STABILITY OF CUBIPOD ARMOURED ROUNDHEADS IN SHORT-CRESTED WAVES. A COMPARISON BETWEEN CUBIPOD AND CUBE ARMOUR STABILITY

Hans F. Burcharth[1], Thomas Lykke Andersen[1] and Josep R.Medina[2]

The paper presents a comparison of the stability of concrete cube armour and Cubipod armour in a breakwater roundhead with slope 1:1.5, exposed to both 2-D (long-crested) and 3-D (short-crested) waves. The model tests were performed at the Hydraulics and Coastal Engineering Laboratory at Aalborg University, Denmark. The model tests showed that Cubipod armour is more stable than cube armour when exposed to longer waves (steepness approx. 0.025) and has equal stability to cubes in shorter waves. The Cubipod armour layer contained due to its high porosity approximately 6-17% less concrete than the cube armour layer. Therefore, it was concluded that per used volume of concrete the Cubipods perform better than the cubes.

Keywords: breakwaters; concrete armour; Cubipod; roundheads; short-crested waves

INTRODUCTION

The roundhead is generally the most exposed part of the breakwater. Moreover, in case of rubble mound structures the needed armour size is larger than in the adjacent trunk. Typically units of almost double mass are needed in the roundhead if high density stones or concrete are not used in the head. The Cubipod as shown in Fig. 1 is a relatively new development, see Gómez-Martin and Medina (2008) for details.

Figure 1. Cubipod armour unit.

The Cubipod is similar to a cube except that it features protrusions on each face to prevent locally strongly varying packing density as well as to increase the friction against the filter layer.

A comparison of the stability of Cubipod and cube armoured roundheads has been performed at the Environmental Hydraulics Institute at the University of Cantabria (Gómez-Martin and Medina 2008) using long-crested waves covering Iribarren numbers in the range 2.0 – 3.4. The tests indicate a slightly better stability of the Cubipods compared to cubes.

A new comparison using short-crested waves was made at the Hydraulics and Coastal Engineering Laboratory at Aalborg University, Denmark (Burcharth et al. 2009).

The stability of Cubipod armour was compared both to earlier model tests with cubes (2004) and new tests with cubes (2009). In all cases were used identical roundhead geometry and test setup in the wave basin.

[1] Dept. of Civil Engineering, Aalborg University, Sohngaardsholmsvej 57, DK-9000 Aalborg, Denmark
[2] Universidad Politécnica de Valencia, ETSI Caminos, Camino de Vera s/n, 46022 Valencia, Spain

ROUNDHEAD GEOMETRY AND ARMOUR MATERIALS

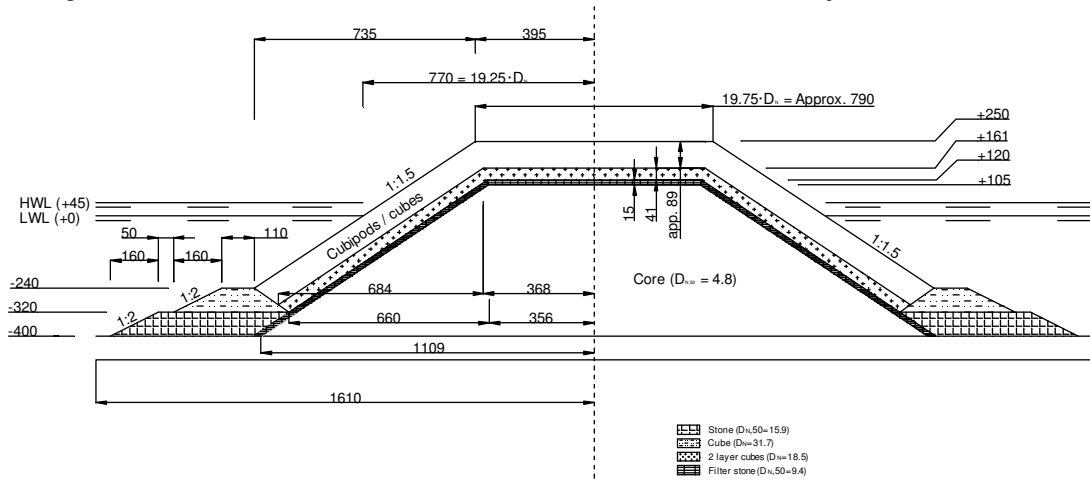Figures 2 and 3 show the model cross section of the roundhead and the adjacent trunk.

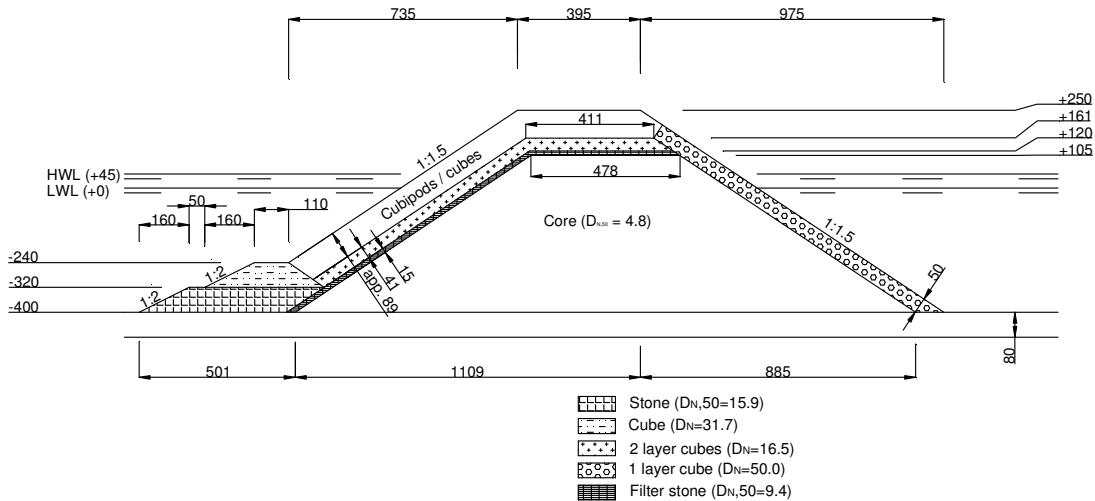**Figure 2. Model cross section of the roundhead (measures in mm).**

Figure 3. Model cross section of the trunk (measures in mm).

The specifications of the materials applied in the models are given in Table 1.

Table 1. Elements used for the model (model scale values).				
Elements	Block size [mm]	Mass density [t/m³]	Mass [g]	ΔD_n [m]
Armour cubes	40×40×40	2.32	146	0.053
Cubipods	35×35×35 (smallest dimension) 52×52×52 (largest dimension)	2.22	128	0.047
Toe parallellepipedes	29×29×37	2.17	69	0.037
Filter cubes – type 1	18.5×18.5×18.5	2.34	15	-
Filter cubes – type 2	16.5×16.5×16.5	2.04	9	-

The core material was narrow graded crushed stones with D_{n50} = 4.8 mm. The Cubipods and the cubes were randomly placed in a double layer. The thickness of the layers was approx. 89 mm. corresponding to approx. 2.2 D_n. Exact thickness cannot be given without a detailed definition of the surface of the armour layers. However, such definitions must be linked to the method of the measuring the surface.

The packing density and the related volume of concrete per unit area varied in the various models as given in Table 2. The area used in the calculation is that of the armour layer surface when taking layer thickness as 2.2 D_n.

Table 2. Packing densities and concrete volumes.		
Tests	Packing density [units/D_n^2]	Concrete volume [m^3/m^2]
Cubipods (2009)	1.23 – 1.24	0.0445 – 0.0449
Cubes (2009)	1.27	0.0474
Cubes (2004)	1.41	0.0525

It is seen that approx. 6-17% more concrete were used in the cube armour layer compared to the Cubipod armour layer.

MODEL LAYOUT

The layout of the model is shown in Fig. 4. The wave generators consist of 25 hydraulic operated snake type flaps with strokes (translation) up to 1.2 m.

An array of seven wave gauges was used to record the directional waves. A three gauge array (always orientation in mean direction) was used as check on results from the seven gauge array.

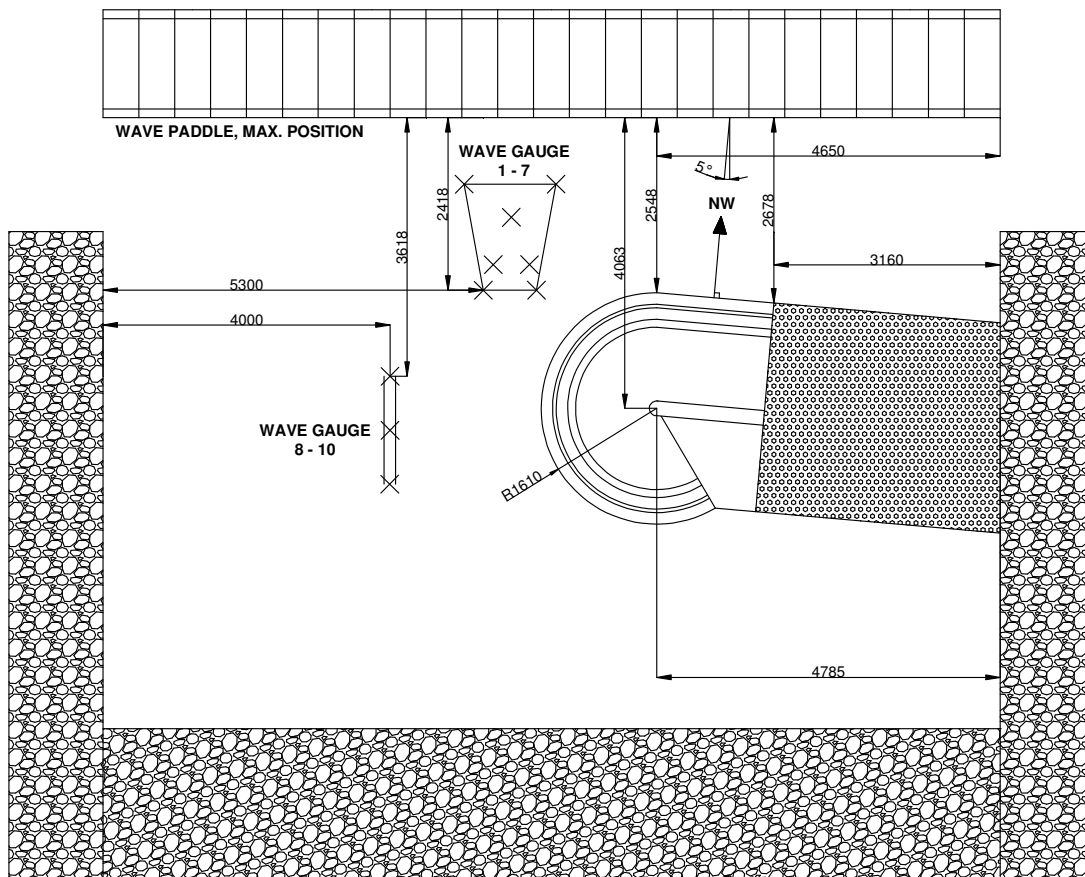A seabed slope of 1:25 was established on front of the breakwater model.

Figure 4. Layout of the model. Measures in mm.

WAVES AND WAVE ANALYSIS

Both short-crested and long-crested waves were generated corresponding to a JONSWAP spectrum with peak enhancement parameter $\gamma = 3.3$. For the short-crested waves was used the Longuet-Higgins spreading function with $s = 15$. The waves were generated online by the AwaSys Program (Aalborg University 2008a). The incident wave spectra were analyzed using WaveLab (Aalborg University 2008b). This software package uses the BDM-method (Hashimoto and Kobune 1988) for directional wave analysis.

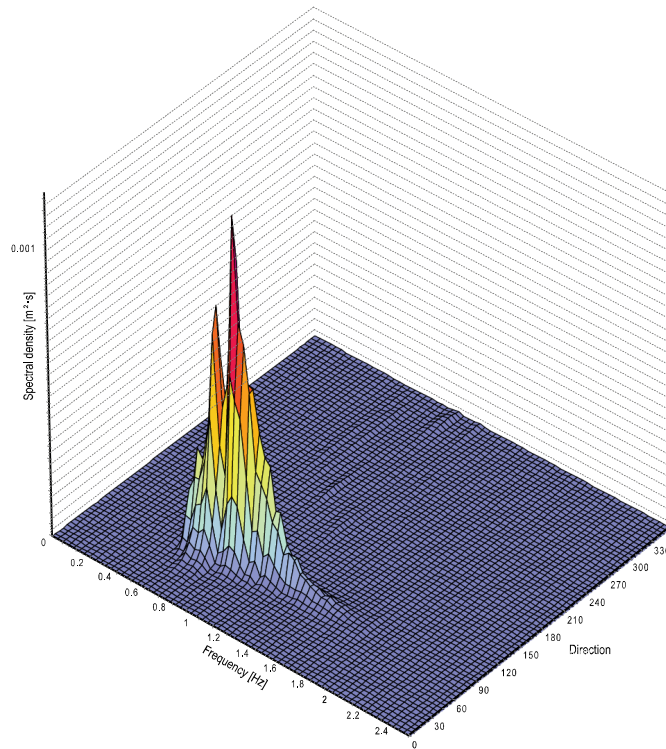An example of the 3D variance spectrum is shown in Fig. 5.

Figure 5. Example of variance spectrum.

Wave steepness were in the range s_{0p} = 0.02-0.05. The Iribarren number range was $I_r = \dfrac{\tan \alpha}{\sqrt{\dfrac{H_s}{s_{op}}}} = 3.0 - 4.4$. The maximum stability number reached among all tests was $N_s = \dfrac{H_s}{\Delta D_n} = 3.4$.

The Reynolds number $\mathrm{Re} = \dfrac{\sqrt{g\, H_s} \cdot D_n}{\nu}$ was approx. $5 \cdot 10^4$, sufficient to avoid scale effects related to armour stability. ν is the kinematic viscosity.

Two mean wave directions were used in the tests: Angle of incidence 0° and 22.5°, cf. Fig. 6.

DAMAGE DEFINITION AND OBSERVATION

The roundhead was divided into sectors as shown in Fig. 6 in order to facilitate determination of the spatial distribution of damage. Note that the sectors are not identical in the tests with Cubipods and cubes. The damage is given for each sector and for the whole roundhead (180° sector) as percentage of units displaced more than one D_n.
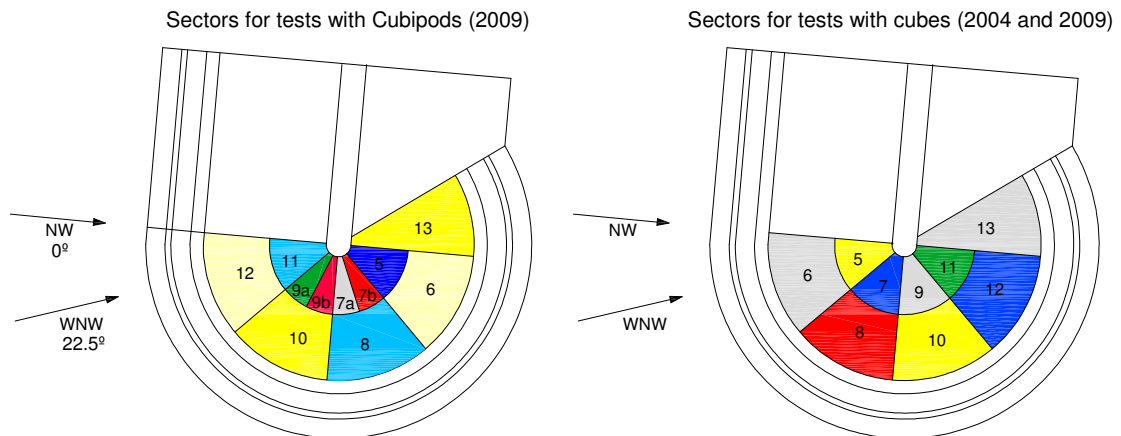

Figure 6. Division of roundheads into sectors.

TEST RESULTS

Typical examples of test results are given below.

2-D Waves

Fig. 7a, 7b and 7c show the damage development in tests with 2-D waves, s_{0p} = approx. 0.04 and angle of incidence 0°.
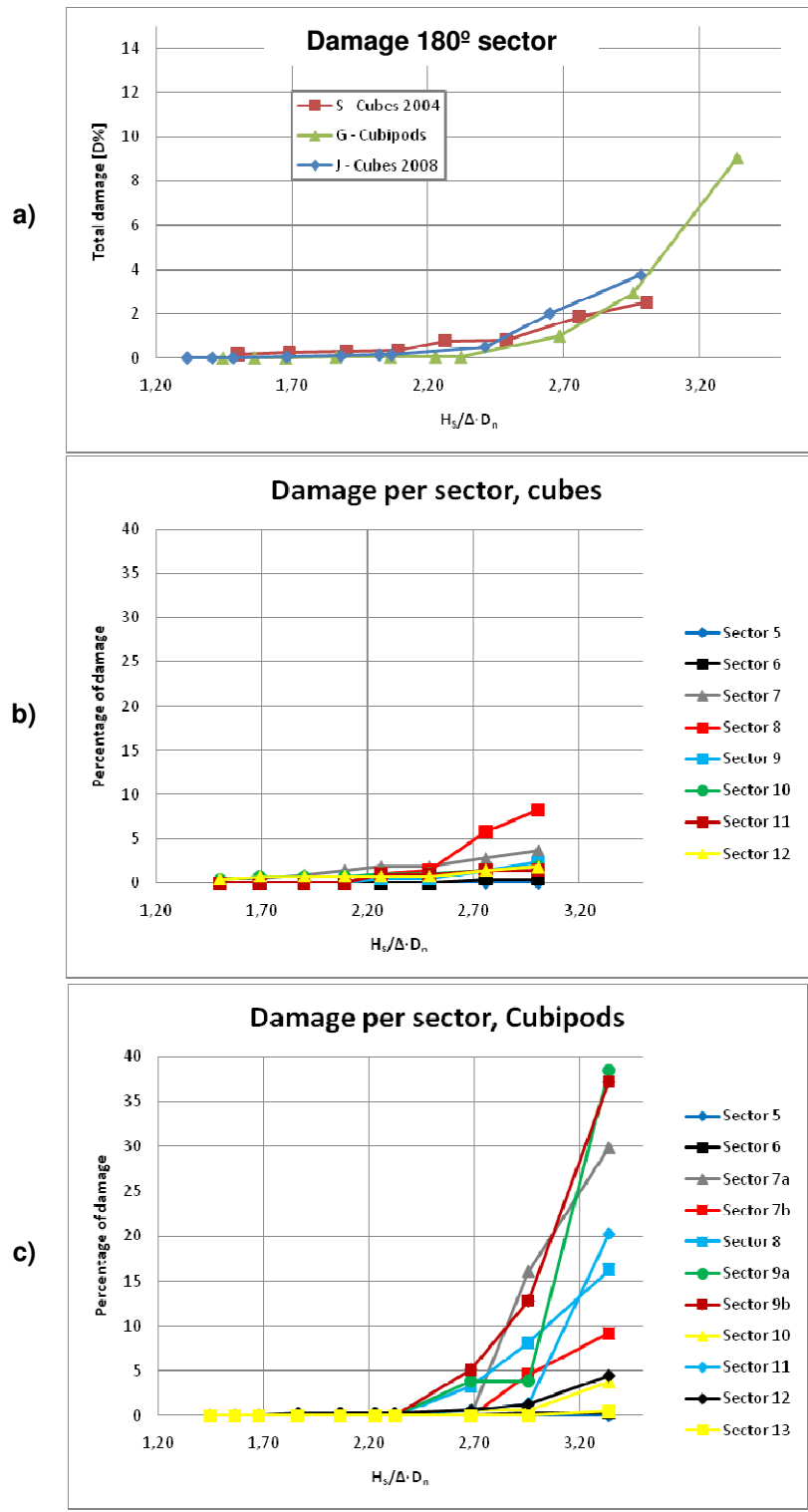

Figure 7. Damage in tests with 2-D waves s_{0p} = approx. 0.04 and angle of incidence 0°.

It is seen that the total damages in a 180° sector is almost the same for Cubipods and cubes. The dispersion of damage over the roundhead is however more pronounces for the Cubipod armour (the larger number of sectors taken into account).

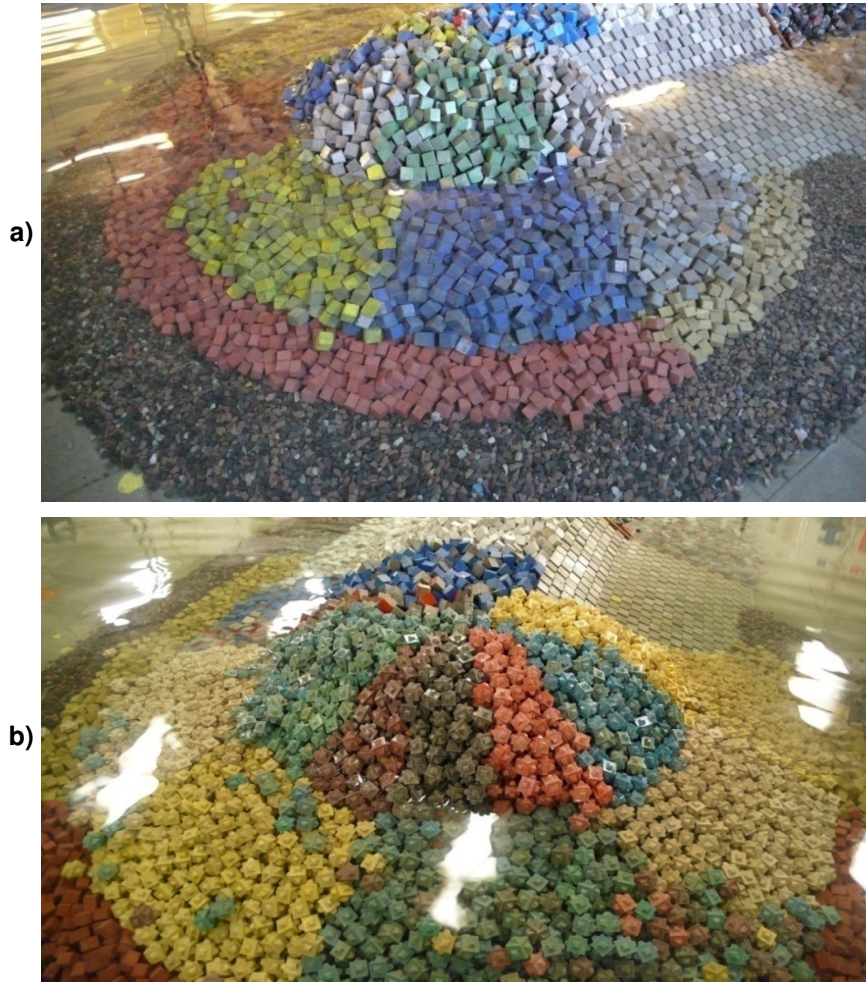Fig. 8a and 8b show photos of the end of the tests presented in Fig. 7.

Figure 8. Photos of the roundheads after exposure to 2-D waves s_{0p} = approx. 0.04 and angle of incidence 0°. a) Cube armour, N_s = 2.98, H_s =15.69 m at scale 1:100. b) Cubipod armour, N_s = 3.34, H_s = 15.67 at scale 1:100.

3-D Waves

Fig. 9a, 9b and 9c show damage in the tests with 3-D waves, s_{0p} = approx. 0.035 and angle of incidence 0°.
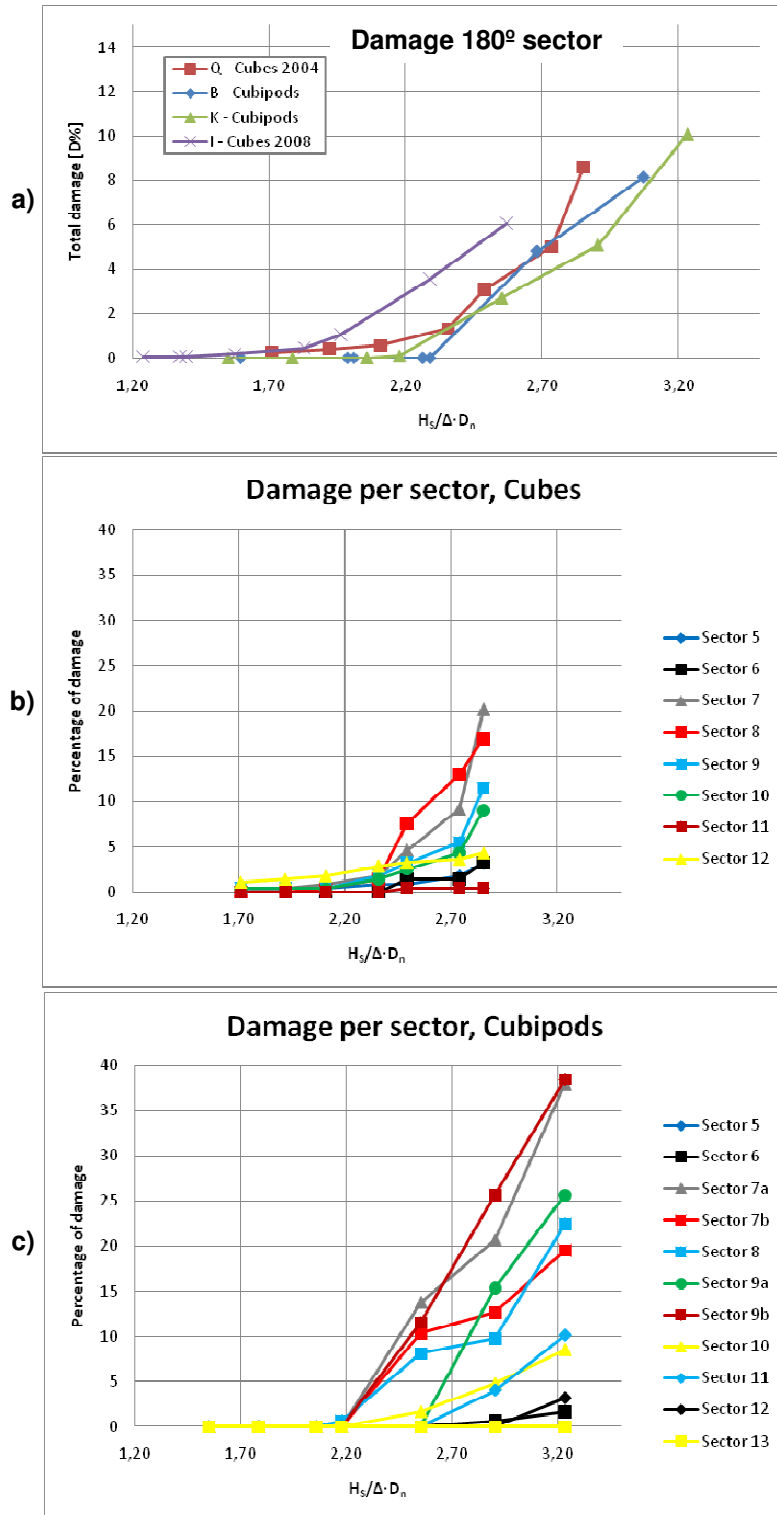
a)

b)

c)

Figure 9. Damage in test with 3-D waves s_{0p} = approx. 0.035 and angle of incidence 0°.

It is seen that Cubipod armour perform better than cube armour. Fig. 10 shows as an example a photo of the maximum observed damage of Cubipod armour after exposure to waves reaching N_s = 3.2. Only at two locations are the filter layer visible over limited areas.

Figure 10. Exposed filter in Cubipod for N_s = 3.2. 3-D waves, s_{0p} = approx. 0.035 and angle of incidence 0°.

Fig. 11a and 11b show damages in Cubipod and cube armour layers over 180° sectors for angle of incidence 0° and 22.5°, respectively.
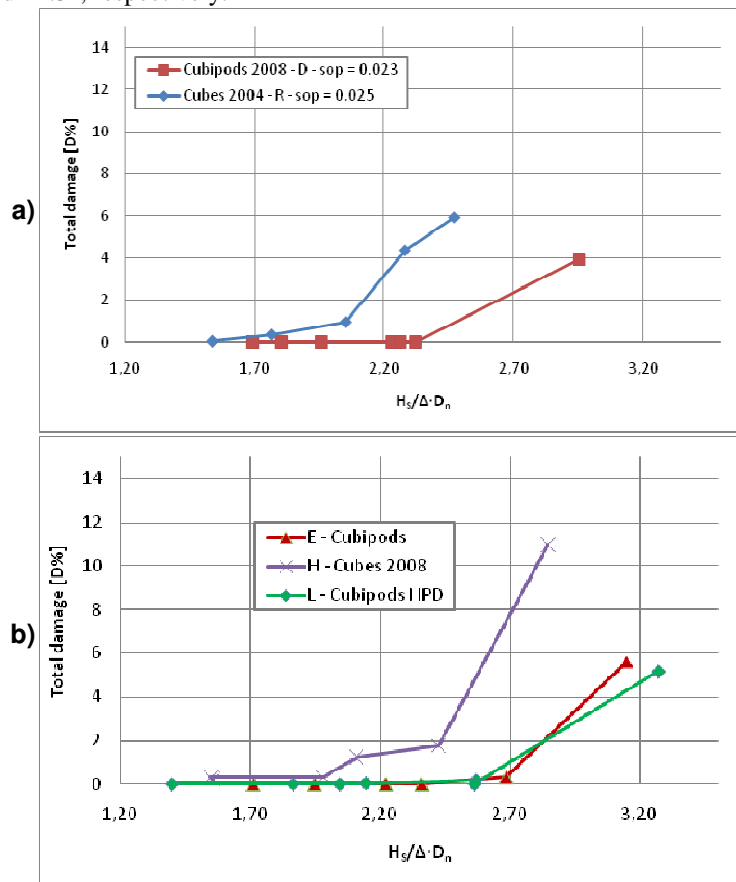

Figure 11. Accumulated damage over 180° sector. 3-D waves s_{0p} = approx. 0.025. a) Angle of incidence 0°. b) Angle of incidence 22.5°.

It is seen from Fig. 11 that in the waves of small steepness, the Cubipod armour is significantly more stable than the cube armour.

The differences in damage between the two types of armour is clearly seen in Figs. 12a and 12b which shows photos of the armour at the end of the test series with 3-D waves, s_{0p} = approx. 0.025 and angle of incidence 22.5°. Note that for the cubes, the reached N_s = 2.85, whereas for the Cubipods N_s = 3.15.
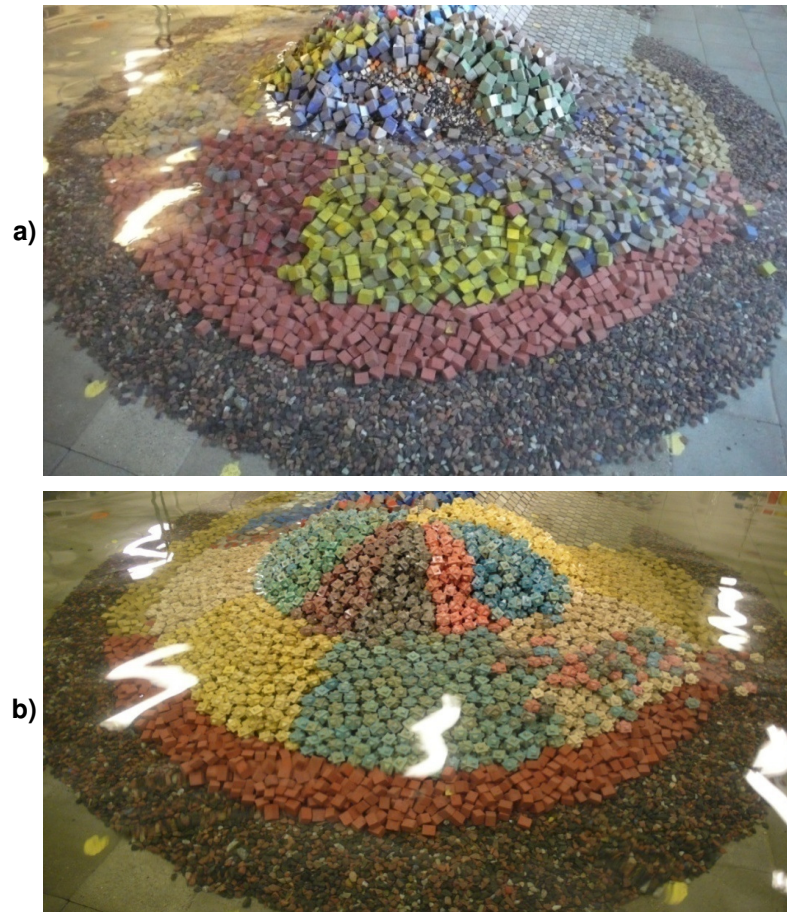

Figure 12. Photos of armour damage at the end of tests with 3-D waves, s_{0p} = approx. 0.025 and angle of incidence 22.5°. a) cube armour, N_s = 2.85, H_s = 14.97 at scale 1:100. b) Cubipod armour, N_s = 3.15, H_s = 14.79 at scale 1:100.

CONCLUSIONS

The following conclusions are limited to comparative tests with only one roundhead geometry, i.e. slope 1:1.5 and a fairly large diameter. Moreover, the waves were non-depth limited. The conclusions extracted from the tests (not all presented in this paper) are as follows:

- In 2-D steep waves (s_{0p} = 0.05): No significant difference in cube and Cubipod stability.
- In 3-D medium steep waves (s_{0p} = 0.035): Cubipods might be marginally more stable than cubes.
- In 3-D long waves (s_{0p} = 0.025): Cubipods are significantly more stable than cubes.
- The stability of both cube and Cubipod armour is reduced in 3-D waves compared to 2-D waves.
- Cubipod armour seems to have reduced stability in steeper waves.
- Cubipod armour stability seems not affected by small changes in laying density in the range 1.24-1.30 units/D_n^2.

In evaluating these conclusions it should be considered that the volume of concrete used in the cube armour layers were 6% - 17% larger than in the Cubipod armour layer. The larger porosity of Cubipod armour is most probably the reason for the better performance of Cubipod armour in long waves. The roundhead stability formula for cubes (Macineria and Burcharth, 2007) can be modified to include Cubipod armour as shown in Gómez-Martin and Medina, 2008.

ACKNOWLEDGMENTS

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