NSW Department of Commerce

Manly Hydraulics Laboratory

# Physical Modelling of Ajacks Units in Wave Flume

**Report MHL1251**
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# PHYSICAL MODELLING OF AJACKS UNITS
# IN WAVE FLUME

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# Foreword

The report was prepared by the NSW Department of Commerce's Manly Hydraulics Laboratory (MHL) on behalf of the Minor Ports Program of the Department of Lands (formerly of the Department of Land and Water Conservation (DLWC)). The physical model design and testing was carried out by Indra Jayewardene and the report prepared by Mark Kulmar and Indra Jayewardene. Drafting was undertaken by Fabiana Calvo, with report production by Megan Jensen.

# Summary

The performance of the Ajacks unit as primary armour was investigated both for the purpose of repairing existing coastal structures and for designing new structures. Relatively small units (less than 4 tonnes in prototype) were used in the test cross-sections as the objective is to initially use the Ajacks unit at locations with a milder wave climate ($H_{sig}$ < 4.0 m). Future repair strategies may use Ajacks units on structures that are presently built of rock armour and Hanbar units. The test series was designed to obtain a comparative assessment of the performance of these units. The ability of the units to interface with each other was also investigated.

The physical model tests were undertaken in two stages:

- *Stage 1* - comparing the performance of double layer rock armour with single layer Ajacks units.
- *Stage 2* -
  - (a) comparing the performance of double layer Hanbar units and single layer Ajacks units
  - (b) comparing the Ajacks unit performance using two sizes of secondary armour
  - (c) investigating the ability of Ajacks units in a breakwater repair to interface with rock and Hanbar armour of much larger (>200%) tonnage
  - (d) comparing the performance of the modified Ajacks unit called a 'Stubby' with other units that were tested.

Based on the two-stage physical model testing regime undertaken for this study, it was concluded:

- Pierson-Moskowitz spectra with 8 s wave peak period were used in the testing. All the tests were performed in a surf similarity parameter ($\xi$) range of 2.8 to 3.9. This range includes the transition of wave breaking from plunging to surging. In previous investigations Ahrens (1975) and van der Meer (1988) classified this to be the region of minimum stability for breakwater units.
- 7.6 tonne quarry rock armour placed in two layers at approximately 67 units/100 m$^2$ resulted in a $K_D$ value of 2.4 at 5 to 10% damage.
- The initial testing to simulate damage to a two-layer 8 tonne Hanbar armour resulted in 5 to 10% damage. The estimated $K_D$ value for Hanbars was 6.7.
- An initial test using a significant wave height of 4.5 m waves with 8 s peak period was carried out on the Ajacks after bedding in the units. After 1500 waves, damage caused the secondary armour and core to be visible. Damage was attributed to toe movement and inadequate placement density (61 units/100 m$^2$) of the units. Damage to the Hanbar interface caused movement in the Ajacks layer.

- The Ajacks unit tests resulted in a $K_D$ value of 48 when the toe was fixed using bundled Ajacks units and the interfaces were stable. The damage level was less than 3%. The placement density was increased to 67 units/100 $m^2$. Smaller secondary armour was used in the Stage 2 testing of this cross-section compared to that used in Stage 1. The wave height was gradually increased during the Stage 2 tests. The $K_D$ values obtained at the O.H. Hinsdale Laboratory at Oregon State University varied from 24 to 292. Both regular waves and irregular waves were used for these tests.
- Due to the Ajacks unit being placed in a single layer, early repair strategies that attend to armour damage have to be planned in order to prevent damage to the secondary armour and core. This early repair strategy is required because in comparison with the armour units placed in two layers the availability of primary armour to protect the secondary armour and the core is reduced
- The Stubby unit and the Ajacks unit performed well on the crest of the cross-section and resulted in minor damage during heavy overtopping conditions.
- 3.5 tonne Stubby units placed in a single layer at a density of 37/100 $m^2$ resulted in a $K_D$ value of 24 when the toe was fixed using bundled Ajacks units and the interfaces were stable. The wave height was gradually increased during the tests.
- The bundled Ajacks units provided a stable toe during Stage 2 of the tests.
- The Stubby unit provided a suitable interface between the Ajacks unit and the larger rock armour.
- In addition to the coefficient of damage, the density of placement, structure slope, wave climate, type of breaking wave, type of interface, type of placement, permeability and therefore the size of core material have to be considered when comparing the Ajacks and Stubby armour unit with other units for design or repair purposes.

# Contents

**1. INTRODUCTION** **1**
1.1 Study Background and Objectives 1
1.2 Characteristics of Ajacks Units 2
1.3 Previous Tests on Ajacks Units 2
**2. DESIGN OF TEST CROSS-SECTION** **3**
2.1 Model Scales 3
2.2 Model Water Level and Water Depth 3
2.3 Model Description and Layout 4
2.4 Model Armour Units 4
2.5 Model Wave Conditions 5
2.6 Simulation of Wave Groups 5
2.7 Wave Runup 6
2.8 Wave Height Parameters for Characterising Breakwater Stability 7
2.9 Performance of Quarry Rock as a Primary Armour 7
2.10 Performance of the Hanbar Unit as a Primary Armour 7
2.11 Performance of the Ajacks Unit and the Stubby Unit as a Primary Armour 7
2.12 Armour Interfaces 8
**3. TESTING PROCEDURE** **9**
3.1 General 9
3.2 Stability Tests 10
**4. TEST RESULTS** **12**
4.1 Stage 1 Test Series Results 12
4.2 Stage 2 Test Series Results 13
**5. CONCLUSIONS AND RECOMMENDATIONS** **15**
**6. REFERENCES** **17**

**APPENDICES**

**A** Symbols
**B** Test Cross-Sections
**C** Grading Curves for Model Rock Armour

# Tables

2.1 Densities, Nominal Weight and Nominal Diameter for Model Ajacks Units and Stubby Units 4
2.2 Details of Model Armour Units 5
3.1 Stage 1 Tests – Wave Conditions and Water Levels 9
3.2 Stage 2 Test Series – Wave Conditions and Water Levels 10
4.1 Ajacks Testing – Stage 1 Test Series Results 12
4.2 Ajacks Testing – Stage 2 Test Series Results 13

# Figures

1.1 Schematic of the Ajacks/Stubby Unit
2.1 Wave Flume Layout
4.1 Tests on 7.6 Tonne Two-Layer Rock Armour
4.2 Tests on 1.7 Tonne Single-Layer Ajacks Cross Section
4.3 Tests on 1.7 Tonne Single-Layer Ajacks Cross Section with Bundled Unit Toe
4.4 Tests on 1.7 Tonne Single-Layer Ajacks Cross Section
4.5 Tests on 1.7 Tonne Single-Layer Ajacks Cross Section with Stubby Units on Crest
4.6 Tests on Rock and Stubby-Interface Suitability
4.7 Tests on 8 Tonne Two-Layer Hanbar Cross Section
4.8 Tests on 3.5 Tonne Single-Layer Stubby Armour Cross Section

# 1. Introduction

## 1.1 Study Background and Objectives

The Minor Ports Program of the Department of Lands commissioned Manly Hydraulics Laboratory (MHL) to undertake a model study to assess the performance characteristics of the Ajacks unit as primary armour for coastal defence works. The test programme was developed in consultation with Mr Frank Atkinson, the inventor of the unit, representatives from Pioneer Concrete Pty Ltd and Mr Steve Driscoll, Manager, Minor Ports Program. Initially the unit is to be used in milder ($H_{sig}$< 4.0 m) environments. In addition to testing the Ajacks unit, as a repair unit for existing coastal structures a modified Ajacks unit (the Stubby) was also tested as an interface between existing armour and the Ajacks unit. The testing was carried out in two stages:

- *Stage 1* - Comparing the performance of double layer rock armour with single layer Ajacks units.
- Stage 2 –
  - (a) Comparison of the Ajacks unit performance using two sizes of secondary armour.
  - (b) Investigating the ability of Ajacks units to interface with rock and Hanbar armour of much larger (>200%) tonnage.
  - (c) Comparing the performance of double layer rock Hanbar units with single layer Ajacks units.
  - (d) Comparing the performance of the modified Ajacks unit or Stubby with other units that were tested.

The initial testing was undertaken in the MHL random wave flume in the presence of Mr Atkinson, the inventor of the Ajacks unit, Mr Wayne Holt, technical manager of Pioneer Concrete Pty Ltd, Mr Mathew Sinclair, marketing manager of Pioneer Concrete Pty Ltd and Mr Steve Driscoll, Manager, Minor Ports Program.

## 1.2 Characteristics of Ajacks Units

Figure 1.1 indicates a schematic of the Ajacks unit. The unit is dimensionally characterised by two ratios, specifically the waist ratio R and the fillet ratios:

$$R = T/L$$

$$S = C/T$$

where

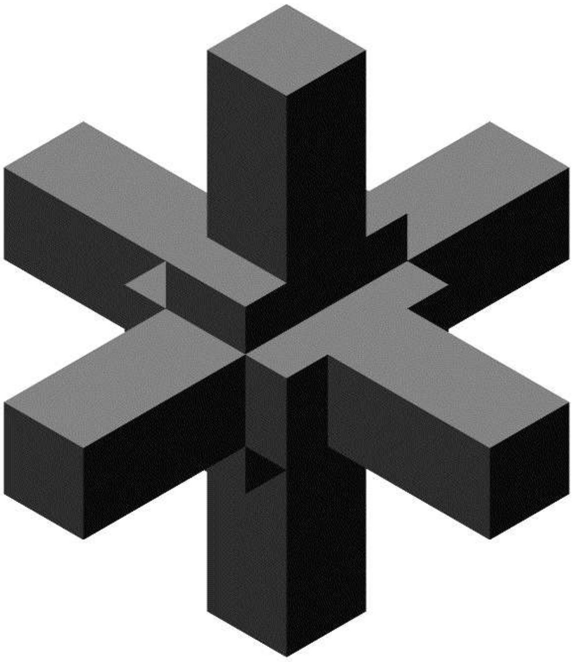
R = waist ratio
T = arm thickness
L = end to end length of unit
S = fillet ratio
C = fillet length along the axis of an arm

The size weight ratio varies with design (waist ratio and fillet ratio, etc.) and the concrete density. The fillet ratio for the Ajacks and Stubby units used in the model were 11/13 and 2/5. The waist ratio for the Ajacks unit is 1/6.3. The waist ratio for the Stubby unit is 1/4.1. The suggested waist ratio of 1/7 is only used as a guide for a balance between structural and hydraulic stability (Amortech 1999).

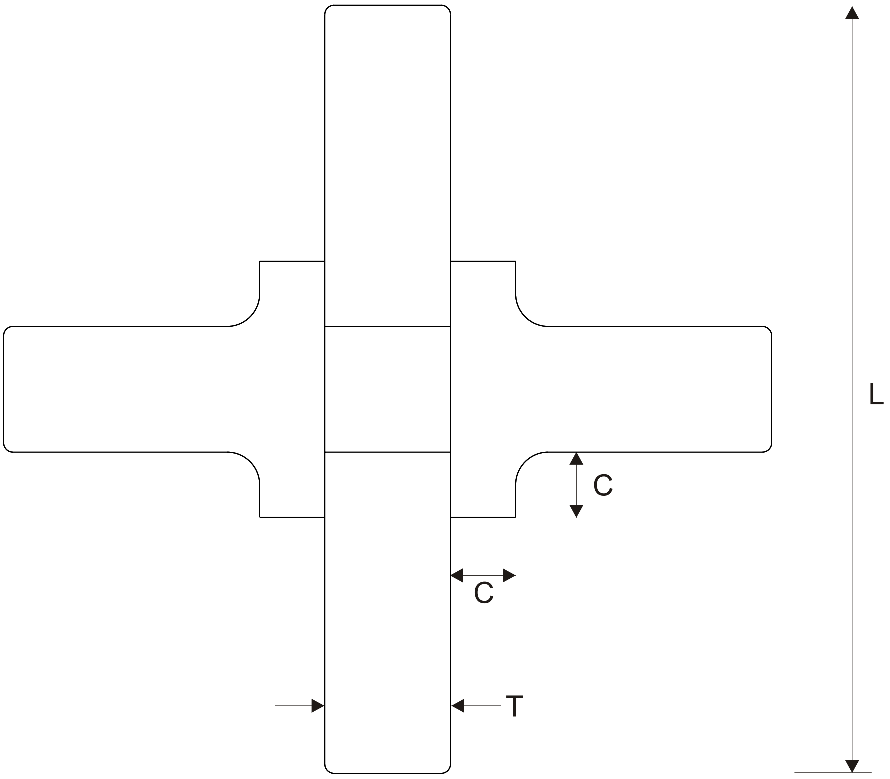
## 1.3 Previous Tests on Ajacks Units

Previous tests have been carried out to evaluate the performance of Ajacks units for coastal protection works (Amortech 1999). The tests were carried out using regular waves. Following are some of the conclusions arrived at in the report:

- Random placement testing indicated sensitivity to packing density. For a 1:2 slope and packing density coefficient exceeding 0.50, $K_D$ values exceeded 50 except for one test that exhibited a 5-unit patch of motion at $K_D = 38$.
- All of the random placement Ajacks tests that demonstrated acceptable hydraulic performance exhibited $K_D$ values either comparable to or significantly exceeding design values of other commercially available armour units. The testing demonstrated greater stability of uniformly placed Ajacks relative to random placement. However, random placement testing demonstrated very good stability characteristics relative to other armour units.
- Hydraulic performance of Ajacks was found to increase with milder armour slope.
- Nearly all of the failures consisted of excessive exposure of under-layer material. All of this armour unit motion occurred in the vicinity of the still water line.
- Selection of a single $K_D$ for general design purposes is not recommended. Important parameters to define a range of appropriate values for design include packing density, wave steepness, breaking versus non-breaking waves, including type of breaking wave, armour slope and core material.



Schematic of Ajacks/Stubby unit




Ajacks/Stubby dimensions

| | Ajacks | Stubby |
|---|---|---|
| S | 11/13 | 2/5 |
| r | 1/6.3 | 1/4.1 |

S* = fillet ratio = C/T
r* = waist ratio = T/L
* model units used for tests

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SCHEMATIC OF THE AJACKS/STUBBY UNIT

MHL Report 1251

Figure 1.1

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# 2. Design of Test Cross-Section

### 2.1 Model Scales

A length scale of 27 was selected based on the availability of model armour units, the size of the MHL wave flume and the need to minimise scale effects. The mass scale was determined from the length scale. The time scale was derived from the length scale using Froudian similitude. The mass scale allows for the differences in density between sea water in the prototype and fresh water used in the model. The Ajacks units were tested along with Hanbars, rock armour and Stubby units. Following are the scale factors used in the model tests:

| | | | | | |
|---|---|---|---|---|---|
| Length scale | $L_r$ | = | 27 | | |
| Time scale | $T_r$ | = | $\sqrt{L_r}$ | = | 5.19 |
| Mass scale | $M_r$ | = | 17,278 | | |

Several investigators have provided indicators of the limiting size of models for reduced Reynolds number effects or scale effects (Dai and Kamel 1969). More recently Cornett (1995) determined the condition for negligible scale effect as:

$$H_{sig} > (\nu \, Re / D_{50})^2 / g = 0.072\,m$$

where

| | | |
|---|---|---|
| $H_{sig}$ | = | Significant wave height |
| $\nu$ | = | Kinematic viscosity = $1.14 \times 10^{-6}$ $m^2/s$ |
| Re | = | Reynolds Number = $2.5 \times 10^4$ |
| $D_{50}$ | = | Nominal diameter of Ajacks primary armour |

The smallest armour unit used on the breakwater head was the 1.7 tonne Ajacks armour that had an equivalent model diameter of 3.5 cm. All tests were undertaken with a model $H_{sig}$ greater than 10 cm.

### 2.2 Model Water Level and Water Depth

The water depth in the vicinity of a breakwater section has a significant influence on the amount of offshore wave energy reaching the structure. It also influences wave runup, drawdown and overtopping forces acting on the structure. It is not only the elevated high water levels during a storm that can affect the breakwater. During times of low water, damage to the toe of the breakwater can also occur during a storm event.

The water depths to be used in the estimation of breakwater armour size are dependent on the still water level (SWL), the mean water level including any wave setup, and the bed levels surrounding the structure. During the first stage of testing it was evident that waves were plunging on the cross-section toe as well as overtopping the structure, therefore the water level was maintained at 0 m AHD throughout the testing.

## 2.3 Model Description and Layout

The study was undertaken in the MHL random wave flume. The flume layout is shown in Figure 2.1. Waves are generated by a sliding wedge wave paddle driven by a servo-hydraulic system. The paddle is controlled by an input signal provided by a personal computer (PC). The operator defines the peak frequency and wave height of a Pierson-Moskowitz spectrum to be generated by the PC. The PC controls the data acquisition from the wave recording probes. The transfer function of the flume was obtained in order to obtain estimates of incident wave height. A three-probe reflection measurement configuration, adopting a method suggested by Mansard (1980) was also used during the tests to differentiate between the incoming waves and reflected waves. A fourth probe was used to measure variations in wave height in close proximity to the breakwater.

An 8 m depth was simulated at the breakwater section in the flume. The depth fell away sharply due to a 1:5 slope a short distance from the toe. The constructed breakwater cross-sections for all the tests are indicated in Appendix B.

Extensive testing carried out by van der Meer (1988) indicates that the permeability of the core has an influence on the stability of the breakwater. Within limits discussed by van der Meer, the more permeable the breakwater core, the higher the stability. Since this investigation compares the performance of differing types of armour units it was necessary to ensure that the core and the toe conditions remained the same during all model testing. Ten to 15 mm diameter blue metal was used for the core. Two types of secondary armour were used in the testing (Appendix B).

## 2.4 Model Armour Units

For the Ajacks unit the nominal diameter was considered to be $D_n$ where $\rho D_n^3 = W_{50}$ and $\rho$ is the density of the unit and $W_{50}$ the nominal weight. Table 2.1 indicates the values for densities obtained for the model Ajacks unit and the Stubby unit as supplied by Pioneer Concrete Pty Ltd.

**Table 2.1 Densities, Nominal Weight and Nominal Diameter for Model Ajacks Units and Stubby Units**

| Type of Unit | Density ($\rho$) (gms/cm$^3$) | Nominal Weight $W_{50}$ (gms) | Nominal Diameter $D_n$ (cm) |
|---|---|---|---|
| Ajacks | 2.19 | 99 | 3.56 |
| Stubby | 2.14 | 220.6 | 4.69 |

Details of the armour units used in the model testing are described in Table 2.2. Grading curves for the model primary rock armour and secondary rock armour are included in Appendix C.

**Table 2.2 Details of Model Armour Units**

| Armour Unit | Prototype Armour Weight (tonnes) | Specific Gravity | Linear Scale | Details of Model Armour Weight and Grading Curve |
|---|---|---|---|---|
| Hanbar | 8.0 | 2.40 | 27 | 419 gms |
| Ajacks | 1.7 | 2.19 | 27 | 99 gms |
| Stubby | 3.5 | 2.14 | 27 | 220.6 gms |
| Rock (Primary Armour) | 7.6 | 2.65 | 27 | $W_{85}$ / $W_{15}$ of 1.6 [1] |
| Rock (Interface Armour) | 5.9 | 2.65 | 27 | $W_{85}$ / $W_{15}$ of 1.3 [1] |
| Rock (Secondary Armour Small) | 0.53 | 2.65 | 27 | $W_{85}$ / $W_{15}$ of 2.6 [1] |
| Rock (Secondary Armour Large) | 1.12 | 2.65 | 27 | $W_{85}$ / $W_{15}$ of 1.7 [1] |

[1] see Appendix C for grading curves of model rock armour

## 2.5 Model Wave Conditions

Random waves were generated according to a Pierson-Moskowitz type energy spectrum. During this model study the spectrum was defined by the wave height and periods given in Table 3.1. The selected design wave conditions resulted in both plunging and surging breakers on the breakwater model. All model tests were undertaken for a duration of 2000 waves.

## 2.6 Simulation of Wave Groups

The importance of examining the wave groups of a wave regime has long been recognised when testing structures in the ocean. However, in the past, coastal engineering design in NSW has generally been based on wave data without specific consideration for groupiness effects. To overcome this shortcoming, which could be significant for some designs, DLWC, as part of its coastal program, initiated a study to investigate and compute the groupiness of wave conditions measured along the NSW coast (Jayewardene et al. 1993). A groupiness factor was used to measure the grouping effect of waves measured offshore by the NSW Waverider buoy network. As a part of this investigation, only a qualitative study was carried out on the effect of grouping on the structure. A time series that resulted in high grouping effects was used for all the tests.

## 2.7 Wave Runup

Wave runup is one of the most important factors affecting the design of coastal structures exposed to wave attack. The stability of a coastal structure could be impaired by even relatively small quantities of overtopping. In order to qualitatively compare rates of overtopping for the different types of primary armour the same wave time series was used for all tests. Care was taken to maintain the crest level at the same height when testing the Ajacks unit and the Stubby unit.

Breakwaters and offshore rubble mound structures are generally designed to allow an acceptable percentage of the waves reaching the crest to overtop the structure. Non-dimensional runup ($R_u$ / $H_{sig}$) has been shown to be dependent on surf similarity parameter ($\xi$), which in turn is used to describe the type of wave break (van der Meer and de Waal 1992). The surf similarity parameter is defined as:

$$\xi = \tan\alpha / (H_{sig} / L_o)^{(1/2)}$$

where

$H_{sig}$ = significant wave height
$L_o$ = wave length
$\alpha$ = angle of breakwater slope

After extensive physical model testing, van der Meer obtained the following relationship for wave runup:

$$R_{u\,2\%} / H_{sig} = 1.5\,\gamma_f\,\gamma_s\,\gamma_\beta\,\xi \textit{ with a maximum of } 3.0\,\gamma_f\,\gamma_s\,\gamma_\beta$$

where

$\gamma_f$ = influence factor for roughness
$\gamma_s$ = influence factor for shallow water
$\gamma_\beta$ = influence factor for oblique wave attack
$\xi$ = surf similarity parameter

The influence factor for roughness ($\gamma_f$) for two-layered rock is estimated to be in the range 0.50 to 0.55. The influence of shallow water ($\gamma_s$) varies from 0.8 to 1.0 due to the 8 to 10 m water depths in front of the breakwater. The influence for oblique wave attack ($\gamma_\beta$) is given as 0.64, 0.86 and 1.0 for the selected testing angles of 60°, 30° and 0° respectively. On the test cross section the angle is approximately 0°. In the test series undertaken in this study the surf similarity parameter ($\xi$) varied from 2.8 to 3.9. This indicates that the wave breaking process went from plunging to surging waves. Ahrens (1975) and van der Meer (1988) suggest that armour stability is a minimum during this breaker transition phase. Also the relationship for wave runup indicates that a time series with a significant wave height of 4.5 m would result in extensive overtopping.

## 2.8 Wave Height Parameters for Characterising Breakwater Stability

It has been recognised that the description of a sea state by its spectral density is inadequate to analyse the stability of breakwaters since the energy spectrum does not suitably characterise the large waves and groups in the sea state. At present some of the parameters used in stability analysis are the Hudson stability number ($N_s$) and the Irribaren number or the surf similarity parameter ($\xi$). CERC (1984) recommended the use of $H_{1/10}$ (average of the largest one-tenth wave heights) instead of $H_{sig}$ in the estimation of the stability number. In this study sea states have been characterised by the traditional method of spectral density and the wave height and wave period associated with the spectrum.

## 2.9 Performance of Quarry Rock as a Primary Armour

Extensive testing of double layer quarry rock using regular waves was carried out by Foster and Gordon (1973) producing values for the coefficient of damage ($K_D$) of 2.4 to 2.8 for breaking waves at damage levels of 1 to 5%. Physical model tests to investigate the influence of oblique random waves at a 5% damage level resulted in $K_D$ values of 1.8 for a normal wave direction and 6.6 at 75° to the normal on a breakwater slope of 1:1.5 (DPWS 1996).

## 2.10 Performance of the Hanbar Unit as a Primary Armour

Several physical model studies have been conducted at MHL using Hanbar units; Port Kembla seawall (PWD 1979), Eden breakwater (PWD 1984) and Ballina South breakwater (DPWS 1997). A $K_D$ of 7.5 was used for the Port Kembla seawall study and for the Eden breakwater study the $K_D$ varied from 3 to 9 for a nominal 5% damage. The more recent Ballina breakwater investigation used a $K_D$ of 6.1 for 15 tonne Hanbar units at a damage level of 2%.

In the Eden breakwater study a density of 23.5 units/100 $m^2$ for 15 tonne Hanbars was initially used during tests on the breakwater head and the placement of 29 units/100 $m^2$ was used for tests on the breakwater trunk. A placement density of 30 units/100 $m^2$ for two layers of 15 tonne Hanbars was used in the Ballina breakwater investigation. The placement densities used in the Forster South breakwater model tests, based on a 1½ layer coverage was 24 units/100 $m^2$.

## 2.11 Performance of the Ajacks Unit and the Stubby Unit as a Primary Armour

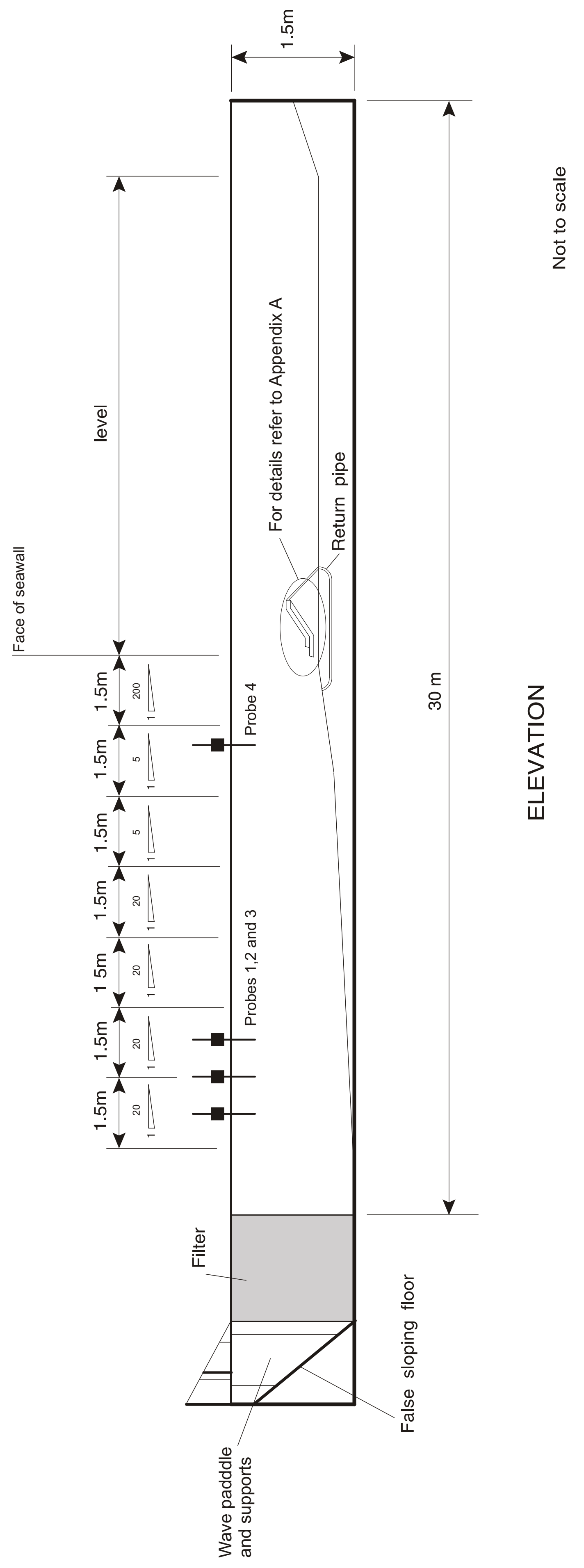
Extensive model tests of Ajacks armour units are reported in Amortec (1999). The report states that porosity and packing density have yet to be established for randomly placed Ajacks. For 152 mm units packing densities ranging from 0.42 (42 units/100$m^2$) to 0.57 (SPM 84) were achieved when randomly placed. The cross-section slope was 1:2. The testing demonstrated greater stability of uniformly placed Ajacks relative to random placement. However random placement testing demonstrated very good stability characteristics relative to other armour units. These tests were carried out using regular waves. The main conclusions of this testing are included in section 1.2 of this report. No previous tests on the Stubby unit are reported in the literature.

## 2.12 Armour Interfaces

Discussion on the performance of armour interfaces is provided by Turk et al. (1994) after investigations made on the Nawiliwili and Kahului breakwaters in Hawaii. The Nawiliwili and Kahului breakwaters are structures where many different interfaces have been used over a period of 90 years. Conclusions specific to these two structures can be summarised as follows.

Different armour types do not interlock well and will tend to show higher than average damage. Concrete armour stone transitions showed higher than average damage. Dolos and tribar armour unit layers that were interlaced tended to show higher breakage than when they were buttressed against each other, although the evidence was not conclusive. Dolos transition between two different sizes showed higher than average breakage if the size separation was of the order of 10 tonnes. Crown armour that was not buttressed against the cap was clearly unstable and showed higher than average breakage.

The test series was not originally intended to investigate the specific behaviour of rock/ artificial and artificial/artificial armour unit interfaces, however the tests provided an opportunity to observe the hydraulic stability of armour interfaces when used in repair or design of breakwaters.

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WAVE FLUME LAYOUT

MHL Report 1251

Figure 2.1

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# 3. Testing Procedure

## 3.1 General

Using the study brief provided by DLWC the original model test series was developed as detailed in Table 3.1. Information on each cross-section, including armour type, size and approximate placement density, together with the wave conditions and water levels used in each test run is tabulated in Table 3.1

**Table 3.1 Stage 1 Tests – Wave Conditions and Water Levels**

| Test No. | Type of Armour | Water Level (m AHD) | Wave Height (m) | Wave Period (s) | Comments |
|---|---|---|---|---|---|
| 1 | 7.6 tonne double layer stone armour at a placement density of 67 units / 100 $m^2$- with large secondary armour | 0.0 | 2.9 to 4.5 | 8.0 | After bedding in the test cross-section at a wave height of 2 m, the wave height was gradually increased |
| 2 (a) | 1.7-tonne single layer random placed Ajacks at a density of 61 units / 100 $m^2$-Test of Hanbar and Stubby interface with large secondary armour. Stubbies were used on toe | 0.0 | 4.5 | 8.0 | After bedding in the test cross-section at a wave height of 2 m, a wave height of 4.5 m was used for the tests |

Figures 4.1 and 4.2 indicate results of the Stage 1 testing. As the water level of 0 m AHD resulted in waves plunging on the toe and also extensively overtopping the crest (Figures 4.5(a) and 4.5(b)) the water level was maintained at 0 m AHD throughout the tests.

Following a review of the first stage of testing, a second series of tests was developed to further investigate the performance of Ajacks units and the modified Ajacks or the Stubby unit. A summary of the wave conditions and water levels used in the Stage 2 test series is given in Table 3.2.

**Table 3.2 Stage 2 Test Series – Wave Conditions and Water Levels**

| Test No. | Repair Strategy Armour [1] | Water Level (m AHD) | Wave Height (m) | Wave Period (s) | Comments |
|---|---|---|---|---|---|
| 2(b) | 1.7 tonne single layer random placed Ajacks at a density of 63 units / 100 $m^2$ .Test of Stubby interface with smaller secondary armour. A specially constructed toe with bundled units was used | 0.0 | 4.5 and 5.6 | 8.0 | After bedding in the test cross-section at a wave height of 2 m, a wave height of 4.5 m and 5.6 m was used for the tests. |
| 2(c) | 1.7 tonne single layer random placed Ajacks at a density of 66 units / 100 $m^2$ to test interface | 0.0 | 4.5 | 8.0 | After bedding in the test cross-section at a wave height of 2 m, a wave height of 4.5 m was used for the tests |
| 2(d) | 1.7 tonne single layer random placed Ajacks at a density of 66 units / 100 $m^2$ | 0.0 | 2.9 to 5.6 | 8.0 | After bedding in the test cross-section at a wave height of 2 m, the wave height was gradually increased |
| 2(e) | 1.7 tonne single layer random placed Ajacks at a placement density of 69 units / 100 $m^2$ using a stone and Stubby interface | 0.0 | 4.5 | 8.0 | After bedding in the test cross-section at a wave height of 2 m, a wave height of 4.5 m was used for the tests |
| 3 | 8 tonne double layer Hanbars at a density of 38 units / 100 $m^2$ | 0.0 | 4.5 | 8.0 | After bedding in the test cross-section at a wave height of 2 m, a wave height of 4.5 m was used for the tests |
| 4 | 3.5-tonne single layer random placed Stubby units at a placement density of 37 units / 100 $m^2$ | 0.0 | 2.9 to 5.6 | 8.0 | After bedding in the test cross-section at a wave height of 2 m, the wave height was gradually increased |

Figures 4.3 to 4.8 indicate results from the Stage 2 tests. A description of the results of the individual tests undertaken in both stages of the physical model investigation is provided in Sections 4.1 and 4.2.

## 3.2 Stability Tests

### *3.2.1 Bedding-in Tests*

A bedding-in test of 500 waves using a wave height of 2 m was completed prior to testing the cross-section under more extreme wave conditions. This procedure was undertaken to ensure that conditions similar to the development of storm wave conditions were simulated and the newly constructed structure was not subject to extreme wave attack without adequate settlement of the armour units.

*3.2.2 Damage Measurement*

Two damage definitions are used in breakwater modelling. One uses the erosion area (S) and requires the use of a cross-section profiler. The other definition, used in this investigation, relates damage ($N_o$) to the movement of a primary armour unit. If the unit moved more than the distance of one nominal diameter ($D_n$) it is considered to be damaged. For the Ajacks unit the nominal diameter was considered to be $D_n$ where $\rho D_n^3 = W_{50}$, and $\rho$ is the density of the unit and $W_{50}$ the nominal weight. Table 2.1 indicates the values for densities obtained for the model Ajacks unit and the Stubby unit as supplied by Pioneer Concrete Pty Ltd. Percentage damage is defined to be the percentage of displaced armour. The total number of units is taken to be the total number of units subject to wave action. For this investigation the total number of units on the cross-section was counted.

It should be noted that for milder wave conditions where runup and rundown does not affect the total length of cross-section, conservative estimates of damage may result when the total number of units on the cross-section is counted.

During testing in Stage 1, some armour units, particularly at the toe of the structure, were observed to have rocking motions. This rocking motion, although not contributing to an increase in damage of the structure, would increase the impact loadings on the adjacent individual units. Tests carried out by van der Meer (1988) indicate damage to a section built with rock armour is dependent on the duration of the storm. No data exists to establish if the stability of Hanbars or Ajacks units is dependent on storm duration, hence in this investigation each test run was carried out for a total of 2000 waves. After each series of 500 waves the damage was noted and the test section was videoed and photographed. The test waves were generated from a selected time series to investigate grouping effects on the structure. Hudson's equation was used to obtain the relationship between dimensionless wave height or stability number ($H_{sig} / \Delta D_n$) and $K_D$ as follows:

$$H_{sig} / \Delta D_n = (K_D \text{ Cot } \alpha)^{1/3}$$

where

$H_{sig}$ = significant wave height
$\Delta$ = relative mass density
$K_D$ = coefficient of damage
$D_n$ = nominal diameter of $M_{50}$ armour
$\alpha$ = angle of breakwater slope

The value of $K_D$ at a given level of damage to a structure was used to compare the efficiency of the Ajacks and Stubby unit with armour units such as quarry rock and the Hanbar. In addition to the coefficient of damage, the density of placement, structure slope, wave climate, type of breaking wave, type of placement and core material have to be considered when comparing the Ajacks and Stubby armour unit with other units for design purposes.

# 4. Test Results

## 4.1 Stage 1 Test Series Results

The details of each individual test run undertaken as part of stage one of the Ajacks physical model study are provided in Table 4.1. Figures 4.1 to 4.8 present a selection of photographs taken during the Stage 1 and Stage 2 of the model tests.

**Table 4.1 Ajacks Testing – Stage 1 Test Series Results**

| Test No. | Repair Strategy Armour | Water Levels (m AHD) | Wave Height (m) | Wave Period (s) | Comments |
|---|---|---|---|---|---|
| 1 | 7.6 tonne double layer stone armour at a placement density of 67 units / 100 $m^2$- with large secondary armour | 0.0 | 2.9 to 4.5 | 8.0 | After 2000 waves at 3.6 m wave height 40 units were displaced indicating a $K_D$ of 2.4. After 500 waves at 4.5 m 70 units were displaced and after 2000 waves 126 units were displaced (Figure 4.1) |
| 2(a) | 1.7 tonne single layer Ajacks at a density of 61 units / 100 $m^2$-Test of Hanbar and Stubby interface with large secondary armour. Rock armour was used on toe | 0.0 | 4.5 | 8.0 | Cross-section was stable up to 1500 waves (Figure 4.2(b)) and secondary armour and core were damaged during the last 500 waves of the test series (Figure 4.2(c). Larger secondary armour (Appendix B) was used for these tests. |

The results of the Stage 1 testing can be summarised as follows:

- The initial testing to simulate damage to a two-layer 8 tonne Hanbar armour resulted in 7.3% damage. The estimated $K_D$ value was 6.7.
- An initial test was carried out on the Ajacks after bedding in the units. After 1500 waves damage caused the secondary armour and core to be visible. Damage was attributed to toe movement and inadequate placement density. In addition, damage to the Hanbar interface caused movement in the Ajacks layer.

Details of the armour damage and aspects of the testing in Stage 1 are provided in Figures 4.1 and 4.2.

## 4.2 Stage 2 Test Series Results

The details of each individual test run undertaken as part of Stage 2 of the Ajacks unit tests are provided in Table 4.2.

**Table 4.2 Ajacks Testing – Stage 2 Test Series Results**

| Test No. | Repair Strategy Armour | Water Level/s (m AHD) | Wave Height (m) | Wave Period (s) | Comments |
|---|---|---|---|---|---|
| 2(b) | 1.7 tonne single layer Ajacks at a density of 63 units / 100 $m^2$. Test of Stubby interface with smaller secondary armour. A specially constructed toe with bundled units was used | 0.0 | 4.5 and 5.6 | 8.0 | 4 units were displaced after 2000 waves at 4.5 m. The toe was constructed using bundled units of Ajacks. Smaller secondary armour (Appendix B) was used. The crest and toe suffered minor damage. This test was used to assess the $K_D$ value at approximately 48 (Figure 4.4 and 4.5) . Failure occurred at 5.6 m (Figure 4.3) |
| 2 (c) | 1.7 tonne single layer Ajacks at a density of 66 units / 100 $m^2$. This was to test interfaces | 0.0 | 4.5 | 8.0 | 6 units were displaced after 1000 waves, 15 units were displaced after 1500 waves, 27 units were displaced after 2000 waves. The initial damage was attributed to unsatisfactory gluing of the units |
| 2(d) | 1.7 tonne single layer Ajacks at a density of 66 units / 100 $m^2$ | 0.0 | 2.9 to 5.6 | 8.0 | No damage was observed up to a wave height of 4.5 m. During the first 500 waves at 5.6 m, 10 Ajacks units were displaced. Failure was experienced during the second 500 waves. This test was used to assess the $K_D$ value at approximately 48 (Figure 4.4 and 4.5). |
| 2(e) | 1.7 tonne single layer Ajacks at a placement density of 69 units / 100 $m^2$ using a stone and Stubby interface | 0.0 | 4.5 | 8.0 | The stone interface was damaged (Figure 4.6). Minor damage was experienced by the Stubby units and the Ajacks units. The Stubby units performed well as an interface between rock and Ajacks armour units |

| | | | | | |
|---|---|---|---|---|---|
| 3 | 8 tonne double layer Hanbars at a density of 38 units / 100 $m^2$ | 0.0 | 4.5 | 8.0 | After 500 waves - 6 units displaced<br>After 1000 waves - 10 units displaced<br>After 1500 waves - 14 units displaced<br>After 2000 waves - 15 units displaced (Figure 4.1). |
| 4 | 3.5 tonne single layer Stubby units at a placement density of 37 units / 100 $m^2$ | 0.0 | 2.9 to 5.6 | 8.0 | After testing with 4.5 m waves 4 units were displaced indicating a $K_D$ of 24. After 500 waves using 5.6 m waves failure was experienced. |

The results of Stage 2 of the testing program outlined in Table 4.2 can be summarised as follows:

- The Ajacks unit tests resulted in high $K_D$ values (48) when the toe was fixed using bundled Ajacks units and the interfaces were stable. The damage level was less than 3%. Consideration has to be given whether in prototype construction it is possible to construct the bundled toe.
- Due to the Ajacks unit being placed in a single layer, early repair strategies have to be planned in order to prevent damage to the secondary armour and core.
- The Stubby unit and the Ajacks unit performed well on the crest of the cross-section and were stable during heavy overtopping conditions.
- 7.6 tonne quarry rock armour placed at approximately 67 units/100 $m^2$ resulted in a $K_D$ value of 2.4 at 5 to 10% damage.
- 3.5 tonne Stubby units placed at density of 37/ 100 $m^2$ resulted in a $K_D$ value of 24 when the toe was fixed using grouped Ajacks units and the interfaces were stable. The damage level was less than 2%.
- The bundled Ajacks units provided a stable toe during Stage 2 of the tests.

Details of the armour damage and aspects of the testing in Stage 2 are provided in Figures 4.3 to 4.8.

(a) Two-layer stone armour with Ajacks toe before testing

(b) Damage to stone armour after 2000 waves Hs = 4.5 m, Tp = 8.0 s

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TESTS ON 7.6 TONNE TWO-LAYER ROCK ARMOUR

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Figure 4.1

DRAWING 1251-04-01.CDR

(a) Ajacks with Hanbar and Stubby interface - before testing

(b) Damage to cross-section after 1500 waves Hs = 4.5 m, Tp = 8.0 s

(c) Damage to cross-section after 2000 waves HS = 4.5 m, Tp = 8.0 s

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TESTS ON 1.7 TONNE SINGLE-LAYER AJACKS CROSS-SECTION

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Figure 4.2

DRAWING 1251-04-02.CDR

(a) Ajacks cross-section with bundled toe units prior to testing

(b) Ajacks cross-section with bundled toe units after 2000 waves
Hs = 4.5 m, Tp = 8.05

(c) Damage to cross-section after 500 waves Hs = 5.6 m, Tp = 8.05



TESTS ON 1.7 TONNE AJACKS CROSS-SECTION WITH BUNDLED UNIT TOE

(a) Wave about to overtop crest Hs = 4.5 m, Tp = 8.0 s

(b) Minor damage to crest after extensive overtopping when using Ajacks units for crest protection
Hs 4.5 m, Tp = 8.0 s

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TESTS ON 1.7 TONNE SINGLE-LAYER AJACKS CROSS-SECTION

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Figure 4.4

DRAWING 1251-04-04.CDR

(a) Wave plunging on toe of cross-section Hs = 4.5 m, Tp = 8.0 s

(b) Extensive wave overtopping of cross-section

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TESTS ON 1.7 TONNE SINGLE-LAYER AJACKS CROSS-SECTION WITH STUBBY UNITS ON CREST

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Figure 4.5

DRAWING 1251-04-05.CDR

(a) Minor damage to crest when using the Stubby unit for crest protection Hs = 4.5 m, Tp = 8.05

(b) Damage to stone interface after 2000 waves. The Ajacks armour was undamaged
Hs = 4.5 m, Tp = 8.0 s

(a) Wave plunging on two-layer Hanbar primary armour Hs = 4.5 m, Tp = 8.0 s

(b) Damage to two-layer Hanbar primary armour after 2000 waves

(a) Stubby armour units before testing

(b) Stubby armour - after 2000 waves four units displaced
Hs = 4.5 m, Tp = 8.0 s

(c) Ajacks armour - damage after 500 waves Hs = 5.6 m, Tp = 8.0 s

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TESTS ON 3.5 TONNE SINGLE-LAYER STUBBY ARMOUR CROSS-SECTION

MHL Report 1251

Figure 4.8

DRAWING 1251-04-08.CDR

# 5. Conclusions and Recommendations

The testing was carried out using irregular waves. The Ajacks units were placed in a single random layer. In this study, the surf similarity parameter (ξ) varied from 2.8 to 3.9. This indicates that the wave breaking process went from plunging to surging waves. Ahrens (1975) and van der Meer (1988) suggest that armour stability is a minimum during this breaker transition phase. The following conclusions can be drawn based on the model testing described in the study.

**Stage 1 Tests**

- 7.6 tonne quarry rock armour placed at approximately 67 units/100 $m^2$ resulted in a $K_D$ value of 2.4 at 5 to 10% damage.
- The initial testing to simulate damage to a two-layer 8 tonne Hanbar armour resulted in 7.3% damage. The estimated $K_D$ value was 6.7.
- An initial test using 4.5 m waves with 8 s peak period was carried out on the Ajacks after bedding in the units. After 1500 waves damage caused the secondary armour and core to be visible. Damage was attributed to toe movement and inadequate placement density. Also damage to the Hanbar interface caused movement in the Ajacks layer.

**Stage 2 Tests**

- The Ajacks unit tests resulted in a $K_D$ value of 48 when the toe was fixed using bundled Ajacks units and the interfaces were stable. The damage level was less than 3%. Smaller secondary armour was used in the Stage 2 Ajacks tests compared to that used in Stage 1. The wave height was gradually increased during the tests. The $K_D$ values obtained at the O.H. Hinsdale laboratory at Oregon State University varied from 24 to 292. Regular waves were used for these tests.
- The Stubby unit and the Ajacks unit performed well on the crest of the cross-section and resulted in minor damage during heavy overtopping conditions.
- The initial testing to simulate damage to a two-layer 8 tonne Hanbar armour resulted in 7.3% damage. The estimated $K_D$ value was 6.7.
- 3.5 tonne Stubby units placed at a density of 37/100 $m^2$ resulted in a $K_D$ value of 24 when the toe was fixed using grouped Ajacks units and the interfaces were stable. The damage level was less than 2%. The wave height was gradually increased during the tests.
- The bundled Ajacks units provided a stable toe during Stage 2 of the tests.
- Due to the Ajacks unit being placed in a single layer, early repair strategies have to be planned in order to prevent damage to the secondary armour and core.

- The Stubby unit provided a suitable interface between the Ajacks unit and the larger rock armour.
- All the tests were carried out at a slope of 1V:1.5H.
- When using the Ajacks unit for repairing structures with existing primary armour such as rock or Hanbar units care has to be taken regarding the difference in armour size as the testing indicated that when large size differentials were simulated damage to the interface resulted. A stable interface was obtained when the 1.7 tonne Ajacks unit was interfaced with the 3.5 tonne Stubby unit.
- In addition to the coefficient of damage, the density of placement, wave climate, type of breaking wave, type of placement, permeability and hence core material have to be considered when considering the Ajacks armour unit for design purposes.
- It is recommended that the Stubby and Ajacks unit be further tested under 3D conditions in a wave basin in order to assess the units' performance under the joint action of currents and waves in a basin.

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# Appendix A

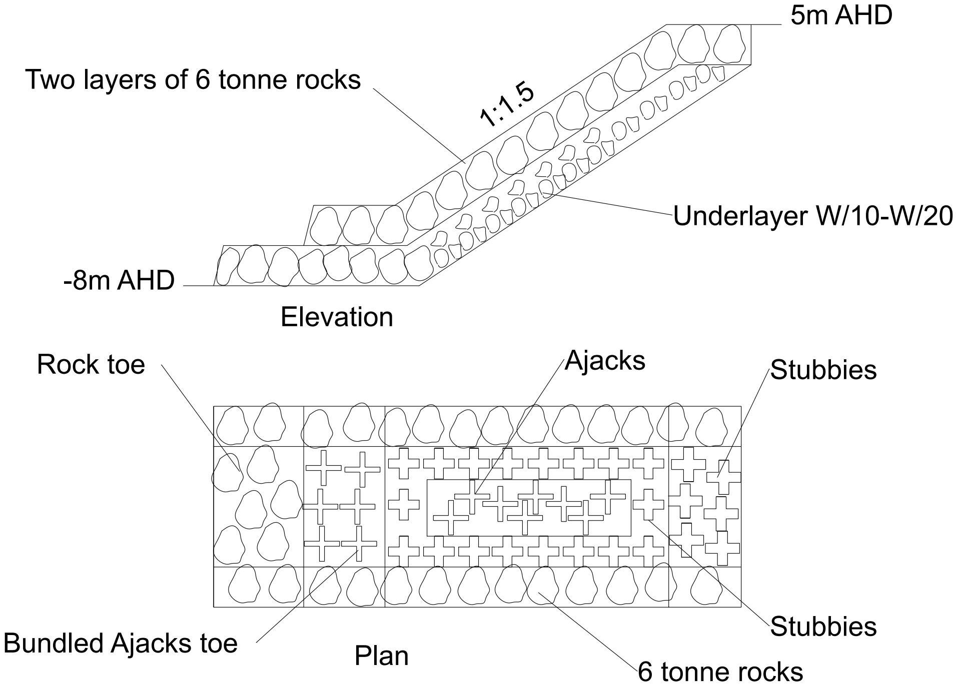
## Symbols

# Symbols

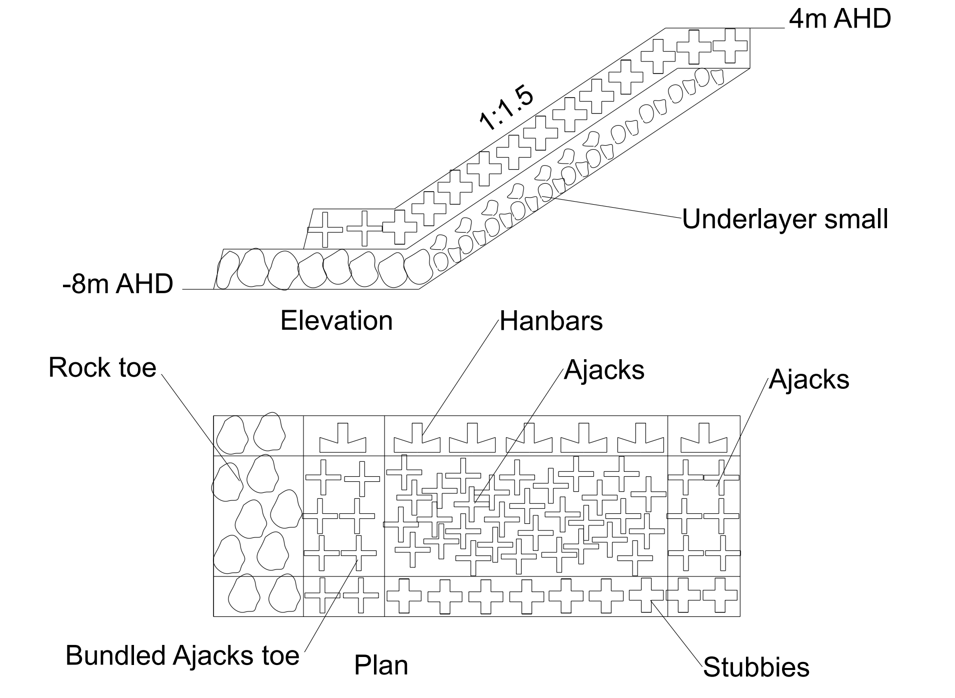
| | | |
|---|---|---|
| $D_n$ | = | Equivalent diameter of $M_{50}$ rock armour |
| GF | = | Groupiness factor |
| $H_{sig}$ | = | Significant wave height of time series |
| $K_D$ | = | Coefficient of damage |
| L | = | Wave length |
| $N_s$ | = | Hudson stability number ($H_{sig} / \Delta D_n$) |
| $T_{P1}$ | = | Peak period of spectrum |
| $W_{50}$ | = | Mass of 50% percentile in rock armour distribution |
| $\nu$ | = | Kinematic viscosity |
| Re | = | Reynolds number |
| $\alpha$ | = | Angle of breakwater slope |
| $\Delta$ | = | Relative mass density |
| $\gamma_f$ | = | Influence factor for roughness |
| $\gamma_s$ | = | Influence factor for shallow water |
| $\gamma_\beta$ | = | Influence factor for oblique wave attack |
| $\xi$ | = | Surf similarity parameter |

# Appendix B

# Test Cross-Sections




CROSS-SECTION 1




CROSS-SECTION 2A

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TEST CROSS-SECTIONS

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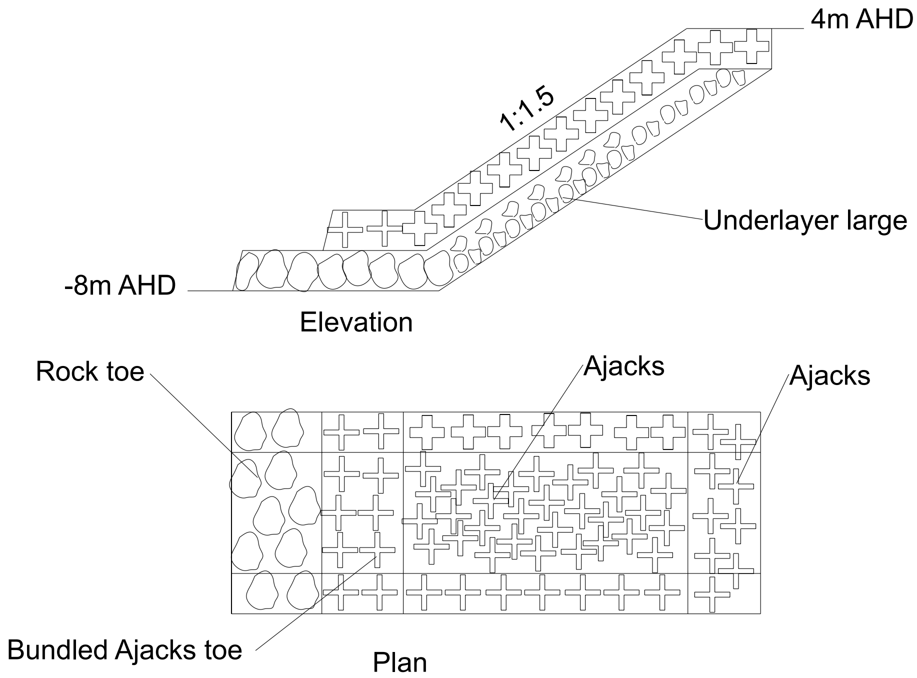
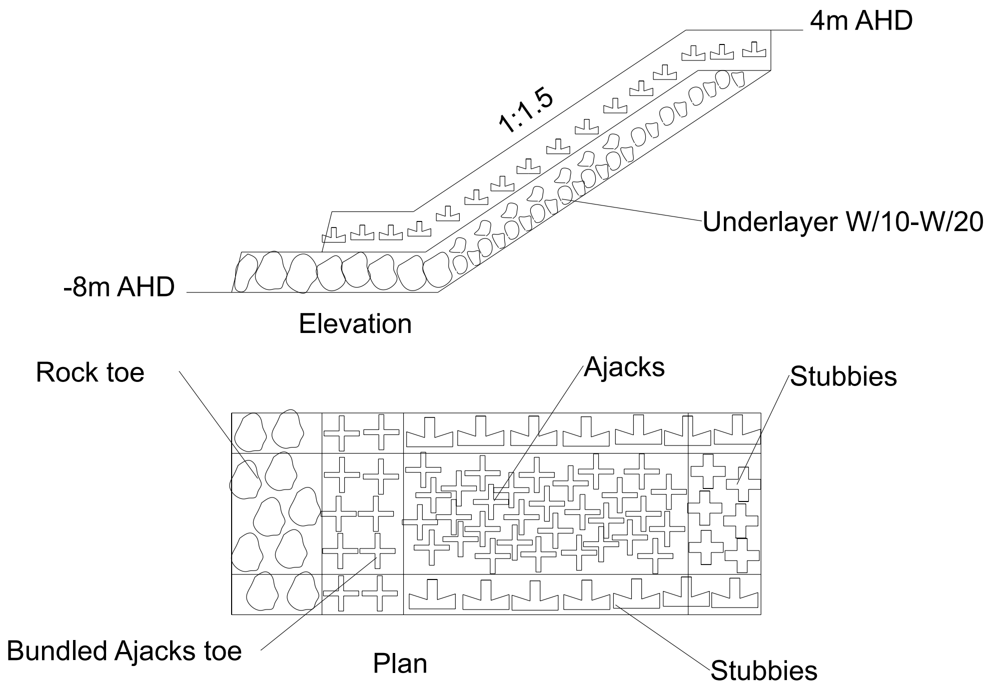
Figure B.1

DRAWING 1251-B-01.CDR




CROSS-SECTION 2B




CROSS-SECTION 2C AND 2D

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TEST CROSS-SECTIONS

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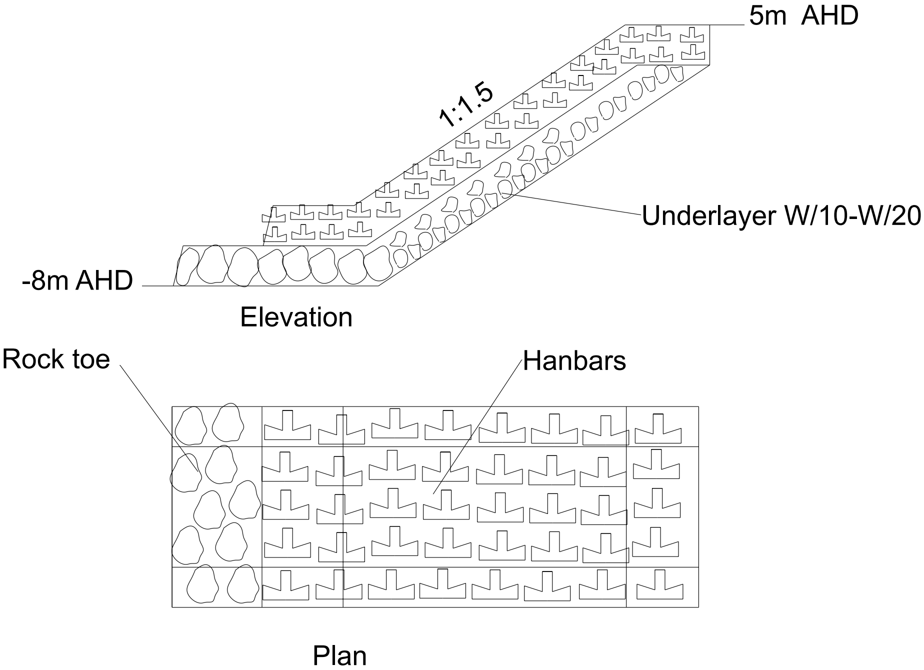
Figure B.2

DRAWING 1251-B-02.CDR




CROSS-SECTION 2E

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TEST CROSS-SECTIONS

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Figure B.3

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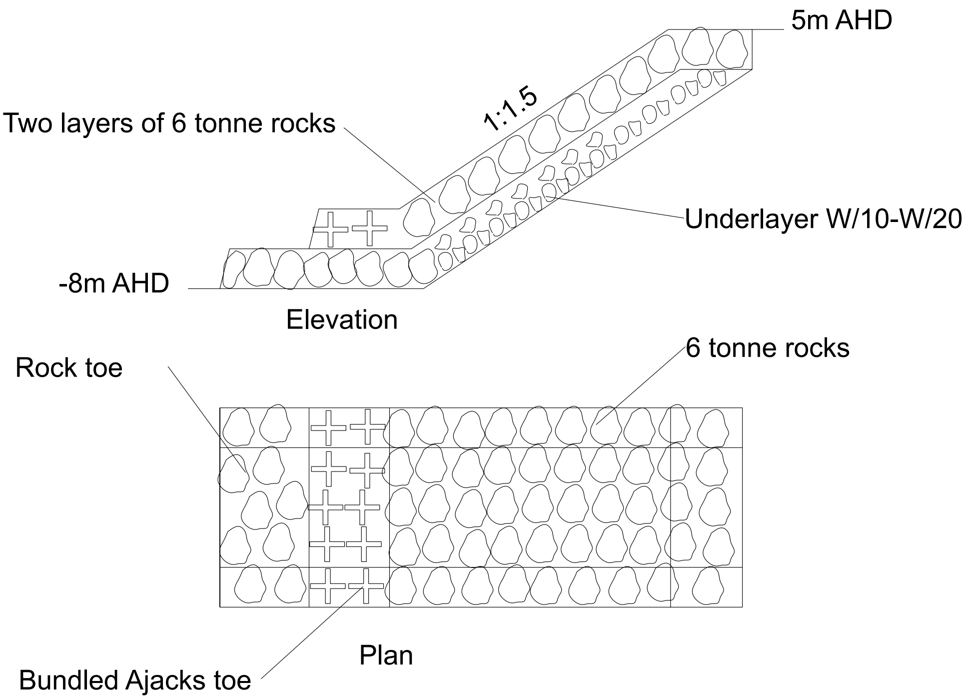
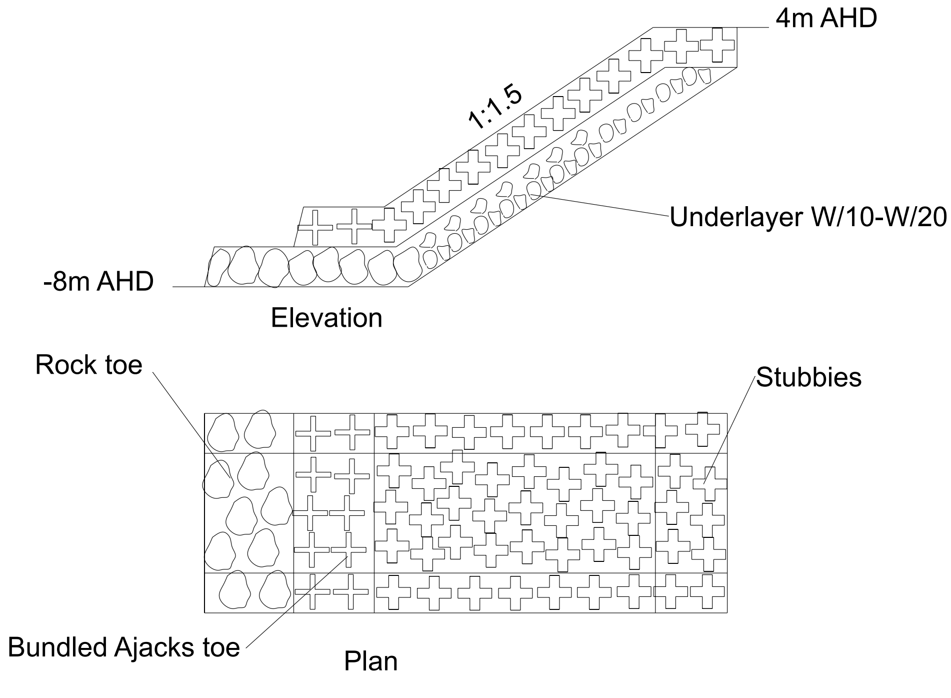



CROSS-SECTION 3




CROSS-SECTION 4

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TEST CROSS-SECTIONS

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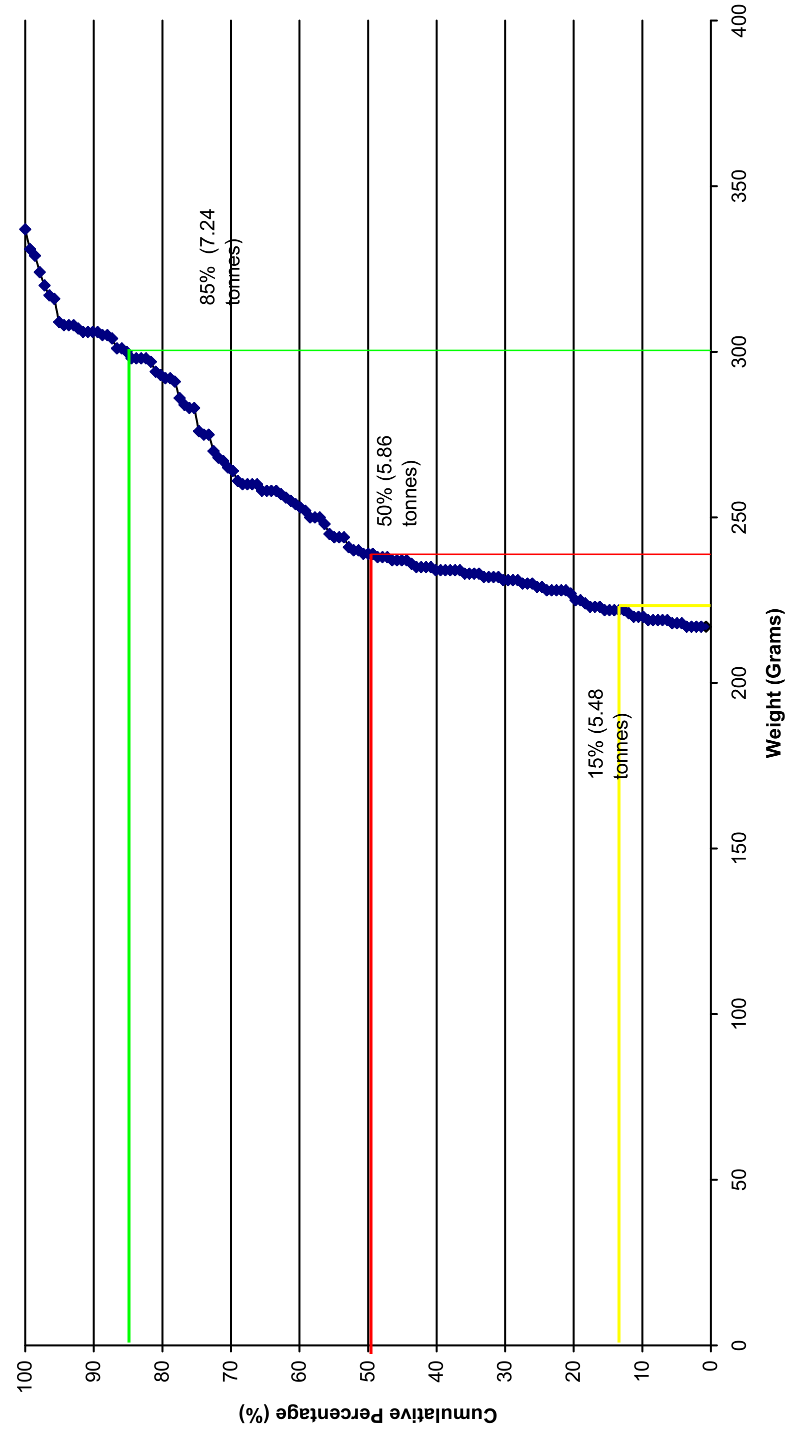
Figure B.4

DRAWING 1251-B-04.CDR

**Appendix C**

**Grading Curves for Model Rock Armour**

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PRIMARY ARMOUR (BLUE SIDE BARS)
AJACKS MODEL

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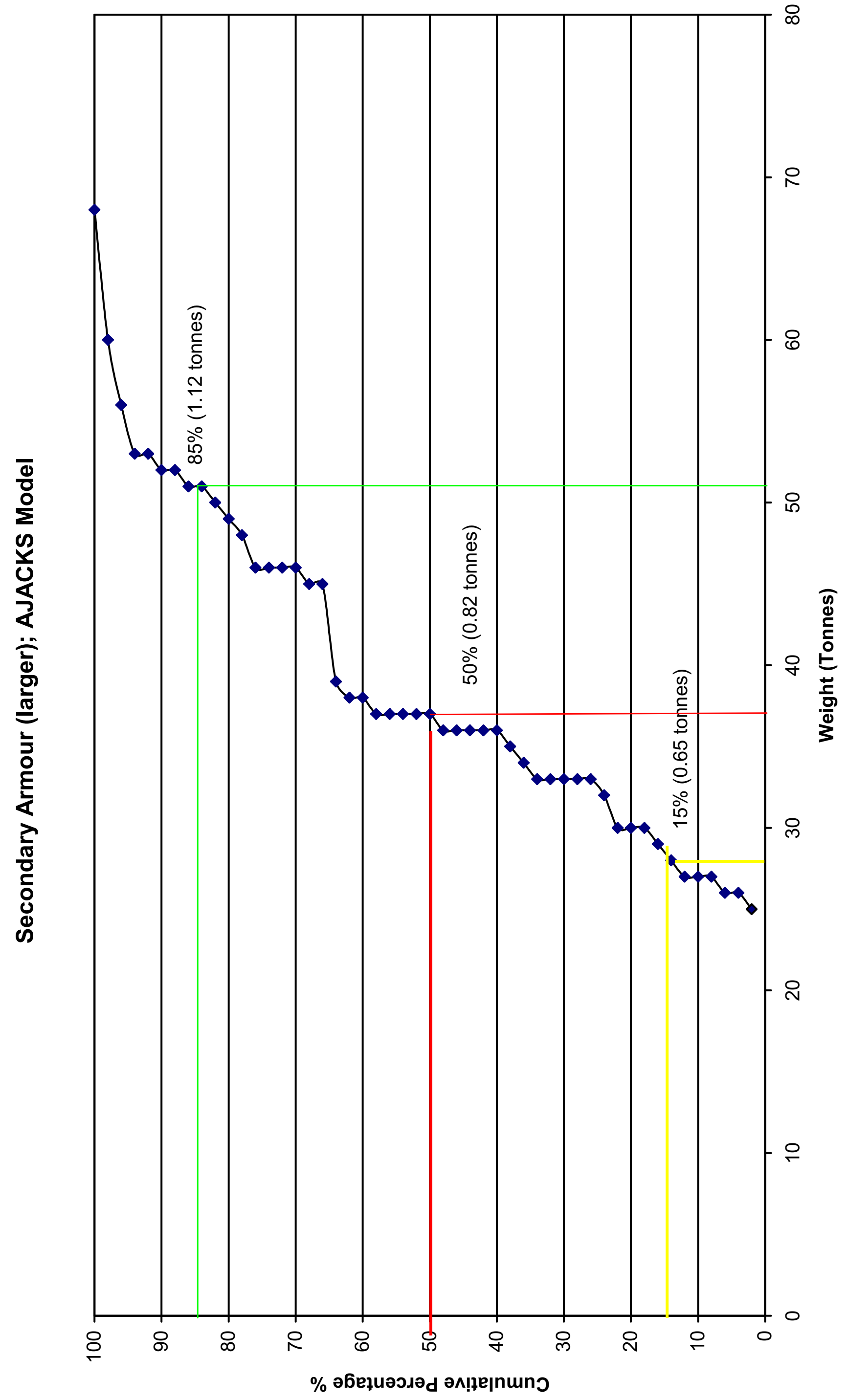
Figure C.1

DRAWING 1251-C- 01.CDR

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PRIMARY ARMOUR (BLUE SIDE BARS)
AJACKS MODEL

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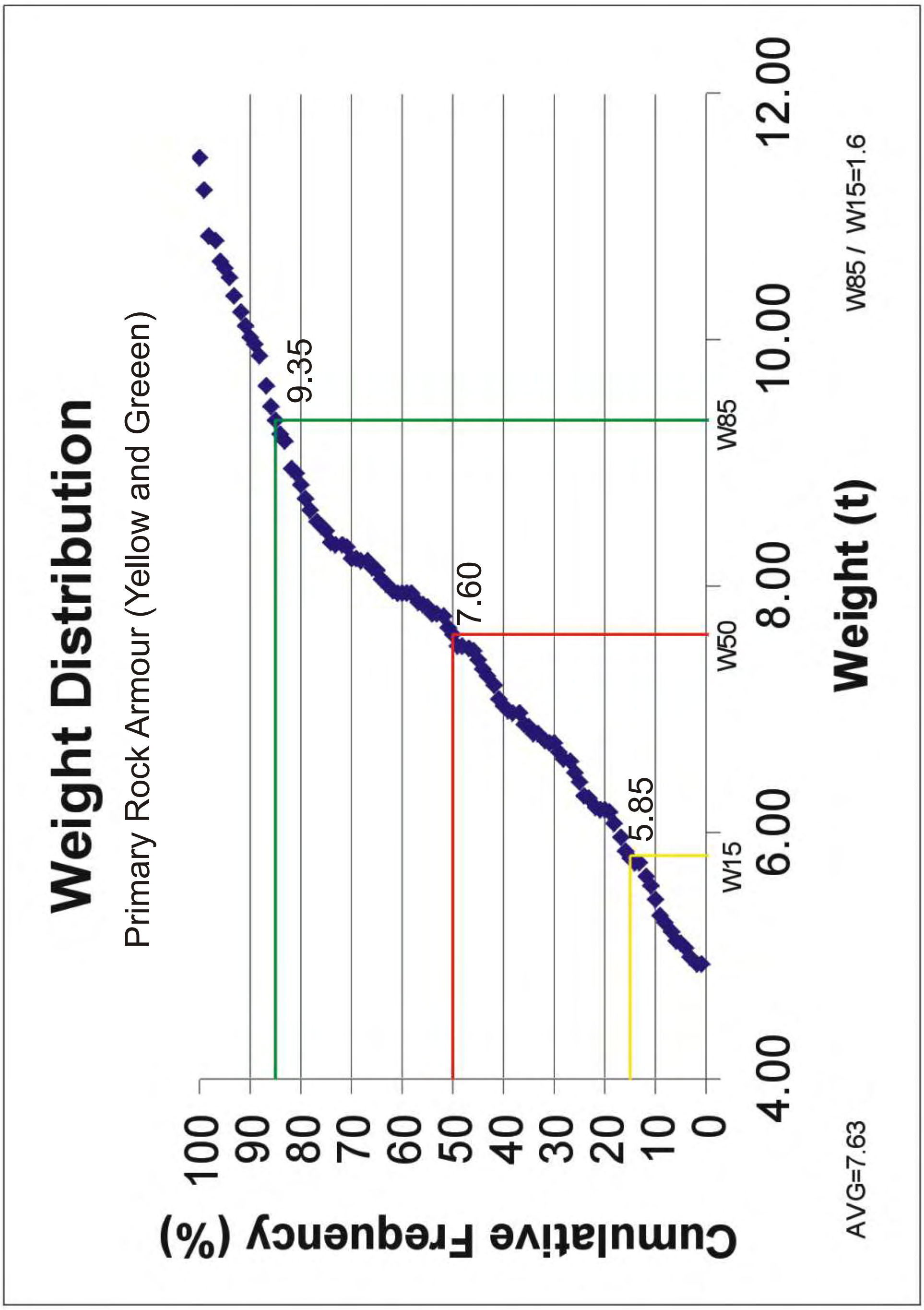
Figure C.2

DRAWING 1251-C-02.CDR

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GRADING CURVE FOR MODEL
PRIMARY ROCK ARMOUR

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Figure
C.3

DRAWING 1251-C-03.CDR

NSW Department of Commerce

Manly Hydraulics Laboratory

110b King Street
Manly Vale NSW 2093

T 02 9949 0200
F 02 9948 6185
TTY 1300 301 181

www.mhl.nsw.gov.au