Determination of the levelling frequency by means of dynamic geodetic modelling

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Each mining engineer has had to deal with deformations of the earth's surface caused by the extraction of minerals. In such cases social interests often are in flat contradiction to economic interests. Current research has to make clear whether a compromise can be found between the required checking of the damage of the earth's surface caused by extraction on the one hand and the reduction of the check measures to an absolute minimum on the other hand.

1. INTRODUCTION

In 1999 and 2000 Ingenieursbureau 'Oranjewoud' B.V. is carrying out an investigation focussing its research on finding a solution for the aforementioned dilemma. In many (Western) countries the people living in the neighbourhood of extraction areas are adopting a more and more critical attitude towards the companies involved in the extraction of minerals. In the Netherlands the onus of proof has become a burning issue. Does the onus of proof of the damage incurred as a result of subsidence lie with the citizen or with the company responsible for the extraction? The latter cannot risk a wrong prediction and requires correct prognoses of the consequences of extraction. In many cases the company is obliged to quantify and thus to check the deformation at regular intervals.

Often the accuracy and reliability of the measurements and subsequently the value attached to the measuring results are not clear. The arguments underlying the measuring frequency are even less clear, if not lacking, and are not based on mathematically founded arguments in most cases.

Reason for 'Oranjewoud' to carry out an investigation, together with the salt mining company Akzo Nobel Chemicals B.V., aiming at the reduction of the frequency and extent of deformation measurements to a minimum. The investigation is concentrating on the extraction area near Winschoten in the northeast part of the Netherlands in the province of Groningen.

In this area (marked out by arrows in figure 1) salt has been extracted up to a depth of over 1 kilometre below ground level for a period of 35 years now. Extraction takes places in two drilling clusters; the Zuidwending cluster and the Heiligerlee cluster. The latter cluster in particular is of importance from a social point of view, since it is situated in the direct vicinity of the city of Winschoten and is causing subsidence in this area.

During the first fifteen years of the salt mining activities a yearly check took place of the subsidence in the area. This check was carried out by means of levelling. Since the subsidence turned out to be limited, it was decided to carry out a check once every two years.

Today opinions are in favour of further reducing this frequency which could mean a considerable saving in cost for Akzo Nobel.

Not only for Akzo Nobel the results of such an investigation are of importance. In principle the results of the investigation could and should be binding for any (mining) industry causing subsidence in whatever way.

However, as already mentioned before, the government imposes stringent regulations on each of the mining companies on this subject.

Figure 1. Salt mining area Akzo Nobel.

2. PROGRAMME OF INVESTIGATION

Aim of the investigation is to find out whether there exists a model by means of which the frequency and extent of the measurements can be optimised. The theory of geodetic deformation analysis, which was further developed at the Technical University of Delft in the nineties, forms the basis for this investigation. This theory analyses the movement of the earth's surface on the basis of measurements carried out at different moments, called epochs.

The (geodetic) model needs to meet the following requirements:

-The model is based on the presence of subsidence data from the past;

-The model needs to be dynamic; this means that the model must be able to calculate the frequency and extent at any moment and when adding new measuring data;

-The model does not take into consideration future influences like planned drillings or planned modifications of the extraction method. This information needs to be integrated into a Geographic Information System (GIS) together with the model data.

The investigation has been divided into four phases (see figure 2):

1 Preparation of the project plan;

2 Preparation of the functional design;

3 Preparation of the software;

4 Implementation on the data and analysis of the results.

The investigation started in the spring of 1999 and will end in the spring of 2000.

The functional design of the dynamic geodetic model forms the most important part of the investigation. During this phase the foundation of the model will be determined. The main activities during this phase include standardisation, modelling, testing, prognosticating and analysing for the purpose of the design of the model (see figure 3).

2.1 Standardisation

The first activity concerns the standardisation of the historical data. The quantity and quality of these data need to be determined. The quality is determined on the one hand by the number of times each measuring point is being levelled and on the other hand by the terrestrial spreading of the measuring points. The quality is determined by analysing the measuring accuracy in the course of the years on the one hand and by determining which external influences are described by the data set as well on the other hand. Besides the extraction of salt there is also question of the extraction of gas and water in the test area.

These influences need to be filtered from the data set to be able to analyse the influence of salt extraction.

The next step in the standardisation of the data is to determine the standardisation method. It needs to be determined which data are indispensable for the final modelling. Furthermore, a methodology has to be selected for the automatic integration of new data into the total data set.

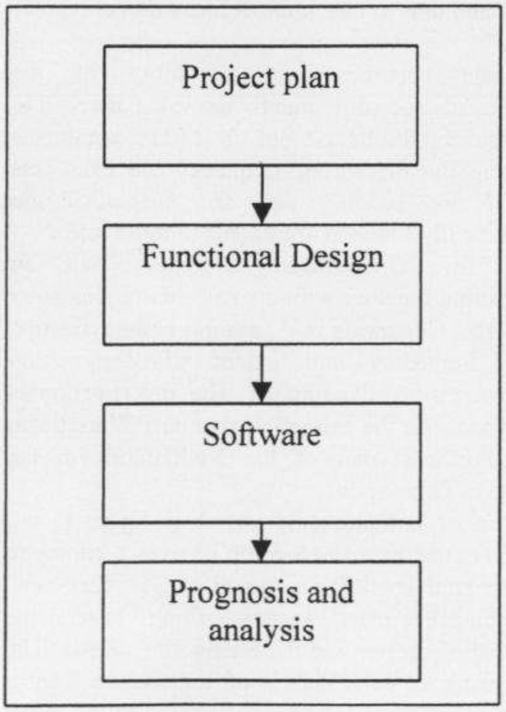
2.2 Modelling

During the second phase it is to be determined which types of subsidence form the basis for the testing of the historical data. These standard types are of major importance for the quality of the final prediction of the subsidence.

The expected subsidence (see figure 4) may have a linear course (points 1, 2 and 3) or a non-linear course (point 4).

The selection of the standard types depends on the quality requirements imposed on the models. The required accuracy between the model and reality is such a parameter. Besides, proximity relations need to be defined first followed by the degree to which these relations have to be taken into account. Such a proximity relation describes the logical dependence

Figure 2. Investigation method.



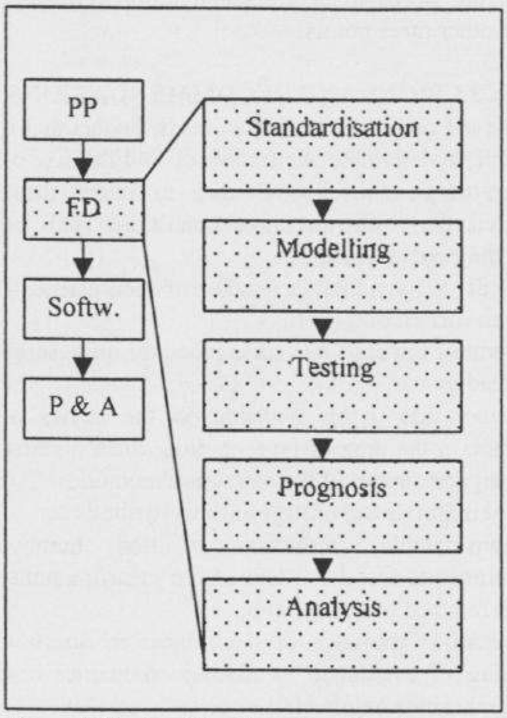


Figure 3 **Parts** of the Functional Design.

of related measuring points. When two measuring points are in the influence zone of the same drilling, the proximity relation is high.

Furthermore, it is of importance to know the minimum quantity of measurements to be made per point before a prognosis of the deformation of such a measuring point can be made.

2.3 Testing

In a next step the models will be tested against the data set. A testing methodology will be selected and the testing parameters will be defined and specified (and determined).

The testing mechanism can make use of nullhypotheses (H_o) and alternative hypotheses (H_a) Examples of distribution types are the Chi-square and the Fisher-distribution.

Furthermore, it has to be determined how functional extensions for instance are processed in case of an H_a When a certain testing methodology has been chosen, parameters have to be determined like:

- -The chance of the He being rejected erroneously;
- -The chance of the He being accepted;
- -The chance of the He being rejected correctly but the H. being accepted erroneously;
- -The internal and external reliability values The internal reliability represents the limit value on an error in the observations, the deformation of a certain measuring point, and the external reliability indicates the influence of a mistake to the value of the limit value on the modelled results.

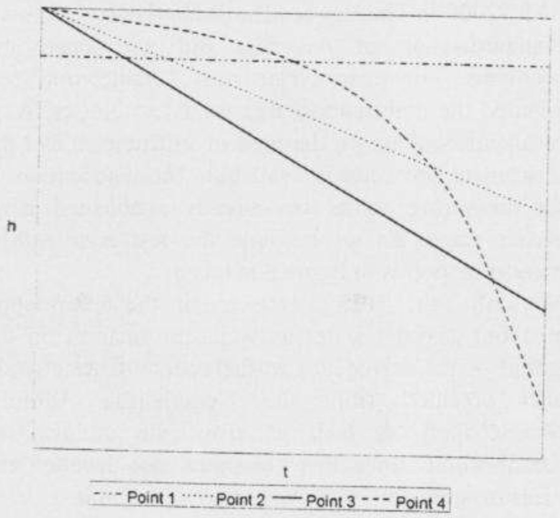


Figure 4. Deformation models of 4 measuring points

2.4 Prognosis

Now that the data have been standardised and the theoretical subsidence models and the testing methodology have been determined, the methodology to prognosticate subsidence can be prepared. The points of attention for this part of the investigation are the determination of..

- -Accepted variance of prognosticated deformation;
- -Type of prognosis method;
- -The data format in which the results will be stored.

2.5 Analysis

The final step will be to determine which analyses will be carried out and which W will be used.

When the functional model has been described, it will be converted into software by means of which the frequency and extent of the deformation measurements can be predicted.

The software can now be applied on the data. The analysis functionality already determined will be used to determine when a measurement will be necessary according to certain conditions. The area to be measured most urgently will be determined as well.

3. RESULTS OF INVESTIGATION

In this section the results of the investigation will be described. At the time of the writing of this article the investigation was in full swing so that a complete review of the results cannot be given yet. However,

the final results will be presented at the symposium SALT2000 in The Hague (The Netherlands).
Standardisation of the data did not cause any problems. For many years now 'Oranjewoud' has levelled the deformation area for Akzo Noises. As a result information on the type of instruments and the instrument precision is available. The distribution of the measuring points was already established at an earlier stage. As an example the test area with 4 measuring points in figure 5 is taken.
Not only salt is being extracted in the deformation area but gas and water as well. Information on the extent of the subsidence in the course of time could also obtained from the Nederlandse Aardolie Maatschappij as well as from the archives of 'Oranjewoud' since this company also levelled the measuring points for the water extraction area.
In the fist instance the data will be tested against two possible types of subsidence: linear subsidence and non-linear subsidence. Testing of the measuring points will be done for each point apart with a recursive approach of the proximity relations, that is to say that the proximity

Figure 5. Test area with 4 (fictive) measuring points.

relations will be considered in the final, overall analysis of the deformation area.
The testing mechanism consists of the standard geodetic deformation analysis; the H_o will be tested against the H_a; the linear subsidence versus the nonlinear subsidence. On the basis of the results of the test a calculation will be made of the trend measured against the reliability of the prediction. The parameters in question, like the reliability criterion, still had to be determined at the time of the writing of this article.
Reference is made to figure 6 for an overall approach of the frequency determined for the fictive deformation area from figure 5. The data from figure 4 have been applied. The approach shows that point 4 in particular needs to be measured more frequently than the other three points.

4. CONCLUSIONS AND RECOMMENDATIONS

The most important conclusion so far is the fact that it is possible to determine the frequency and the size of the measuring grid. To be able to make these predictions the following three conditions shall be met for the case in question:
-In the past a considerable number of measurements have been carried out;
-Extraction of minerals has taken place for quite some time already;
-Information has to be available on the causes of subsidence in the area of investigation. Such a cause may be an adjustment of the extraction method.
The most important advantages of this method are:
-A (considerable) reduction of the number ofmeasurements and the extent of the measurements, which is reduced to a minimum;
-The scientific approach of the subject in question thus being of assistance to mining companies and (local) authorities involved;
-The information obtained on the subsidence during the (longer) period of extraction.
The model applied can he used for all types of different minerals and mining activities. However, fundamental choices need to be made again and again, since local circumstances are decisive for the choice of parameters. The scientific approach of this subject is of importance though, which can be considered as a support for both mining companies and government.

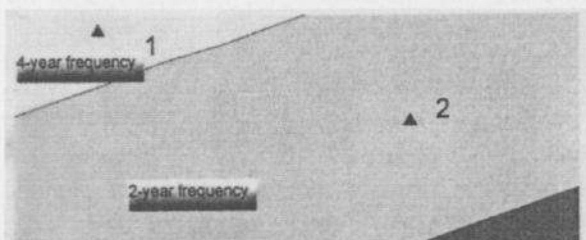


Figure 6. Frequency determination (by means of GAS).