

REPORT

Peer Review additional information

Cause of building damages
related to deep subsidence and
heave due to gas extraction

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Peer Review additional information

Cause of building damages related to deep subsidence and heave due to gas extraction in Groningen and gas extraction and storage in Norg.

	Name	Role
Author	Bas Dijkstra (Movares)	Facilitator/editor
Author	Iunio Iervolino	Reviewer

Executive Summary

The Minister of EZK (Dutch Ministry of Economic Affairs and Climate) gave substance to a request from the Dutch House of Representatives from 19 November 2021, to explore whether a joined research question can be formulated in consultation with local residents, municipalities and provincial governments with the goal to clarify causes of damages in the two specific areas. Local residents raised the desire for an independent peer review of the recently conducted studies.

The review of the original studies are covered in the review report with identification D79-CWS-HS-RAP-22007458, issued on 2-11-2022. The conclusion of the original review is that only the study on indirect causes of damage, executed by Deltares needed no further clarification. The studies on deep subsidence and building damage, executed by TU Delft and TNO did, however, raise numerous questions. These questions and concerns have led to the production of an additional information set, in which several topics have been deepened and specific reactions were given on the review remarks.

The review of the study on deep subsidence (1B) was conducted by Dr. Ivan Vasconcelos (geotechnical expertise), as was the INSAR data analysis (1C). The review of the literature survey (1A) was conducted by Professor Junio Iervolino (expert on building damage mechanisms / geotechnical), as were building damage modelling (1D) and quantification of probability. Both experts reviewed the main document (01). See the original review report for more details.

Unfortunately, Ivan Vasconcelos was no longer available to perform a final verification of the correctness and completeness of the information in relation to his review remarks. Therefore, Junio Iervolino was asked to conduct a scientific review of the additional information with regard to deep subsidence. As his area of expertise is somewhat different, but has certain overlap in several areas he was asked to perform his second review with focus on the aspects mentioned below:

- Verify completeness of the response of TUD and TNO with regard to the review remarks of Ivan Vasconcelos
- Estimate the correctness of the additional information from a scientific point of view where possible (considering you are dealing with a different area of expertise to some extent)
- Identify particular aspects that might need additional review on content if deemed necessary
- Summarize conclusions in a brief memo

The reviewer overall considers the responses with regard to building damage and quantification of probability sufficient considering the purpose of the study, although the missing experimental validation remains a main shortcoming of the study altogether with regard to generalizability of the results.

In summary the reviewer was convinced by the rebuttals and additional work carried out on deep subsidence aspects from a scientific point of view.

Altogether the presented additional information has been deemed sufficient with regard to addressing the previous observations from the peer review, summarized in the following point:

- possibility to consider stiffer masonry, different foundations and no connections to transversal walls.

given the perceived scope of the studies and restrictions with regard to possibility of experimental validation within that scope. The scope being:

- The IMG requests advice from TNO and TU Delft on to what extent subsidence and land-uplift is occurring above and in the vicinity of the Groningen gas field and the Norg underground gas storage and whether this surface deformation can directly lead to the initiation or worsening of damage to buildings.
- If TNO and TU Delft's research confirms that the surface deformation leads to the initiation or worsening of damage to buildings, the Institute would like to be advised about which methods an expert should use to determine in individual cases whether a defect or damage to a building has been or could have been caused or worsened by this type of ground movement.

Therefore, no further analysis is required.

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Introduction and scope

The Minister of EZK (Dutch Ministry of Economic Affairs and Climate) gave substance to a request from the Dutch House of Representatives from 19 November 2021, to explore whether a joined research question can be formulated in consultation with local residents, municipalities and provincial governments with the goal to clarify causes of damages in the two specific areas. Local residents raised the desire for an independent peer review of the recently conducted studies.

The review of the original studies are covered in the review report with identification D79-CWS-HS-RAP-22007458, issued on 2-11-2022. The conclusion of the original review is that only the study on indirect causes of damage, executed by Deltares needed no further clarification. The studies on deep subsidence and building damage, executed by TU Delft and TNO did, however, raise numerous questions. These questions and concerns have led to the production of an additional information set, in which several topics have been deepened and specific reactions where given on the review remarks.

The peer review of the additional information focuses on the extent to which the original review remarks were answered and clarified. TU Delft and TNO have produced a number of documents as a response to the original review:

- Cover letter containing flow chart (02 20230901 Cover Letter to Appendixes v4)
- Tables containing reactions to review remarks (04 20230906 Tables with Point-wise Responses to External Review v3)
- Memo containing a formal response to the peer review (AGE 23-10.024 - Additional analysis subsidence evaluation Norg and Groningen - 10082023 -final)
- Report Response to review comments (R12185 ZEA IMG)
- Appendixes G-J (03 20230908 Appendixes G-J Final v6)

In chapter 1 different aspects of the review process are given. Chapter 2 presents the details of the review of both building damage and deep subsidence aspects. Lastly, chapter 3 summarizes the conclusions that can be made based on the results of the review.

1 Review process

The review of the additional information was conducted at request of the Dutch Ministry of Economic Affairs and Climate (EZK). EZK requested Movares to again act as facilitating party for the review. The goal of using a facilitating role in the review was to speed up the review process, ensure the review was conducted without conflict of interest, and lastly to ensure that the review will be complete and clearly presented. It should be noted that Movares had no previous involvement in the reviewed studies or affiliation with the people that have conducted the reviewed studies.

The original reviewers were identified and selected based on the following criteria:

- No previous involvements with the studies to be reviewed.
- No previous involvements with NAM or affiliated organizations
- High level of expertise in the area of knowledge relevant for (parts of) the review.
- Availability.

Each of the reviewers was assigned parts of the studies based on their respective area of expertise in which several reviewers had some overlap in parts to review. Furthermore, reviewers were free to comment on other parts of the studies if deemed relevant.

The review of the study on deep subsidence (1B) was conducted by Dr. Ivan Vasconcelos (geotechnical expertise), as was the INSAR data analysis (1C). The review of the literature survey (1A) was conducted by Professor Iunio Iervolino (expert on building damage mechanisms / geotechnical), as were building damage modelling (1D) and quantification of probability. Both experts reviewed the main document (01). See the original review report for more details.

Unfortunately, Ivan Vasconcelos was no longer available to perform a final verification of the correctness and completeness of the information in relation to his review remarks. Therefore, Iunio Iervolino was asked to conduct a scientific review of the additional information with regard to deep subsidence. As his area of expertise is somewhat different, but has certain overlap in several areas he was asked to perform his second review with focus on the aspects mentioned below:

- Verify completeness of the response of TUD and TNO with regard to the review remarks of Ivan Vasconcelos
- Estimate the correctness of the additional information from a scientific point of view where possible (considering you are dealing with a different area of expertise to some extent)
- Identify particular aspects that might need additional review on content if deemed necessary
- Summarize conclusions in a brief memo

His review on the subsidence part, is similar to the one of a journal editor who is asked to assess rebuttals to expert reviewer's comment. The additional review by Iunio Iervolino was submitted in written form. Movares combined the separate memos into a single report (this report). Iunio Iervolino reviewed the final document and agrees with the content as a correct representation of his findings.

2 Results

2.1 With regard to Building damage modelling

Reviewed documents:

- AGE 23-10.024 - Additional analysis subsidence evaluation Norg and Groningen -
- 10082023 - final; R12185 ZEA IMG;
- 03 20230908 Appendixes G-J Final v6;
- 04 20230906 Tables with Point-wise Responses to External Review v3.

Apart from the desirable experimental validation, most of the concerns raised in the first review were resolved. This has led to less optimistic conclusions by the researchers compared to the first round with regard to building damage. With regard to the UGS Norg, the conclusion of the additional studies complies with the conclusion from the original study. With respect to the Groningen field there is a minor difference between the conclusion of the additional studies and the conclusion from the original study.

For details with regard to the conclusions the reviewer refers to the conclusions of the additional information and original reports.

In the following paragraphs comments are made on specific documents. These are included more for the record, as feedback from the first review, rather than because they require further elaborations. The comments are provided for the specific documents they apply to.

Response to the review comments – Summarizing report on additional studies into the direct effects of deep subsidence (10082023 - final; R12185 ZEA IMG)

In the initial framework of the research question, emphasis was given to the exacerbation of existing damage to buildings. However, the analyses, which consider deep subsidence, often (but not always) start from intact structures, as if they were damaged by that single action. This is clearly stated in the document. Nevertheless, since the margin for no damage is minimal, starting from structures already subject to other actions, it may not be possible to generally state that deep subsidence causes no exacerbation of present damage or makes structures more vulnerable to earthquakes (according to the reviewer, based on researchers' work). The scope of the study is whether building damage can be caused by deep subsidence and uplift. Other direct causes are outside the scope of the study. As an example variations in temperature are mentioned on page 11 of the report. The approach to focus on undamaged structures has the advantage of being able to isolate the effects of deep subsidence, leaving out other (previous) causes.

As stated on page 3 of the report the indirect effects of deep subsidence were not considered. These effects were studied separately by Deltares and are outside the scope of the study by TNO and TU Delft.

The researchers believe that it is not necessary to study already damaged structures for the purpose of this research. This conclusion seems agreeable based on the rebuttals.

The conclusions also mention that in two areas (near Warffum and Bedum), the probability is greater (but still very small) that deep subsidence can have led directly to minor building damage, assuming a transfer of actions in the foundations which decreases from 100% to 50% (which is less precautionary). Even with 100% transfer, the modelled deformations and damages to the buildings are relatively small.

Lastly, the reviewer is pleased that the review was helpful in identifying critical aspects in their analyses, and the cited references now align with the observations made in the first round of reviews.

Additional analysis subsidence evaluation Norg and Groningen (AGE 23-10.024)

It appears that the comments from the first round of reviews led to an increase in the actions on the models to be included in the analyses, although they always seem to be below the thresholds to cause visible damage.

The reviewer notices that some discussions on the uncertainty are still imprecise. For example, on page 11, it is stated that the total uncertainty is given by the product of two factors, whereas the given relationship applies to the sum of two independent random variables (without stating the independence hypothesis). The same comment applies to most of the formulas describing uncertainty management. Here, the reviewer is mainly pointing to imprecise formulations. Because he is unable to reproduce the results, he cannot speculate on possible errors in the uncertainty of the calculation.

Table with Point-wise Responses to External Review (04 20230906)

On one hand, in the replies to the comments there is extensive reference to identifying cracks from visible damage. On the other hand, the models used are of the smeared-crack type. Therefore, they provide average strain but do not indicate how the cracks occur (for the same strain, there can be many small cracks or a few large ones, or anything in between). Related to this issue, one of the newly cited references provides a value of about 0.08% strain to determine the extent of damage.

Regarding modeling in appendix H point 3, it appears simplistic, although it heavily depends on soil mechanics, which is outside my expertise. This modeling justifies the transfer of strain from 100% to 50%. Geotechnical models of deep soil subsidence result in deformations of at most less than 0.01%, so if there are no concerns about these strains being too small, this is consistent with structural models (in accordance with the literature) that do not show damage with such small actions.

A few specific comments on the reply table:

10.3 Due to the complexity of the problem as a whole (and the very large number of linear and nonlinear processes involved and the need to calibrate their parameters), the lack of experimental validation in masonry significantly affects the generalizability of the conclusions in this study. A numerical work without experimental validation has intrinsic limits. Nevertheless, the conclusions are positive on the numerical part, given the caveats.

Given that experimental validation is important, according to the reviewer, it is up to the client(s) to evaluate whether to extend the study to include experimental validation.

10.4 Decoupling the actions, the models generally (though not always) refer to intact structures, which is not precautionary. However, the revisions attempted to address this issue in certain ways.

11.3 No visible damage does not necessarily mean no risk of interaction with other actions. Nevertheless, it is claimed that this is beyond the mandate.

16.3 Even if 100% soil deformation is transferred, rigid foundations filter the propagation of the deformation and damage to the superstructure, as acknowledged in the appendices.

2.2 With regard to Deep subsidence modelling

Reviewed documents:

- AGE 23-10.024 - Additional analysis subsidence evaluation Norg and Groningen
- 10082023 - final; R12185 ZEA IMG;
- 04 20230906 Tables with Point-wise Responses to External Review v3.

As mentioned before, Iunio Iervolino was asked to perform a scientific review of the subsidence hazard part of the additional information and the response to reviewers' comments (i.e., those from Dr. Ivan Vasconcelos). He accepted the assignment and reviewed all the documents provided related to the subsidence hazard in addition to his review of the other aspects.

In the following paragraphs replies are given to the specific questions that Movares asked. Iunio Iervolino states that most of the concerns raised were appropriately addressed/rebutted.

Completeness of the response of TUD and TNO with regard to the review remarks

The research group has replied/rebutted all the comments of the reviewers in document 04 20230906, the most important of which were related to the treatment of uncertainty in subsidence modelling, the refinement of the approach and the data series analysis processing.

The general approach taken for the replies is that, although the remarks are acknowledged as correct, the additional work (on top of the already executed additional analyses) it would require to address them is not worthwhile (and/or is not within the original mandate) as it would likely not change the overall conclusions of the study. This is a statement of the researchers. The reviewer has not enough information to agree nor disagree with this.

The rebuttals are generally convincing. The additional work carried out to address some of the comments of the reviewers, a brief overview of which is given in the following paragraphs, also seems convincing scientifically, although with some comments.

Correctness of the additional information from a scientific point of view

Document AGE 23-10.024 reports about the further consideration of uncertainties in subsidence hazard (2D) modelling. The work is systematic and clear, and it helps to reach its purpose. Nevertheless, some assumptions on stochastic modelling still seem simplistic and unjustified in places (for example, there is no supporting information to assume normal or lognormal distribution). Also, the relationship between the variances and the mean are not fully adequately supported. Also, the fact that the different uncertainties depend on the same mean, yet are treated as independent, needs deepening.

Document R12185 ZEA IMG has the interesting aspect of quantifying the subsidence risk integrating subsidence hazard and structural fragility, for both Norg and Groningen, in a similar fashion as it is done for transient ground deformation for seismic risk. The reviewer especially praises this approach, which he thinks should not be left at the preliminary stage and should be systematically applied to the built environment in The Netherlands exposed to mining-related hazards.

Identify particular aspects that might need additional review on content

Despite the fact that the reviewer is not an expert of the field, he was able to follow the documents and review their technical content. On this basis, despite the research group has rebutted many reviewer's comments, it has also performed additional investigations, aimed at consolidating the previous results without changing the general approach. Although the reviewer has some comments on uncertainty treatment, the additional studies address the concerns raised.

The only remaining issue could be the need of a 3D approach rather than the 2D taken. However, given the magnitude of the effects estimated with the 2D approach that are unlikely to change in a 3D environment, the reviewer tends to agree that this could be not necessary in this mandate.

3 Conclusions

3.1 With regard to Building damage modelling

The reviewer overall considers the responses with regard to building damage and quantification of probability sufficient considering the purpose of the study, although the missing experimental validation remains a main shortcoming of the study altogether with regard to generalizability of the results.

3.2 With regard to Deep subsidence modelling

In summary the reviewer was convinced by the rebuttals and additional work carried out on the subsidence part.

Altogether the presented additional information has been deemed sufficient with regard to addressing the previous observations from the peer review, summarized in the following point:

- possibility to consider stiffer masonry, different foundations and no connections to transversal walls.

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Therefore, no further analysis is required.

3.3 Overall conclusion

As it happens in all reviews of research work, the criticism of the reviewers is addressed by authors in a way the opinions may still be different. Nevertheless, with regard to the studies by TNO and TU Delft the rebuttals and additional information were more agreed by the reviewer than not agreed. Overall the reviewer is of the opinion that the main concerns are adequately answered, leaving only minor concerns open for discussion. Therefore, the final overall conclusion is positive, given some criticism that could be addressed in further research in the future.

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