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SYMPOSIUM: QUATERNARY CHANGES IN LEVEL, ESPECIALLY IN THE NETHERLANDS

TIDE-GAUGES, SUBSIDENCE-GAUGES AND FLOOD-STONES IN THE NETHERLANDS

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INTRODUCTION

Reliable data are rather scarce, which is to be regretted, because subsidence[2] of the Dutch soil is one of the main threats to the existence of the Netherlands as a nation; if not at this moment, it will be in the future.

The C-14 investigations made for the Delta-Commission by Prof. Hl. de Vries of Groningen show the age of the bottom of the "lower" peat layer to be about 7200 years. As this layer is about 18 metres below H.W. (the height where plants start to grow), the *average* subsidence has been about ¼ metre/century. If the subsidence should continue at the same rate, we would after another 7200 years need high dikes. Though this could be done technically, the threat of salt-seepage would be very serious. Only a short coast could provide a maximum of defence.

For practical purposes we need to know:

(1) how much the sea-level rises as compared to Dutch Ordnance Datum (N.A.P.);

(2) the rate of subsidence of our dikes and buildings.

These figures are not the same. In the past, investigators (myself included) used the data of the Rijkswaterstaat (Public Works Department), gained from the many gauges placed along the coast and estuaries of our country and published annually since 1854. Further research has shown me, however, that this method is far too simple and that it leads to incorrect conclusions. Since 1945 I have therefore renounced the correctness of the conclusions I published in 1936 (VAN VEEN, 1936, 1945).

DUTCH ORDNANCE DATUM (N.A.P.)

In 1682 Burgomaster Hudde had eight marble stones built into the new sea defence works of Amsterdam. There is still one left. The height of the water level in the Amsterdam tidal harbour was measured every hour of the day and night. There is an interruption of 15 years when some supervisor destroyed those readings. The average tide was about 1 foot, and the N.A.P. was originally (1682) meant to be the average H.W. at Amsterdam. Now, in 1954, it is about mean sea level, from which a rough average subsidence figure of about 5 to 6 cm per century can be deduced.

The graph of those readings is given in figure 1. I must consider this graph as the most accurate one concerning our subsidence. The graph ends when the Zuiderzee was closed in 1932. In 1872 the IJ was closed, so that the tide has not reached Amsterdam since then. The dots between 1872 and 1932 give a spread of some centimetres. This is largely due to the discrepancies caused by levelling between the N.A.P.-stones at Amsterdam and the gauges outside the IJ-dam, a distance of several kilometres. My study of this N.A.P.-graph has been published in an earlier paper (VAN VEEN, 1945). The conclusions reached were:

1. The Hudde-stones did not sink much between 1700 and 1860. Or, if they did sink appreciably, the sea level would have sunk almost the same amount.
2. The Hudde-stones showed an accelerated sinking since 1860. It is now about 16 cm/century. The last Hudde-stones (they disappeared gradually) may have sunk because of heavier traffic across the bridges in which they were built.

Amsterdam is perhaps not a very good place to establish an Ordnance Datum. The soil consists of a soft peat layer, but the houses and other structures like bridges and locks are built on poles. During the last war I had the privilege to see a map, made by the Survey Office of the Municipality of Amsterdam, which showed that all houses and structures of that town subsided, old ones as well as new. The map was lost during the war, but I remember subsidence figures of 20 to 40 cm in some decades. The Oude Kerk (Old Church) and the Royal Palace were among the least sub-

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[2] Subsidence, or relative subsidence, here includes compaction, rise of sea level, tectonic movement, etc.

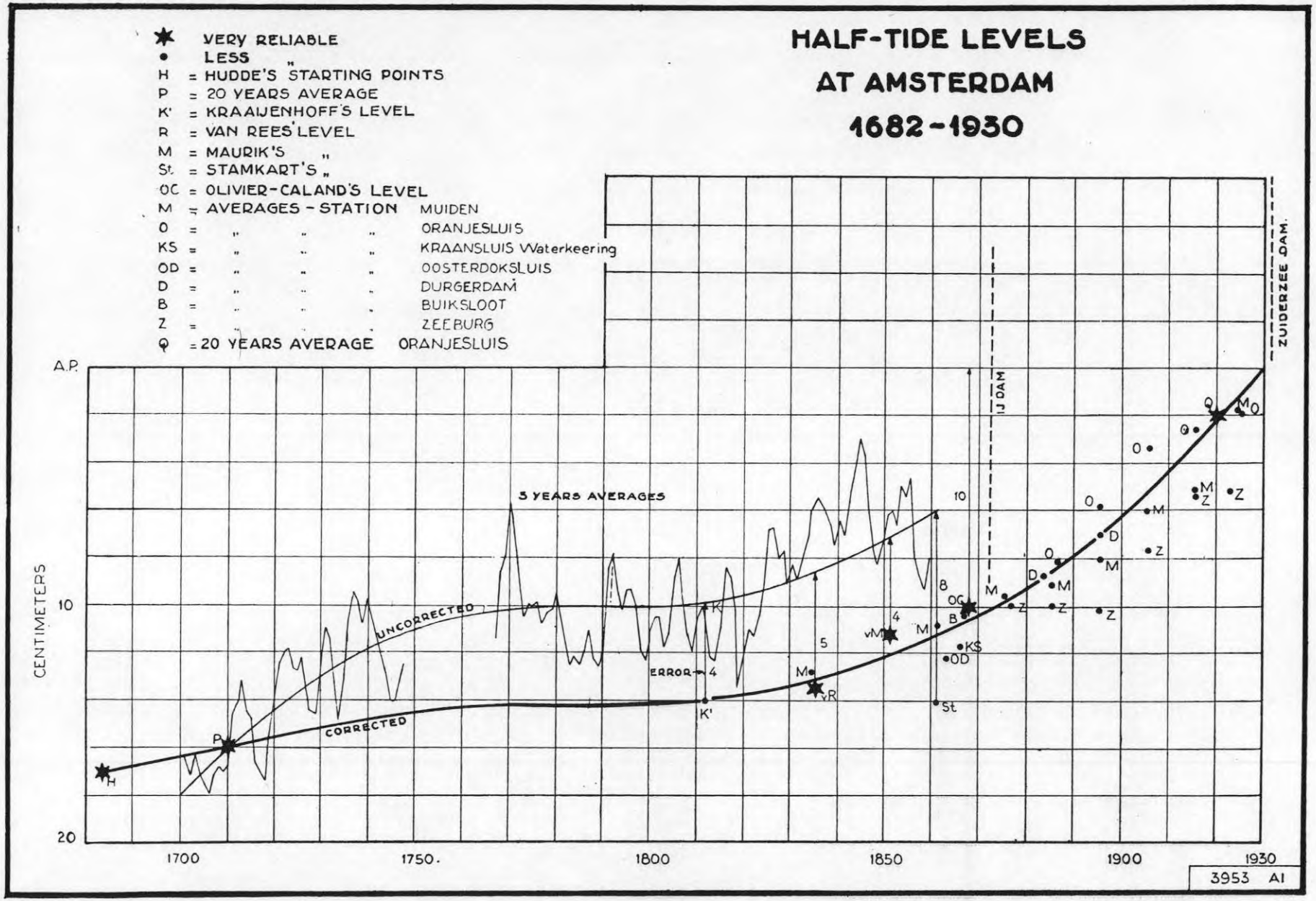

Fig. 1 — Half-tide levels at Amsterdam, 1682—1930.

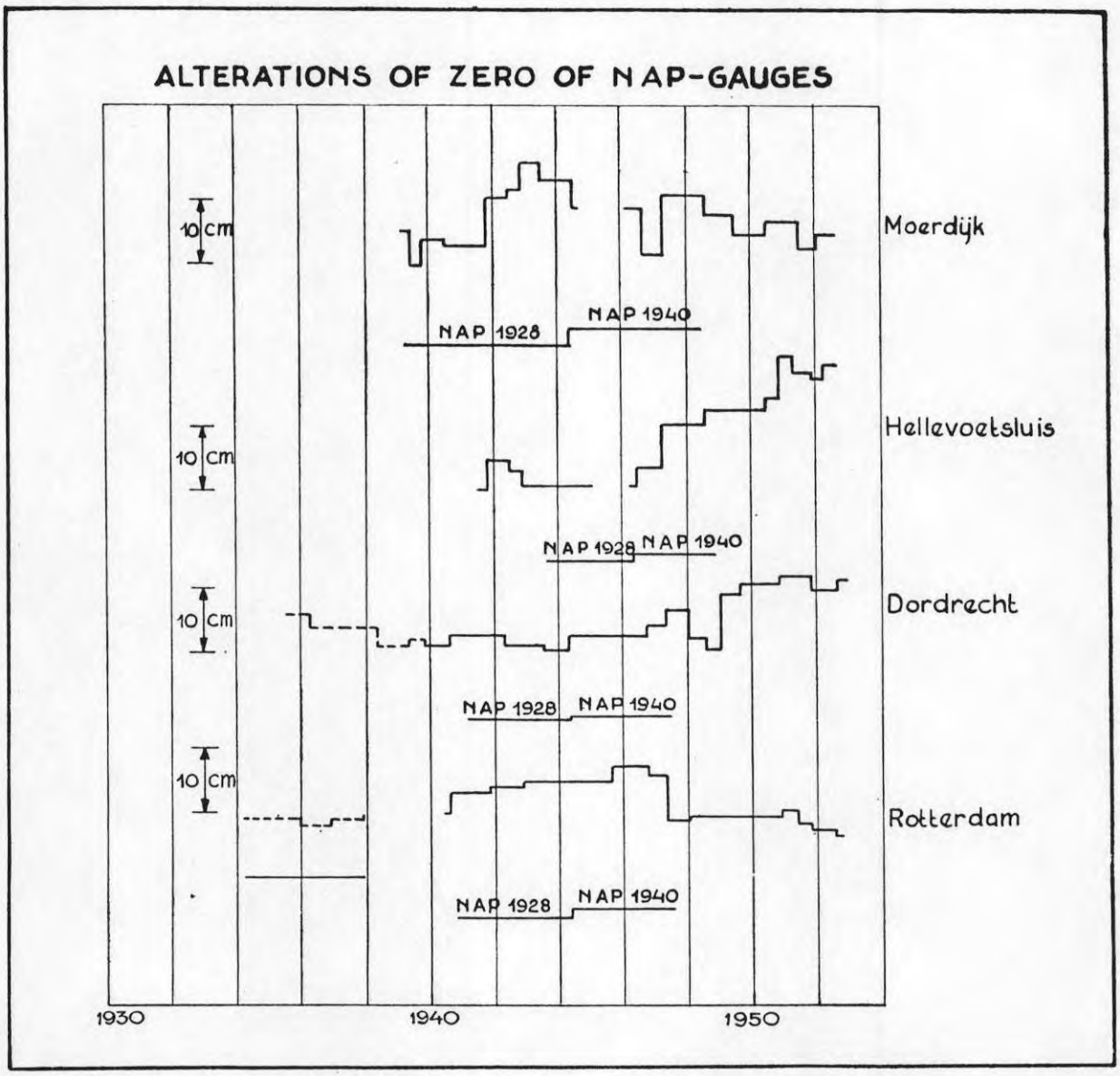

Fig. 2 — Alterations of zero of N.A.P.-gauges.

siding structures. They had the same rate of subsidence as the N.A.P.-stones, placed in 1682.

SUBSIDENCE GAUGES

The Netherlands have no subsidence gauges, but they may be built soon. A subsidence gauge for a sandy soil may be constructed as follows: a *tube* long enough to reach into the sand bottom; in it an iron *rod* resting, without friction caused by the inner sides of the tube, on a large block of concrete at about 22 m depth. The tube should not rest on that block, because it will take friction from the settling sand around it and therefore would exert too great a force on the concrete block. The gauge should be on the beach and the tide should be measured daily at the iron rod, preferably however, the mean sea level instead of the tide. The tide could be damped out (choked) in the same way as the *medimariometre* in Brest does.

If we placed such subsidence gauges at Cadzand, Schouwen, Scheveningen, Petten and Terschelling we could learn to know our subsidence data on those spots. They should not be placed near estuaries, because the mean sea level and tides would change there, owing to future technical works and natural silt movements. Only Scheveningen and Petten are not influenced by estuaries.

One of those two subsidence gauges could be used as the new Dutch Ordnance Datum,

the old one at Amsterdam being not very reliable [3].

REGISTERING AND NON-REGISTERING N.A.P.-GAUGES

The non-registering gauges seem to be the best, because the registering apparatuses need more adjustment. An unnoticed error of only 1 cm will be read as 20 cm, because the scale of registration is 1 to 20 as a rule.

Of course, we always will need N.A.P.-gauges, we cannot possibly do without them. They are adjusted at irregular intervals by means of levelling procedures which are more or less accurate. If a surveyor finds a mistake of say + 5 cm, he changes the position of the N.A.P.-gauge. If his successor, a year or so later, finds a mistake of — 6 cm, he again changes it. This goes on continually (fig. 2). The readings have to be altered also.

N.A.P.-gauges are continually moved up and down. Their purpose is not to give subsidence-figures, but to give the exact height of N.A.P. all over the country. They are wholly unfit to be used as subsidence gauges. If we could assume that there were no mistakes at all in those continual levellings, all our N.A.P.-gauges would give the subsidence curve of the Hudde-stone at Amsterdam, in Delfzijl as well as in Cadzand. The difficulties of re-correcting the readings on the often corrected N.A.P.-gauges are legio.

In 1950 I asked surveyor J. M. Saarloos to investigate some old fixed gauges and bench marks which had escaped attention (or nearly so) of our very active Waterstaat people. The result of his study (SAARLOOS, 1951) was:

Locality		*subsidence*
Terschelling	(since 1832)	7 cm/century
Katwijk	(since 1767/1805)	7 ,,
Brielle	(since 1747/1815)	7 ,,
Petten	(since 1860)	3 ,,

I would not say that the figures of 3 to 7 cm per century are very exact. They agree more or lss with the graph of figure 1, however.

DIKE SUBSIDENCE

A dike settles *extra* because of pressure on the sub-soil, because of shrinkage of its own body, and because of weather erosion. The maximum amount we found for an important dike was in the order of 3 m in a century, often it is no more than ½ m per century, or even less. Not much is known about dike subsidences.

The Delta Commission ordered an investigation of the settling of dikes, but the results are not available as yet. It is an historical as well as an archeological investigation. For one of the main dikes of the Netherlands the levellings since 1552 were discovered in one of the archives. It is an interesting study which, so far, seems to show that the surge of 1570 was a very high one, that most of our dikes in the Southwest were then very strong indeed, and that the *extra* subsidence of dikes seems to be considerable.

It would appear that it is impossible to deduct geological subsidence from the flood damages in certain centuries. Those flood damages were caused largely by lack of maintenance of the dikes. Vierlingh's advice (1575) to level all dikes once in 7 years has never been taken to heart. Dikes will sink.

In the southwestern part of the Netherlands about 20 so-called *flood stones* have been put into the best constructed buildings to record the height of floods. They may be reliable, or not very much so. A series of them is at Willemstad (fig. 3). The flood of 1775 was an excessively high one, higher than the one in 1570. According to the frequency curves of to-day a flood of the same height as that of 1775 now occurs once in every 5 years on an average! This is an example how our buildings and dikes are sinking.

The house at Willemstad was built by Prince Maurits about 1600 for military purposes. The soil is normal sandy marsh silt, and as the house stands at the harbour, one gets the impression that if it has sunk more than one metre in 350 years, as the stones would imply, the whole village and its harbour terrains and quays must have sunk about the same amount. The dike which runs through Willemstad perhaps more, because it is heavier.

The average "subsidence" which might be deduced from these "flood stones" is about ½ metre per century, but this is not exact because the presumption that the old floods were of the same intensity as the flood of 1953 may be wrong. Instead of "intensity", however, we should use the word "surge", a surge being the wind-effect above ordinary high water.

We have some vague idea, based on our preliminary studies, that the floods of 1570, 1682, 1775, 1776 and 1953 are comparable in „surge". Those were at least the highest in the

[3] There is a "zakbaken" at Rotterdam now, made by the Municipality. This "sink-beacon" is not a gauge, however. It is only a bench mark or municipal ordnance datum.

southwest. *If* they had the same surge, the "flood-stone subsidences" for the most reliable stones are as follows:

Locality		*subsidence*
*Goesse Sas	1682—1953	0.35 m per century
*Willemstad	1775—1953	0.64 „ „ „
Brielle	1775—1953	0.33 „ „ „
*Maassluis	1775—1953	0.49 „ „ „
Vlaardingen	1682—1953	0.51 „ „ „
Delfshaven	1776—1953	0.45 „ „ „
*Rotterdam	1775—1953	0.46 „ „ „
Kralingse Veer	1775—1953	0.52 „ „ „
Gouderak	1717—1953	0.46 „ „ „
	average	0.47 m per century

* means most reliable, average 0.49 m per century.

unprecedented flood. We never can say: "we have had it".

(2) The rate of subsidence of the old houses, dikes and other structures seems to be much greater than the rate of subsidence of our Ordnance Datum. It would be unsafe to calculate the height of our works with the subsidence data based on the Ordnance Datum at Amsterdam, or any other bench mark of the past.

The ancient dike builders had no Ordnance Datum. They had a better level to start from, namely the average High Water Level (mail-vloet). When the mean sea level rose, or better

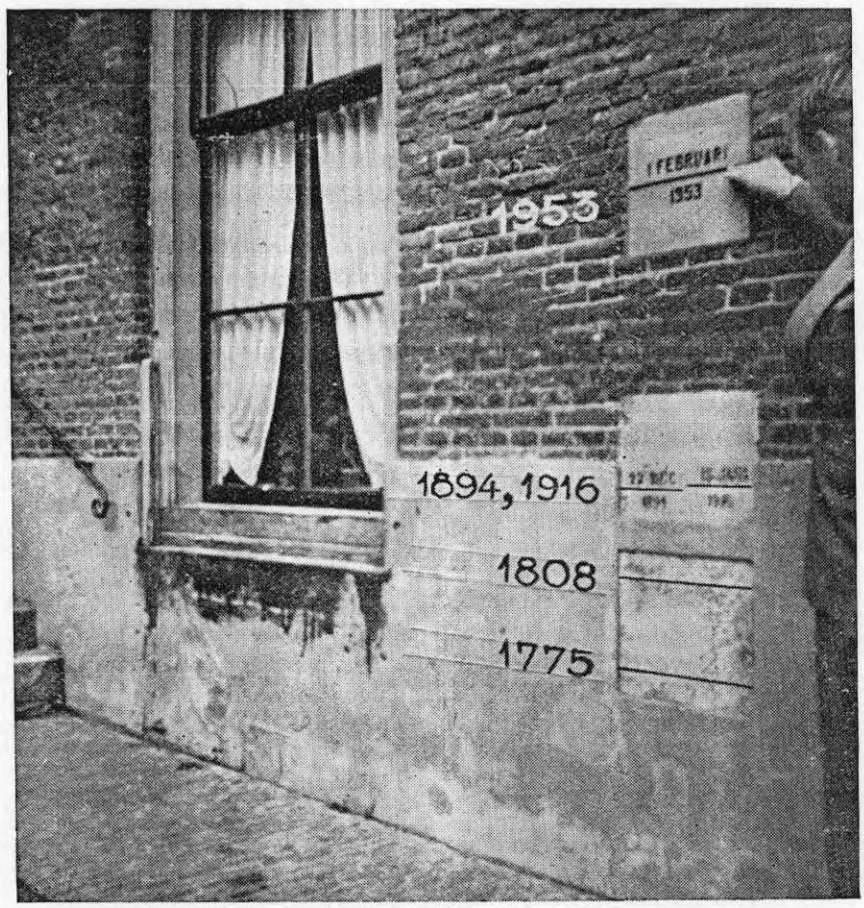

Fig. 3 — Flood stones at Willemstad.

Of course we do not know with sufficient exactness whether the surges of 1682, 1775, 1776 (same height as 1775) and 1953 were about the same, but the flood stones give some other more definite information:

(1) The records are being broken again and again. The rate is about once in 30 to 40 years as an average. We are lead to the conclusion that every few decades we must expect a flood which is 20 to 30 cm higher than the last

still (as the amplitude of the tide may change too), when the H.W. level rose, their dikes had to be raised because the height of the dikes was fixed at a certain amount of feet above H.W. Or, otherwise, they fixed the height of the dike in relation to the highest point of their saltings (gorzen). When the water rose because of tectonic, climatic, or morphological influences, the saltings would rise with it, and therefore the height of the dikes.

The ancient engineers were therefore concerned with "surges" only. As soon as they started with "fixed points", like the top of a certain bridge or lock, their dikes became unsafe .

We, modern engineers, need the fixed points but let us beware of them! They will sink.

FIELD SUBSIDENCE

In marine marshes ridges may be noticed. They are filled-up creeks, whose fillings have settled less than the surrounding country. In the Wash-area they are called 'roddons'. The height of those ridges may be several feet, showing that different soils settle at different rates.

Marine silt, on which most of our dikes are built (quite comparable with the soil on which the dikes of the Wash are built), settles less than moor or marine clay. Still, 'good' sandy soil may also settle considerably as can be observed at the fillings of the bed of the Old Rhine, e.g. at Alphen. The land, originally washed up until a height of the ordinary saltings (about a foot above the H.W. of that time) lies now 2.20 m below the H.W. of our time. As the mouth of the Old Rhine was shut off from the sea about 1000 years ago, the settling appears to be 0.25 m per century.

Subsidence gauges as described above will give the subsidence of a layer at say 20 m depth below sea level. The layers above that depth are younger and as they have a greater pore-volume, they will settle more, that means. to say *extra*. This extra settling often would appear to be far more than the settling of the 'sink-beacon', founded at a depth of 20 m.

CONCLUSION

(1) We need subsidence gauges. They must be entirely incorrectable and may not show the height of N.A.P.

(2) The data of the N.A.P.-gauges should not be used any more for deducting the figures for our soil subsidence.

(3) We expect much from the C-14 method, but we doubt whether it will be useful to fix the subsidence graph for recent centuries.

(4) We expect to learn something more about the subsidence of our dikes and buildings from historical and archeological evidence.

(5) We expect that in the future engineers may be able to forecast the settling of dikes, locks and houses with sufficient accuracy.

(6) Probably the rising of the sea level in relation to our most reliable bench-marks has not been much between 1700 and 1860. It may have risen more after 1860, and may be about 7 to 16 cm per century now, but we are not sure about it. Nor do we know whether our subsidence figure for bench-marks and gauges is the same for all places along our coast.

(7) Many of our old dikes, old houses and old locks in the Western part of the Netherlands seem to have sunk about ½ m per century. Several fields have sunk more than that, and some good sandy fields ¼ m per century.

(8) The flood-stones indicate that, roughly speaking and as an *average*, we must expect every 30 or 40 years an unprecedented flood wich *is* about 20 to 30 cm higher than the former unprecedented flood. The word "is" may be read "seems to be", because we deal with relativity. For practical-reasons the word "is" must be used. There is no safety-factor in the mentioned figures as yet.

(9) Reliable technical data about our subcidence are scarce, and even poor.

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VEEN, J. VAN (1936) — Onderzoekingen in de Hoofden. Landsdrukkerij, 's-Gravenhage. 252 pp.

——, (1945) — Bestaat er een geologische bodemdaling te Amsterdam sedert 1700? Tijdschr. Kon. Ned. Aardr. Genootsch. (2), 62, pp. 2—36.

DISCUSSION

Mr. Wemelsfelder (Public Works Dept.) agrees with Dr. Van Veen as to his main conclusions, but not with regard to his evaluation of tide gauge readings. These tide gauges have to be continually corrected so as to indicate the same level as that of Amsterdam (N.A.P.). After repairs or cleaning they differ from N.A.P. and are then corrected to their true position directly afterwards. This does not mean that during the time before cleaning and correcting. they indicated a wrong level, as was surmised by Van Veen. Consequently Van Veen's opinion, that the tide gauge readings are untrustworthy is not justified. They show a general rise of the sea-level of 15 cm per century (fig. 1, p. 220).

The fluctuations are due to the weather conditions which change from year to year. Those fluctuations are obviously the same for all the gauges and not caused by correcting them.

One of the consequences of the "new look" is that our levellings can be checked. If the subsidence of the Hudde-stone is 15 cm/c the figures for all other NAP-gauges should also be 15 cm/c, because

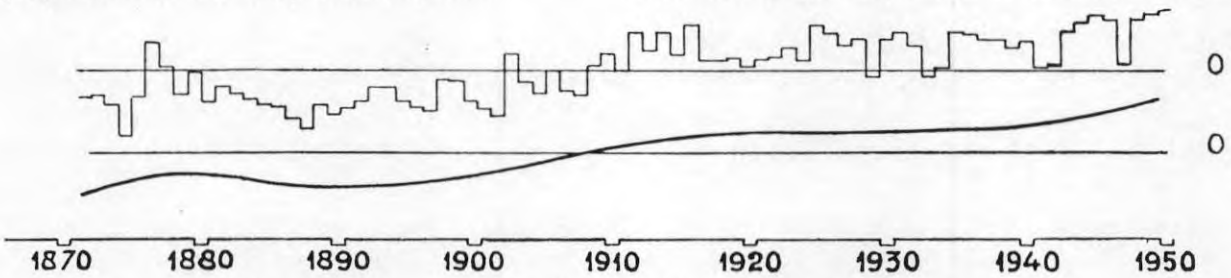

Fig. 1 — Annual mean sea-level of 9 tide gauges from 1870 up to 1950.

The figure of 15 cm per century is obtained from our best tide gauges, and is consequently better than that deduced by Saarloos from neglected gauges.

Van Veen's conclusions from flood stones also need a slight correction. The number of floods equal to that of 1953 during the last 500 years should be 1 or 2 instead of 5 to 7, and the figure of 47 cm is too large.

These few objections, however, do not detract from the validity of Van Veen's general conclusions.

Mr. Wiggers (Soil Survey N.O.P.) considers conclusions from "flood stones" not very helpful, as only superfloods are recorded; the inferred figures cannot be used statistically.

Dr. Van Veen, who could not be present at the symposium, contributed the following written comment.

I. *Evidence of NAP-gauges*

Mr. Wemelsfelder's idea seems to be that I attacked the validity of the readings at the NAP-gauges. This was not my intention. I am sure that great care has been taken for the zero of the NAP-gauges to be at the same level as the main bench-mark at Amsterdam indicates. I gave my figure 2 in order to show that the NAP-gauges as well as its readings have been corrected (need to be corrected) so much that it is extremely difficult (or impossible?) to re-correct these readings. I should be very pleased for anybody to use the wellknown published data of levels at, say, Brouwershaven, and be able to find the subsidence-graph for that or any other important station. There is perhaps still a possibility that the endeavours of almost a century, to find our subsidences by means of gauge-readings, may meet with some success.

Mr. Wemelsfelder is quoted as having said that the NAP-gauges "show a general rise of the sea-level of 15 cm per century". This is not the wording I should prefer. There is not one subsidence figure for the whole country, but as many as there are points in the verticals of the different places (fig. 1, p. 221). I could accept the wording: "The average figure obtained from the NAP-gauges is x cm/c." This means that if the levelling mistakes, etc. are left out, the Hudde-stone at Amsterdam seem to subside to that amount. For the moment I cannot say whether I agree with x = 15 cm for the subsidence of the Hudde-stone. It would require a special study.

we deal with two items only: sea-level and the NAP-plane.

The evidence of some main stations mentioned in the published official NAP-books (decades averages) is as follows for the 50 years-period 1901/10—1941/50, High Water data.

Rate of subsidence for HW at

Cadzand	27.5	cm/c
Vlissingen	23.0	,,
Veere	22.5	,,
Zierikzee	19.5	,,
Brouwershaven	12.8	,,
Hellevoetsluis	15.5	,,
Hoek van Holland	8.0	,,
IJmuiden	24.5	,,
Delfzijl	22.3	,,
N. Statenzijl	28.0	,,

The divergence from 8 tot 28 cm/c for our HW's may be partly due to hydraulic changes, but these changes are not great, except for Harlingen, Den Helder, Vlieland and Terschelling (Zuiderzee-enclosure), which have been left out. Here follows a list for half tides (practically average sea-level) for the 70 years' period 1881/90—1941/50.

Rate of subsidence for

Cadzand	7.5	cm/c	(1881—1930)
Vlissingen	19.5	,,	
Westkapelle	27.3	,,	
Veere	10.0	,,	
Zierikzee	13.8	,,	
Brouwershaven	13.7	,,	
Hellevoetsluis	16.2	,,	
Hoek van Holland	19.7	,,	
IJmuiden	12.5	,,	
Den Helder	14.7	,,	
Harlingen	9.0	,,	
Vlieland	25.0	,,	
Oostmahorn	1.3	,,	(1901—50)
Delfzijl	21.7	,,	
N.Statenzijl(HW)	28.0	,,	(1881—1940)

The divergences for this group lie between 1.3 and 28.0 cm/c. The distances of the stations from Amsterdam may have some influence.

The divergences mentioned ask for some study and explanation, if we want to have them decrease in the future. We can leave this to the assigned authorities. The ultimate aim to have no divergences any more is utopian, of course, but perhaps there is a hope that our NAP-gauges can be managed in such a way that accuracy within a decimetre is

reached: this would be a feasible aim.

A better aim would be to establish several Ordnance Subsidence "Zakbakens" at our coast, and use these as the starting points of our precision levellings, not Amsterdam. This is the way, I believe, in which Great Britain tackles the problem "within 30 or 40 years (as a rough average) the incredible high flood of the past will be surpassed by a still higher flood", because this has happened 5 times since 1775, and why not expect a sixth? Strictly speaking, this applies to the house at Willemstad only.

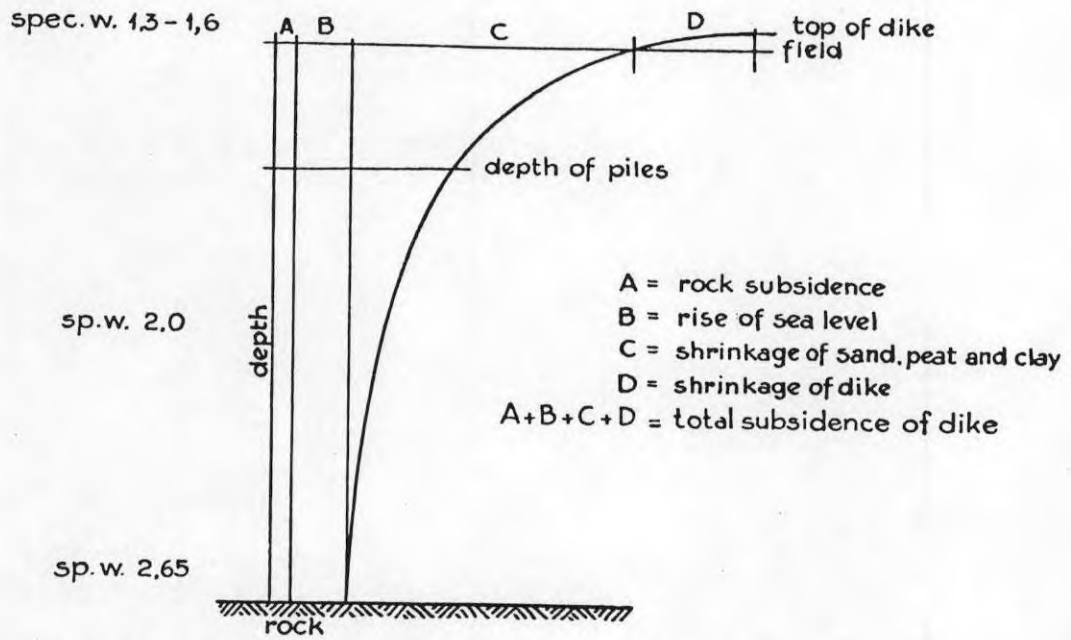

Fig. 1 — Scheme of subsidence factors in a vertical A and B may be negative; C and D vary much according to place. Ultimately the top-layers will shrink until a specific weight of 2.65 is reached (after eons).

of subsidence. We should cease to measure our sea-level by way of levellings over a distance of hundreds of kilometres. The ideal for basic subsidence research is to have no levellings and no tide gauge apparatuses, but simply a pole on the sea-shore or in an open harbour. The pole should have a fixed gauge, proof against any correction that Man might want to make.

II. *Evidence of flood-stones*

Mr. Wiggers considers conclusions drawn from flood-stones very definite.

One of my main conclusion (nr. 9) is that reliable technical data, derived from gauges and bench-marks (flood-stones included) in the Netherlands, are poor. Now that we have learned that in our search for subsidence figures, we cannot rely on the data obtained from NAP-gauges, we, engineers, are surrounded by an impressive void. We only have the following poor instruments to go by: (1) the Hudde-stones at Amsterdam, (2) the bench-marks of Saarloos' study, (3) the flood-stones. Perhaps Saarloos overlooked one or two bench-marks which might be valuable. It is gratifying that the evidence of the Hudde-stones does not greatly contradict the evidences gained from the bench-marks studied by Saarloos.

The flood-stones are our "signs on the wall", easy to read. My conclusion 8 for the house at Willemstad is even self-evident. It has been a good idea of our forebears to record their super-floods in this way. The stones of fig. 3 speak as follows:

It is superfloods which are our enemies, not the daily ones, and how glad we must be that a few of them have been recorded on houses, because we live in houses, and the level of NAP is doubtful and an unseen item. Statistics of floods may lead to interesting facts, as our thorough studies have proved since 1939 and earlier, but the practical results of those statistics are again rather poor. There have been only a few high floods since the reading of NAP-gauges started; we lack experience in high floods. Only time, past and future, can cure this lack. Hence the value of historical research, and the study of flood-stones and their sub-soil as compared to the sub-soil of dikes and other structures.

There are three stones in fig. 3. The lowest obviously is from 1808, the middle one from 1916; the marks of 1775 and 1894 are perhaps slightly erroneous, since they will have been inserted in 1808 and 1916. Flood-stones, however, are among the best witnesses we have so far.

A subsidence figure of 47 cm/c as a rough average for the houses in which the flood-stones are built, is a moderate one. We know dikes whose tops sink at a rate of 100 to 300 cm/c, but also some whose rate of subsidence is small. It much depends on the subsoil, therefore on the field-subsidence. Dikes, houses and fields will sink more than bench-marks and gauges, see fig. 4, but the fact is that we know very little about the settling of dikes, houses and fields. The responsible authorities of one of the southern provinces gave a figure of 65 cm/c for the average settling of their dikes. Local soils, the

age of the dike, etc. must cause many differences. Perhaps the 65 cm is not correct.

Mr. Wemelsfelder contests that the number of floods since 1940, equal to that of 1953, should be one or two, not five. My wording was more prudent. I spoke of "a vague idea" that the five floods of 1570, 1682, 1775, 1776 and 1953 are comparable in surge. I allowed for some spread. This was based on new studies in historical archives under the supervision of the competent historian Mr. S. J. Fockema Andreae, and also on those published by the State-Committee for the investigation of the 1916-flood, especially Mr. Schotel's contribution to it.

III. *The way ahead*

The study of the tide-gauges, bench-marks, flood-stones and levellings inevitably leads to the conclusion that we must make a (new?) start. There has been much talking and writing since 1570 (see Steenhuis, 329 Dutch publications before 1917) about the most deadly threat this country has to meet, and it was only Burgomaster Hudde and the men of the flood-stones who took action and gave their offspring an opportunity to solve the all-important problem. We still have no subsidence beacons along our coast. Also the dikes are not yet levelled once in 7 years, as Vierlingh (1575) already advised, by competent experts (accurate levelling is an expert's job). The NAP-gauges have a different function, they cannot serve two purposes.

If we, in 1954, would make this start, future generations of Dutch people would bless us as we bless Hudde.

In the meantime we ourselves have started to study our historical floods, the soils underneath the flood-stones and dikes, etc. (competent archeologists, historians and experts in Soil Mechanics are involved) but the harvest of that study cannot but be scanty compared with what future generations will reap when we, the 1954-generation, make the "zakbakens" along our coast now. Also the levelling of our dikes by acknowledged experts should be started now, and the work should be done frequently, regularly, continually.