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Energy Market Directorate

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Project description

Technical Review of TNO's Bergermeer Seismicity Study

Introduction

In the near future TAQA Energy B.V. wants to utilize the depleted Bergermeer gas field as an Underground Gas Storage facility. The Netherlands Organisation for Applied Scientific Research (TNO) has performed a study regarding the seismic risk of the injection/production activities and is called the *Bergermeer Seismicity Study*. Assumptions made in the report have raised questions and concern among the local community. They fear that the gas storage activity will cause severe earthquakes and damage to their homes. Therefore, the Minister of Economic Affairs has been asked to have the report of TNO reviewed by an independent expert. This Project Description contains the scope of work for this technical study.

Deliverables

The Ministry of Economic Affairs expects :

1. A report containing:
    a. a critical technical review of the assumptions, conclusions and recommendations of the *Bergermeer Seismicity Study*, TNO report 2008-U-R1071/B, 6 November 2008.
    b. answers to the questions raised by the "Gasalarm2 foundation" and the Soil Movement Technical Committee (see appendices)

The report as mentioned should be submitted in both hard copy (20 copies) and in electronic form. The final report will be preceded by a draft report.

Optional:

2. An oral presentation in the municipality of Bergen (The Netherlands) for representatives of the local community.

Timing

The report is to be completed and delivered by September 21st, 2009.

Remarks:

1. Some of the questions raised in the appendices will need an explanation from the governmental experts who are involved in the Bergermeer project. The

Directorate General for Energy and Telecom
Energy Market Directorate

Our ref.
ET/EM / 9135720

Ministry of Economic Affairs is willing to organize an information meeting between the reviewer and these experts.

2. TAQA Energy B.V. supports the study and is willing to supply any information needed.

Reports supplied:

- Logan, J.M.; Higgs, N.G.; Rudnicki, J.W.; Seismic risk assessment of a possible gas storage project in the Bergermeer field, Bergen concession, 1997
- Van Eck, Torild; Goutbeek, Femke; Haak, Hein; Dost, Bernard; Seismic hazard due to small-magnitude, shallow-source, induced earthquakes in The Netherlands ; KNMI scientific report, 2004
  http://www.knmi.nl/~goutbeek/Submitted-seismic-hazard.pdf
- Van Eijs, R.M.H.E.; Mulders, F.M.M.; Nepvue, M.; Kenter, C.J.; Scheffers, B.C.; 2006; Correlation between hydrocarbon reservoir properties and induced seismicity in the Netherlands. Engineering Geology, 84, 99-111.

Reports or papers that need to be purchased can be reimbursed.

Directorate General for Energy and Telecom
Energy Market Directorate

Our ref.
ET/EM / 9135720

Appendix 1: Questions of the Gasalarm2 foundation

1. Is the assumption of TNO justified that the changes of the thickness of the reservoir develop gradually during injection and production?
   (i.e. that the change of the thickness [compaction and decompaction] follows the pressure change in a gradual way and that the reservoir is in an equilibrium condition every time).

2. TNO uses elasto-plastic geomechanical models to calculate potential slip on a faultplane. A critical geometry of reservoir and fault structure is chosen, which is sensitive for reactivation of the fault. Plastic slip is calculated on the fault, during depletion and injection, each time in an elasto-plastic equilibrium condition.

   Question: Is the above mentioned approach of TNO correct to calculate the maximum potential slip that can occur, especially during the injection phase? (Clarification: Gasalarm2 assumes that in reality asperities may be present on the fault, preventing movement along the fault during the depletion phase.

3. (With reference to the calculations in chapter 7 in the TNO report)
   Gasalarm2 assumes, that in the injection phase tremors with magnitudes of 3.4 up to 3.8 might occur. This hypothesis is based on the assumption that asperities are present along the fault plane, causing slip not to occur along the whole fault during the depletion phase.
   Remark State Supervision of Mines: during re-pressurization of the reservoir, decompaction of the reservoir-rock will take place and therefore in an uplift at the surface. The potential relative shear displacement (slip) on the fault will decrease.

   Question: What is the opinion of the expert(s) about the suggested magnitudes?

4. Figure 3,2 of the Seismicity Report shows a 3D view of the Bergermeer gas field (based on a model of Horizon 2006). From this view Gasalarm2 concludes, that the main (internal) fault may be longer than anticipated. According to Gasalarm2 the length of the fault is probably 4.1 to 5.9 kilometres and not 2.5 kilometres. Consequently, Gasalarm2 assumes, that the probable size of the reactivated part of the fault plane may be much

larger than is stated in table 2.2 of the TNO report (page 18) and therefore the potential magnitude of earth tremors may be much higher (M=4.1).

Question: What is the relation between the length of the fault plane, the probable activated part of the fault plane during the events and the maximum magnitude of a seismic event? How important is the estimation of the total length of the central fault?

5. Maximum magnitude issues.
   - TNO conclusion 7: "During injection, the largest slip ***observed in the geomechanical models*** corresponds to seismic magnitudes ranging between 2.4 and 2.7."
   - TNO page 85: "For the range of seismic magnitudes ***expected*** during the injection stage (2.4 to 2.7)..."
   - TNO conclusion 8. The maximum possible seismic magnitude is 3.9. Larger magnitude earthquakes are improbable due to the limited dimensions of the faults.
   - Gasalarm2: Occurrence of earth tremors with magnitudes larger than 4 are possible during the gas storage project Bergermeer

   Question: what is the opinion of the expert(s) about the different views of TNO and Gasalarm2, taking into account the arguments about the size of the probable activated part of the fault plane and the possibility that in the depletion phase, slip on the fault plane may be prevented by one or more asperities.

6. Gasalarm2 assumes that the stabilisation of the fault structures at reservoir level due to the pressure-increase (during injection) will be negligible. The assumption is based on table 7-1 of TNO's Seismicity report.
   TNO assumes that the re-pressurization of the reservoir will lead to a more stable fault structure (see chapter 6.3 of the TNO Seismicity Report)

   Question: what is the opinion of the expert(s) about these different views?

7. Gasalarm2 observes that for the operating phase of the Bergermeer Gas Storage reservoir only the first production/injection cycle is modelled by TNO. According to Gasalarm2 this is erroneous. Gasalarm2 expects, that the continuing cycle of alternating production and injection will cause erosion of the fault planes. To the opinion of Gasalarm2 it is also an omission that the seismic risk of the recovery of the working gas at the end of the storage

period is not taken into account.
TNO has made a recommendation (page 87, number 3) to extend the current report with an analysis of subsequent injection/production cycles to investigate the temperature distribution and the rock response (e.g. fatigue effects).

Question: what is the opinion of the expert(s) about the missing geomechanical analysis of the subsequent injection/production cycles? Is this analysis essential to draw conclusions about the seismic risk of the injection/production activity? Or can this analysis be characterized as a "fine tuning" of the model?

8. Gasalarm2 believes, that TNO has made the wrong basic assumptions in their model, because they don't assume inhomogeneous properties of the reservoir rock and non-elastic (irreversible) deformation behaviour.

   Question: what is the opinion of the expert(s) on this subject?

9. According to Gasalarm2 the temperature effects are not addressed in a satisfactory way in the TNO- report

   Question: what is the opinion of the expert(s) on this subject? Has TNO made the wrong assumptions or did they investigate these effects in an insufficient way ? (e.g. the distance to the faults, the heating by compression, long term effects; a large surface area of the reservoir is influenced by temperature effects, etc.)

10. Gasalarm2 fears that injection of production water in the well BGM-4 will cause a weakening of the rock salt caprock, resulting in a sudden stress-release. They suggest that the production water can pollute the groundwater due to an upward or a sideward migration.

    Question: what is the opinion of the expert(s) on this subject?

11. Additional question about the focal mechanism
    At the end of chapter 6 (page 81) of the TNO report concludes:
    "All plastic fault displacements observed during depletion and injection are normal faulting movements. This means a discrepancy exists between the interpretation of focal mechanisms reported by the KNMI (reverse faulting mechanism) and the displacement mechanisms from the geomechanical

Directorate General for Energy and Telecom
Energy Market Directorate

Our ref.
ET/EM / 9135720

analysis (normal faulting mechanism). It is noted that in an extensional tectonic setting such as the setting for the Bergermeer Field, predominantly normal fault movements are expected."
This remark was based on the figures 6 and 7 of a report from the seismological department of the KNMI with an interpretation of the focal mechanism of the Bergermeer events. The report (in Dutch) can be found at: http://www.knmi.nl/bibliotheek/knmipubTR/TR239.pdf

Question: what is the opinion of the expert(s) about the focal mechanism of the Bergermeer earthquakes (see figures 6 and 7 of above mentioned report).

Translation of captions:

Fig. 6: Schematic representation of the central fault in the Bergermeerfield. The epicentres of the earthquakes are indicated with an asterisk. The fault formed in an extensional setting, currently the focal mechanism is a reverse fault.

Fig. 7: Overview of the epicentres of the earthquakes near Alkmaar and Bergen aan Zee. The location of the gasfields are indicated in grey and the faults in black.

Directorate General for Energy and Telecom
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Our ref.
ET/EM / 9135720

Appendix 2: Questions of the Soil Movement Technical Committee

The following questions were asked by the Tcbb (Technische commissie bodembeweging; english: Soil Movement Technical Committee):

1. What is the opinion of the evaluator on the risk estimates and are they compatible with the physics (ref. TNO report and KNMI risk reports)?

2. The fault dissecting the Bergermeer field is (partly) sealing: what pressure difference between the hanging- and foot-wall may cause earthquakes?

3. The Tcbb considers the possibility of seismic monitoring at reservoir level, since only larger events (M>3) have been recorded with the current monitoring system. Is this a justified approach or are there alternatives?

4. How is excessive movement to be prevented? Can this be done by changing the rate or volume (maximum pressure difference) of production?