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Reactie TNO-AGE op eindrapportage Long Term Subsidence Fase 2 (LTS-II)

Geachte

U heeft mij op 20 april 2017 mondeling verzocht om een beknopte samenvatting te geven van de bevindingen van in zijn rol als waarnemer namens TNO-AGE bij het LTS-II project.

De bijlage bij deze brief bevat de door u gevraagde samenvatting.

Ik vertrouw er op u hiermee voldoende te hebben geïnformeerd.

Met vriendelijke groet,

Hoofd Adviesgroep Economische Zaken

Bijlage bij brief kenmerk 17-10.054 van 8 mei 2017

Role of TNO-AGE regarding the LTS-II project

Figure 1 from NAM's report dated 31.1.2017 is incorrect in that it suggests that TNO-AGE has been member of the LTS-II Technical Steering Committee. From the very start of the LTS-II project, TNO-AGE has clearly taken the role of **observer.** The rationale for this was to be informed on the project progress and from there be in the position to quickly advise to Sodm and the ministry of Economic Affairs, as soon as the project reports would become available.

Scope of this summary of findings

This summary of findings on the LTS-II reports starts with a number of general technical remarks and then focusses on specific geomechanical aspects. Reservoir modeling, geodetic aspects, as well as a detailed review on the generic ESIP workflow fall beyond the scope of this summary.

General technical remarks

Maturity of ESIP technology & general applicability

As advised from the LTS-I project, a prime goal of LTS-II was to develop, implement and test a method for – so called – confronting geomechanical model outcomes with geodetic data in an objective way (i.e. without user interference). That goal has been reached for the major part, be it that there are issues remaining on the statistical weighing and final test statistics, that TNO-AGE feels should be addressed before applying ESIP on a routine basis.

Complexity of the Ameland case

The rationale for choosing Ameland as the test case in LTS-II was the long history (some 30 years) of measured data, as opposed to the much shorter history of other gas fields in the area. However, it has to be recognized, that the Ameland case probably is the most complex case of subsidence due to gas extraction to be found in the Netherlands, because of:

- large initial overpressure;
- GWC not seen by wells;
- potentially connected to a large lateral aquifer;
- complex overburden geometry (underneath the flank of a huge salt dome);
- conventional geodetic benchmark network only on a narrow strip along the isle of Ameland, otherwise a far more sparse GPS network.

Of course ESIP as such cannot solve this complexity: the input models and model parameter ranges determine the quality of the ESIP outcome. Rather, the results of the Ameland test case point in the direction of that complexity. It is noted, that most - if not all - of that complexity has been discussed before in various earlier studies by NAM and others.

Confronting geomechanical model outcomes with geodetic data

The Ameland test case in LTS-II in fact has been only a single pass confrontation against the 2014 data set. In what TNO-AGE would consider a normal operational mode, over time one would make regular comparisons of forecasted subsidence against measured data and from there determine, if and when there is a need to revise or refine the geomechanical model set (or the geodetic network for that matter). This 'learning process' could have been emulated using ESIP, but even the simplest test (take the first halve of the time series to predict the second halve and then test against the full data set) has not been performed by NAM. TNO-AGE would strongly favor such a test before applying ESIP in a routine mode on the Wadden Sea gas fields.

Inherent non uniqueness

In the LTS-II report, the reservoir model (incl. the aquifer part), the compaction model and the influence function are described as separate entities. In the opinion of TNO-AGE, more attention should have been given to the fact that these three potential contributors to time dependence cannot fully be disentangled by the lack of specific calibration data, in particular on the in situ compaction field. As a result, there is freedom for the ESIP simulator (or in fact any other tool) to distribute time dependence over these three main contributors and therefore the end result to a certain extent carries an inherent non-uniqueness. This becomes particularly important when realizing, that the influence function (including the time dependent salt flow) has no net effect on the subsidence bowl volume. Hence, if the time dependence in the influence function is underestimated, there may be an overestimation of the time dependence in the reservoir (and aquifer) compaction – and vice versa-, which would have a direct impact on the time evolution of the subsidence volume rate.

Objective function

From a regulatory point of view, the final goal is to assess the time evolution of the subsidence bowl volume rate (within the relevant sand sharing areas, caused by all relevant gas fields in the area), including its uncertainty. The LTS-II team has chosen to go for the measured double differences from the geodetic side and to confront these with the double differences predicted by the geomechanical models. Although that approach has technical advantages (primarily from the geodetic side), it does make the connection to the final goal (bowl volume rate) less transparent and potentially overly sensitive to systematic errors in the determination of the bowl shape and position, whereas the volume-effect could be small or even absent.

Geomechanical aspects

After the final LTS-II reports became available on 31.1.2017, inspection of the results led to additional questions to NAM. Below the points raised by TNO-AGE on specific geomechanical aspects are summarized.

Compaction models

In the LTS-II reporting, a set of four compaction model equations is described (linear, bilinear, time decay and rate type). The rationale behind such a set should be, that they represent a sufficiently broad spectrum of independent models with different physical backgrounds.

In reality, the actual compaction **physics** is not known in very much detail. Most of the compaction equations used are of a purely empirical nature at best. The only candidate model that represents most of the conceivable physical processes and also has been tested in representative laboratory conditions is the Rate Type Compaction Model (RTCM, see the thesis of J.A. de Waal and reports in the series of LTS-I results).

In addition, the **mathematical** form of the compaction equations is such, that they are members of the same mathematical family, and therefore not independent. Specifically:

- Linear is a special case of the bilinear model (no pressure yield point), which in turn is a special case of RTCM (i.e. for no creep);
- Linear is a special case of time decay (for very short time constants), which in turn is a special case of RTCM (i.e. without any elastic component).

Therefore, from a mathematical point of view, it would be sufficient to use only the RTCM compaction model and let ESIP decide on its parameter values.

At this point however, we reiterate the above statement, that in situ calibration of the compaction field is absent. Hence, bringing in **constraints** to the RTCM parameters (either a priori or a posteriori) from laboratory data is likely to be useful if not necessary, while also taking into account the initial heavy overpressure of the Ameland gas field (whick also holds for its neighboring fields Nes, Moddergat, Anjum, in the Lauwerszee Trough).

Influence functions

Choice of influence functions
The LTS-II team has chosen two types of influence functions that translate reservoir compaction into subsidence: 1) the semi-analytical AESubs model from TNO, 2) the Knothe function. It is noted, that the Knothe function does not have time dependence and therefore has a limited value in the LTS-II research, where time dependence is the key question.

Calibration of AESubs to GeoMec

NAM has put a lot of effort to calibrate the AESubs influence function to that of the full 3D geomechanical GeoMec model of the Ameland area. Quite some – not physically justified – adjustments turned out to be necessary to obtain a reasonable match. This raises the question, to what extend AESubs actually is superior to Knothe, other than – in principle – being able to model time dependence in the subsidence bowl shape.

Geometrical effect (time independent)?

AESubs and Knothe have in common, that they project deformation at the reservoir level strictly vertically into a subsidence bowl. However, the output of the ESIP Ameland case shows that the assumption of a strictly vertical projection is not supported by the data: this observation is derived from east-west profiles over isle of Ameland provided by NAM, showing the best geomechanical model outcome (according to ESIP) against the geodetic data: a time independent east-west lateral shift in the order of 800 to 1000 meters turns up. This feature has been observed in earlier studies. TNO-AGE reckons this may a geometrical effect of the overburden structure, dominated by the huge salt dome ranging in thickness from 200 to 2000 meters over the size of the Ameland gas field and advises to verify this geometrical effect.

Geometrical effect (time dependent)?

In addition to the time independent geometrical effect, there may be a time dependent effect on the position (and shape) of the subsidence bowl. In the LTS-I series of studies ordered by NAM, the university of Utrecht has done a geomechanical 3D modeling exercise of the subsidence over the Ameland field, introducing linear salt creep as a time dependent (creep) phenomenon in a 3D setting, representing the geometry and geomechanical properties of the overburden. That study shows a time dependent lateral translation of the deepest point of the subsidence bowl. The rate of this lateral shift is governed by the assumed effective viscosity of the Zechstein salt formation overlying the Ameland field. The university of Utrecht has adopted an effective salt viscosity of 10^{18} Pa.s: in that case a lateral movement of the subsidence bowl is modeled in the order of several hundreds of meters in northerly direction over a 300 year period. However, if the value of salt viscosity in the order of 10^{16} Pa.s is adopted- as derived from the nearby Barradeel salt mining project -, this lateral movement process is speeded up by two orders of magnitude, bringing it in the time frame that is relevant for the LTS-II study.