CASE STUDIES IN DAMAGE AND REPAIR STRATEGIES FOR TRAINING WALLS AND BREAKWATERS ON THE NSW COASTLINE POST-JUNE 2016 STORM

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Abstract

Over the last two decades, the Department of Industry – Lands and Water (DoI – LaW; formerly Crown Lands) along with Manly Hydraulics Laboratory (MHL) has been involved in the numerical and physical modelling, supervision and auditing of repair strategies of training walls and breakwaters on the NSW coastline. It could be broadly stated that each training wall and breakwater has experienced a very specific 'destructive storm event' depending on the wave height, wave period, storm duration, water level, wave direction and state of repair of the training wall or breakwater immediately preceding the storm event.

The June 2016 storm was such a destructive event for a number of the structures on the NSW coastline. The 10 May 1997 storm was another destructive event where, although the offshore wave heights were equated only to a 1–2 year ARI storm, 20 units of 40 tonne concrete blocks were moved out of position during the night at the Coffs Harbour east breakwater in contrast with a 30–40 year ARI storm having moved a single 28 tonne Hanbar in September 2009.

This paper draws on the extensive combined experience of DoI – LaW and MHL to trace the history of modelling, assessment techniques and maintenance issues relating to the repair of breakwaters and training walls resulting from the June 2016 storm. The paper will also provide an insight into lessons that have been learnt and present successful repair strategies from the past decade that withstood the storm. Some suggestions for future repair strategies and proposed timing based on recent examples of life cycle analysis utilised in the USA are introduced in this paper.

The June 2016 storm

The offshore wave data (Figures 1 and 2) collected at approximately 80 m depth indicates for approximately 48 hours (4 June to 6 June) all seven NSW offshore buoys recorded a NE-E storm direction which later evolved to an E-SE direction. The event was not extreme in terms of the storm peak significant wave height for most areas, being characterised by non-directional Average Recurrence Intervals (ARIs) of less than one year at Byron Bay to about seven years at Crowdy Head (Table 1), although these ARIs do not consider the effect of wave direction on probabilities, including the unusual coincident bi-directional storm wave conditions (Figure 4). The indicated ARIs are based on data only up to 2013 and exclude also the coincident elevated ocean water levels resulting in more rare combined probabilities. However, the storm peak significant wave height recorded at Eden had an ARI of about 85 years and a maximum individual wave height of 17.7 m. This is now the largest wave recorded by the NSW Waverider buoy network since records began in February 1974. This largest wave was recorded at 4:30 am on Sunday 6 June 2016, being characterised by a wave period of

14.1 seconds and being 2.8 m higher that the previously largest measured individual wave of 14.9 m recorded by the Sydney Waverider buoy on 21 April 2015.

It should be noted that the NSW storm wave ARIs are currently being reviewed and it is expected that in the case of Eden, for example, the non-directional ARI for the June 2016 storm will reduce from 85 years to about 30 years following the inclusion of several major recent storm events in the storm database since 2013 (MHL 2017a).

Since 95% of storm data on the NSW coastline originates from a S-SE direction the storm resulted in relatively unusual damage on breakwaters and training wall structures. The associated water levels were also high and contributed to the damage. Exceedance wave heights based on directional data indicate that when the storm was from a NE-E direction the return periods were very high and gradually reduced when a more E-SE direction dominated. The directional spectra recorded at the Sydney buoy on 5 and 6 June (Figures 3 and 4) indicate this clearly.

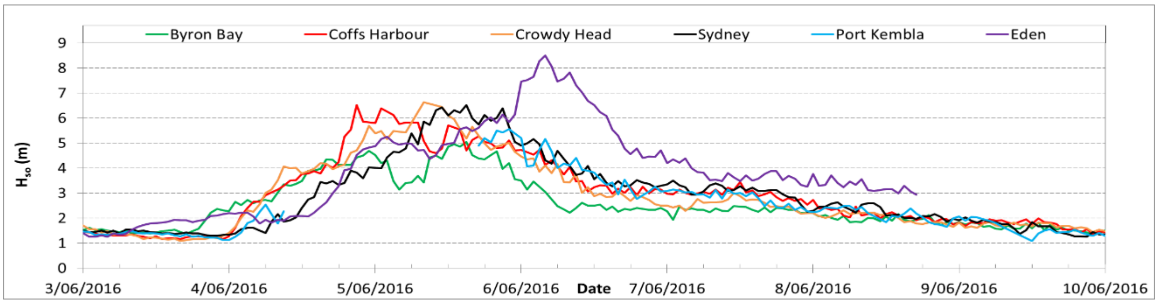


Figure 1 Wave height history on NSW coastline during June 2016 storm

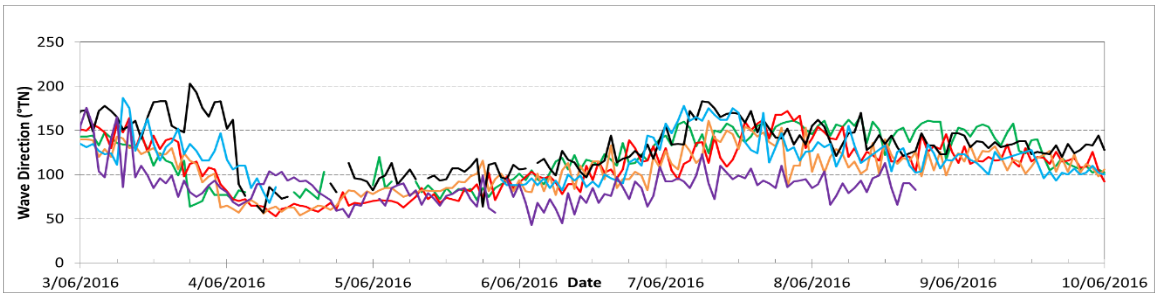


Figure 2 Wave direction history on NSW coastline during June 2016 storm

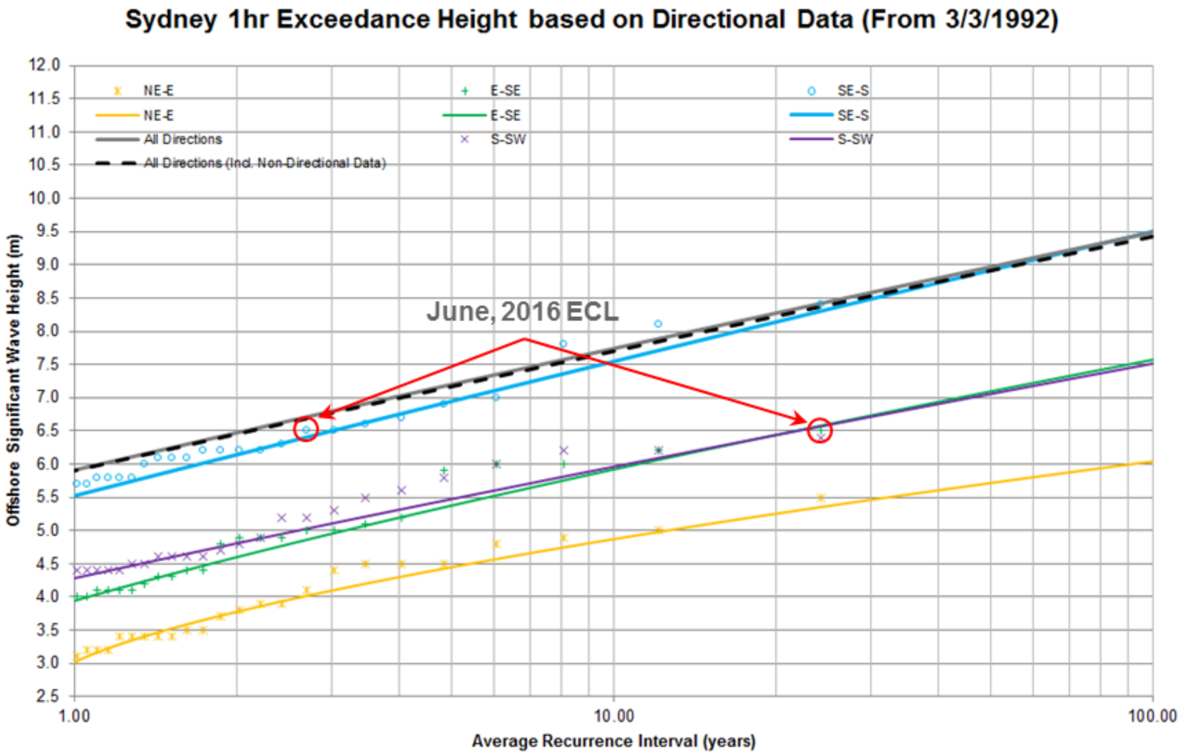
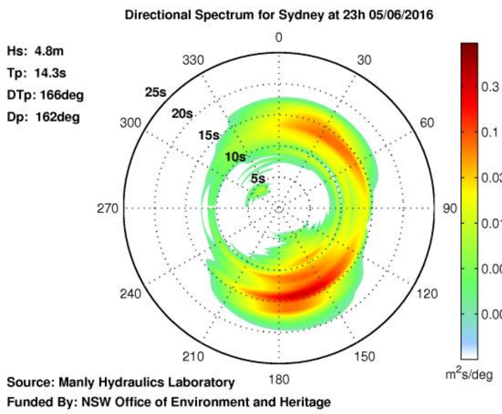


Figure 3 1-hr ARI based on the Sydney offshore buoy based on directional wave measurement



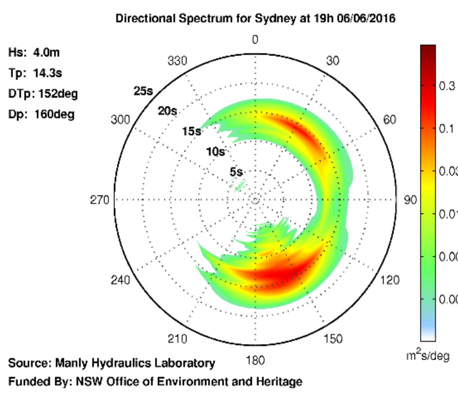


Figure 4 (a) Directional spectra indicating bi modal nature of storm recorded at the Sydney buoy on 5 June 2018

Figure 4b Directional spectra indicating bi-modal nature of storm recorded at the Sydney buoy on 6 June 2018

Table 1 indicates that when peak wave heights were measured the direction of the storm wave period was at 77 to 103 degrees (NE-E to E-SE).

Table 1 Wave height return periods based on measured maximum wave height

	Date/ time	Storm largest H_{max} (m)	Co-incident H_s (m)	Storm peak H_s (m)	Storm avg. T_p (s)	Storm avg. dir (º)	Approx. ARI (years)
Byron Bay	5/06/2016 1:00	11.6	4.33	5.02	12.5	100 (E)	< 1:1
Coffs Harbour	5/06/2016 3:00	11.2	6.07	6.35	12.8	90 (E)	1:4
Crowdy Head	5/06/2016 8:00	13.3	6.57	6.72	13.0	93 (E)	1:7
Sydney	5/06/2016 15:00	12.0	6.53	6.53	13.5	103 (ESE)	1:2
Port Kembla	5/06/2016 23:00	11.1	5.83	5.83	13.5	96 (E)	1:2
Eden	6/06/2016 4:30	17.7	8.46	8.46	15.1	77 (ENE)	1:85

Historic context of breakwater and training wall repair strategies in NSW

In 1993 MHL was commissioned to undertake an asset assessment of 63 river entrance training walls and breakwaters constructed on the shoreline of NSW (Coltheart 1997). The results were used to provide a basis for a repair strategy and prioritisation of future remediation. Since 1993 the various government agencies that undertook the maintenance of the breakwaters have maintained a database of expenditure on these 63 structures.

As a result of this work and subsequent further storm damage to breakwaters at Ballina south (1997), Coffs Harbour east (1999) and Forster (2004), the breakwater heads were repaired by the Department of Lands, Minor Ports Division (presently DoI – LaW). Concrete Hanbars were used in 1999, 2001–02 and 2004 respectively utilising designs finalised mainly by 2D and 3D physical models and numerical modelling utilising the numerical model REF/DIF (1995–2013) and more recently utilising Boussinesq (BW) modelling. Table 2 indicates the assessed condition of concrete armoured structures during the 1993 survey and more recent surveys prior to the 2016 storm. Since 1999 mainly concrete Hanbars have been utilised for repair of training walls and breakwater heads (Jayewardene, Driscoll and Jacobs 2009) instead of rock due to the scarcity of large (>10 tonne) rock for repair .Table 2 indicates the damage to some of these structures during the 2016 storm. Table 2 also indicates the breakwater heads that had concrete primary armour protection during the 1993 survey. The repeated asset assessments identified areas on a number of the structures that had suffered significant storm damage and required repair. In all instances the units used for repair were Hanbars (Figure 10a). This was largely based on the comparative performance of these units and the relative costs (Hanley and Brown 1980). Similarly Table 3 indicates training walls that used rock armour and the subsequent damage during the 2016 storm, and outlines related repair strategies.

Table 2 Damaged training wall/breakwater heads utilising concrete armour units before and after 2016 storm

Site	Armour size W_{50} 1993–94 survey type of armour and condition	Revised W_{50} after physical modelling	Condition (pre-2016 storm)	Condition (post-2016 storm)
Ballina North	30t blocks/rocks	Ballina north repaired 2012 with 8, 12 and 16t (head) Hanbars	Good	Good
Ballina South head	30t blocks/rocks requires urgent repair	15t Hanbars (Jayewardene and Young 1999), 2015	Good	Good
Coffs Harbour East	40t blocks (1941–42) requires urgent repair after 1997 storm	28t Hanbars (Jayewardene, Driscoll and Pascoe 2001) 16, 22 and 28t Hanbars (2013)	Good but monitored constantly	Good Good
Coffs Harbour North	5t	12t Hanbars	Poor. Overtopping causing damage to marina and sand ingress to the harbour	Poor. Breakwater severely damaged. Most extensive damage to the marina and boardwalk assets ever recorded
Forster head	9t rocks required urgent repair (MHL 2004)	12t Hanbars	Was scheduled to be repaired	Extensive damage to head
Wollongong South	12t Hanbars (142 units 1975–78), 11t Hanbars (28 units) requires repair		Good	Damage to heritage wall and crest
Bellambi	12t Hanbars (400 units 1979)		Good	Good
Ulladulla North	12t Hanbars (1975)		Good	Good
Ulladulla South	12t Hanbars (1975)		Good	Good
South Narooma	12t Dolos (1978)	Hanbars (2014)	Good	Good

Table 3 Damaged training wall/breakwater heads utilising rock armour units before and after 2016 storm

Site	Armour size W_{50} 1993–94 survey type of armour and condition	Revised W_{50} after numerical/physical modelling	Condition (pre-2016 storm)	Condition (post-2016 storm)
Tweed Heads	Repaired $350,000 3000t of up to 7t rock on southern side of structure 2007. 1000t of up to 12t rock October 2015	Ballina north repaired 2012 with 8, 12 and 16t (head) Hanbars	Repaired	Good
Pottsville North	5t rock	No modelling	Poor	Increased damage, unravelled and not performing the design intent
Pottsville South	5t rock	No modelling	Poor	Increased damage, unravelled and not performing the design intent
Clarence North	10–20t rock	REF-DIF (1996) BW modelling (2015)	Repaired	Crest damage and ocean side damage at the head
Clarence South	10–20t rock	REF-DIF (1996) BW modelling (2015)	Under repair	Increased damage on head
Coffs Harbour North	5–8t rock, limited 8t cubes	Berm of 5–8t rock overlain by 12t Hanbars and 20t containment Hanbars following 3D physical modelling	Poor	Upgraded breakwater completed October 2018
Nambucca	10t blocks		Good	Good
Port Macquarie North	5–10t rock	No modelling	Was scheduled to be repaired	Extensive damage to head
Port Macquarie South	7–10t blocks		Good	Good
Crowdy Head South	5–10t rock	Modelling in 1996	Repaired	Extensive damage to crest
Swansea North	5–10t rock		Damaged?	
Moruya North	5–10t rock		Good	Extensive damage to crest
Narooma North	5–10t rock		Good	Damage to 30m trunk on ocean side

Examples of breakwaters that were damaged on the north coast during the 2016 storm

Figures 5 to 9 indicate breakwaters that were fairly severely damaged during the June 2016 storm. Some of this damage at recently repaired structures, caused by the NE-E direction, may be attributed to placed (rather than random) rock on the trunk due to better repair machinery resulting in a smoother trunk face, and resultant higher wave runup and increased damage to the crest as experienced on the Clarence north training wall. Damage to the head of Clarence north (Figure 5c) and Port Macquarie north (Figure 7) training walls may be reduced by replacing rock with higher coefficient of damage (K_d) Hanbars or by special placement of rock on the head (Figures 12b and 12c) as was done on the Yaquina jetties by CERC (1987) in the USA, greatly reducing the annual damage to the head. Higher K_d values are associated with higher efficiencies in armour units. For example, K_d values for randomly placed two layer rock in breaking waves are approximately 2–3 and for Hanbars they are estimated to be 5–7.

Figure 8a indicates damage due to a 40-year ARI storm on Forster head. Figure 8b indicates far more extensive damage due to the June 2016 storm assessed at 4–7 year ARI. Although the June storm was of smaller return period (Table 2) the damage was more extensive than was the case in the 2009 storm. The Forster head was scheduled to be repaired in the imminent future when the storm struck, which emphasises the importance of timing of repairs in reducing extensive damage to a structure due to a destructive storm event.

Figure 5a Clarence north training wall prior to 2016 storm (drone photo courtesy DoI – LaW)

Figure 5b Clarence north training wall crest damage post-June 2016 storm (drone photo courtesy DoI – LaW)

Figure 5c Clarence north training wall crest post-June 2016 storm – closer view of crest damage

Figure 6a Coffs Harbour north breakwater storm, June 2016

Figure 6b Damage to boardwalk and marina following storm. Damage to assets other than a breakwater costing greater than $2m has never been recorded before in NSW

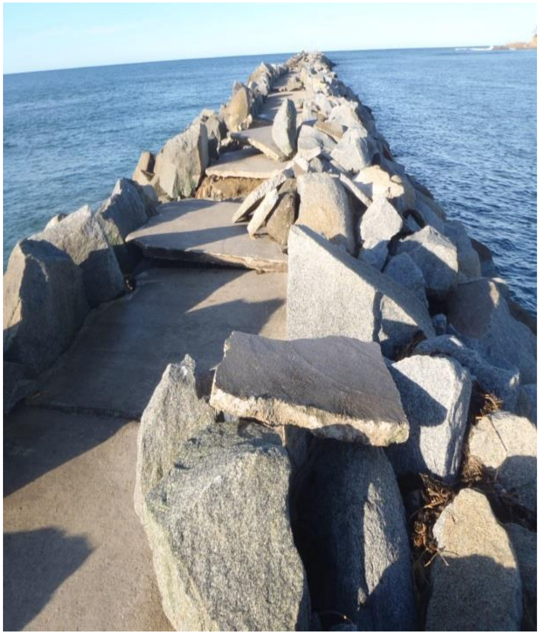
Figure 6c Completed breakwater showing 5m berm of 5–8t rock overlain by 12t Hanbars with 2 x 20t Hanbars as containment on seaward side

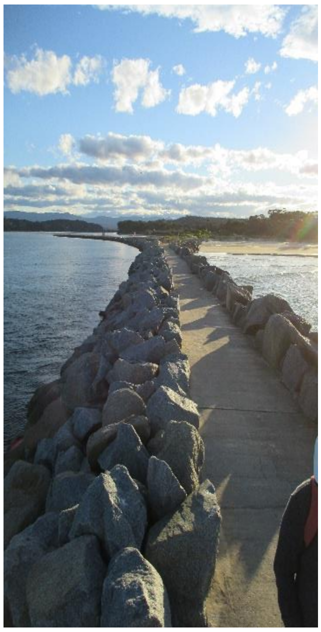
Figure 7 Port Macquarie north training wall head post-June 2016 storm (drone photo courtesy DoI – LaW)

Figure 8a Forster head damage after 1-in-40-year ARI storm in 2009

Figure 8b Forster training wall – extensive head damage post-2016 storm

Figure 8c Post-2016 storm damage to Narooma north training wall





Figures 9a and 9b Moruya North crest post-June 2016 and 2014 after repair

Breakwaters and training walls during the 2016 storm

Figure 10a indicates the relative performance of concrete armour units in comparison with rock armour as modelled at MHL for the Ballina south head, where Hanbar units replaced existing rock armour in 1997 (MHL 1997). This structure was repaired in 2007 utilising 7t armour and in 2015 utilising 12t armour. The Ballina south head was relatively undamaged during the June 2016 storm, indicating that timely repair had prevented damage. The Coffs Harbour east breakwater is an example of a breakwater that was damaged badly in a 2-year ARI storm in May 1997 when 20 units of 40t concrete blocks were displaced on the breakwater (Figure 10b) and after subsequent modelled repair strategies were utilised in 2001 and 2012 withstood the June 2016 storm with relatively minor damage (<1%). Figures 10c and 10d indicate the two Hanbar units that were displaced during the 2016 storm.

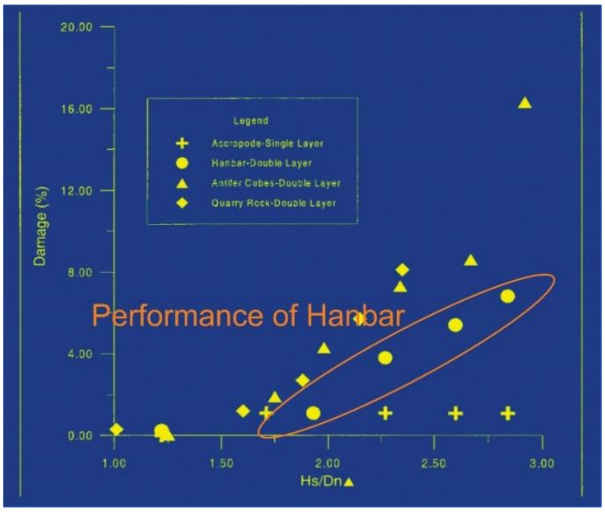
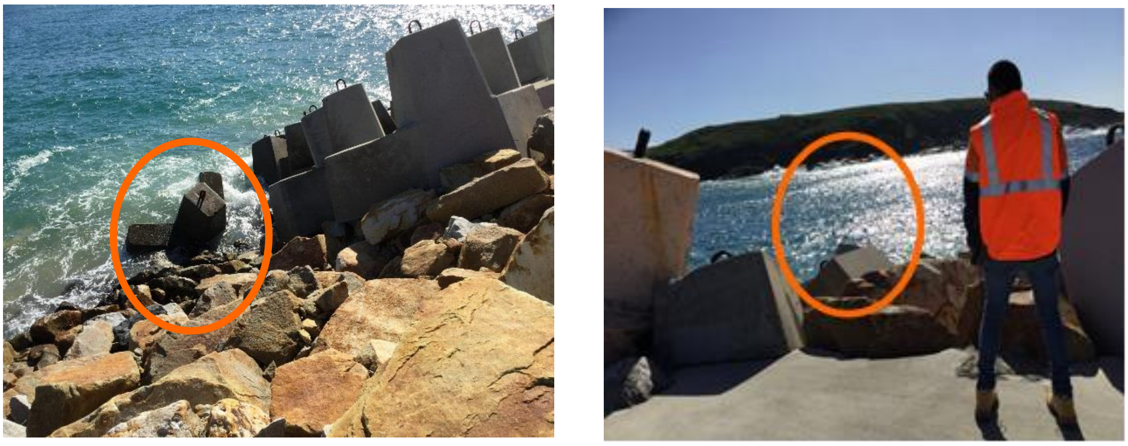


Figure 10a MHL physical modelling comparing Accropode, rock, Antifer cubes and Hanbars (MHL 1997)

Figure 10b Coffs Harbour east breakwater head indicating locations of 40t concrete blocks displaced in the May 1977 storm



Figures 10c and 10d Relatively minor (<2%) damage to Coffs Harbour east breakwater head after June 2016 storm

The training wall at Narooma north is an example where the existing berm (Figure 11) on the ocean side is likely to have prevented serious crest damage, unlike the damage that occurred along 400 m of crest on the ocean side of the Clarence north training wall (Figures 5b and 5c) and the crest damage to the Moruya north training wall (Figures 9a and 9b).

Figure 11 Relatively minor (<2%) damage to Narooma north training wall crest (in comparison with Moruya north) possibly due to unique berm construction on ocean side

Some issues relating to post-storm repair and contractor audits

DoI – LaW has been very proactive in auditing repairs carried out under its contracts for repair. Figure 12a indicates non-conformances relating to rock armour specifications in the post-storm repairs to the Clarence training walls when audited (MHL 2017b) which were rectified after audit.

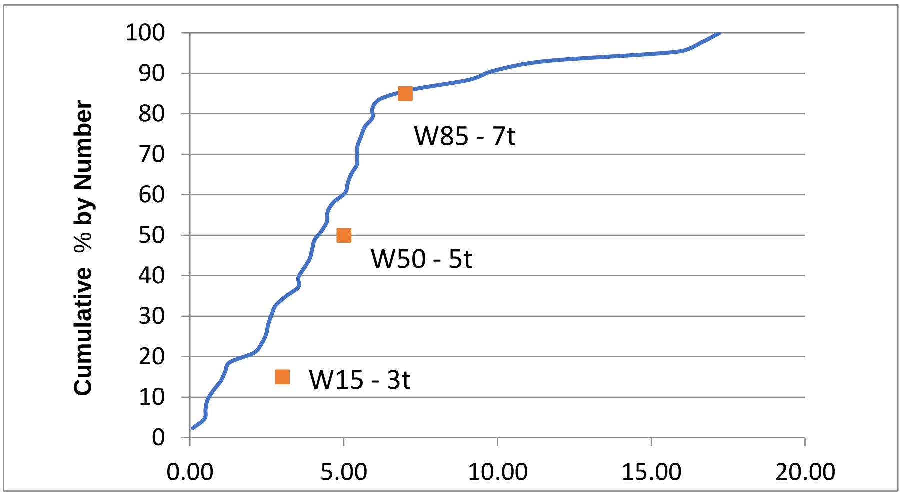


Figure 12a Armour distribution by number (CIRIA Rock Manual)

Table 4 The relevant statistics of distributions in Figure 12a – Ch 625–Ch 635

Parameter	By weight*	By number	Spec requirement
W85	15.95	6.75	7
W50=W	5.66	4.17	5
W15	3.56	1.07	3
W85/W15	4.48	6.31	2.33

*MHL2420 indicates 2.33 for B grade armour +W50 is within 10% of specification

Figure 12b Special placement K_d = 4–8 (CERC)

Figure 12c Special placement K_d = 8–10(CERC)

Future strategies for optimising repair timing for training walls and breakwaters

At present DoI – LaW has put together an extensive database of the timing and the costs of training wall repair carried out over the last two decades. This has helped to guide a successful maintenance campaign in the past decade. Over the last decade the Coastal Engineering Research Centre (USA) has developed life cycle analysis for the repair of breakwaters and training walls. The goal here is not to design to a specific design period such as 50 or 100 years as is done in NSW. The goal is to maximise net economic benefits, to determine which of the alternative repair strategies has the lowest risk and produces the highest benefits. Herein risk is defined as the product of the probability of consequences and the cost of these consequences. Melby (2010) outlines this approach which may assist in developing future repair strategies.

Some conclusions and recommendations relating to lessons learnt from breakwater damage due to the June 2016 storm

Following are some of the conclusions and recommendations to result from the post-storm surveys of the training walls and breakwaters.

North Coast breakwaters

- The NE-E direction of the storm resulted in extensive crest and head damage to the Clarence north training wall.
- In instances where severe head damage was observed such as Clarence north, Clarence south and Port Macquarie north training walls, rock placement (Figures 12b and 12c) with appropriate longer axis providing higher Kd values (>4) as utilised in CERC (1987) may have resulted in less damage.
- Forster head, where repairs were just about to commence, sustained very heavy damage to the head when compared to previous storms. This was attributed to the current state of disrepair of the training wall head (Figures 8a and 8b).
- Use of improved repair machinery may have resulted in smoother faced batters on the ocean side of the training wall which in turn may have resulted in higher volumes of runup and subsequent crest damage as viewed at the Clarence north training wall.
- The berm on the Narooma north wall appeared to provide protection to this wall. Consideration could be given to designing berms to mitigate crest damage where increasing crest height would be less cost beneficial.
- Modelled and repaired breakwaters such as Coffs Harbour east breakwater were subject to very little damage compared to the Crowdy Head breakwaters.

South Coast breakwaters

- The Wollongong south breakwater is subject to extensive overtopping and the heritage wall was damaged. The heritage wall will most probably continue to be damaged unless protective armour or an engineered berm is placed in front of the wall.
- The Moruya north crest was badly damaged and this will continue unless a wall of armour is placed on the head and crest to reduce overtopping from the ocean side.
- Although the storm proved to be a trigger for the collapse of approximately 40 m of training wall at Narooma north the failure may be attributed to long-term scouring of the toe since 2011.

Some recommendations

- Initiate a system of life cycle analysis in tandem with physical and numerical modelling similar to the Monte Carlo type of analysis carried out at CERC in the USA to ensure timely repair of training walls such as the Forster training wall head.
- Utilise high K_d armour placement at training wall heads that extend into deeper water such as the Clarence north and south training walls to reduce the requirement of very high tonnage rock to reduce damage.
- Investigate the possibility of berms on the ocean side at locations where they may prove effective such as the current protection afforded to the Narooma north training wall.
- Utilise MHL's directional wave generator to test future repair design strategies using bimodal spectra.

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