors. It is noted that the weighting factors may be project and Client specific. As such, Client input may be required to define appropriate weighting factors. The result of this task, and the outcome of Phase I, is the selection of one (or more) design concept(s) for detailed design development.

Phase II - Detailed Design Development for Selected Alternative(s)

Task II-1 - Initial Design Development
Initial design development for the selected alternative(s) is generally undertaken using a combination of desktop analyses and the prior experience of the design team. The desktop analyses are generally based on the application of internationally accepted empirical

methodologies (i.e. from coastal engineering design manuals and published technical papers). This task should consider the following issues:

- Armour layer stability (toe, front slope, crest and rear slope);
- Filter/core/bedding requirements;
- Toe details (considering local scour and long-term erosion);
- Wave runup/overtopping/transmission/agitation;
- Functional requirements (access, berthing, facilities, utilities, navigation aids).

Refined design cross-sections are then developed for representative sections/zones of the breakwater, leading to an updated quantity estimate for each alternative. Updated unit costs are applied to these quantities to provide a comparative estimate of costs for each alternative. A final evaluation of the design alternatives is then completed (perhaps by updating the matrix comparison completed in Task I-3), leading to the selection of the final design concept for implementation.

Task II-2 - Detailed Design Development and Optimization
Detailed design development and optimization is generally undertaken using a physical model. Although significant advances have been made in recent years with numerical models, a physical model remains the best tool available to assess the complexities of wave-structure interaction.

A physical model investigation is recommended for large projects, and is essential for unique or complex structures. The cost of a physical model, although significant, is generally more than offset by cost savings associated with design optimization that would not have been possible without the model. All four projects described later in this paper utilized extensive physical modeling to support the design process.

Task II-3 - Final Design Development
Final design development includes a detailed and critical review, analyses and interpretation of key issues, including:

- Design criteria;
- Design conditions;
- Preliminary designs;
- Physical model results;
- Construction issues;
- Cost.

This is followed by the development and optimization of key structural components, and the definition of specific design details (transitions, terminations, etc.).

Task II-4 - Plans and Specifications
The plans and specifications are the basis from which the Contractor builds the breakwater. These “Contract Documents” must “communicate” the overall “intent” of the Engineer’s design to the Contractor. As such, it is essential that the plans and specifications provide a clear, concise, thorough and accurate description of the final design, including geometric requirements,

material specifications, etc. In addition, the specifications should define specific requirements for a systematic and detailed quality control and quality assurance (QC/QA) program. The importance of the plans and specifications can not be overstated, as missing or erroneous information, duplication and inconsistencies will lead to disputes and claims during construction.

Phase III - Construction

It is preferable, if not essential, that the design team be involved in the construction phase. This provides continuity to the project, in particular allowing the design team (the "Engineer") to monitor construction and provide input to the Contractor and Owner regarding the "nature" and "quality" of the construction relative to that assumed in the design. The level of support provided by the Engineer to the Owner during the construction phase may vary, but generally includes input to following activities.

Task III-1 - Bidding
The Engineer may support the Owner in a number of areas, such as the pre-qualification of bidders, the preparation of bid documents and the review/evaluation of bids.

Task III-2- Construction Administration/Observation
The Engineer may provide various services related to construction administration/observation over the duration of project construction. This may include full-time representation at the project site ("Resident Project Representative") and/or quarry, or a reduced role (Expert Review) with visits to the project site at selected/critical stages during the construction period.

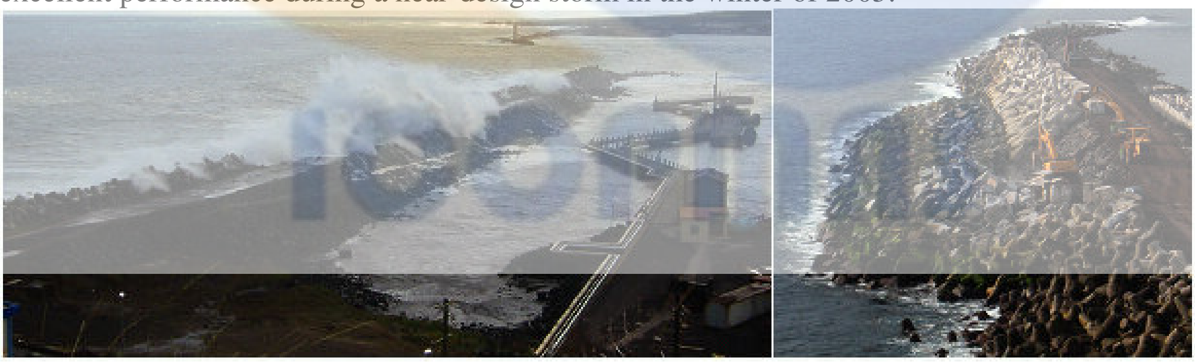
Obviously, high quality construction is essential to the long-term success of any project. There are many examples where poor construction has resulted in damage to and failure of coastal structures. A good design is no guarantee against such problems. As such, the design team should insist on a significant role during project construction.

RECENT PROJECT SUMMARIES

Toronto Western Beaches Watercourse Facility - Ontario, Canada
This fast-track project involved the planning, design and construction of a $20 M, 600 m long rubblemound breakwater in order to protect a new flatwater race course along the Lake Ontario waterfront in Toronto. The breakwater is constructed in depths of 5 to 7 m, with a design wave height of Hs ~ 4 m. Numerous breakwater design concepts were considered, including steel sheet pile cells, concrete caissons and conventional and non-conventional rubblemound designs. The fast-track schedule was a key consideration, with the environmental assessment, design and construction to be completed within approximately 18 months. A detailed evaluation of these alternatives led to the identification of a rubblemound breakwater as the preferred design concept. Extensive physical model investigations at CHC in Ottawa, Canada were undertaken to evaluate alternative rubblemound designs, leading to the development of a non-conventional "wide armour layer" design. The breakwater was constructed over the fall/winter of 2006-07, on budget and ahead of schedule. The new facility hosted the International Dragon Boat Federation Club Crew World Championships in August 2006.

Lajes Field Breakwater Rehabilitation - Azores

This project involves the design and phased construction of a major rehabilitation of a damaged tetrapod breakwater that protects a critical US military installation in the Azores. The breakwater has a long history of damage and repair, with extensive damage caused by a number of severe storms in the early 2000s. The repair concept consists of a "hybrid" design, including a "revement" of Core-Loc units protecting the upper slope of the existing breakwater, and a wide berm of armour stone placed in front of the Core-Locs and over the existing rubblemound to dissipate wave energy. The breakwater is exposed to severe storm conditions every winter, with a depth-limited design wave height of Hs ~ 8 m. The proposed design was model tested at the USACE/ERDC/CHL in Vicksburg, USA, with construction being implemented in several phases due to budget and weather constraints. The partially completed rehabilitation demonstrated excellent performance during a near-design storm in the winter of 2005.



Port d'Ehoala - Madagascar

This project involves the construction of a new port facility in southeastern Madagascar. The site is exposed to persistent South Atlantic swell waves, with the extreme design conditions (depth-limited Hs ~ 7.5 m) caused by tropical cyclones. Various design concepts were considered for the 600 m long breakwater, including concrete armour units and various berm breakwater configurations (single and multi-class berms). Initial investigations identified the multi-class berm design as the preferred concept. The concrete armour unit alternatives were deemed too risky due to the requirement to place large armour units in persistent and significant swells, with the associated risk of breakage. An extensive 3D physical model investigation was undertaken at HRW in the UK to develop and optimize the breakwater design. The port construction contract has recently been awarded, with breakwater construction scheduled to begin in early 2007.

Matane West Breakwater Rehabilitation - Québec, Canada
This project included the assessment of historical damages to a large breakwater in Québec, and the development of rehabilitation designs for critical locations. Two specific problem areas were identified, including the armour stone trunk (with a history of recurring localized damage) and the tetrapod roundhead (with two failures since completion in 1970). Baird's assessment identified a number of potential causes for the damage, including undersized armour units, stone degradation, and possibly displacement of tetrapods by severe ice action. Initial design investigations were undertaken to assess alternative rehabilitation concepts, leading to an extensive model investigation for two concepts, one using Accropodes and the other using a multi-class berm. The physical model investigation was undertaken at CHC in Ottawa, Canada. Ultimately, the berm design was selected for implementation due to its lower estimated cost, and also a reduced risk of damage by ice. Funding constraints may require phased implementation, with the first phase (reconstruction of the roundhead) anticipated in 2007 and the second phase (reconstruction of the armour stone trunk section) to follow in 2008.

SUMMARY

This paper provides an overview of the design process applied by Baird to breakwater structures. This design process has evolved through practical experience gained on a wide range of coastal engineering projects implemented around the world over the past 25 years. The paper also includes brief summaries of four recent projects that required the development of unique breakwater designs to meet project specific constraints, criteria and requirements.

The following comments are highlighted for the consideration of other breakwater designers:

- Physical modeling remains the best tool available to assess the complexities of wave-structure interaction. A physical model investigation is recommended to support design development for large projects, and is essential for unique or complex structures.
- The plans and specifications "communicate" the overall "intent" of the Engineer's design to the Contractor. It is essential that the plans and specifications provide a clear, concise, thorough and accurate description of the final design, as well as specific requirements for a systematic and detailed quality control and quality assurance (QC/QA) program.

- The design team (the "Engineer") has a key role to play during construction, providing input to the Contractor and Owner regarding the "nature" and "quality" of the construction. There are many examples where poor construction has resulted in damage to and failure of coastal structures. A good design is no guarantee against such problems. As such, the design team should insist on a significant role during project construction.