A Dynamic Approach to Determining Waterway Capacity

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Abstract
Determining waterway capacity is essential in making decisions to develop infrastructure that will affect that capacity. Conventional methods of determining waterway capacity do not adequately replicate operational activity. This reduces the probability that design objectives for infrastructure developments will be delivered in operation.

Consideration is given to the requirements of determining waterway capacity for a channel deepening project. Conventional methods and their deficiencies are discussed. An alternative method is outlined. This method utilises operational decision making procedures and systems in simulation models to determine waterway capacity and the effect of changing channel dimensions on that capacity. For the methodology to be effective, the systems and procedures used must engender consistent, repeatable decision making.

A case study is presented of the application of this methodology to channel design at the Port of Newcastle. This includes a description of the implementation of a Swell Analysis and Underkeel Clearance System (SAUCS) and the use of that system in the analysis of waterway capacity for the purpose of investigating various channel design scenarios.

The requirements for determining an optimum channel design are discussed. This includes consideration of the competing requirements of different waterway activities.

Finally, consideration is given to the broader application of this methodology by integrating with simulation models of other waterway activities. This can provide a more complete quantification of waterway capacity in that all activities relying upon the waterway resource are factored in when quantifying capacity.

1 Introduction

An article discussing waterway capacity (Blume 2005) recently appeared in a PIANC magazine. This article calls for waterway managers to consider waterway capacity in much broader terms than just the ability of the main shipping channels to accommodate large vessels. Reading this article in light of OMC International's (OMC) recent experiences in channel design prompted the question, "Are traditional methods of determining waterway capacity adequate to support decision making for major infrastructure development projects, particularly for the design of channels to accommodate large vessels?"

This paper ponders the obstacles to accurately quantifying waterway capacity and presents a methodology that has been applied to overcome many of those obstacles. Consideration is primarily given to waterway capacity in terms of large vessel access through port approach channels. However the obstacles and solutions posited for this narrow consideration of port access can be equally extended to a broader consideration of waterway capacity.

2 Background

It is first necessary to define what is meant by "*accurately* quantifying waterway capacity". This is not to consider waterway capacity more broadly as suggested by Blume – those issues have been adequately covered. Rather, to determine waterway capacity for the purpose of assessing the merits of a proposed infrastructure development such that the predicted capacity will correlate accurately with the operation of the waterway following completion of the development.

To accurately quantify waterway capacity is surely crucial for waterway managers considering infrastructure developments. Only with reliable predictions is it possible to state to all development stake holders that in undertaking the development the effect on waterway capacity in operation will be X, and to be confident that in operation X will be achieved. Stake holders could make their assessment of the merits of the development based upon reliable information about its operational outcomes.

The experience of OMC has been that whilst considerable time and resources may be spent attempting to determine waterway capacity in planning for infrastructure developments, the result usually falls well short of accurate quantification. A complicating factor for Australian ports in determining waterway capacity is irregular exposure to wave events which cause enormous variations in depth requirements for the safe passage of large vessels.

In the case of planning a channel deepening project, a common method of determining waterway capacity is with reference to a particular vessel size and wave and tide event. That is, to design channel depths such that adequate underkeel clearance (UKC) will be ensured for vessel *A* on all occasions when the tide level exceeds *X* metres excluding occasions when the most severe *Y* percent of wave conditions prevail. An example of a waterway capacity statement would then be; a proposed channel design will guarantee 14.0m draft access with 1.5m tidal assistance during 95% of wave events (i.e. excluding 5% of the most extreme wave events).

When such a statement of waterway capacity is provided, stake holders should ask, how are these numbers arrived at and what evidence can be provided that this statement will correlate with operational waterway capacity?

These questions should be asked because the determined waterway capacity is crucial to the justification of the project. The vagaries of project outcomes that these waterway capacity statements can disguise include:

1. What is the range of vessels that have been considered in determining waterway capacity? 14.0m draft vessels vary considerably in their other dimensions and handling characteristics. Furthermore, the same vessel can be loaded to a draft of 14.0m in a variety of configurations, each making it more or less responsive to a given wave environment.

2. How is a 95% wave event to be interpreted? A 95% wave event is referring to the extremeness of the wave condition – i.e. 5% of wave events will be worse. What is meant by "extreme" – higher peaks, longer period, unfavourable direction, more sudden arrival? "Extreme" should refer to the capacity of an event to cause vessels to move and to the capacity of waterway operations to respond to the arrival of the event. In light of point 1, the 95% condition should be determined by considering the coincidence of a range of wave events with a range of vessels.

3. For the vessels and wave and tide events considered, how was it determined that the limits of depth requirements were being reached? Was a gross UKC allowance applied, or was each of the factors that will reduce UKC (squat, heel, wave response) individually calculated? What is the accuracy of the method used and how were the uncertainties accounted for?

4. To what extent have operational rules that will be used to determine access through the waterways been considered in determining waterway capacity? If operational rules have not been considered or indeed they are unknown, then statements of waterway capacity are meaningless for operations.

5. If operating rules have been considered, to what extent do they lend themselves to a accutate quantification of waterway capacity? For example, if a static rule is used for determining tidal windows for vessels transiting a waterway and that static rule is known to be inadequate in certain environmental conditions, how are the limits of that rule determined in operation. Commonly, it is left to the pilot's discretion to determine limiting conditions, perhaps with the guideline of a limiting wave height. In terms of determining waterway capacity this is problematic because opinions of limiting conditions will vary between pilots. This variability does not lend itself at all well to accurate quantification so cannot be considered systematically in determining waterway capacity. In this case, use of the static rule to determine waterway capacity will not produce a result that correlates with operations.

6. To what extent have other operational constraints been considered such as vessel manoeuvrability limits and current forces, availability of navigation aids, night restrictions on sailings, berth availability, tug availability and the cargo supply chain to the ship? All of these factors, if not considered adequately will cause operating waterway capacity to diverge from design capacity.

Stakeholders must put these questions to waterway managers to assess the value of infrastructure developments in terms of their own interests, be they safety, economic or environmental. Waterway managers should be able to demonstrate that the waterway capacity statement provides an accurate indication of operating capacity following the development. The applicability of the waterway capacity statement to operational capacity should not be marred by systematic flaws in the methods used to determine waterway capacity or by separation of infrastructure design and operation.

3 Methodology

Continuity between design objectives and operational outcomes is achieved by comprehensively defining the operational environment and then using the operational processes to drive the design.

In the case of designing a channel, the methodology to apply that will ensure correlation between design objectives and operational outcomes is as follows:

1. **Comprehensively determine the operational environment**. This means developing a system that ensures operational safety in all conditions; benign, extreme or changing. The system should include the following components:

a. Hardware systems to monitor environmental conditions.
b. Software systems to analyse environmental data and assess the effect of conditions on vessel sailings.
c. Documented procedures for the operation of these systems, including how and when to interpret the data.

The accuracy of the system must be known and the users of the system must have confidence that it will ensure operational safety for the passage of vessels through the designated waterways in all conditions. In this way the variance of sailing decisions can be minimised allowing accurate quantification of waterway capacity for any given event.

2. **Collate information on vessel movements**. It is necessary to understand and quantify the range of vessels that might be required to transit the channel, the manoeuvres they perform and speeds at which they transit and the range of environmental conditions to which they will be exposed. The vessels should include realistic ranges of dimensions, hull shapes and load states. Environmental information should include joint occurrence information of different met-ocean effects.

3. **Simulate waterway activity**. Simulate each vessel transit and environmental condition combination using the operational system. For each simulation, the minimum channel dimensions for safe passage through each segment of the waterway should be determined.

4. **Query the result-set of simulations**. The results of simulations can be queried by:
   a. Setting environmental and sailing constraints as the limits of safe passage to determine the minimum channel dimensions required, given those limits.
   b. Setting the channel dimensions and determining the constraints that will apply as the limits of safe passage.

Either querying method will result in waterway capacity quantification for a particular channel design that will correlate with operational capacity.

4 Case Study – Port of Newcastle

In early 2004, OMC was part of a successful tendering group (with Lawson and Treloar) to provide a Swell Analysis and Underkeel Clearance System (SAUCS) to the Newcastle Port Corporation (NPC).

NPC manages the Port of Newcastle which is the economic and trade centre for the resource rich Hunter Valley and for much of the north and northwest of NSW.

The Port of Newcastle is the worlds largest coal export port, with over 3000 shipping movements annually handling cargo in excess of 82.7 million tonnes per annum (mtpa), of which coal represents more than 90% of the throughput tonnage.

There are tidal restrictions on deep draft vessel movements to and from the Port of Newcastle. This situation is complicated by irregular exposure to severe ocean swells at the port entrance.

4.1 SAUCS Implementation

SAUCS was to be implemented primarily to assist with monitoring the prevailing environmental conditions at the port and to assess the effect of those conditions on vessel sailings, concentrating particularly on UKC. To this end, SAUCS was implemented in a staged process:

1. Design and documentation of standard operating procedures and work flows to describe how the system would integrate with existing operations. This included the modes and timing of data flow to the system and the dissemination of outputs to port operations personnel. Areas where new procedures or changes to existing procedures were required were identified.

2. Design and specification. This included functional design to ensure all functional requirements of the system would be met by the proposed solution. Environmental and vessel transit analysis was also conducted to provide a complete understanding of met-ocean conditions at Newcastle. In particular it was necessary to understand the interaction between the complex wave environment at Newcastle and vessels transiting the port entrance channel. The system includes two Datawell Directional Waverider Buoys to provide redundancy in the measurement of the wave environment. UKC analysis is performed using OMC's DUKC® technology.

3. Implementation. The hardware and software components of the system were installed and commissioned. Users of the system were provided with training in its theory and operation. Full scale measurements of vessel motions will be undertaken as a final validation of the DUKC® modelling.

The implementation process involved a rigorous assessment of all environmental conditions. All the relevant parameters of the prevailing met-ocean conditions are monitored by quality assured systems with redundant backups. The dimensions and load characteristics of each vessel are considered independently for each transit by the DUKC® to determine all UKC factors as the vessel makes its transit. DUKC® modelling considers the prevailing met-ocean conditions and net UKC is always maintained above agreed limits consistent with international guidelines and the capabilities of the models. There are specific guidelines for the operation of the system set out in the port's operating procedures.

SAUCS has provided NPC with scientifically verifiable processes of assessing vessel movements which conform to consistent and agreed levels of safety. The consistency and repeatability engendered by the system lends itself well to simulation analysis to determine waterway capacity.

It was with the expectation of this outcome that NPC included channel design analysis as part of the tender specification for the SAUCS project.

4.2 Channel Design Analysis

Having configured and installed the SAUCS including DUKC® software and procedures for its operation, it was possible to perform channel design analysis as described in section 3.

The requirements of each step in the channel design methodology were met as follows:

1. **Comprehensively determine the operational environment**. The requirements for a comprehensive understanding of operating conditions and a system to provide accurate sailing advice have been met by the implementation of SAUCS as described in section 4.1.

2. **Collate information on vessel movements**. The existing channel can accommodate cape sized vessels with drafts up to 15.5m. An increase of approximately 1.0m was selected for the channel design. Analysis was performed on 15.5m draft vessels to quantify the existing channel capacity and on 16.5m to 17.5m draft vessels to quantify the capacity of various dredging options.

   OMC maintains a database of all vessels that use DUKC® systems. This database was queried for cape sized vessels loaded with coal with drafts of 15.5m to 17.5m. This yielded approximately 100 vessels with a range of dimensions and stability characteristics as would be expected to call at Newcastle presently and following the deepening.

   Vessel transits to be modelled included departures from the Kooragang and Dyke deep draft berths and northern and southern departure tracks from the breakwaters.

   A complete set of met-ocean data was available for the period 2002 to 2004 at approximately 1 hour intervals. Analysis during the SAUCS implementation process demonstrated that this data-set is representative of the met-ocean conditions experienced at Newcastle over the past 14 years when key parameters are compared.

3. **Simulate waterway activity**. DUKC® simulations were undertaken in accordance with SAUCS operating procedures to determine UKC requirements. For each environmental data set 15.5m to 17.5m draft vessel (chosen randomly from the vessel data-sets) were simulated transiting from the Dyke and Kooragang berths and following the northern and southern departure tracks. In total, over 150,000 transits were simulated. For each simulation the UKC profile (UKC requirements for each segment of the channel from berth to deep water) was created. This information allowed the minimum depth requirements to be determined for each UKC profile.

4. **Query the result-set of simulations**. To quantify the capacity of the port channels in their existing configuration, the results of the 15.5m draft sailings were queried with the existing channel dimensions applied as a constraint. This accurately quantified the existing channel capacity as a percentage of occasions when 15.5m draft vessels can safely transit the channels. It also allowed the quantification of the minimum tide for the commencement of a transit and the limit of wave conditions for safe passage.

   A series of potential new channel designs was developed by first querying the transits database to determine the depth profile required to allow close to 100% access. Other designs were developed by applying constraints on wave and tide conditions or by specifying depth in certain areas and querying for the percentage of vessels that would be able to pass.

   Through comparison with the existing channel capacity results, NPC was able to make an assessment of the relative gains of each potential new channel design. **NPC can have confidence that these potential gains will correspond to operational gains because the designs were generated and analysed using simulation models subject to actual operational constraints**.

4.3 Optimal Channel Design

Ultimately it is the responsibility of the waterway manager to decide upon the optimal channel design for their operation and present this to the stakeholders. What is optimal will vary depending upon the often competing requirements on the waterway as a resource. These could include:

1. The cost of deepening in different areas in terms of economics and environmental effects.
2. The risk of unknown costs of dredging in different areas in terms of economics and environmental effects.
3. The economics of operating the waterway in terms of cargo throughput.

4. The responsibility of the waterway manager to ensure safety.
5. The requirement that the waterway manager can be seen to be running an economic and safe operation so the stakeholders will have confidence in using that waterway.
6. The interests of other waterway users such as recreational groups.

The methodology described in this paper and applied at the Port of Newcastle allows the waterway manager to appreciate the effect of deepening in various areas in terms of the effect it will have on operations. For example, for waterways exposed to high swells it should be appreciated that the benefits of deepening in the swell affected areas will be acutely subject to the law of diminishing returns. The further the channel is deepened, the rarer are swell events requiring that deepening for safe passage of vessels. The benefit of deepening in terms of increased port access reduces.

This information is fundamental to points 1 to 5 above. It should also be considered fundamental in terms of providing other waterway users with confidence that decisions that may affect their activities are based on reliable information. That is, in the cost-benefit equation used to justify the proposed design, the benefits are meaningful in that they will be realised in operation.

5 Future Developments in Channel Design

This methodology of determining waterway capacity can be seen as a first step towards Blume's call for a more comprehensive consideration of waterway capacity.

OMC has begun investigating a broader application of this methodology by integrating it with more comprehensive waterway infrastructure activity simulation. In the case of port infrastructure developments this includes integrated simulation of the land and water sides of port activities.

Simulation models are in common use in assessing the requirement for infrastructure development at ports. However they tend to concentrate mostly upon land-side activities. Simulations of water-side activities are crude in that broad statistical assumptions are used in place of operational decision making procedures and systems. The crudeness of these assumptions robs the simulations of the capacity to accurately mimic operations and more importantly to detect the subtleties of the effect on operations that can result from infrastructure changes.

For example, consider a port using a DUKC® to determine sailing drafts and times. It will often be that the choke points in the channel controlling sailing times and drafts are not the shallowest points in the channel. Deepening the shallowest points may have no effect on sailings, whilst deepening the choke points could greatly increase drafts and sailing windows. Further, there will be a limit to the benefit achieved from deepening each choke point as the control will move to other areas.

Approximating DUKC® sailing advice with static or statistical advice in simulations of waterway activities will not detect these subtleties. The resulting errors can be significant. Not only will sailing drafts not correspond with operations, but over time the number of vessel movements will differ.

These errors can be greatly reduced by integrating operational systems such as DUKC® with waterway activity simulation models. Simulation models can also be extended to include other waterway activities be they recreational or commercial.

This can be achieved now. The methodology and technology exists. Modern computers are up to the computational task. The only obstacles are:

1. Waterway managers must have in place procedures and systems that lead to consistent operational decisions which enable repeatability in simulations. These systems should also preserve decision making information.

2. Stakeholders in waterway infrastructure developments demand that accurate quantification of the effect of developments on waterway capacity be provided. Statements of waterway capacity should correlate from design to operation.

The resulting simulations will provide more accurate quantification of waterway capacity. The potential for infrastructure projects to succeed will increase because the projected outcomes and therefore the objectives that justified the project will be achievable in operation.

6 Conclusions

- Accurate quantification of waterway capacity is essential in assessing the merits of proposed waterway infrastructure developments.

- Conventional methods of quantifying waterway capacity are inadequate in that they are unable to realistically capture the operational constraints that ultimately govern waterway capacity.

- Waterway capacity can be accurately quantified by simulating waterway activities with models that employ operational decision making procedures and systems. Those procedures and systems must engender consistent, repeatable decision making.

- A methodology for applying operational decision making procedures and systems to quantify waterway capacity has been successfully applied to the Port of Newcastle channel design. This has provided NPC with a clear appreciation of the consequence, in terms of changed waterway capacity, of various deepening scenarios. This information will assist NPC in determining a channel design that is optimal considering the requirements of the waterway stakeholders.

- This methodology can be extended to integrate with more extensive simulation models of waterway activities to comprehensively determine waterway capacity in the broad terms outlined by Blume.

7 References

Blume, A. L. (2005) *Toward a Better Understanding of Waterway Capacity*, PIANC Magazine AIPCN No 118.