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Review and rebuttal of the paper

Rocking of single layer armour units measured by embedded sensors

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Editor handling the paper: Miguel Esteban

**General rebuttal of remarks on first submission, so explaining second revision of:
*Rocking of single layer armour units measured by embedded sensors.***

We would again like to thank the reviewers for the time and effort they put in the careful review and useful suggestions.

We are glad that reviewers 1 and 3 accepted the manuscript, and are grateful for the further feedback of Reviewer 2. We regret that we missed the error that occurred in the figure numbering in our last version, such that the manuscript was hard to read. Of course we have fixed this.

Additionally we also received comments by the editor which we treat similarly below.

Below we repeat the entire text of the review comments in blue, and added numbering. After each comment or suggestion we reply to this in black, and indicate what we changed to the paper, together with an indication of the line number in the new document.

Reviewer #2

2.1 This study focuses on a single layer, but some brief discussion to multiple layers would be interesting.

First few lines have been rephrased, and some more info on double layer interlocking units has been added:

“In the middle of the 20th century interlocking concrete units like Tetrapods and Dolosses were introduced as breakwater armour. These units with interlocking shapes are typically randomly placed in a double layer and have an increased stability compared to the then standard cubical blocks. This interlocking was optimized through subsequent research and experience, while the structural strength of the units was not given enough attention. This led to several failures of large breakwaters in the 1970’s and 1980’s due to breakage of concrete armour units (e.g. Baird et al., 1980, Juul Jensen 2023). Subsequently, significant research was carried out on the wave-induced rocking and subsequent breakage of units like Dolosses, cubes and Tetrapods (Burcharth et al. 1991, Van der Meer & Heydra 1991). However rocking-induced unit breaking can also occur in single layer units that have been used since the invention of the Accropode™ in 1981. ...” (line 4)

2.2 L6: "This research" Whose research is this research?

The first lines have been rephrased. This reference has been removed.

2.3 L16: "State of the art" This subtitle seems unnecessary.

All unnumbered subtitles in the introduction (Background, ... , Outline) were indeed temporary aids to structure the introduction, which have remained in the text. All have been removed. Also the subtitles in Model Setup have been removed.

2.4 Equation 1: Is 1 the upper limit for this probability? Can a range of probabilities be specified?

Thanks for pointing this out. These equations can indeed give exceedance probabilities > 1 for low impact velocities, which cannot be true. As this is the (combined) equation from literature, we included her "for $P_{exc} < 1$ ". Furthermore, below the equation it was added:

"This relation apparently is valid for the extreme tails of the distribution only, as it leads to exceedance probabilities larger than one for low rocking impact velocities.."

(Line 29)

2.5 L24: Does waterline mean water surface? Or the boundary between armour and water?

As it pertains a vertical distance, both are equivalent. Changed to 'mean water level' for clarity. (Line 32)

2.6 L24: Is this "impact velocity" a maximum velocity or average velocity?

This is the velocity at the moment of impact, so for the wave under consideration it typically is the maximum / peak velocity. Added "(the velocity of a rocking unit at the moment of impact with a neighbouring unit)" (Line 31)

2.7 L38: "previous studies" rather than "MSc studies"

We wanted to indicate that these previous (MSc) had not been published in peer-review journal(s), so constitute "gray literature". Therefore we feel this needs to be mention, but this can indeed be indicated in a less indirect fashion. Also an introductory line has been added. The remark has been changed to.

"Recently some studies have been undertaken on load on and rocking of units. Several initial, non peer-reviewed studies report tests on a schematized set-up with ..."

(Line 46)

2.8 L41: "a much lower sampling frequency" lower sampling time or higher sampling frequency?

The statement is correct, or at least how we intended it, but apparently confusing. The sentence refers to the approach of L_e , where the motion of the unit prior to the impact is resolved, and which is also utilized in the present paper (see image below). The impulse

during the impact is obtained by integrating the acceleration during the impact with much higher sampling frequency, denoted by ‘approach CUR’ below.

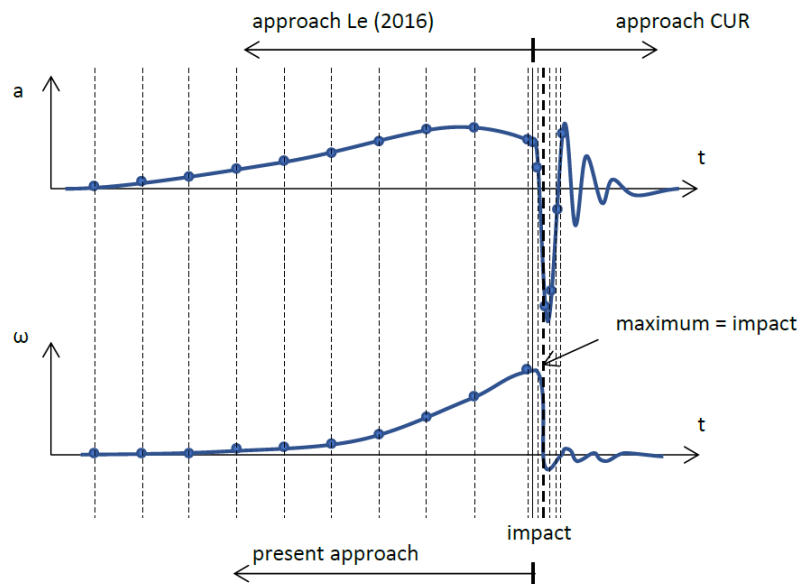


Figure 2. Schematic representation of the time variations of acceleration a and angular velocity ω during rocking and collision (starting at vertical solid line). Dashed lines show sampling times.

The sentence has been adapted to:

“This method of determining the impact velocity just prior the impact requires a much lower sampling frequency than integration of the acceleration during the short-duration impact.” (Line 50)

2.9 L92: How about the weight of small chip?

All weights were taken into account when determining the required weight of the lead weights (see approach in Caldera 2019). To clarify this the sentence was changed to: “Lead was placed in the legs in order to make the weight and weight distribution of the complete instrumented unit assembly equal to that of the other model units, following the approach described by Caldera (2019).” (Line 101)

2.10 L141: $D_{n50} = 1 \text{ cm}$ should be changed to 10 mm to use the same unit as D and D_n . Adapted as requested. (Line 149)

2.11 Figure 5: Baseline of acceleration drifts and does not seem to coincide with zero.

The measured acceleration includes gravitational acceleration, which is one of the reasons why the actual acceleration is difficult to measure. This is explained in the text from line 194. Due to the rocking process the orientation of the unit, and with that the three local components of the acceleration sensor change with respect to gravity. This is explained from line 208 in the paper. Hence the change is not due to the sensor which was checked for this. This is explained from line 125 in the paper.

Changes to clarify this:

-In caption of Figure 5: changed for \vec{a}' to \vec{a}_{tot}

-Added to the caption of Figure 5: “(components in local frame of reference including gravitational acceleration)”

-Added a sentence to indicate this explicitly when discussing Figure 5: “This can be seen around 1350 s in the top-most panel of Figure 5 (and in a more pronounced way in Figure 8, later). (Line 209)

-updated the entries to the symbol list:

acceleration vector (without gravitational acceleration)	\vec{a}	m/s ²
measured acceleration vector (local unit axis), which includes \vec{g}	\vec{a}_{tot}	m/s ²
components of measured acceleration vector (local unit axis)	a'_x, a'_y, a'_z	m/s ²

2.12 L201: What does "required" impact velocity mean?

Obtaining this quantity is the basic aim of the paper (line 84), hence it is required.

We have now repeated this aim at the start of the section (line 215):

“For each event where an instrumented unit hits a neighbouring unit the rocking impact velocity needs to be obtained.”

2.13 Also, "no integration" for what?

Removed”... , and no integration is necessary to obtain the impact velocity”. This sentence referred to the other approach previously used to obtain the impact velocity, where the acceleration during the impact was integrated, and can indeed be removed here for clarity. (Line 217)

2.14 L221: "the downward rocking motion early in the downrush cycle." Meaning of this sentence is not very clear.

Indeed the word ‘cycle’ is not clear. We interchanged it with ‘phase’, which was used a few sentences earlier. Now the sentence reads:

“As the gravity acts downward, the upward rocking motion occurs later in the uprush **phase of the wave**, and the downward rocking motion early in the downrush **phase**.”
(line 231)

2.15 L225: Is there any criteria to identify short rocking duration?

The adverb ‘short’ was added to indicate that all rocking events were short, so not to indicate that we only analyzed the shorter rocking events. Hence the adjective ‘short’ has been removed. The line now reads:

“The resultant rotation angle during a rocking event was obtained by integrating the absolute rotational velocity over the duration of the rocking motion.”
(line 239)

2.16 L226: "total rotation angle" -> I feel "resultant rotational angle" would be closer what this equation implies.

Changed as requested (in all instances where the term was applied in the paper).

2.17 Equation 5: Please write the definition of "a" in front of cosine.

The term refers to the inverse cosine, and an abbreviated computer language form, 'acos' was used: acos has been changed to arccos, and the font to regular to show it is an operator and not a symbol. (eq. (5))

2.18 Figure 8: Addition of a figure showing the time-series of wave may be helpful for readers to understand the reason of a couple of distinctive rotational motions.

Unfortunately we do not have wave measurements at the slope; the waves were measured halfway the flume and the slope. Moreover, the (stand alone) embedded sensors are not synchronised with the wave gauges. Hence we are unable to link the wave signal to the unit motion for the tests conducted in this study.

We added this to the Discussion section: "Extra measurements like synchronized wave gauges at the slope or video images could be used in future studies to better interpret the measurements."

(line 467).

2.19 L271: Which "Figure"?

Something went wrong with the automatic figure numbering with the last save to pdf (it indeed looked terrible, apologies). All figure numbers in captions and references have been manually replaced.

2.20 Figure 90: This should be Figure 10.

Adapted, see 2.19.

2.21 Figure 90: The color of two lines should be different with the scatter plot color.

Lines have been made gray.

(Figure 10)

2.22 L318: Check the figure numbers in the whole manuscript carefully.

Done, see 2.19.

2.23 L363: Figure number is missing. Identifying each line is difficult, please consider distinctive colors.

The difference in line thickness has been made more pronounced, and we use an extra line style.

(Figure 15)

EDITOR

E.1. Line 5: I don't think „irregular shape“ can be used to define tetrapods... they are all regular! (quite beautifully regular... in my opinion...).

'Irregular' changed to 'interlocking' (line 5)

E.2. Line 5: Maybe „These units are typically randomly placed in two layers and possessed an increase stability...“

Sentence adapted (line 5)

E.3. Line 47: This sentence does not indicate what was tested. Can you please check and revise? The entire paragraph then becomes unclear, as the methodology you are describing in the first sentence should inform the logic of the other sentences...

Added "...where the units are instrumented with embedded motion sensors". (Line 48)

E.4. Line 53: And found what?

Added "..., where the largest forces were found on the unit around the water line."
(Line 54)

E.5. Line 83: This just repeats the previous two sentences, so delete (I think this happened because you had subdivided this section)

Agree. Removed "as a direct measurement of the rotational impact velocity is used presently".

E.6. Line 131: "..., as a direct measurement of the rotational impact velocity is used presently' change to „was the most important factor to be measured“?

Removed "..., as a direct measurement of the rotational impact velocity is used presently" (line 129)

E.7. Line 141: Blue?

The instrumented units are positioned in one row, so are the white and black ones. – not the off-white and blue ones.

Added "...with non-instrumented units (beige and blue)..." after normal armour layer (caption figure 3)

E.8. Line 151: Figures have to be placed AFTER they are introduced in the text (so, Fig 4 needs to be moved to the end of this paragraph)

Figure 4 has been moved to end of section.

E.9. Line 162: This appears misleading, given what you say in the next sentence. It seems to imply that you placed all 9 units at the same elevation, which contradicts next sentence. I suggest deleting.

Changed to “For each test series nine instrumented units were typically placed in a row at one of three elevations. The different elevations used for the instrumented units (centre of mass at elevation) were $z_b = -2D_n$, 0, and $+2D_n$ from the water line, or the 11th, 15th and 19th row from the bottom.” (Line 157)

E.10. Line 172: “...steepness of $sp = 4.4\%$, which resulted in the applied wave periods.“Unclear what you mean. Better to delete?

Deleted as requested. (Line 168)

E.11. Line 222: Why „required“?

Entire sentence has been removed (was double). There were more changes. Start of paragraph now reads: “For each event where an instrumented unit hits a neighbouring unit the rocking impact velocity needs to be obtained. Assuming that the main mode of movement is rotation, as the word rocking implies, the (peak) instantaneous rotation speed just prior to impact is directly related to the impact velocities of one unit onto another.” (Line 215)

E.12. Line 241: Figures need to be shown after they are first mentioned, not before
Figure 6 has been placed one paragraph downward.

E.13. Line 244: “to first experience the uprush peak” -> ”to indicate the uprush peak“?”
Sentence changed to: “Hence for a pair of closely spaced peaks it assumed that the first peak is the uprush peak.” (Line 232)

E.14. Figure 7: Figures need to be shown after they are mentioned... this figure is too far down

Later under 2D-assumption again a reference is made to Figure 7.a (added now), and there reference is made to 7.b as well. Therefore the position of this particular figure has not been altered.

E.15. Line 295: This paragraph and the figure that follow are very unclear
& Line 296: “Several tests are given per test run, as several instrumented units were applied per test” -> Unclear what this means. The rest of the paragraph becomes difficult to understand...

& Caption figure 9: The caption says „, so the value is repeated for the (typically) 8 to 9 instrumented units“ but this is not the case, see for example the leftmost part of the middle graph, which has 17, 21, 22, then 6x5...

In answer to the three remarks above, the first sentences of the paragraph were changed to:

“In Figure 9 an overview is given of the maximum absolute rotational velocity, $|\omega|_{\max}$ for all instrumented units and test runs, as a proxy for the intensity of rocking. On the horizontal axis the tests series number is typically repeated several times, as several instrumented units were applied per test series in a row. As sometimes a single instrumented units was placed at a different elevation, also single entries of a tests series number can be seen. The figure shows ...”

Caption changed to:

“Figure 9: Overview of maximum absolute rotation rate $|\omega|_{\max}$ for all measurements by single unit/test run-combinations. The x-axis gives the test series, so the value is repeated if several instrumented units were applied simultaneously.

Top, middle and bottom graph show the highest, middle and lowest position of the instrumented units, respectively”

E.16. Line 302: Unclear what this „sign“ means in “...the signal of the rotation with sign...” -> I suggest deleting these words, the nuance is unclear

Changed to “... rotation rate ω_s ... “ (line 296)

E.17. Line 315: Exceedance probability of what? What is being exceeded?

The line says “..exceedance probability of the number of events in all test runs ...”

Changed to “...the number of events in a test run...”. (line 308)

E.18. Line 317: Not sure this is something that can really be inferred from this graph?

The graph does not show waves on it..

The probability is the probability per wave and per unit... So if an average single unit is regarded, it is the mean probability of the fraction of the number of waves for which of rocking events occur.

E.19. Line 320: “events” -> “„rocking events“?”

Altered as requested (line 312)

E.20. Figure 11: Parameters in the figure need to be in italics

Changed as requested (Figure 11)

E.21. Caption figure 11: Events of what?

Changed to “rocking events”

E.22. Line 332: You deleted figure number

Added the number 12. (line 325)

E.23. Line 333: You deleted figure number

Added the number 12. (line 326)

E.24. Line 354: Slightly unclear... you mean „with respect to wave height“?

Changed as requested (line 359)

E.25. Figure 14: This figure needs to be placed after it is mentioned in the text

Changed as requested.

E.26. Figure 15: Figures need to come after they are mentioned in the text...

Changed as requested.

E.27. Line 401: Unclear what you mean by „most damage to rock and stresses“

Added the bold parts below:

“For collapsing waves most damage to rock (Van der Meer 1988) and **highest stresses inside units** (e.g. Cornett and Mansard 1994) were previously observed **at elevations around the water line.**” (Line)

E.28. Line 408: What about them? You did not finish your sentence

Added the bold part below:

“The along-slope settlements (downward is positive) of the units during the tests, as obtained from correlation of pictures of the slope before and after the tests (Hofland & Van Gent 2016) **are shown in Figure 16.**” (line 395)

E.29. Caption figure 16: I don't think this is the correct term

Changed the bold part below:

“The dashed lines indicate the **elevations of the instrumented units in the various measurements.**”

E.30. Caption figure 16: ” The z-coordinates of the two images roughly match” Unclear what you mean. There is only one image in the figure.

Changed the bold part below:

“The z-coordinates of the **units in sub-figures 16.a and 16.b** roughly match.”

E.31. Line 419: “largest loads” -> Is load given in Figure 16?

Changed to:

“At this highest elevation, the width averaged settlement is in the order of $0.4D_n$,”

The reference to the test run for which the figure is made was removed, as that is confusing. (Line 413)

E.32. Line 460: “Sokolewicz’ year?”

Added “(1986)”. (line 447)

E.33. Line 481: “visually observed“?”

Changed as suggested.

E.34. Line 484: Unclear what you mean by this „scale of the problem“?

Changed the bold part below:

“However, as similar dimensionless impacts lead to higher stresses when **the size of the units (and waves)** increases, the rocking impact velocities can be used together with a mechanical model of the internal stresses to estimate the allowable rocking motion when larger units or different concrete quality are used.” (Line 479)