Response to Referee reports for NHESS-2021-180

R#: Referee number (1 or 2); C#: Comment/Response number; A: Authors' response.

Line number in **Original MS** (dated 20210708): OL #

Line number in **Marked copy** (dated 20210916): ML #

* Procedure of Revision

(1) The original MS (nhess-2021-180) submitted was called "nhess-2021-180 20210708".

(2) Referee 1 (RC1) gave his comments in a file "nhess-2021-180-RC1" and authors submitted response with file named "nhess-2021-180-RC1-AC1-supplement" (dated 20210819 ?). This revised MS is call "Interim MS".

Subsequently, Referee 1 has indicated that he is satisfied with authors' response.

(3) Referee 2 sent his comments in a file entitled "nhess-2021-180-RC3" (dated 20210824).
The authors have further revised the "Interim MS", based on Referee 2's "nhess-2021-180-RC3", Especially, in Abstract, Introduction and Definition of erosion risk etc.

(4) Only Referee 2's comments are dealt with in this response file called "**Marked copy**" (**attached**),
In which Referee 2's comments are shown in RED, and authors' additional revision in yellow shading.

(5) A "**Clean copy**" is then produced by removing all colors (except that in Figures). Result is **attached**.

* Please Note

In response to the report given by referees' 1 and 2, several key words have been modified and applied in the revised MS as follows:

(1) Interpretation, etc. → Assessment, assessing or assess

(2) Sediment budget reduction potential W_c & A_c → Potential Background Erosion Area (PBEA) A_b
Potential Background Erosion Width (PBEW) W_b

(3) Longshore sediment deposit potential W_d & A_d → Potential Reshaping Erosion Area (PREA) A_r
Potential Reshaping Erosion Width (PREW) W_r

(4) Cross-shore sediment retreat potential W_e & A_e → Potential Episodic Erosion Area (PEEA) A_e
Potential Episodic Erosion Width (PEEW) W_e

Terms in (2) – (4) appear in [ML 123-129] and [ML 140-144].

(5) Encroachment accumulative curve → Combined potential erosion risk curve (CPERC) [ML 148-161].

General Comments from Referee 2 and authors' response

R2C1) The manuscript needs a thorough revision of the English language. Grammatical errors (and unusual sentence constructions) are very frequent throughout the manuscript and will not be indicated here except in selected cases. This is not a trivial thing because it will affect the message you want to convey.

AC1) Thank you. We have improved the readability of the MS.

R2C2) The title does not adequately reflect the content of the paper. The use of the word "interpretation" in the title (and throughout the manuscript) is misleading and provides no useful information. You can simply change "Quantitative interpretation" by "Assessment".

AC2) As suggested, "interpretation" has been replaced by "assessment":

Original title: "Quantitative interpretation of risk potential of beach erosion due to coastal zone development"

Revised title: "Assessment of potential beach erosion risk and impact of coastal zone development: a case study on Bongpo-Cheonjin Beach."

R2C3) One important thing to mention explicitly is that the method you are presenting is only valid (or it has been developed) for bay/pocket beaches where the lateral ends bound a closed sedimentary cell. This should be included in the introduction to adequately frame the methodology to be presented.

AC3) Thanks for your comment.

Now the term "coastal cell" and "embayment" are explicitly used in the MS.

Actually, in field condition, the mechanism associated with beach erosion downdrift of a harbor or large protruding structure occurs not only within an embayment but also on a straight beach. It can also transform a stretch beach into an embayment.

R2C4) [OL 37-47] Essentially, in this paragraph you are stating that erosion is a multi-scale (temporal and spatial) process. Please add some references on this from theoretical and/or practical standpoints (e.g. Toimil et al. 2017; Ballesteros et al. 2018).

Toimil et al (2017). Managing coastal erosion under climate change at the regional scale. Coastal Engineering, 128, 106-122.

Ballesteros et al. (2018). Erosion consequences on beach functions along the Maresme coast (NW Mediterranean, Spain). Natural Hazards, 90(1), 173-195.

AC4) Thanks. Suggested reference of Toimil et al (2017) and Ballesteros et al (2018) are now appears in Sect. 1 Introduction [ML 39-49] and Sect. 2 [ML 93-96], with brief explanation, as well as in References [ML 473-474 and 580-581].

R2C5) [OL 58-59] This is only valid for closed littoral cells (such as bay/pocket beaches).

AC5) This sentence is replaced by "It is well known that wave diffraction and change in longshore sediment transport direction occurs downdrift of a harbor where shoreline reshaping begins, resulting in updrift accretion and downdrift erosion." [ML 60-61]

R2C6) [OL 60] Change "to estimate the correlation of ..." by something like "to assess/predict the longshore sediment transport rate ...".

AC6) The phrase is revised as "to assess/predict longshore sediment transport rate in a wave-sediment environment" [ML 63].

R2C7) [OL 62] This means that the study (and method) you are going to present is only applicable to areas influenced by coastal structures. This is related to comment [3]. In fact, the method you are presenting is valid for bay/pocket beaches where you modify one of the ends by including a structure.

AC7) Similar to our response in AC3 and AC5 above, when wave field changes downdrift of a harbor or large protruding coastal structures, the extent of erosion could spread further downdrift over a long stretch of 3-4 km, or more, as witnessed in Japan. This then transform an initially straight beach into an embayment. Hence, the application of PBSE model is not limited to bay/pocket beaches initially.

The original sentence of "However, it is still mostly dependent on the empirical models in estimating the equilibrium shoreline in the vicinity of harbor breakwaters or coastal structures." [OL 62-64] is written as

"Empirical models have been used to estimate the equilibrium shoreline in the areas affected by harbor breakwater." [ML 63-64].

R2C8) [OL 80] "Encroachment accumulation curve". The use of this term seems rather "forced" and without an explanation it is difficult for a reader to understand what it refers to. I recommend to look for an alternative (and more intuitive) term (e.g. erosion cumulative curve).

AC8) Thanks for suggestion. Now we use "combined potential erosion risk curve" (CPERC) to replace the "Encroachment accumulated curve". The CPERC accumulates (sum up) the risk of the three components examined [see also ML 116-117].

R2C9) [OL 80-89] Although the basic definition of the encroachment accumulation curve (or alternative term, see [8]) can (and, probably, must) be introduced here, most of the paragraph can be moved to methods.

AC9) Thanks for suggestion. In the revised MS, a clear definition of CPERC is given under Sect. 2.3 [ML 155-158], together with Fig. 2 [ML 180].

R2C10) Please include a paragraph where you explicitly state the aim of the paper. Something like "The main aim of this work is ……."

AC10) Thanks for suggestion. The aim of this study is now explicitly stated [ML 76-79], followed by the structure of this MS [ML 80-88]. .

R2C11) [OL 110-113] Change the paragraph by something like "we present a method to assess the potential erosion risk induced by the cumulative action of processes acting at different time scales". In this first section it is also necessary to specify the conditions for which the methodology is developed.

AC11) Thanks for suggestion. We revise this paragraph as "In this study, we present a method to assess the potential erosion risk by the combined action of processes acting at different time scales and with minimal basic survey data." [ML 102-103].

We also append the reference of Ballesteros et al (2018) and Toimil et al (2017) in this section (Sect. 2) [ML 92-95], and in Introduction [ML 42-49], which have included the condition of how the methodology is developed.

R212-1) [OL 115] Where does this definition come from? It is not the usual definition of risk.

AC12-1) The expression of risk in Eq. (1) [ML 113] is defined [ML 111-112] and five source references are appended [ML 105-109].

R212-2) [OL 119-120] "planar ultimately damaged by erosion according ...". What does "damaged" refer to?

AC12-2) Here "damaged" means property affected by beach erosion risk, and "planar area ultimately damaged by erosion according to the development of the watersheds, land and coast" represents the beach area where the property or infrastructures are damaged by storm or beach erosion.

The original sentence is rewritten as "the value of R is the beach area likely to be damaged by erosion due to development in watershed, on land, and in coastal water." [ML 114-115]. The word "ultimate" is also removed.

R2C12-3) [OL 121] What is the "sand buffer zone"?

AC12-3) The "sand buffer zone" represents the back beach and dunes with vegetation where storm would not

attack in one in 2 - 3 years. The original sentence "The sand buffer zone does not cause damage even if erosion occurs, and is excluded in the damage evaluation as a section that recovers over time." [OL 121-122] is awkward and irrelevant, hence deleted.

R2C12-3) [OL 123] Now, you use the term "vulnerability". This introduces another term that, again, does not follow the usual way of usage. Please consider to rephrase the entire paragraph (Lines 115-124).

AC12-3) The short sentence that includes the word "vulnerability" is removed, and the entire paragraph [OL 115-124] under Sect. 2.1 is rewritten as [ML 109-117] "In the same context, risk is usually assessed by the time-averaged amount of damage, and its evaluation is possible through time domain, frequency domain, and probability domain analysis. In frequency domain, potential risk R is defined as the product of consequence (i.e., factor or mechanism) C and frequency F such as,

$$R = CF \quad (1)$$

In this study, *R* is the beach area likely to be damaged by erosion due to development in watershed, on land, and in coastal water. The frequency F on the right-hand-side of Eq. (1) corresponds to the frequency of erosion risk from the equilibrium shoreline to the landward erosion limit. Where several erosion causes (factor) exist, total erosion risk is taken as the sum of the risk from each contributing factor."

R213-1) [OL 126] "planar are change of the beach" → "eroded beach surface"

AC13-1) Thanks. Now, the phrase of "eroded beach surface area" is used as suggested. [ML 119].

R213-2) Please make a reference to Fig 1.

AC13-2) While revising the MS, Figures 1 and 2 in the original MS have been swapped, and now become Figs. 2 and 1, respectively. The first reference to the new Fig. 1 is on [ML 157], while that for Fig. 2 on [ML 177].

R213-3) [OL 128] "high wave incidence" → "storm impact"

AC13-3) Thanks. The phrase "storm impact" is now used [ML 121]

R213-4) [OL 134] "previous two cases" → "first two cases"

AC13-4) The original sentence [OL 134-135] "For the previous two cases, the concept of frequency is not established, but for the last, beach erosion due to high wave incidence, the frequency *F* is estimated through the statistical analysis of shoreline survey data." is now rewritten as "For the first two erosion factors, the concept of frequency is not required as beach erosion is irrecoverable, but for the third factor, the return frequency (period) of storm occurrence should be considered because wave heights and periods vary with the strength of the storm." [ML 136-138]

R2C13-5) [OL 146-147] "reduction in sediment budget from river supply Wc". This is very restrictive definition since this component will be present there even in the absence of a river. Why not use something more generic like "long-term or background erosion"? For instance, this would also include "alongshore sediment deposit" → alongshore sediment redistribution

AC13-5) The original sentence in Sec 4.2 [OL 146-148] of "…includes the effect of (1) reduction in sediment budget from river supply W_c, (2) alongshore sediment deposit due to harbor breakwater construction W_d, and (3) cross-shore sediment retreat by high waves W_e which has different values depending on the frequency." is rewritten as "… includes the effects of (1) background erosion resulting from decrease in

sediment budget due to watershed development, sand dredging, or extraction, (2) alongshore sediment redistribution and shoreline reshaping due to harbor construction, and (3) short-term erosion due to episodic storm, respectively." [ML 174-175].

R2C13-6) [OL 157] "origin of the circle" → It is not necessarily a circle ("reference pole"?)

AC13-6) Thanks. Now "reference pole" is used instead of the original "origin of the circle" [ML 158]. In addition, we append a new sentence: "If the shoreline is not well fitted into a circle, as in the example of Fig. 1, after finding the curve that best fits the shoreline, it is appropriate to set the fitting curve as EOSL and r in the direction perpendicular to the shoreline." [ML 166-167].

R2C13-7) encroached boundary" → beach landward limit? hinterland?

AC13-7) Thanks. Now, "beach landward limit" is used [ML 157].

R2C13-8) "encroached aspect" → boundary configuration?

AC13-8) Thanks. Now, "boundary configuration" is used [ML 158].

R2C14-1) [OL 169] Eq (2) → Eq (3)

AC14-1) Thanks. The original expression "In Eq. (2), r is…." [OL 169] now becomes "The abscissa r in Fig. 2 is…" [ML 185].

R2C14-2) [OL 169] is substituted for → is substituted by

AC14-2) The original sentence "… if the shoreline retreat W_t of Eq. (2) is substituted for r, the erosion width invades the encroachment zone and the planar area where damage occurs is obtained. This area corresponds to a consequence C of Eq. (1), …" [OL 169-171] is rewritten as "If the combined potential shoreline retreat W_t in Eq. (5) is substituted by r, the CPERC can also represent an area corresponds to a consequence C in Eq. (1)." [ML 185-186].

In addition, the following sentences ", where frequency *F* can be regarded as one-year frequency in the case of W_c and W_d, on the other hands, W_e depends on the frequency of high wave incidence. Therefore, if concepts of the erosion potential and the encroachment accumulation curve are applied, the risk in Eq. (1)…"[OL 171-173] are revised as ". To calculate the CPERC area, the frequency related to the background PBEA and PREA can be regarded as one per year ($F_{br} = 1/yr$), while that for the PEEA (F_e) depends on the frequency of storm occurrence. Therefore, the combined risk R in Eq. (1)…" [ML 186-188].

R2C14-3) [OL 176] This will depend on the time scale of the study and the relative magnitude of each component.

AC14-3) The original paragraph [OL 176-179] is deleted and the methodology for assessing the three contributing components in the combined potential erosion risk curve (CPERC) is explained in Sect. 3.1, 3.2 and 3.3 [ML 192-282].

R2C14-4) [OL 177] "if the buffer section is sufficient" → "if the beach is wide enough"?

AC14-4) Please refer to AC14-3 above.

R2C14-5) [OL 178] change "quantitatively estimating" by "assessing"

AC14-5) Please refer to AC14-3 above.

R2C15-1) Please change the section heading. This is not "interpretation". Here you are describing how to compute/calculate each component.

AC15-1) The original section title "3. Quantitative Interpretation" [OL 180] is replaced by "3. Assessment of Erosion Risk for Contributing Components" [ML 192]

R2C15-2) [OL 186-188] Here you say the same two times in a slightly different way.

AC15-2) The original sentence of "where Q_{in} is the rate of sediment discharge into the beach and Q_{out} is the sediment leaving from the beach. Representing Q_{in} is the amount of sediment from the river and representing Q_{out} is the sediment discharge lost to the sea due to the action of waves. If we express the loss rate to wave action as a function of the constant value of sand loss rate K, the following equation is established:" [OL 186-189] is revised as "where Q_{in} is the rate of sediment discharged from river (a point source), and Q_{out} is the rate of sediment leaving the cell (a sediment sink alongshore and offshore) due to wave action. The latter is constant due to continuous wave action. If $Q_{in}<Q_{out}$ and the difference ($\Delta Q_p = Q_{in} - Q_{out}$) is expressed as the product of a sediment loss constant *K*, then the change in beach sediment volume *V* (Lee and Lee, 2020) can be given by," [ML 197-199].

R2C15-3) [OL 191] "vertical height of the littoral zone" → if you are using the concept of depth of closure (dc), this will be the vertical dimension of the active beach. Moreover, if this component is associated with the long-term (which is the one relevant for the changes in the sediment budget you are referring to), you need to consider (mention) how this will affect dc.

AC15-3) Thanks for your comments. For practical engineering application, the depth of closure may be regarded as a near constant for a sandy beach, such as that at Bongpo-Cheonjin in Korea (see Fig. 6 in this paper on ML 256), despite the variation of beach profiles and shoreline positions. To support this point of view, we also append cited four references and state as "Many studies have been performed to determine the berm height and closure depth D_s (Rosati, 2005; Cappucci et al., 2011; Cappucci et al., 2020; Pranzini et al., 2020). Although closure depth varies with wave climate and sediment particle size (Hallermeier, 1981), judging from observed beach profile data, its value has been shown to remain reasonably constant over several decades." [ML 206-209].

R2C16-1) Please consider to change the section heading. Maybe something like "Alongshore sediment redistribution"

AC16-1) Thanks for suggestion. Now, the original section title "3.2 Longshore sediment deposition potential" [OL 205] is replaced by "3.2 Shoreline reshaping due to harbor construction" [ML 224].

R2C16-2) [OL 206-207] Changes in the wave field along the beach will be induced by a modification of the wave diffraction pattern. In other words, this erosion component will only be present if a coastal structure is built (which will modify the position of the diffraction pole) or if the incident wave direction changes.

AC16-2) The original sentence of "The longshore sediment deposition potential is defined as the planar area of the depositional zone caused by the deformation of the shoreline due to wave field changes. The parabolic bay shape equation (PBSE; Hsu and Evans) is applied…" [OL 206-207] is now revised as "Harbor construction on sandy coast often changes the wave field, generating new wave diffraction and nearshore current patterns. It also causes 'shoreline reshaping' with downdrift erosion accompanying by updrift accretion. Although the amount of sediment may maintain within a cell, erosion risk area called PREA induced by the redistribution of littoral drift can be assessed by an empirical shoreline model of parabolic type (i.e., PBSE; Hsu and Evans, 1989)." [ML 225-228].

R2C16-3) [OL 228] β' is not indicated in Fig 5. Please indicate it, and how to measure (it is not evident from the

angle β' shown in Fig 11)

AC16-3) Figure 5 is redrawn, showing both β and β' [ML 251].
Definition of β' is given as "In Eq. (14) and Fig. 5, β' is the angle between the focus point (i.e., the breakwater tip) and secondary breakwater." [ML 246], and the relationship between β and β' is plotted in Fig. 11 [ML 351].

R2C16-4) Eq (13) → I think that by substituting the values of the example shown in Fig 11 in eq (13), the results are different to those by using eq (14). Can you check it?

AC16-4) Sorry, the original Eq. (13) $\frac{A_r}{a^2} = \frac{1}{2}[\cot(\pi - \beta') + \cot\beta] + \frac{1}{2}\left(\frac{\beta}{\sin\beta}\right)^2 \left(\frac{1}{\pi-\beta'} - \frac{1}{\beta}\right)$ has a slight typo-error.
Its correct form (Now called Eq. 14) is $\frac{A_r}{a^2} = \frac{1}{2}[\cot\beta' + \cot\beta] + \frac{1}{2}\left(\frac{\beta}{\sin\beta}\right)^2 \left(\frac{1}{\pi-\beta'} - \frac{1}{\beta}\right)$.

However, both the original Eq. (14) and the new Eq. (15), $A_r \cong a^2\left(\frac{28.8}{\beta'} - 0.004\beta\right)$, are correct. The result given by the new Eq. (14) is slightly different from that of Eq. (15), because the latter is an approximate solution.

R2C17-1) [OL 239] Please mention that the surveys per year (four in your text) should adequately reflect t seasonal variations of shoreline position and the effect of storm impacts.

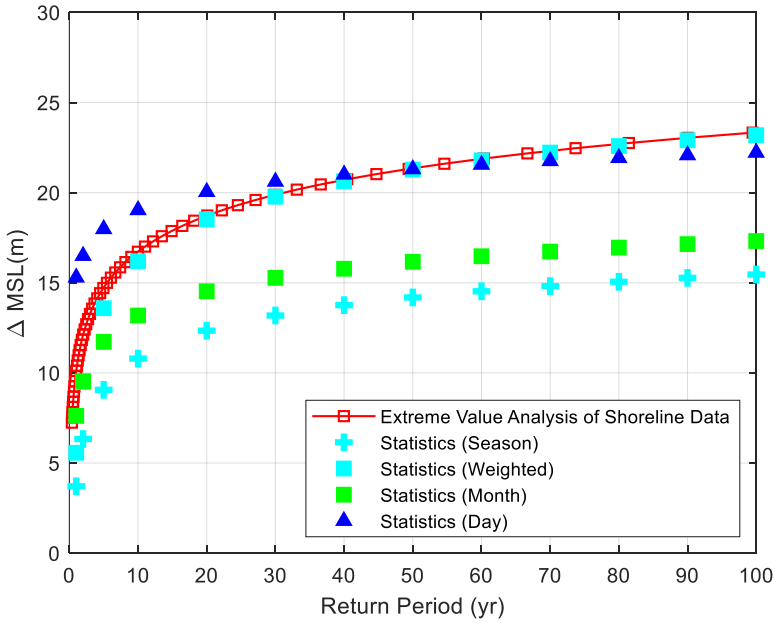
AC17-1) First, the original section heading "3.3 Cross-shore sediment retreat potential" [OL 236] is revised as "3.3 Shoreline retreat due to episodic storm" [ML 253].

On "Shoreline survey data performed four times a year show the distribution follows the normal distribution as shown in Fig. 6." [OL 239-240]; we have appended a sentence to explain the effect of seasonal survey data on storm impact by stating that "Although these surveys were intended to present seasonal changes in shoreline variability, unlikely to reflect short-term changes during storm, it is confirmed that a series of survey data is sufficient for including storm effect if the sampling data of more than 8 years are multiplying by a weighting factor of 1.5 to the result of probability analysis comparing with the extreme analysis (from CCTV images 1-2 times a day) at Tairua Beach in New Zealand (Montaño et al, 2020)." [ML 257-261].

R2C17-2) [OL 254-256] When estimating the shoreline retreat associated with a return period, this is usually done after fitting an extreme distribution to shoreline retreat data. These data must reflect the impact of storms in your study site. Just by taking four measurements per year, you are not sure they are properly reflecting this component.

AC17-2) We are happy to provide additional information to support our response AC17-1 above, as follows:

The results of our probabilistic analysis on shoreline survey data conducted at random four times a year can be compared with the results of extreme analysis on the annual maximum shoreline erosion width data, which are extracted from CCTV images 1-2 times per day at Tairua Beach in New Zealand (Montaño et al., 2020). We find that, by a weighting of 1.5 times to the result of the probability analysis, its result is similar to the result of the extreme analysis. Therefore, if there are long-term survey data to perform extreme value analysis for about 20 years or more, then it would provide more reliability, but even with data that is randomly observed 4 times each year as in this study, it can approximate the variability of the shoreline. It is thus confirmed that prediction of storm event is possible. The results in the figure below are quoted from a follow-up paper (in writing) for estimating the erosion width according to the reproduction period from shoreline survey data observed 4 times a year.



R2C18-1) [OL 286] Fig 8 is not necessary.

AC18-1) Thanks. Figure 8 is deleted, as suggested, and the citing phrase "(Fig. 8)" on [OL 286] is removed (see [ML 300.]

R2C18-2) [OL 315] Change Fig 11 to Fig 10.

AC18-2) Following the deletion of Fig. 8 in the original MS, each of the original figure numbers from 9 to 15 are reduced by 1, thus becoming Figs. 8 – 14, respectively, in the Revised MS.

In addition, all the sub-section headings under Sect. 4 are revised:

4.1 Study site description [OL 271]→ 4.1 Site description [ML 286]

4.2 Sediment budget reduction in this study [OL 293] → 4.2 PBEA due to development in watershed [ML 305]

4.3 Longshore sediment deposition potential caused by the construction of harbor breakwater [OL 316] → PREA caused by construction of harbor breakwater [ML 333]

4.4 Cross-shore beach retreat due to the high wave incidence [OL 337]→ 4.4 PEEA due to shoreline retreat during storm [ML 355]

4.5 Erosion risk potential at Bongpo-Cheonjin Beach [OL 347] → 4.5 Combined potential erosion risk at Bongpo-Cheonjin Beach [ML 365]

R2C19) I would not say that this section is properly a discussion. This can be included in the methodology section. Here you need to discuss the applicability and limitations/uncertainty of the method. It will also be relevant to compare the proposed methodology with other existing approaches.

AC19) The original 5. Discussion [OL 370-406] is properly revised and itemized from (1) to (5), starting from the purpose of applying this study to an embayed beach, and then how to enhance the applicability to different coastal environments. [ML 396-436]. Figure 16 in the original MS [OL 377] is deleted.

The first two items are as follows:

(1) Although the purpose of this study is to apply an assessment method to Bongpo-Cheonjin Beach, which is a shallow embayment or a semi-closed coastal cell, the method proposed is not limited to headland-bay beaches. It is also applicable to open beaches with suitable modification to the mechanisms examined in this study. [ML 399-401]

(2) The proposed *combined potential erosion risk curve* (CPERC) includes individual risk component assessed for background sediment from a river at updrift, a fishing harbor with breakwater extension and storm waves in winter. The construction of CPERC is based on a simple arithmetic sum to represent the case of worse scenario, rather by a multivariable regression analysis. It cannot predict the temporal change of erosion risk. To improve the reliability of this method, the temporal beach change and the scale of each contributing factor versus time must be examined, especially from that induced by the episodic storm which occurs only sporadically, whereas the other two are either almost constant or increasing gradually. [ML 402-408]

Items (3) – (4) suggest method/equation to calculate the temporal variation of beach erosion risk for the three contributing components examined in this study. [ML 409-436]

R2C20-1) Most of this section is more of a summary than conclusions.

R2C20-2) [OL 420-428] Part of this could be included in the discussion section.

AC20-1 & -2) Thanks for the suggestion.

The original section 6 “Concluding Remarks” covers 33 lines [OL 407-440]. It was unnecessarily long. As suggested, this section is shorten, now covering 21 lines [ML 438-459], by expanding Section 2, especially in sub-section 2.2 “Definition of beach erosion risk”, which now covers 28 lines [ML 118-146], compared to the original length of 10 lines [OL 114-124].

As the aim of this study is to apply the CPERC method to Bongpo-Cheonjin Beach, we feel that the outcome of the engineering solution should be included in the Conclusion.

This section is rewritten.