Stability of slurry trenches near railway

Stabilité de tranchée à près de chemin de fer

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ABSTRACT

In Almelo, the Netherlands, a construction of concrete floors and diaphragm walls is built to bring the present railway below surface. During construction the trains use a temporary railway track that is close to the building activities. For the construction of diaphragm walls trenches are made in the underground near the temporary railway line. The stability of the trenches is secured by bentonite slurry. In this situation trains are passing at a distance of a few meters. The stability of the slurry trenches has been analyzed with the method described in DIN 4126. This code however does not specify how dynamic actions from passing trains are to be taken into account. Passing of trains causes excess pore pressures and accelerations in the underground. These pore pressures and accelerations have a negative influence on the stability of the trench. The influence has been calculated with Finite Element Method.

The pore pressures and accelerations in the subsoil below and beside the railway were measured during two days and the passing of many trains. The measurements clearly show the passing of trains. The stability of the trench during passing of trains has been analyzed with the results of the measurements.

RÉSUMÉ

A Almelo, aux Pays-Bas, un ouvrage consistant en un plancher de béton et des parois moulées est en construction pour faire passer la ligne de chemin de fer actuelle en souterrain. Pendant la construction, les trains utilisent une ligne temporaire proche du souterrain. Pour la construction des parois moulées, des tranchées sont creusées à proximité de la ligne temporaire.

La stabilité des tranchées a été assurée par une suspension de bentonite. Les trains passent à une distance de seulement quelques de mètres de ces tranchées. La stabilité des tranchées avec la bentonite a été analysée avec la méthode décrite dans la norme DIN 4126. Cette norme ne spécifie pas toutefois comment les charges dynamiques des trains doivent être calculées.

Le passage des trains provoque une surpression de l'eau et des accélérations dans le sous-sol. Les surpressions dans les pores et les accélérations ont une influence négative sur la stabilité de la tranchée. Les pressions dans les pores et les accélérations sous et à côté des voies ont été mesurées pendant deux jours, pendant lesquels de nombreux trains sont passés.

Les mesures montrent clairement l'influence du passage des trains sur les pressions et accélérations. La stabilité de la tranchée au cours du passage des trains a été analysée a partir des résultats des mesures.

Keywords : slurry trench, railway, dynamic action, excess pore-pressures, measurements

1 INTRODUCTION

In Almelo, the Netherlands, the railway is constructed below surface over a length of 1100 m. During construction the trains use a temporary railway. Just beside this railway a diaphragm wall was made. The passage of trains is negative for the stability of the slurry trench.

The estimation of the stability of the trench in this situation is work for specialists. The influence of the passage of trains was calculated. The calculations show that the stability of the trench on some locations is critical.

Due to the uncertainties in the calculations and the critical situation on some locations measurements in the subsoil were executed during the passing of trains. These measurements were analyzed and led to a better knowledge of the impacts in the subsoil and on the stability of the slurry trench.

2 PROJECT DESCRIPTION

The railway Almelo-Hengelo crosses the inner city of Almelo over a distance of about 3 kilometers. The railway is used by 12 trains in one hour. The railway is a barrier for the traffic in the city and led to some accidents on the crossing with roads. Construction of the railway below surface reduces the barrier and leads to a better social climate near the railway.

During construction the normal train schedule must be maintained. The trains use a one-way temporary railroad beside the existing railway. The existing railway is removed and on this place the new railway is realized in a deepened construction of concrete walls and floors.

The space for construction is limited. The distance from the outside of the wall to the heart of the temporary railway is between 3.2 m and 5.6 m.

The project "Almelo Verdiept" is built by the Dutch contractor Van Hattum en Blankevoort.

3 GEOTECHNICAL DESCRIPTION

The surface level is about NAP (Dutch reference level) +11 m. The subsoil mainly consists of sand. On most locations the subsoil can be divided in two sand layers (2-layer soil profile). On some locations a layer of clay is present between the sand-layers (3 layer soil-profile). For the calculations both soil profiles are considered.

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The design value of the groundwater-table is NAP +9.7 m. In the calculations a value for the highest groundwater-table of 10.3 m was used.

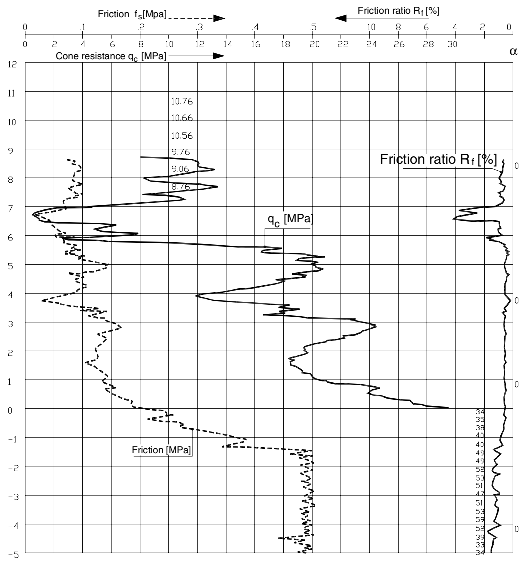

Figure 1. Cone Penetration Test

4 CRITICAL CROSS SECTION

The distance between the outside of the slurry trenches and the center of the temporary railway is between 3.2 m and 5.6 m. The calculations of the contractor showed that the stability of the slurry trench is adequate if for the distance of 3.2 m a section- width of 2.9 m is used. For the distance of 5.6 m a section width of 7.6 m is applicable.

The distance of 3.2 m is on two locations where escape routes are planned in the definitive tunnel construction. These locations were critical because of the short distance and the use of so-called Z-sections (figure 3).

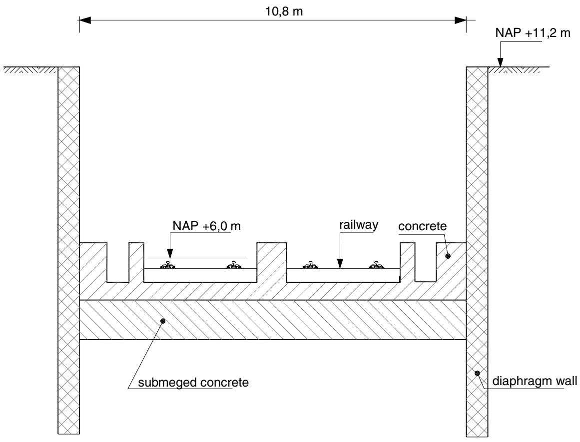

Figure 2. Cross-section

5 STABILITY OF SLURRY TRENCH

The stability of the trenches was calculated by VWS Geotechniek. The stability was calculated with the program GGU trench. This program is based on DIN4126 (2004). DIN 4126 works with overall-safety, based on calculations with characteristic values of soil parameters.

DIN 4126 has following requirements:

1. The pressure of the slurry is higher than water-pressure
2. The micro-stability of the trench is adequate
3. The safety against a draw-down of the slurry level is enough
4. The safety against sliding in of soil in the trench is enough

In the calculations two variants were distinguished. The first variant is the situation during digging of the trench. The slurry level is NAP +11.2 m and the volume-weight of the slurry is 11 kN/m^3. In the second variant the slurry is cleaned of sand. The slurry level is NAP +11.5 m and the volume-weight of the slurry is 10.4 kN/m^3. In both situations the slurry level is high enough to satisfy the first requirement. However the passing of the trains can generate accelerations and excess porepressures in the subsoil, which enlarges the water-pressure.

The micro-stability depends on the soil-properties (grain size) and the characteristics of bentonite-suspension. To guarantee micro-stability the yield stress τ_y of the bentonite-suspension must be higher than 25 N/mm^2 [1] This requirement is adequate for the present soil (sand and loam). The draw-down of the slurry level is negative for stability. Therefore the level is regularly controlled. The stability of the trench must be adequate. According to DIN 4126 the required safety-factor is 1.3 for the case that a load is present within a distance of 0.7*trench width. If the distance of the load is larger, the required safety is 1.1 DIN 4126 does not describe how to take into account the effect of dynamic loads.

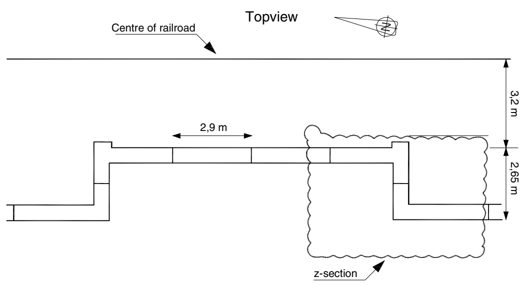

Figure 3. Top view of a critical cross section

6 INFLUENCE OF TRAINS

An effect of passing trains is the dynamic loading of the underground. From experiences it is known that the dynamic load is higher than the static load. The increase of the load depends on the interaction between train, rails, sleepers and subsoil. According to literature the dynamic factor is between 1.1 and 1.6. In the calculations for Almelo a dynamic factor of 1.5 is used.

Besides, passing of trains leads to excess water-pressures in the subsoil. This is negative for the stability of the trench. Two-dimensional calculations with FEM (Plaxis) were made to estimate the water-pressures generated by the trains. For a train with a load of 40 kN/m^2 a maximum water-pressure of 16.5 kN/m^2 was calculated.

With the dynamic factor and water-pressures new calculations with GGU trench were made. The results showed that the safety against sliding was adequate. The safety requirement 1 of the DIN, bentonite pressure over water-pressure was very small

(1.08). Due to the uncertainty of the dynamic factor and calculated water-pressures, a measurement plan was made.

7 MEASUREMENTS

On one location 3 piezometers and 1 acceleration-meter (turbocone) were placed in the subsoil below the railway. De acceleration-meters measure in 3 dimensions. At a distance of 3.25 m from the heart of the railway 3 piezometers and 2 acceleration-meters were placed. Measurements were done during two days. The first measuring day was before digging the trench. On the second measuring day the trench was dug and filled with bentonite. The measurements were done during 5 hours per day. During the measurements 99 trains passed the measurement location.

For the stability of the trench the horizontal acceleration is important. The measurements show that the maximum horizontal acceleration differs considerably for each train. Most trains gave accelerations below 1 m/s^2. The maximum horizontal acceleration was 2.1 m/s^2. The maximal vertical acceleration for this train was 5.3 m/s^2. These accelerations were measured during the passing of a cargo train on the first day. The train had two locomotives and 35 wagons. Although the wagons were rather similar in shape and loading, the measured accelerations differed a lot. Most wagons gave accelerations of less than 1 m/s^2; two wagons gave accelerations of about 2 m/s^2.

All measurements show that the acceleration beside the railway were clearly lower than below the railway. A relation between the axe-loads of the train and the accelerations was not found.

In general no relation between waterpressures and passing of trains was found. The average waterpressure corresponds to a groundwatertable of NAP +9.5 m. In some cases the passage of a train could be seen in the water-pressure.

If, as usual, the dynamic load is modeled as a static load with a dynamic factor, the measured maximal vertical acceleration of 5.3 m/s^2 can be translated in a dynamic factor of (9.81+5.3)/9.81 = 1.54.

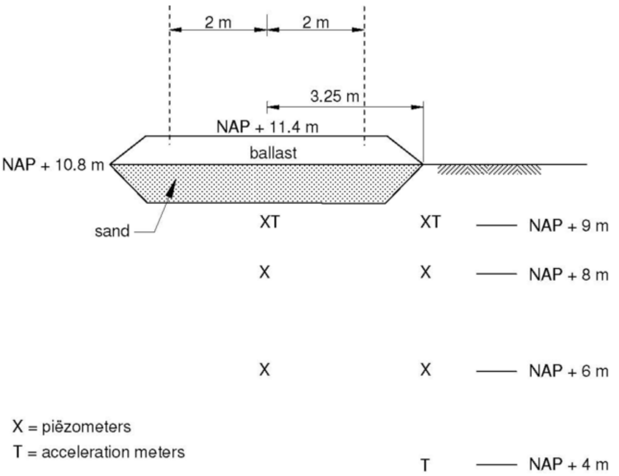

Figure 4. Cross section with location of measurement tools

8 HORIZONTAL SOIL ACCELERATION BY TRAIN

Besides the described method to take into account the dynamic load by applying a dynamic factor on the static load, it is also possible to use the measured horizontal acceleration. DIN 4085 (2007) gives a formula for the horizontal force on an infinite long wall:

$E_{a;dyn} = ½*\gamma*h^2*0.75*b_h/g$ [1]

In this expression:

- b_h = horizontal acceleration [m/s^2];
- g = gravity acceleration [m/s^2];.
- γ = volume weight of sliding soil-body [kN/m^3];
- h = height of sliding soil-body [m]

For the stability of the sliding soil-body the average horizontal acceleration on this soil-body is normative. The horizontal acceleration was measured on 3 locations. The measured values are translated to an average horizontal acceleration on the soil-body. This average acceleration depends on the size of the soil-body and the wave velocity. The size of the soil-body was estimated from calculations with GGU trench.

An analysis of the measurements shows that the frequency of acceleration is about 80 Hz. The wave-velocity is about 800 m/s. For fully saturated sand a wave velocity of about 1500 m/s is expected. The wave-velocity is probably lower because the upper part of the sandy subsoil is partly saturated.

The acceleration of the whole soil-body is not in phase. This effect was calculated by applying a phase shift. The present acceleration at a distance R from a starting point follows from:

$A_{hor} = 3.1*R^{-1.4} * \cos(2*\pi*R/L + \varphi)$ [2]

In this expression:

- L = wave length [m]
- φ = additional phase-angle [rad]

Figure 5 shows that the accelerations are not in phase. In some parts the direction of acceleration is in opposite direction. The calculated average acceleration is a_{hor} = 0.51 m/s^2. The force, $E_{a;dyn}$ caused by horizontal acceleration was multiplied by panel width and added to the static horizontal force.

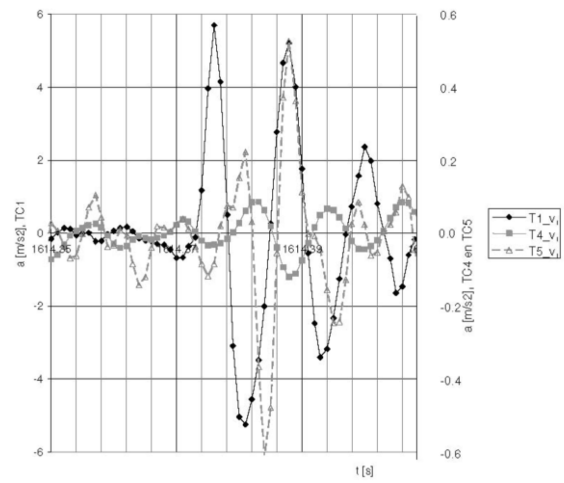

Figure 5. Measurements of accelerations

9 EXCESS POREPRESSURES CAUSED BY TRAIN

The crossing of the normative wagon shows an excess porepressure of maximum 8 kPa on NAP +8.2 m below the centre of the railway. At this moment the other piezometers do not show excess porepressures. The piezometers on NAP +6 m and NAP +6.2 m never show any excess porepressures.

Therefore excess porepressures below NAP +6.2 m are not taken into account.

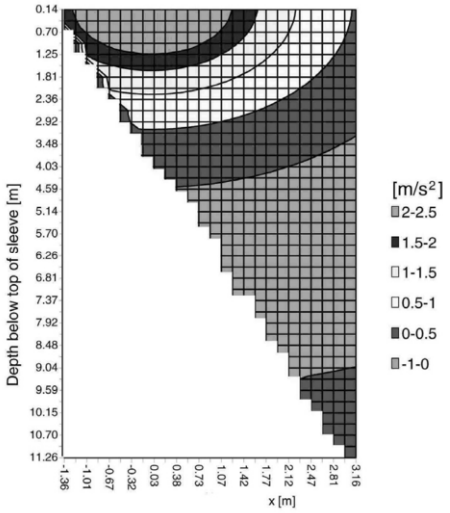

Figure 6. Calculated accelerations

10 RESULTS OF CALCULATIONS

The analysis of trench stability was done for a cross section with a minimum distance of 3.2 m between the outside of the trench and the heart of the railway. The maximum accelerations were combined with an excess porepressure of 5 kPa in the sliding soil-body. The calculated stability factor is 1.16. The required safety-factor in DIN 4126 is 1.3.

The safety-factor of 1.16 was found during the crossing of one train-axe during 10 hours of measuring. The time in which the safety is lower than the required 1.3 is less than 0.01 second.

The chance on instability of the trench is acceptable because this period is very short and the soil is stronger during very short loads than during permanent loads. For sand this so-called load rate effect is about 5-10% (Nguyen Quang Huy 2008).

In all cases the pressure of bentonite is higher than the porepressure, including the measured excess porepressure.

11 CONCLUSIONS

In the Netherlands DIN 4126 is often used for the verification of trenches supported by bentonite, made for diaphragm walls. This regulation does not describe how the influence of a dynamic load beside the trench has to be calculated. In Dutch practice a dynamic factor of 1.5 is used.

Trains cause accelerations and excess pore pressures in the subsoil. The measurements show that the combined effect of horizontal acceleration and excess porepressure is more critical that just calculating with a dynamic factor of 1.5.

A building up of excess porepressures during train passing wasnot found in this rather porous sandy soil.

The highest accelerations werenot found during passing of the heaviest trains. It seems that highest accelerations are caused by coincidental abrased wheels or axes. The highest water-pressures do not coincide with the highest accelerations.

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