To: NL Ministry of Economic Affairs
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From: Groningen Scientific Advisory Committee:

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Progress note Groningen Scientific Advisory Committee

1 December 2015

The Groningen Scientific Advisory Committee (SAC) monitors and reviews the investigations performed by NAM or its contractors as part of the development of the Groningen Winningsplan (WP) 2016. The role of the SAC is to ensure the quality, completeness and impartialness of these investigations.

This note summarizes the SAC observations on the focus of NAM's research program. It has checked the findings against the most recent versions of the Study & Acquisition plan and the progress/plans presented by NAM during the V2 workshop on Hazard and Risk Assessment on 3 & 4 November 2015 in Assen. Prior to this workshop representatives of the SAC participated in four Expertise Workgroup meetings (Seismological Model 2 June 2015; Ground Motion Prediction (GMPE) 17 September 2015; Groningen Pressure Maintenance 24 September 2015; Fragility & Risk Metrics 9 October 2015).

The SAC views, presented below, are based on data, reports and presentations provided by NAM, up to 4 November 2015. All available documents can be found in the SAC-shared folder within Dropbox. A 2-page summary of NAM's Probabilistic Hazard and Risk Assessment for Induced Seismicity Groningen – Interim Update 7th November 2015 – is given as a addendum to this note.

General

The November 2015 workshop was most effective and started with the outcome/status overview and subsequently the details on how these were arrived at. That enabled the SAC to focus more on matters that have higher impact on the outcomes.

In general, the SAC members are impressed by the quality of the work performed within the project, which is of high scientific level. NAM/Shell/contractor staff involved are genuinely

aiming for a best possible hazard and risk quantification within the constraints of time and data available. The researchers involved are open-minded and willing to communicate and discuss the results of their work.

From V1 to V2 Hazard and Risk Assessment: Observations

1. Uncertainty in GMPE has by far the largest impact on the results, also in V2. The impact on PGA (Peak Ground Acceleration) maps and hazard is limited going from V1 to V2. Impact on risk is much larger, about a factor of 10 reduction in risk numbers. If this outcome is correct the safety problem is becoming manageable. NAM is of the opinion that they can demonstrate that they meet the proposed norm at a 33 BCM production scenario. External risks (industrial, infrastructure, flooding etc.) are not in the presented risk numbers. At the moment these numbers only include risk from building collapse.

2. It makes sense to prioritize on a clearly-defined track towards assessment of risk for residents, while it is also in line with the norms of the Commissie Meijdam. However, major public concern is related to the risk to assets, i.e. the damage to houses. Therefore we would expect that the risk assessment also addresses a more complete quantification of risk to assets, or at least gives a road map how this will be done in the future.

3. Production scenarios have not been optimised on risk and are mainly dictated by the present operational constraints. In particular the two lower production scenarios have not been optimised on risk. Production is reduced in areas with relatively low seismicity. Production is not reduced in the south and not in the southwest where seismicity is higher and increasing. As a result, the calculated impact of production changes on risk is limited. In contrast, the housing strengthening is prioritised in areas with high seismicity. The resulting comparison of its impact with that of production measures is therefore arguable.

Seismological Model

4. The seismological model, which is a base for the further hazard and risk assessment, has reached a level of sophistication that makes it suitable for the purpose of developing the Winningsplan 2016. Being built on experience from the Groningen field, in particular the subsidence history, it is likely to predict the near future behaviour in an adequate manner.

4. In a longer time perspective, it is important to incorporate a better link between processes driving seismicity (stresses and stress changes on faults). In its current form, we do not see how pore pressure increase (for instance as a result of a longer production stop, or as a result of injection for pressure maintenance) could be handled. In the long term we believe the predictability of any model relies heavily on having the physics incorporated in as correct manner as possible, and at the same time being able to calibrate with relevant field data.

5. The inherent complexity and the potentially large impact of "the engine" on the outcome of the Winningsplan call for detailed sensitivity analysis. The difference between the three different compaction models is of little relevance for the outcome of the risk analysis. This could mean that the compaction models are very similar in terms of what they predict for

the near future, or that the cumulative strain is more important than the incremental strain for the outcome.

6. It is important to see how Mmax but also related parameters like b-values influence the final risk. Plans for future data collection, and how these are going to affect updates on predictions, are of great importance for the long-term production and associated safety.

Pressure Management

7. One way to reduce remaining uncertainties might be the "Meet-en-Regel-Protocol" (Measurement and Control Protocol). The "Meet-en-Regel-Protocol" plays a key role for the public, therefore it should be simple and transparent also for non-scientists. The version of the "Meet-en-Regel-Protocol" as presented during the workshop was immature. No specifics were presented on how to decide on which action to take in response to which measurements. Mention was made of a more specific document, but no details were presented.[1]

8. No link was made between the "Meet-en-regel-protocol" and potential control actions related to: 1) reducing gas production rates to allow relaxation of compaction-induced stresses, and 2) pressure maintenance through nitrogen injection to reduce compaction. The general public often suggests these as solutions, and therefore we believe it needs to be clarified by NAM to what extent the underlying assumed relationships can be confirmed/dismissed/quantified and why these potential solutions are not used in a control strategy.

Risk Metrics

9. NAM believes the present risk calculation is probably still conservative. Not clear if this is indeed the case. A list of conservative assumptions taken in the risk assessment was compiled by NAM and presented. Conservative assumptions are to be avoided as much as un-conservative assumptions in risk assessment. This is because conservative assumptions also bias the risk, impairing cost-benefit-based decision making; i.e. the ultimate goal of risk assessment. In any case, it is worthwhile to keep track, explicitly, of the conservative assumptions still remaining while progressing toward their removal.

10. It was claimed the 'engine' simulates a non-stationary process of earthquakes and then of consequences. This is only partially true. In fact, damage accumulation in successive events is neglected in the vulnerability (fragility) modelling. Moreover, using, in each simulation's run, the same fragility functions, implicitly means to assuming that each damaged (collapsed) building is instantaneously rebuilt and that residents can die more than once. In summary, non-stationarity, if any, is only in the hazard and not in the other components of the risk assessment.

[1] Post-workshop note: The Readers' Guide in the Interim Update report of 7 November 2015 states that the Meet-en-Regel Protocol "ensures the continuous data acquisition and monitoring needed for the Hazard and Risk management". This seems indeed a key aspect of "measurement protocol", however, the "control" part is missing.

11. The risk coming from the falling objects (e.g., chimneys) is still modelled separately from the risk following structural damage and it is also outside the 'engine' so far. In the case there will be an integration of this potential cause of fatality, if deemed relevant to the risk, it seems not an easy issue to address given that the considered objects are part of the building, and their collapse is not independent from the behaviour (and virtual collapse) of the structures they belong to.

12. Some so-called epistemic uncertainty is still assigned based on expert judgment in V2 fragilities. Similarly, the effect of strengthening of buildings on fragilities is arbitrarily assigned. These points seem to reflect a level of detail in modelling different from the rest at this stage. These issues should be more formally addressed toward the Winningsplan 2016.

13. Stochastic spatial dependence of ground motion intensity is not yet fully modelled. In particular, the intra-event residuals are uncorrelated, while it is inherent to the model the (likely strong) correlation carried by the mean of the GMPE and by the inter-event residuals. It was not entirely clear whether (or when) full stochastic dependence will be accounted for the Winningsplan 2016.

14. It seems that cluster-triggering events follow an independent and stationary increments process (i.e. homogeneous Poisson), while the aftershock are sampled according to ETAS (Epidemic Type Aftershock Sequence) models. This seems not the standard way ETAS model is used, as it does not require distinction between triggering events and aftershocks, while all events come from the same model. We wonder whether and how declustering of the catalog to generate the triggering events is carried out to make sure to not over-produce seismic events with this simulation approach.

15. It could turn out difficult to find the houses that need strengthening. At the moment the category of a house is assigned probabilistically. That is not a problem when calculating average risk levels. A large number of houses will need to be inspected to find the category of each individual house. Secondly there is a large variation of the fragility curves within each category. Effect could be that the majority of houses in the weakest categories will need to be strengthened to make certain that all the truly weak building are incorporated. NAM's estimate of a factor of 2.5 for these two effects combined might be a considerable underestimate.

16. The group risk numbers shown seem to be P50. This is not a useful number. For earthquake group risk the fulllogic tree needs to be incorporated to calculate the mean risk.

17. NAM proposes to use activity level as "gebruiksruimte" and not risk. This is not a good approach as the effects of the e.g. b-value cannot be taken into account this way. A field wide PGA "gebruiksruimte" seems a better approach.

Recommendations

18. It is clear that the big picture is coming together in the V2 hazard and risk assessment. Now that different pieces of work are linked in the so called 'engine', the need for a back-analysis of the results produced seems necessary. Moreover, a number of issues, which may

be relevant are still left to future work, or rely on expert judgment, waiting for modelling with a level of detail comparable to the rest.

19. To gain further confidence, it would be beneficial if a third (independent) party could test the 'engine' as a whole. By reproducing NAMs forecasts this third party could get an understanding of the little screws that might be adjustable in the process and assess their combined impact on risk. This is of particular importance since NAMs results draw a clear picture regarding the efficiency of mitigation measures (i.e. impact of reducing production is relatively minor).

20. We would like to see a more detailed presentation of the current risk assessment in the framework of NAM's/Shell's internal HSE Management System. We advise to seek contact with professionals with a systems and control background in the process industry to assist in developing the Meet-en-Regel Protocol. Suggestions for names: Dr. K.C. Goh (Shell), Prof. Bjarne A. Foss (Norwegian University of Science and Technology (NTNU)), Prof. B. Erik Ydstie (Carnegie Mellon University, USA), Prof. Wolfgang Marquardt (RWTH Aachen University, Germany).

What's next?

Follow-up expertise workgroup meetings have been planned in the first quarter of 2016.

Early March 2016, a Mmax workshop is organised by NAM. Several experts have proposed values or distributions for Mmax. As the Mmax potentially has a large impact on the hazard assessment, NAM would like to use a formal and recognized process for expert opinion elicitation and aggregation, resulting in a well-documented Mmax (distribution) estimate. They will follow a SSHAC (Senior Seismic Hazard Analysis Committee) process of the US Department of Energy and Nuclear Regulatory Commission (NRC). SAC members are approached to be observer in this technical peer review.

May/June 2016 - Milestone workshop for Winningsplan 2016 (NAM, Assen)

Lucia van Geuns
Chair Groningen Advisory Committee

The Hague, 30 November 2015

Addendum to SAC progress note December 2015

NAM's Hazard and **Risk** Assessment for Induced Seismicity Groningen – Interim Update 7th November 2015

Summary

Conclusions

- This update to the May 2015 Probabilistic Hazard and Risk Assessment (PHRA) evaluates the risk to residents from failure of buildings as a result of induced earthquakes due to gas production from the Groningen field. This information may be used to assess the acceptability of the risk compared to the risk norm, and to determine the appropriate mitigation measures to ensure continued safety of residents.
- Key conclusions of the November 2015 updated PHRA include:
- The November 2015 PHRA update shows that no houses exceed a risk of 10^{-4} (i.e. consistent with the criteria proposed by the Meijdam Committee) for a 33 bcm scenario, for 2016–2021.
- In the longer term (2017-2021), the scope of the structural upgrading programme, will depend on further reduction of the uncertainties in the PHRA (risk assessment). In the current PHRA update, the programme until 2021 encompasses some 5,000 buildings for a 33 bcm/annum scenario.
- Based on a production scenario of 33 bcm/annum, no more than a few hundred additional buildings are likely to require upgrading each year after 2021. The total size of the structural upgrading programme also depends on the effectiveness with which these buildings can be identified through inspection. As a consequence, buildings that do not require upgrading might actually be upgraded. The actual scope of the upgrading programme will therefore be wider.
- Seismic hazard maps indicate a smaller geographical area is exposed to significant (> 0.25 g PGA) ground accelerations for 2016–2021 than was projected for the same period in the May 2015 PHRA report. The reduced hazard area is consistent with KNMI's PGA map update published in October 2015 and now reflects the improved ground motion prediction method, based on the detailed description of the soil layers in the Groningen field area.
- For the first time it is possible to match a fully probabilistic risk assessment to an established risk norm. This outcome was achieved by comprehensive studies of building materials and construction in the area, advanced fragility modelling and the results of a shake table test of a Groningen-type terraced house.
- The building fragility studies reveal that in general buildings built in the 1960s and 70s are much stronger than originally thought. Particularly SiCa bricks that are often used for load bearing interior walls have a greater resilience to earthquakes than previously estimated.
- All studies supporting this PHRA assessment have been reviewed through an independent peer review process conducted to international scientific standards.

Background to this Study

- A Study and Data Acquisition Plan describes the objectives and interdependencies of all the studies and research efforts into induced seismicity being undertaken by and on behalf of NAM. The plan was first shared with SodM and the Ministry of Economic Affairs (Ref. 2) in November 2012 and was made public in early 2013.
- As part of the original Study and Data Acquisition plan, a probabilistic hazard and risk assessment (PHRA) for the Groningen gas field region was proposed. The original probabilistic hazard assessment (PHA) and scenario based risk assessment for the Groningen field were published in December 2013 as part of the 2013 Production Plan (*Winningsplan*) update. The next update to the PHRA will underpin the 2016 Winningsplan for the Groningen field to be submitted to SodM in mid-2016.
- The six-monthly updates provide insight into the progress of the assessment of the hazard and risk of earthquakes versus the assessment that underpinned the 2013 Winningsplan update.
- NAM continues its Study and Data Acquisition Plan which:

- is based on specific evidence and targeted data
- involves many Dutch and international experts, including those from academia, university laboratories, independent experts, commercial parties and consultants
- is subject to an extensive voluntary assurance and verification programme, through an independent peer review process conducted to international scientific standards.

New in this November 2015 update:

A deeper level of analysis and more data specific to Groningen

- Revised static and dynamic reservoir modelling (with improved history match to production, pressure and subsidence data).
- Improved seismic model.
- A major update of the model used to predict ground motion. The updated equation now also incorporates such factors as area-specific details of shallow sub-surface and soils. Data from the newly available geophone network have contributed to this.
- New data on strength of buildings and building materials from lab tests, tests in pilot houses and shake table testing conducted in Italy. This was used to update building fragility relationships.
- Updated exposure to risk for people, reflecting more comprehensive work on collapse hazard. Furthermore, the risk of falling objects outside of buildings has also been studied.
- This work has resulted in the first quantified probabilistic risk assessment by location. In the previous May 2015 update the risk data were qualitative, as the results had not been fully calibrated to sufficient actual data.

Study Scope

- In this update, NAM has evaluated both the risk in the near term (2016-2017) and the measures necessary to maintain risk within acceptable levels during that period. The risks were assessed on the basis of the criteria laid down by the Meijdam Committee.
- This evaluation was conducted for three production scenarios: 33, 27 and 21 bcm/annum.

Further work

- Study and data acquisition work will continue to improve understanding of the specific hazard and risk situation in the Groningen field area.
- The main work planned between now and the PHRA updated for the mid-2016 Winningsplan update is as follows:
- Continue the experiments and studies to understand the fragility of buildings. Incorporate additional data from field and building tests.
- Set up an expert panel to establish the maximum magnitude for earthquakes in the Groningen field.
- Further refine the GMPE and seismological model.
- Independent external oversight for the studies supporting the Hazard and Risk Assessment in the Winningsplan 2016 is provided by the Scientific Advisory Committee (SAC), chaired by L. van Geuns, which was installed by the Minister of Economic Affairs.

Many activities are aimed primarily at preparing the Hazard and Risk Assessment for the Winningsplan 2016, but many other activities are geared to developing a broader understanding of the physics of induced earthquakes. These activities will not be completed by mid-2016, but may provide further insights and a broader foundation for the Hazard and Risk Assessment of the Winningsplan 2016.