Classification of pile foundations

Classification des fondations sur pieux

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SYNOPSIS: Subsidence due to the planned reclamation of the Markerwaard could cause damage to a population of 80.000 houses in the surrounding areas. This study gives the network measurement system and one part of the method to classify the susceptibility for damage.

1 INTRODUCTION

The Zuiderzee project started in the centre of the Netherlands more than 50 years ago. Four large polders have been reclaimed in the former Zuiderzee; the fifth polder, the Markerwaard, is still under study. The area consists of a Holocene toplayer of clay, peat and sandy layers with a thickness of 6 to 15 m. The underlaying Pleistocene layer mainly consists of sand to a depth of 200 m with up to three separating clay layers. The waterdepth is 2 to 5 m. For the reclamation of the Markerwaard the phreatic water table will be lowered by 6 m. This will cause seepage from the Pleistocene sandlayers and a drop in the piezometric head of the groundwater in this layers. In the sandlayers the drop extends to the surrounding areas. The calculated drop ranges from 1.25 m to less than 0.25 m at a distance of 10 km inland (figure 1). The lowering of the piezometric head has only a minor influence on the phreatic watertable in dry periods, but in the Holocene layers the piezometric head drops with increasing depth. This will cause subsidence. Calculations have been made using available data about the different layers (Hannink 1984). Houses based on strip footings or slab foundations will partially follow the subsidence of the bottom. Subsidence causes negative skinfriction on piles. Investigation of the amount of negative skinfriction, the distribution of the forces over the shaft and the bearing capacity of piles lead to the conclusion that also settlement of wooden piles could be expected. Concrete piles have relatively more resistance against the additional negative skinfriction. These first calculations were based on a small number of representative data about piles, bearing capacity and negative skinfriction. The results of this calculations are given in table 1. A method to get detailed information about the quality of pile foundations is discussed in this paper.

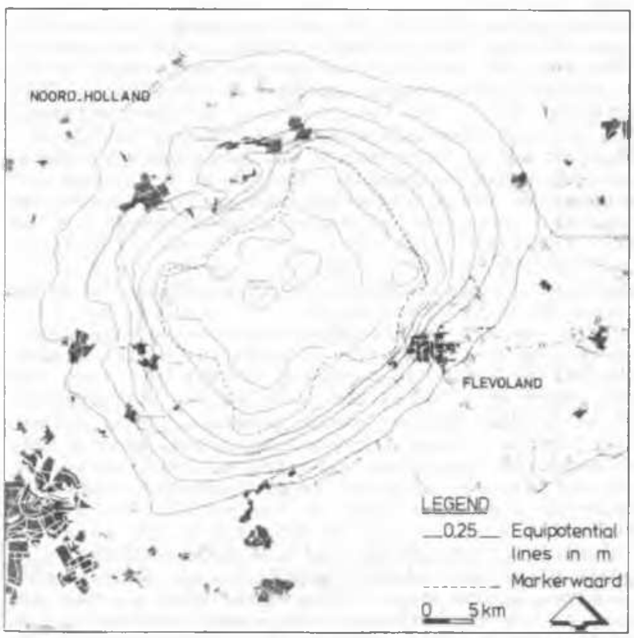

Figure 1. Expected drop in piezometric head at reclamation of the Markerwaard.

table 1. Calculated effects of the reclamation of the Markerwaard in Noord-Holland.

Subsidence over a period of 30 years	
- average in urban areas	34 mm
- range in urban areas	20 - 75 mm
- maximum outside urban areas	120 mm
Settlement (average/maximum) over a period of 30 years	
- strip footings/slab foundations	24/53 mm
- wooden pile foundations	8/18 mm
- concrete pile foundations	2/4 mm

In the area of Noord-Holland 80.000 houses are affected. The expected damage on a single building will be limited, but the total amount of possible damage could be high. In the area of Noord-Holland also without reclamation of the Markerwaard subsidence and settlement takes place. This finds its origin in a lowering of the phreatic water level for agricultural purposes, earlier reclamations of small inland lakes and sandfilling for buildingprojects in urban areas. The settlement of buildings ranges from zero to 5 mm/year with an estimated average of 1 to 1.5 mm/year. To limit damage as much as possible subsidence and settlement in relation with the reclamation of the Markerwaard should be avoided or kept small. Values in the same range as it takes place nowadays is expected to be acceptable. This can be reached by spreading the expected subsidence and settlement evenly over a period of 30 years. Therefore a system of infiltration wells is needed. The infiltration wells compensate the fall in piezometric head during a certain period of time. The effects of reclamation and the counter measures must be registrated with a measurement and control system.

2 SET UP OF A MEASUREMENT AND CONTROL SYSTEM

The planned measurement system gives information about the steps in the proces of reclamation and its consequences. This involves the following aspects:
- changes in the piezometric head;
- changes in the phreatic level;
- subsidence;
- settlement of buildings;
- occurrence of damage.

With the results of this measurements the predicted effects have to be checked and have to be separated from the changes in piezometric head, subsidence and settlement generated by other causes.

The planned network measurement system consists of:
- measurement system for hydraulic parameters:
  - piezometric head of the Pleistocene groundwater (190 observation wells);
  - phreatic level of the groundwater (300 observation wells);
- measurement system for vertical displacement:
  - subsidence of the different Holocene layers (37 places with 5 layers each);
  - settlement of buildings (750 buildings);
  - differential settlement of buildings (300 buildings);
- architectural survey to registrate damage (750 buildings).

The network will be installed five years before the start of the reclamation and will be in place during 30 years after the start of the reclamation. The system contains a network in the affected area and a reference network outside the affected area.

The subsidence and settlement is relatively small and with the planned counter measures evenly spreaded over a long period. Settlement of this order will hardly cause any damage. The buildings that are most susceptible for damage will first show any damage. If damage occurs the counter measures can be adjusted. Damage and claims for repair of buildings less susceptible for damage in relation with the reclamation of the Markerwaard can be compared with the damage, if it occurs, of the more susceptible buildings.

A system is needed to classify the susceptibility of buildings. The appointment of reference cases is based on soil parameters, quality of the foundation, quality of the construction, location, the drop in piezometric head, environmental aspects affecting possible damage and its historical importance (figure 2). The reference cases should represent the different types of buildings and cover the total area. This paper discusses the method of calculation the riskfactor rp for pile foundations.

3 CLASSIFICATION OF PILE FOUNDATIONS

This paper shows a method for a comparison of the quality of pile foundations. The quality is given

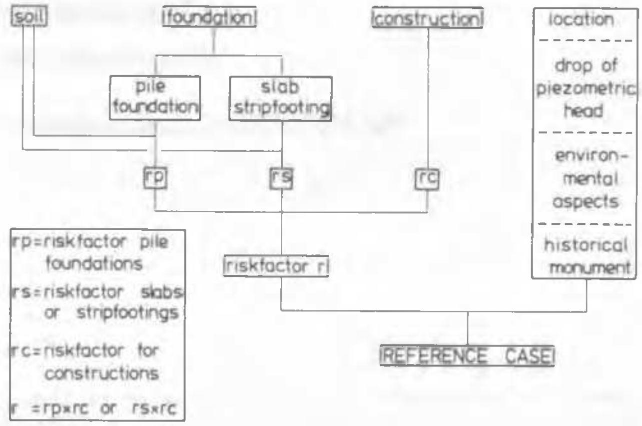

figure 2. Relations of aspects involved in the choice of reference cases.

as a riskfactor rp. The factor rp is based on information from the local archives such as type of piles, dimensions, foundation depth, pile driving data and soil data, mainly available as CPT (Cone Penetration Test) results. The factor rp is mainly related to the chance for unequal settlement of piles. Unequal settlement is related to differential settlement of buildings, it is the most important cause for possible damage. The factor rp is calculated from five partial factors. The different factors will be discussed here.

factor rp1

The factor rp1 is related to the rate of overburden of the piles. The calculation is based on the results of the CPT. The CPT is generally used in the Netherlands to design piles, the results are still available in the local archives. Inside the old cities additional CPT's are made. About 7000 CPT's are available now in the affected area. The rate of overburden is the quotient of ultimate design load Qd and ultimate bearing capacity Qb. The ultimate design load is given as Qd=Qp+Qn, in which Qp is the maximum external pile load and Qn the negative skinfriction. The external pile load Qp contains the dead weight of the construction and a variabel part for loads, wind or snow. In design a maximum load is taken into account, in reality the loads are often not present in their fully extension. For reasons of geometry sometimes piles have been added. In that case the dead weight per pile is less. The real load on the piles is often not as big as the ultimate design load, but it depends on local and coincidental circumstances.

Negative skinfriction occurs when subsidence takes place. The amount of negative skinfriction depends on type and layering of the soil and the processes that cause the subsidence. The subsidence in the area is often generated by a lowering of the phreatic groundwaterlevel or a fill of sand. In that case subsidence, correlated to the relatively increase in grainstress, takes place in the upper part of the soil profile. In case of a drop in the piezometric head, caused by the reclamation of the Markerwaard, subsidence takes place at a lower level. A representive CPT is given in figure 3. This shows that at reclamation of the Markerwaard settlement occurs in the lower compressible layers. The sandy layers will develop additional negative skinfriction. Skinfriction in this layer did often not occur before and is not taken into account in the design. The negative skinfriction is calculated from the CPT with the method of Begemann (Begemann 1977). This method is based on the results of pulling tests on piles and CPT's. The method is chosen thanks to the great number of CPT's available. Differences in cone resistance will reflect in differences in negative skinfriction and it makes it possible to compare results on a local base.

The negative skinfriction is taken from Qn = 0.8 * Pc * Ql * C * H, in which

Qn = negative skinfriction (kN);

0.8 = factor based on the difference between the speed of pulling in pulling tests and negative skinfriction;

Pc = pilecoefficient, depending on the type of piles and the type of soil (see table 2);

Ql = average local friction (kN/m2), measured with a CPT with friction jacket or based on the relation between CPT and local friction (Begemann 1977) (see table 2);

C = circumference or perimeter of piles;

H = thickness of the layer (m).

table 2. Pilecoefficient and local friction.

type of soil	pilecoefficient Pc		average local friction Ql/ cone resistance qc
	wooden pile	concrete pile	
fine sand	0.65	0.30	0.0160
clayey sand	0.70	0.31	0.0260
clay	0.7	0.40	0.0415

The calculation of the ultimate bearing capacity Qb is based on the CPT and pile loading tests (v.d.Veen 1953). The point resistance Qpp is calculated as a weighted average cone resistance at a depth of 8 times the circumference or perimeter of the pile above the piletoe and a depth ranging between 0.75 and 4 times the circumference or perimeter underneath the piletoe. In design this value is divided by a safety factor ranging from 1.7 for wooden piles to 2.5 for cast in situ piles. This method is generally accepted in the Netherlands and frequently confirmed with test-results.

Positive skinfriction is calculated in the same way as the negative skinfriction Qs = ps * Ql * C * H, in which Qs = positive skinfriction (kN) and ps = empirical factor depending on the type of piles (Begeman 1977).

table 3. Relation between positive skinfriction and cone resistance.

Type of piles	Ps*Ql/qc
wooden piles	0.012
cast in situ concrete piles	0.01
prefab concrete piles	0.008

qc=cone resistance(kN/m2)

Negative skinfriction only occurs in these regions in the compressible layers with peat, clay and silty or fine sands; positive skinfriction only occurs in the deeper and coarser sandlayers. The empirical data from table 2 and 3 are taken for this case with the given soil profile from figure 3. The factor rp1 is correlated to the values of Qd/Qb = (Qp+Qn)/(Qpp+Qs).The chosen values are given in figure 4 together with the values for the other factors. For values of Qd/Qb less than 0.8 no significant deformation takes place. Even the piles that are loaded to their maximum value are able to bear this load. When the value of Qd/Qb increases some piles will show larger deformations. This deformations only take place for piles with the largest load and/or the lowermost bearing resistance. When the value of Qd/Qb increases more piles will show larger deformations, redistribution of loads takes place resulting in a somewhat more uniform deformation. Due to differences in design load and bearing capacity even at high values of overburden differences in deformation remain. For concrete piles the differences in external pile load are generally smaller.

factor rp2

Negative skinfriction is related to the subsidence of the soil surrounding the piles. In case the ultimate design load Qd is greater than 0.8 times the ultimate bearing capacity it will result in a vertical displacement of the piles. Hannink found a vertical displacement of 35 to 60% of the subsidence in this area (Hannink 1984).

In the present situation subsidence takes place mainly in the upper compressible layers resulting in negative skinfriction in the upper layers. Reclamation of the Markerwaard causes also subsidence in the lower compressible layers resulting in negative skinfriction in the lower sand, clay and peat layers (figure 3). The additional negative skinfriction in the lower sandy layers causes a relatively large increase in negative skinfriction with a possibility of exeeding 80% of the ultimate bearing capacity. The riskfactor rp2 is for that reason directly related to the amount of expected subsidence in the lower clay and peat

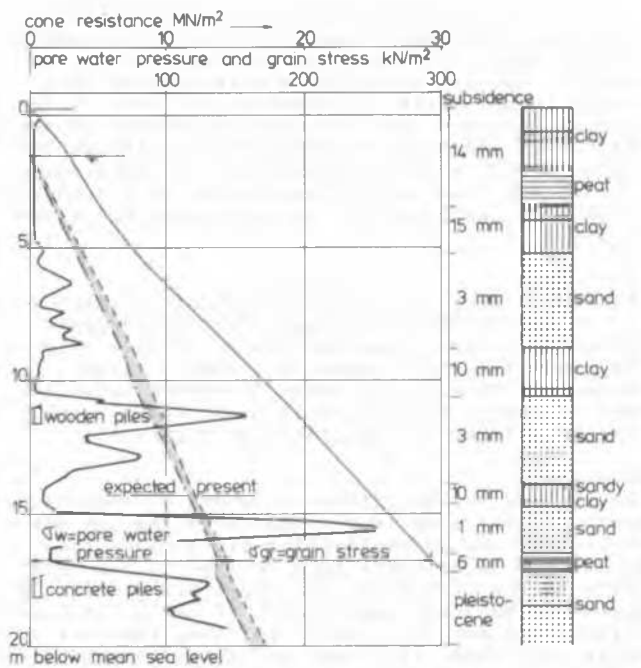

figure 3. Example of soilprofile

Qd/Qb	rp1 wooden piles	rp1 concrete piles	subsidence	rp2	differences in CPT (MN/m2)	differences in depth of piletoe (m)	rp3	number of CPT's	rp4	appartments per building	rp5	Size (m2)
<0.8	0	0	< 5 mm	0.3	<1	<0.5	.8	>25	0.9	<= 2	0.8	<= 250
0.8-1	3.0	1.5	5-10 mm	1.0	1-5	<0.5	.9	25-10	1.0	2- 6	0.9	250- 750
1-1.3	2.5	2.0	10-15 mm	2.0	<1	0.5-1.5	.9	<10	1.1	6-10	1.0	750-1500
>1.3	2.0	1	>15 mm	3.0	1-5	0.5-1.5	1.0			10-12	1.1	1500-2500
					1-5	>=1.5	1.1			>12	1.2	>2500
					>5	<1.5	1.1					
					>5	>=1.5	1.2					

figure 4. Choosen values for the riskfactors.

layers. The subsidence is calculated with the formula of Terzaghi. The compressibility coefficient is taken from the predictive study of Hannink (Hannink 1984). These data are correlated to the CPT with the following relation:
c=7.5+17.5*qc, if qc <0.5 MN/m2 and c=13.75+5*qc, if qc >0.5 MN/m2 with: c = compressibility coefficient and qc= cone resistance (MN/m2).
The chosen values for the factor rp2 are given in figure 4. Values of expected subsidence in the lower compressible layers smaller than 5 mm are neglible in comparison with the present deformations. Expected subsidence due to the reclamation of the Markerwaard will not exceed 20 mm in the lower compressible layers. Only in the case the sandy layer is not present in the Holocene it is not possible to separate the upper and lower compressible layers clearly. In that case however the increase in negative skinfriction is relatively small and the vertical displacement of the pile will also be small.

factor rp3
Factor rp3 takes into account differences in bearing capacity of the soil. The uniformity is ruled by two aspects. One of the aspects is the difference in cone resistance at the level of the pile-toe. These differences are direct related to the ultimate bearing capacity (v.d.Veen 1957) of the piles. The second aspect is the difference in piletoe level. If large differences excist in bearing capacity the pile is often placed at a deeper level. Larger differences in level of the piletoe indicate that the cone resistance is not uniform in one project. Especially in larger projects the CPT's show differences. If differences are too big, the project is divided in a number of smaller projects. The chosen values are given in figure 4.

factor rp4
The reliability of the information is related to the number of CPT's available for one project. Differences are recognized sooner if more data are available. This means that with a larger number of CPT's the accuracy increases, with a smaller number there is more uncertainty resulting in a higher riskfactor (see figure 4).

factor rp5
The size of the buildings or number of appartments per building is of importance for the prediction of the susceptibility for damage. This factor has to be taken into account in the first place in the riskfactor for constructions rc. On the other hand the same number of CPT's gives a higher accuracy for a small building than for a larger building. The range of factors chosen for rp5 are given in figure 4.

The factors as mentioned before will be multiplied to the riskfactor rp. From the chosen values it appears that only the factors rp1 and rp2 could make the riskfactor rp zero or very small. The factors rp3, rp4 and rp5 are of minor influence. In this calculation CPT's are chosen that give the highest value of Qd/Qb and subsidence of the lower compressible layers.

The riskfactor rp = rp1*rp2*rp3*rp4*rp5 ranges from zero to 14.26. A first calculation of 375 projects showed the following results:

for 167 projects rp = 0 - 1;
for 98 projects rp = 1 - 2;
for 79 projects rp = 2.5 - 5;
for 31 projects rp = 5 - 14.26.

Only for the cases with a riskfactor higher than 5 the factor rc should be taken into account to be able to select the most susceptible buildings with a pile foundation.

The available data are stored to the computer. In this way it is possible to change the values for the riskfactor easily. After several changes and adaptions in the used schematisations of the data and the choice of the chosen values the highest riskfactors were found for the foundations with relatively the highest susceptibility for unequal settlement of the piles possibly resulting in differential settlement of the buildings.

4 CONCLUSION

The chosen method is usefull as an instrument to classify a large amount of data. The chosen risk parameters depend on the local circumstances such as soil profile and the effects of the expected changes such as caused by a reclamation. It could serve also maintenance programs or investigations in relation with renovation and rebuilding. It makes it possible to compare on a uniform base the quality of a large amount of buildings.

5 REFERENCES

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