LAND SUBSIDENCE IN THE NETHERLANDS

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Abstract
Part of the Netherlands is situated below Mean Sea Level. Therefore subsidence of dikes, etc, protecting the country against the water, may be dangerous. Several repeated levellings have been carried out to study land subsidence. The vertical crustal movements, resulting from the first-order levellings (1875-1885, 1926-1940, 1950-1959 and 1965-1980) are discussed.

Problems related to the maintenance of a network of benchmarks are indicated, one of the problems being the fact that there are no stable rocks in the Netherlands for the foundation of the benchmarks.

A short description is given of the method of hydrostatic levelling, used in the coastal area to transfer Amsterdam Ordnance Datum to natural and artificial islands (off-shore structures) with a very high accuracy. Since 1962 a subcommission of the Netherlands Geodetic Commission studies natural as well as human caused land subsidence. In this subcommission various sciences are represented. A short survey is given of the problems studied by the subcommission, including the movements caused by the extraction of coal, gas, salt, oil and water.

Introduction
The Netherlands is a small country in north-western Europe, in the Rhine estuary, situated at the North Sea. About 20 per cent of the surface of the Netherlands lies below mean sea level. Even nearly 38 per cent of the country actually lies below high water level. The country is protected against the sea by natural dunes and islands and by man made dikes.

The Dutch people being familiar with the water feel pretty safe behind their dunes and dikes. They have built towns, ports and major industries in the vicinity of the sea and at the moment about half of the total population is living in the low-lying part of the country. The situation proved to be vulnerable: during a dreadful storm tide on 1st February, 1953 a number of dikes collapsed and large areas in the south-western part of the Netherlands were flooded. Nearly 1800 people lost their lives.

The reconstruction of the dikes started soon, also the Delta Plan was designed. This great hydraulic project includes shortening of the shoreline of the Netherlands by connecting islands in the delta by dams. The existing dikes were raised to a design height taking into account the estimated subsidence of the shore relative to mean sea level.

N.A.P.
At present in the Netherlands all height data are related to N.A.P. (Normal Amsterdam Peil = Ordnance Datum of the Netherlands). The history of N.A.P. has been described by Van der Weele (1971).

As early as 1565 in old documents regarding Amsterdam a water level is mentioned that might be the origin of Amsterdam Datum. A hundred years afterwards 8 marble benchmark stones were placed in newly built sluices provided with a groove and bearing the inscription: "Sea-bank's height, being 9 feet 5 inches above town datum".
Amsterdam Datum is expected to have been the height of mean summer high tide of the IJ, at that time the tidal harbour of Amsterdam being in open connection with the North Sea, via the Zuiderzee. See Fig. 1. A municipal water office was established to measure and register water heights once or twice per hour. Consequently a long series of tide gauge observations exist, from 1682 to 1930. The registration ended in 1930, because in that year the Afsluitdijk is in construction transforming the Zuiderzee into a lake insensible to tidal effects.

In the eighteenth and nineteenth century Amsterdam Datum gradually came in use in a larger area, even in a part of the neighbouring countries Belgium and Germany. In 1818 Amsterdam Datum is prescribed as the official Ordnance Datum of the Netherlands to be used as a reference for tide gauge observations and for the determination of the heights of dikes along the rivers. It has been used to define the datum of several levellings ever since carried out over the whole country.

Unfortunately the N.A.P.-stones disappeared, the last of them in 1953. In stead of them a 23 m long foundation-pile has been placed at the Dam in Amsterdam in the centre of the city now acting as fundamental benchmark. Also a second pile at Amsterdam is installed to visualize N.A.P. This pile has been used as a test-pile during the construction of a tunnel. During a test this pile has been loaded with a weight of 850 tons showing no vertical movement.

Relative sea level rise
Along the shore of the Netherlands part of the North Sea 9 tide gauge stations have been observed since 1870, providing us with a lot of valuable information. It was decided in 1829 to maintain the zero points of all tide gauges in the Netherlands at N.A.P.-level. As a consequence the various
Tide gauge observations do not indicate local (tectonic) movements, but will give the subsidence of the Ordnance Datum at Amsterdam relative to sea level. The registered observations have been thoroughly studied by a number of scientists. Van Veen (1945) constructed a curve of the rise of half tide level with respect to the N.A.P., based on the observations by the municipal water office at Amsterdam as well as on observations of the tide gauges in the Zuiderzee and along the shore. He computes a rise of sea level of about 17 cm/century.

Thus the assumption of a future relative rise of sea level of about 20 cm/century as estimated by Van Veen and Waalewijn (1960) seems to be safe. This value has played a role in the fixing of Delta heights of the dikes along the shore. However, a very recent statistical analysis of the data of the North Sea tide gauges made by Van Malde (1983) seems to indicate a rise of mean low tide of 10 cm/century and a rise of mean high tide of 25 cm/century. Although a certain margin of safety has been calculated in fixing Delta heights, the question of the rise of sea level asks for careful study.

Subsidence of the land

Another question is whether the other parts of the country rise or subside. This question can be answered on the basis of a comparison of the results of repeated precise levellings of a wide network of very stable founded benchmarks. In the past centuries a large numbers of benchmarks has been placed, but unfortunately all of them have disappeared, even the 8 fundamental benchmarks in the sluices at Amsterdam. The oldest still existing benchmark was placed in about 1850.

At present the Dutch network comprises about 45,000 benchmarks, most of them being round bolts placed in houses and stable buildings like churches, sluices, viaducts, etc. See fig. 2. There stability depends on the foundation of these buildings and on geological conditions, and last but not least on human activities like mining of coal, oil, gas or salt, water withdrawal, reclamation of land, etc. These benchmarks are mainly used for many technical purposes: deriving heights for the design and the construction of roads, bridges, buildings, etc. For these technical purposes relative accuracy of provided heights is more important than absolute accuracy.

However for scientific reasons a number of very stable founded benchmarks with very accurate heights is needed to be able to determine tectonic movements. For that purpose since 1926 a number of specially constructed underground benchmarks has been placed at locations selected on the advice of the Geological Survey of the Netherlands.

The problem is that there is no stable rock on the surface of the country; approximately half of the surface of the Netherlands is covered by Holocene sediments of clay, sand and peat, which attain thicknesses up to 20 m. In these areas compaction can be relatively great in relation to the tectonic movements. Therefore the underground benchmarks were founded in the Pleis-
tocene. In places where the Pleistocene layers are found on the surface concrete blocks were constructed (See Fig. 3). In the Holocene regions concrete foundation-piles were placed resting on the sandy Pleistocene underground. Depending on the depth of the Pleistocene the length of the piles may go up to 43 m. At present there are 150 underground benchmarks, of which 100 have been placed since 1950.

The Survey Department of Rijkswaterstaat of the Ministry of Transport and Public Works is in charge of the maintenance of the network of benchmarks, including the publishing of heights. To be able to check the once published heights and to correct them if necessary, the benchmarks are relevelled at more or less regular time intervals. For that purpose 4 first-order levellings have been carried out during the last century, followed by lower-order densification levellings. These first-order levellings took place in the period 1875-1885, 1926-1939, 1950-1959 an 1965-1980 respectively. The adjustment of these levellingnets result in heights with regard to N.A.P. as visualized at Amsterdam; consequently the calculated rise or subsidence of parts of the country is always relative to Amsterdam.

A problem is that the lifetime of most benchmarks is limited. It is found that every year about 2-5 per cent of the total amount of benchmarks disappears. As a consequence the number of benchmarks common to several first-order levellings is rather small: the first and second levelling had approx. 460 common points, there were about 300 benchmarks common to the first, second and third levelling, and all four levellings had only 72 common points.

Edelman (1954) compared the heights of the 460 common points in the first and second levelling mentioned before. He found considerable and irregular subsidences in the northern part of the country, more than 10 cm, and a rise of about 40 mm in 50 years in the southern part. See Fig. 4. He concluded a tilting of the Netherlands along an axis through Amsterdam in WSW-ENE direction.

However, due to instrumentation, the structure of the net, etc. the first
levelling and its results are assumed now to be less reliable than the more recent levellings. It should further be borne in mind that the underground benchmarks have been placed since 1926, so the local subsidences may be partly explained by the poor foundation of buildings where the benchmarks were.
Fig. 5 Preliminary results of comparison of the levellings of 1926-1940, 1950-1959 and 1965-1980, indicating tectonic movements relative to Amsterdam.
placed. As a consequence of all of this the results of the third and fourth levelling will not be compared to the first but to the second levelling.

The results of the third levelling indicate no significant change in the respective heights of the underground benchmarks. While adjusting the measurements the levelling net is therefore not fixed on the fundamental benchmark at Amsterdam alone but on all underground benchmarks in the country, their heights assumed to be unchanged. The same method has been applied in the adjustment of the fourth levelling although several underground benchmarks seem to have significantly changed in height. By this method the nets have been transformed being the reason that the resulting heights of the normal N.A.P.-benchmarks are "heights for practical use" and are not suitable for the purpose of scientific research.

At the moment a thorough study of the last 3 levellings is being carried out using a computer. Differences of heights of very stable points in the 3 levellings, in combination with their precision, will be statistically tested to be able to reach conclusions on land rise or subsidence since 1926. Fig. 5 shows a preliminary result of a comparison of the heights of 66 underground benchmarks included at least twice in the second, third or fourth levelling. The resulting rise or subsidence is expressed as a velocity in mm/year. To roughly indicate the precision of the calculated movements the double standard deviation is also rendered.

Absolute movements
An ever intriguing question is the following: Is Amsterdam stable or not, or in other words: is it possible to compute absolute movements? The answer is: not at present, may be in the future by observing gravity in combination with first-order levellings.

Another possibility to get an idea now of absolute movements is to combine the Netherlands levelling network with networks of neighbouring countries which one supposed to be stable and to adjust them as a whole. It has been decided to try it in that way.

The DGK-Arbeitskreis für Rezente Höhenänderungen (1979) published a Map of Height Changes in the Federal Republic of Germany. It came out that the Arbeitskreis is willing to cooperate with other countries in order to extend this map to Western Europe. The Geodetic Institute of the University of Hannover will act as a central computing centre. After final check of the relevant Dutch levelling data they will be made available to the computing centre.
Hydrostatic levelling

Levelling is normally carried out with the help of an optical levelling instrument and rods. Typical for optical levelling is that a section to be levelled is divided into a number of stretches of 80-100 metres each. The mean square error of first-order levelling is 0.7 mm/√km or better. The usual methods are not suitable to transfer levels to islands or off-shore structures.

The Danish professor Nørlund put the method of hydrostatic levelling for the first time into practice in 1938 and used it with great success for a levelling across the Great Belt. Afterwards Waalewijn (1964) developed this method and brought it into practice for a large number of off-shore measurements and measurements through rivers and canals.

The method of hydrostatic levelling is based on the law of communicating vessels. Fig. 6 shows the principle. If a pipe is filled with a liquid the surfaces of the liquid in both ends of the pipe will always coincide with a level surface, i.e. the surfaces of the liquid have the same height. There are a number of factors effecting the accuracy. The liquid has to have a constant temperature; if the air pressure is not equal on both sides of the pipe the surfaces of the liquid have not the same height; there is an astronomical effect caused by sun and moon. It is a must that there are no air bubbles in the pipe.

In practice a lead pipe is used with an internal diameter of 10 mm, with walls 3.5 mm thick and with steel wire reinforcements to raise the tensile strength of the pipe. The weight of the pipe having an external diameter of 35 mm is about 3 kg/m. The pipe is always kept filled with water; the level of which can be observed by gauge glasses at both ends of the pipe during measurements.

The Survey Department owns a number of pipes with different lengths. So levellings can be made with coupled pipes with a total length of about 10-20 km. Undoubtedly this device is the heaviest levelling instrument in the world! The pipe is installed in our cable-laying vessel "Niveau", niveau being Netherlands for "level", and laid out and taken in by means of a winch. The accuracy of hydrostatic levelling is high: 0.5 mm per 5 km. This high accuracy is only reached when systematic effects mentioned before are eliminated.

Problems studied at present

It will be clear that it is of vital interest that sea level movements and land subsidence are studied carefully. The Netherlands should have an open eye to future movements to be able to take precautionary measures such as raising the dikes along the sea and the rivers. For that reason the Netherlands Geodetic Commission set up a Subcommission on Crustal Movements in 1962. Representatives of various sciences viz. geology, seismology, hydrology, geophysics, geodesy, oceanography, soil mechanics and mining take part in this subcommission. It's task is to study recent crustal movements, both horizontal and vertical. Therefore the subcommission planned the following activities:

- gathering all available information in order to obtain a picture of recent movements and of the relative position of the land surface and mean sea level,
- repeating measurements to study recent movements, and setting up new measurements in proper areas to fix the present situation for future comparison,
- co-operation with the International Commission on Recent Crustal Movements.
Waalewijn (1966) gives an enumeration of the points of interest of the subcommission, which is updated in the following lines. Fig. 7 shows the location of several of the sites mentioned.

In the Netherlands much attention always has been paid to the problems discussed here. As has been mentioned before relative sea level movements of the North Sea have been measured and studied since 1682. However the problem itself is not a regional, but a global one. Therefore the Geological Survey of the Netherlands initiated an international Sea Level Project, which was executed under auspices of the UNESCO. In the project called: "Sea-level movements during the last deglacial hemicycle (about 15,000 years)" more than 20 countries actively participated. This project stimulated the gathering of information additional to the many sea level data collected and evaluated by several scientists in the past. Van de Plassche (1982) describes the Netherlands effort in his thesis: Sea-level change and water-level movements in the Netherlands during the Holocene. His study results in a most probable mean sea level curve for the Netherlands.

The subcommission attaches great importance to the study of future developments in sea level movements. Since several years all over the world much attention has been paid to the increase of the concentration of carbon dioxide in the atmosphere and to the (resulting?) melting of ice in Antarctica, possibly causing a worldwide change in sea level. The subcommission tries to formulate a national project to study the sea level rise in the future 500 years.

The subcommission also pays attention to tectonic movements. The first
order levellings intended to study tectonic movements over the country as a whole have already been mentioned. Besides local tectonic movements are investigated. In the south-eastern part of the country some important underground faults are known. Some levelling lines crossing a fault line have been measured several times. To investigate horizontal shift of the Peel-boundary Fault a network of stable points will be installed. The situation of which will be fixed by very accurate distance and angular measurements.

In the Netherlands a number of salt-domes are known. The subcommission initiated to start measurements of heights on and around several of these salt-domes not being exploited at that time.

Approximately half of the surface of the Netherlands is covered by Holocene sediments; their compaction can be considerable which make dikes very vulnerable in these regions. In recently reclaimed polders landsubsidences of not less than about 1.50 m may be expected to occur in the first century after reclamation. In this symposium several papers are devoted to the problem resulting from the construction of polders.

Movements as a result of human activities in general occur in areas where coal, gas, salt, oil or water extracted. Coal mining over a period of about 75 years caused subsidences of more than 10 m. Production of gas in the very large Groningen gasfield which started 20 years ago is expected to result in surface subsidences of more than 25 cm in the far future. In both regions subsidence is monitored by repeated levellings as well as gravity measurements. Problems related to mining activities are discussed in a paper presented by Pöttgens in this symposium.

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