Construction of infrastructure with extreme subsidence at Semarang Indonesia

Kevin Veraart[1], Mees van de Pas[1], Thijs Oudshoorn[1] and Laurens Advocaat[1]

[1]Rotterdam University of Applied Sciences
RDM-kade 59
3089 JR Rotterdam
The Netherlands

ABSTRACT

In the northern part of Semarang (Indonesia) there are often flooding's. The flooding's are affecting the daily life because the roads are flooding first. These flooding's are caused by the combination of sea level rise and extreme land subsidence. The land subsidence is about 1 to 17 cm a year. This land subsidence is caused by the weak soil conditions, water extractions and the heavy weight infrastructure constructions. It is very important to protect the main roads against the flooding. The local engineers keep levelling the roads by adding new asphalt layers which make the road constructions heavier and result in more land subsidence. It's a fact that the land subsidence can't be taken away but the local engineers don't have the knowledge to use innovative, lightweight materials so the land subsidence can be minimised. In the Netherlands we use building materials as Plastic, wood, lava rocks and water buffer crates to make lightweight road constructions. We investigated the main road at the Kaligawe area Semarang. We designed 5 different road constructions and calculated the land subsidence in a period of 10 years. As result we found out that using the PlasticRoad construction will minimize the land subsidence the settlement will be minimised. The land subsidence after 10 years will be 0,432 metres. Besides the PlasticRoad can storage water in the structure, the construction functions as culvert underneath the road. The elements are made of plastic which can be made of recycled plastics and reduces the plastic waste in the area. And finally the elements can be lifted easy so if necessary the road can be levelled by using bamboo chips.

Keywords: Flooding, Land subsidence, Light-weight road constructions, innovations, Excel calculation sheet

INTRODUCTION

Social problem

Due to the changing climate, extreme weather conditions are becoming common. These extreme weather conditions often lead to undesirable situations. Because the public space cannot withstand these extreme situations, there are major problems for the surrounding population. As a result, the residents of Semarang are hindered in their daily lives.

When a flooding occurs, it is possible that this will lead to the loss of livestock, damage to houses, crop destruction, failure to provide adequate infrastructure facilities and even loss of human lives. The water management in the area will also be disrupted, which significantly increases the risk of diseases. In the event of a river flood, the situation is fairly perceptible, so that the consequences can generally remain limited. But if an high sea level occur it is often a fast-developing process, which means that people have less time to be able to act appropriately.

Due to the fact that rivers flow outside their banks infrastructure such as roads, bridges and power stations, are disrupted. Or this infrastructure is even completely unusable for the inhabitants of Semarang. In this situation the economic activities come to a standstill. Various other processes come possible also to a standstill that are important to provide the residents with their daily needs. Think of the cultivation of crops and the transport of food. The distraction of these processes makes it difficult for some people to provide their own and their families with daily needs. When the production crops are disrupted, this can also lead to major problems later in the year, as this may cause a shortage of food.

Figure 1: Social problems Semarang. Source: (Abidin, et al., 2012)

Due to the flooding in Semarang, the existing water management system is being disrupted. This means that water used for preparing food and washing of the people is polluted. Since this water is provided with all pollutions that are present in the public space. These consequences of the flooding will lead to diseases being much easier to spread across the population of Semarang.

Figure 2: Water quality Semarang. Source: (Daga, 2016)

In addition, floods can lead to pysically problems for humans. Since they see their daily life being affected by the water. This situation is often harder to process for children than for the elderly. And because large parts of the infrastructure are lying flat in Semarang, they are also unable to flee the situation. Because this situation is occurring, the chances increase that people loses confidence in the political board. Since they are apparently not in a position to provide their residents with a safe living environment.

Technical problem

Land subsidence in Semarang has been widely reported and its impact can be seen already in daily life (as mentioned above). The economic losses caused by land subsidence in Semarang are enormous; since many buildings and infrastructures in the industrial zone of Semarang are severely affected by land subsidence and its collateral coastal flooding disasters.

Many houses, public utilities and a large number of populations are exposed to this silent disaster. The corresponding maintenance cost is increasing by year. Provincial government and communities are required to frequently raise ground surface for keeping roads and buildings dry.

Land subsidence is not a relatively new phenomenon for Semarang, which has experienced it since more than 100 years. Based on the levelling surveys conducted by the Centre of Environmental Geology from 1999 to 2003 it was found that the relatively large subsidence were detected around Semarang Harbour, Semarang Tawang Railway station, Bandar Harjo and Pondok Hasanuddin. The Land subsidence at these locations are ranging between 1 to 17 cm/year (Tobing and Murdohardono, 2004; Murdohardono, 2007). Results give that the northern coastal areas of Semarang are subsiding with rates larger than 8 cm/year. These areas are generally composed by swamp deposit of soft clay soil. (Abidin, et al., 2012)

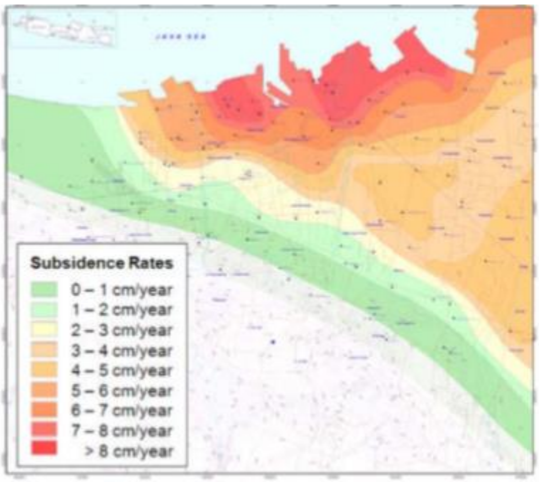


Figure 3: Subsidence rates Semarang. Source: (Abidin, et al., 2012)

The land subsidence resulted that around the halve of the area of Semarang is laying below the Mean Sea Level (or MSL) of the Java Sea. (Abidin, et al., 2012)

Land subsidence in the northern part of Semarang is believed to be caused by the combination of natural consolidation of young alluvium soil, groundwater extraction and load of buildings and structure. According to van Bemmelen (1949), muddy sedimentation in the coastal areas of Semarang occurred at least 500 years ago. Therefore, it can be expected that the coastal natural consolidation of young alluvium soil will have significant contribution on the relatively large observed subsidence in the coastal areas of Semarang. (Abidin, et al., 2012)

Besides the natural consolidation of relatively young alluvium soil, land subsidence in Semarang may also partly be caused by excessive groundwater extraction. Groundwater extraction in Semarang city in increasing sharply since early the 1990s, especially in industrial areas. According to Marsudi (2001) the number of registered wells in 200 is 1050. The excessive groundwater extraction introduced land subsidence on the surface. (Abidin, et al., 2012)

Background

Semarang is the capital of Central Java province, located in the northern coast of Java island, Indonesia. Semarang covers an area of about 37.366 hectares or 373,7 km^2, with the population of about 1,8 million people in 2017 (Dr. Abdul Rochim, 2017). Topographically, Semarang consisted of two major landscapes, namely lowland and coastal area in the north and hilly area in the south. The northern part, where are the city centre, railway stations, airport and harbour is relatively flat while the southern part have bigger slopes and an altitude up to about 350m above sea level. The northern part has relatively higher population density and also has more industrial and business areas compared to the southern part. (Abidin, et al., 2012)

Figure 4: Location of Semarang. Source: (Abidin, et al., 2012)

Knowledge gap

In Semarang the roads are engineered with heavyweight materials. The roads are most of the time constructed with asphalt. When de road construction settle they put a new layer of asphalt on top. This make the construction heavier each time This takes place once a year. This results in faster subsidence. The knowledge of using lightweight innovative materials for road construction is not present by the engineers in Semarang. They only think in a traditional way for constructing roads.

As mentioned earlier an extra layer of asphalt is putted on top of the existing road construction to level the road. This causes an extra weight that makes the settlement of the land bigger in a certain period. There is minimum knowledge of the results in land subsidence and the road constructions.

Figure 5: Road leveling in Semarang. Source: (Rochim, 2017)

Objective

The objective of this paper is to design an road construction for the city of Semarang witch cause the least land subsidence in a period of 10 years. By investigation of several diverse road construction we are going to determine the land subsidence. Besides we offer the local government several innovative ideas for road constructions in their area.

Research questions:

- How to calculate land subsidence (method)?
- How to minimize land subsidence caused by roads?
- How much land subsidence causing the traditional roads in 10 years?
- Which lightweight road structures are used in the Netherlands?
- How much land subsidence caused the described road structures in 10 years?

Study Area

For this study a main road in the northwest of the city of Semarang (Kaligawe) is selected. Kaligawe area is one of the main routes of North Java Coastal traffic and also the gateway of Semarang city from the east. Since more than 5 years this area proned by flooding due to a combination of land subsidence, increasing influence by tidal movement from sea the inability of free flow discharge of river water. In periods of flooding long traffic jams occur for more than 10 kilometres in length. (Wahyudi, Adi, & Lekkerkerk)

Within the Kaligawe area many stakeholders/ functions suffer from flooding. The main functions within the Kaligawe area are industrial environments, offices, education, hospitals, and settlement of housing. Losses of the flooding are becoming more serious and increasing over time, major impacts of the flooding are traffic congestion, road damage, environmental and economic disruption of national scale. (Wahyudi, Adi, & Lekkerkerk)

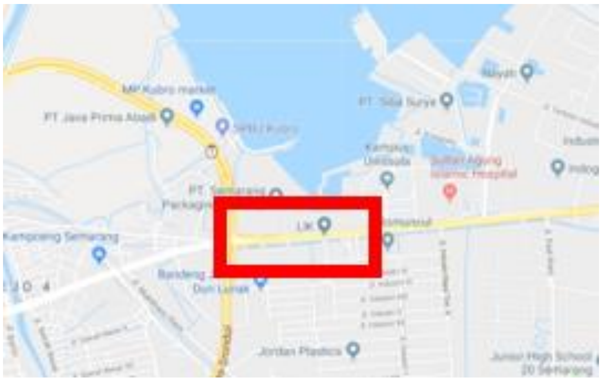


Figure 6: Location of study area. Source: (Google, 2019)

METHODS

Local inhabitants

For understanding the situation in Semarang we spoken to Wisnu Wardana. He is a local who studies civil engineering. Wisnu works at a project at the Rotterdam university of applied sciences. He gave us data about the local situation. This is necessary because we never visit Semarang ourselves. He told us for example how the government dealing with the subsidence right now.

Literature review

De first step for designing a road construction is to investigate the diverse type of materials that can be used or the different principles to construct an road. The research took place on the internet. There we found several websites and digitalised document of numerous innovation of road construction that are recommended for building on top of very subsidence ground.

Koppejan method

The Koppejan method is named after the engineer A.W. Koppejan who in the 1950s often carried out examination in the laboratories in Delft (The Netherlands). He produced the first version of the Koppejan method. A few years later, various professors made minor adjustments and improvements in the method and calculation. The calculation is based on the theory of Prandtl, originating from soil mechanics. (Sewnath, 2018)

In the engineering a relatively simple and reliable method for calculating the subsidence by loadings is developed. The Koppejan method is an calculation method on the basis of a cone penetration test at the location. It would be even better to perform a pile loading test on the pile, in which the pile is loaded, for instance by concrete blocks on a steel frame, with a test load approaching its maximum bearing capacity. This is very expensive and the cone penetration test (CPT) is usually considered reliable enough. (Baars, 2012)

In a homogeneous soil it can be assumed that under static conditions the failure load of a long pile is independent, or practically independent of the diameter of the pile. This means that the cone resistance measured in a CPT can be considered to be equal to the bearing capacity of the pile top. In reality the soil around the pile tip usually is not perfectly homogeneous. Very often the soil consists of layers having different properties. For this case practical design formulas have been developed, which take into account the different cone resistance below and above the level of the pile tip. Moreover, in these design formulas the possibility that the failure mode will prefer the weakest soil can be accounted for. In engineering practice the Koppejan formula is often used. (Baars, 2012)

To calculate the subsidence the theorie and formula of Koppejan is applied. Depending on whether the load of the road construction is bigger than the preconsolidation pressure (P_g), the following formula is

$$Z_{z+i} = d\left(\frac{1}{C_{p1}} + \frac{1}{C_{s1}}\log t\right)\ln\left(\frac{\overline{\sigma_k}+p_g}{\overline{\sigma_k}}\right) + d\left(\frac{1}{C_{p2}} + \frac{1}{C_{s2}}\log t\right)\ln\left(\frac{\overline{\sigma_k}+\Delta\sigma_k}{\overline{\sigma_k}+p_g}\right)$$

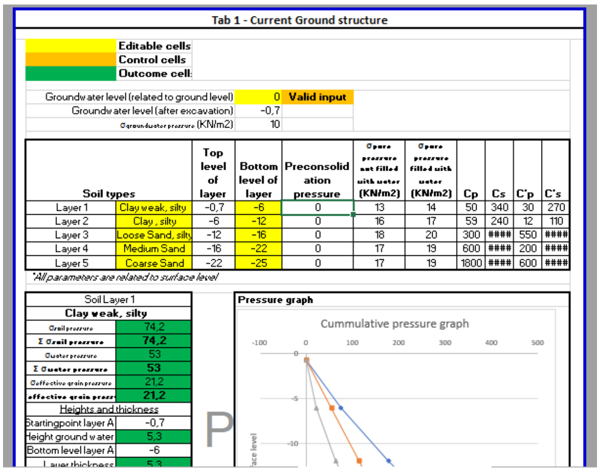
If the preconsolidation pressure is bigger than the load of the road construction the following formula is use

$$Z_{z+i} = d\left(\frac{1}{C_{p1}} + \frac{1}{C_{s1}}\log t\right)\ln\left(\frac{\overline{\sigma_k}+\Delta\sigma_k}{\overline{\sigma_k}}\right)$$

The parameters in the formulas above are:
Z_{z+i} = Subsidence of the layer (metres)
d = Layer thickness (metres)
Pg = preconsolidation pressure (KN/m2)
σ_k = ǩ = Average grainpressure per layer (KN/m2)
$\Delta\sigma_k$ = Load (KN/m2)
Cp_1= Cp = Primary compression coefficient below preconsolidation pressure (-)
Cs_1 = Cs = Secular compression coefficient below preconsolidation pressure (-)
Cp2 = C'p = Primary compression coefficient above preconsolidation pressure (-)
Cs2 = C's = Secular compression coefficient above preconsolidation presssure (-)
t = Time of subsidence calculated (days)
t_0 = 1

Excel calculation sheet (Koppejan)

We designed our own Excel calculation sheet for calculating the soil settlement. The Excel calculation sheet is an simplified way of the calculation with the Koppejan method. The divers ground parameters for the location can be filled in. These parameters needs to be investigated by doing a cone penetration test. Besides the external loading can be selected. Finally the time period for settlement needs to be filled in. The Excel calculation sheet calculates the settlement of the soil by external loading for a specific location.



Soil types		Top level of layer	Bottom level of layer	Preconsolidation pressure	σpore pressure not filled with water (KN/m2)	σpore pressure filled with water (KN/m2)	Cp	Cs	C'p	C's
Layer 1	Clay weak, silty	-0,7	-6	0	13	14	50	340	30	270
Layer 2	Clay , silty	-6	-12	0	16	17	59	240	12	110
Layer 3	Loose Sand, silty	-12	-16	0	18	20	300	####	550	####
Layer 4	Medium Sand	-16	-22	0	17	19	600	####	200	####
Layer 5	Coarse Sand	-22	-25	0	17	19	1800	####	600	####

*All parameters are related to surface level

Soil Layer 1	
Clay weak, silty	
σsoil pressure	74,2
Σ σsoil pressure	74,2
σwater pressure	53
Σ σwater pressure	53
σeffective grain pressure	21,2
σeffective grain pressure	21,2
Heights and thickness	
Startingpoint layer A	-0,7
Height ground water	5,3
Bottom level layer A	-6
Layer thickness	5,3

Figure 7: Screenshot D-Settlement.

D-settlement

D-settlement is a computer software which is used to control our self-created (simplified) Excel calculation sheet. The software is being developed by Deltares Systems, a Deltares company. D-Settlement is a dedicated tool for predicting soil settlement by external loading. D-Settlement accurately and quickly determines the direct settlement, consolidation and creep along verticals in two-dimensional geometry. Deltares has been developing D-Settlement. (Deltares systems, 2016)

D-Settlement provides a complete functionality for determining settlements for regular two-dimensional problems. Well-established and advanced models can be used to calculate primary settlement/swelling, consolidation and secondary creep, with possible influence of vertical drains. Different kinds of external loads can be applied: non-uniform, trapezoidal, circular, rectangular, uniform and water loads. Vertical drains (strips and planes) with optionally enforced consolidation by temporary dewatering or vacuum consolidation can be modelled. D-Settlement creates a comprehensive tabular and graphical output with settlements, stresses and pore pressures at the verticals that have to be defined. An automatic fit on measured settlements can be applied, in order to determine improved estimates of the final settlement. Finally, the bandwidth and parameter sensitivity for total and residual settlements can be determined, including the effect of measurements. (Deltares systems, 2016)

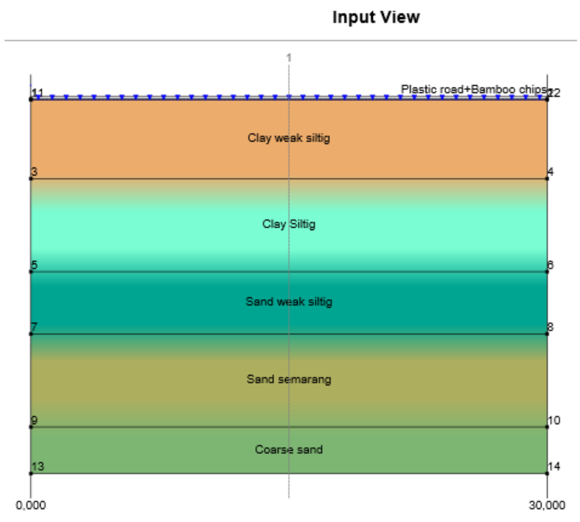


Figure 8: Screenshot input D-Settlement

RESULTS

Innovative light-weight road constructions

As result of the literature review for innovative light-weight road constructions we found several (concept) ideas.

Water buffer crates

A water buffer crate is a water-permeable box that is used for storing and infiltrating water. The boxes are made of plastic, which can contribute to the plastic problem in the area. To prevent the crates from flowing with sand, they are packed with a geotextile filter cloth. By placing these crates in the foundation of a road. The rainwater that falls on the paved surface of the road can obtained under the road. This boxes are also extra storage for the surrounded open water. A crate would have a weight of 11 kg and a capacity to store 290 litres of water.

Figure 9: Water buffer crates. Source: (Beuker kunststof leidingsystemen, 2019).

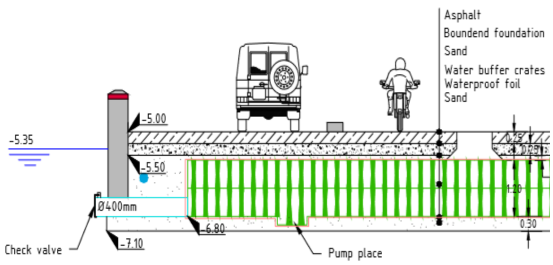


Figure 10: Design water buffer crates.

PlasticRoad

The PlasticRoad is a road construction which is based on recycled plastic. It is prefabricated and features a hallow space that can be used for various purposes. This includes water storage, transit of cables and pipe. In addition, the element are four times lighter than the traditional road structure as we know them in The Netherlands. The additional benefit of the PlasticRoad is, that it can be made from recycled plastic. Which may contribute to the plastic problem in the area. And when the construction is realized, it does not need a lot of maintenance and has a relatively longer service life then standard road constructions. During the lifetime of the PlasticRoad is it easy to adjust the height of the structure.

Figure 11: Visualisation PlasticRoad. Source: (PlasticRoad, 2019)

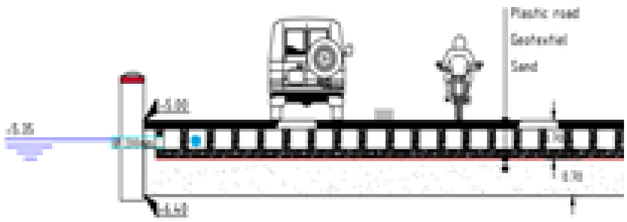


Figure 12: Design PlasticRoad.

Lava stones/Bamboo chips

Road foundations in The Netherlands are constructed from different materials. Granulate is normally applied on the top of the sand layer. This is a relatively heavy material which does not benefit the subsidence of the ground. It is possible to replace this material for lava stones or bamboo chips. The benefits of lava stones are the fact that it is a porous and relatively light material with a high water permeability and storage capacity for water. By applying a foundation of lava rocks with grade 4-32, 48% hollow space is realized in contrast to the mixed granulate. A detrimental effect on the foundation is caused due to the fact that the gradation 0-4 is missing. There is a low cohesion between the different rocks, this makes the stability of the foundation a lot lower. The bamboo chips is an material with the same properties.

Figure 13: Lavastones and bamboo chips. Source: (Alibaba.com, 2019) (Tuindomein.nl, 2019)

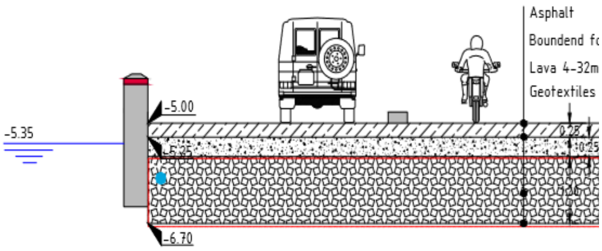


Figure 14: Design lava stones.

Land subsidence by Excel calculation sheet
Our own developed Excel calculation sheet calculates the land subsidence based on the Koppejan method. As input of the Excel calculation sheet we selected the nearest soil conditions (at KUBRO market) as shown in the figure below.

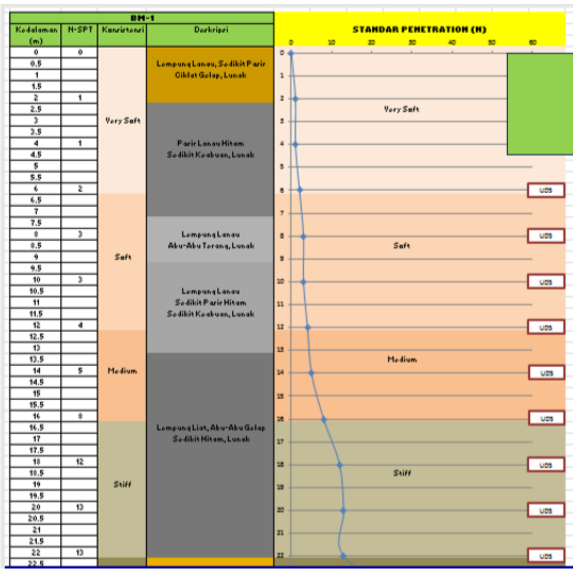


Figure 15: Soil conditions study area. Source: (Rochim, 2017)

Besides we calculated the weight construction of the innovative light-weight road constructions described above. The results are showed in the table below.

Innovative construction	Weight (kg)
Traditional asphalt unbounded foundation	2800
Asphalt + water buffer crates	2330
Asphalt + lava stones	2470
Asphalt + bamboo chips	1990
PlasticRoad +sand	1505
PlasticRoad + bamboo chips	1820

By the input for the Excel calculation sheet results in the following land subsidence after a period of 10 years for each type of road construction.

Innovative construction	Land subsidence after 10 years (m)
Traditional asphalt unbounded foundation	0,681
Asphalt + infiltration crates	0,599
Asphalt + lava stones	0,624
Asphalt + bamboo chips	0,534
PlasticRoad +sand	0,432
PlasticRoad + bamboo chips	0,502

Control calculation D-Settlement
In D-Settlement are the same situations calculated by existing (complex) software to evaluate our designed Excel calculation sheet. The results below show a little deviation between the results of the calculation sheet so we can conclude that the Excel calculation sheet is a good approach of the land subsidence.

Innovative construction	Land subsidence after 10 years (m)
Traditional asphalt unbounded foundation	0,74
Asphalt + infiltration crates	0,68
Asphalt + lava stones	0,70
Asphalt + bamboo chips	0,62
PlasticRoad +sand	0,48
PlasticRoad + bamboo chips	0,58

DISCUSSION

Delivered information

Several documents with local data, for example soil conditions are send to us by the Unissula university of Semarang. Because we as team never visit the study area and besides did not do the investigation of for example the soil condition ourselves we assumed that the delivered data is 100% correct. Besides we did not received every needed data so we made several assumptions for the calculation of the land subsidence. For example the groundwater level and values in the Koppejan method.

Land subsidence in the past years

For the Cp and Cs in the Koppejan method we assumed the values. The exact values on location were not available so we did a search on the internet for representative values. The values effect the result of the calculation based on the subsidence of the past years at the location. For an accurate result of the land subsidence the actual Cp and Cs value needed to be determined on location.

Investigation of required road level

We investigated the land subsidence of 6 different road constructions in a time period of 10 years. For making sure that the roads can't be flooding with high seawater conditions there needs to be an investigation of the sea level rise so the road level can be designed at a minimum height.

Investigation soil conditions/road constructions

We designed an simplified excel calculation sheet for making quick calculations of settlement based on the soil conditions and the weight of the road constructions. There are only 3 soil conditions send by the university of Unissula. For applying the Excel calculation sheet at random places in Semarang (and other parts of Indonesia) there are more cone penetration results needed.

Besides we investigated 5 different road constructions. There are probably a lot more lightweight road constructions available which maybe causing less land subsidence. More investigation on the type of road constructions are necessary.

Availability and cost of materials

We don't exactly know which kind of materials are available at Semarang and the cost of it. This research has to be done by locals because they have the knowledge of the possibilities of suppliers.

CONCLUSIONS

In the northern area of Semarang where important facilities of the city are located as the harbour, train station, hospitals, offices and the main roads are often flooding's which influence the daily life of the locals. These flooding is caused by the sea level rise and the land subsidence in the area. At the moment the local government construct the roads in a traditional way with heavy weight building materials. When the roads are to low (caused by land subsidence) an extra layer of asphalt is applied on top of the construction to level the road. This way of road construction make the land subsidence worse.

By using light weight road construction materials the land subsidence can be minimized. By using the following construction (innovative)materials the weight of the road construction (and the land subsidence) can be decreased:

- Water buffer crates
- PlasticRoad
- Lava stones
- Bamboo chips

By using the Koppejan method the land subsidence for the main road in the Kaligawe area over 10 years is calculated. In 10 years the PlasticRoad causing the least land subsidence (0,432metres). Besides the PlatsicRoad construction has the following benefits:

- Hollow construction which functions as culvert (and water storage) underneath the road.
- The elements are made of recycled plastic wich can reduce the plastic waste in the area
- The elements can be easy filted so if necessary the road can be leveld by using bamboo chips.

ACKNOWLEDGEMENTS

We thank the Unsissula university (Semarang Indonesia) for oblique several documents with data about the soil conditions of area of Semarang. We thank our teachers, E.A. Schaap, W.J.J.M. Kuppen, J. Lekkerkerk and J.M.P.A. Langedijk for explanation of the case and suggestions of the project that led to improvements in this investigation. Also we thank W. Wardana and the students of the Unsissule university for the information about the situation in Semarang so our results are more representative for the project location. This work was supported by Rotterdam University of applied sciences.

LITERATURE CITED

Abidin, H., Andreas, H., I., G., Sidiq, T., Mohammad Gamal, M., Murdohardono, D., & Yoichi, F. (2012). Studying Land Subsidence in Semarang (Indonesia) Using Geodetic Methods . Sydney.

Alibaba.com. (2019). Bamboo Chips For Sale . Opgehaald van Alibaba.com: www.alibaba.com/product-detail/Bamboo-Chips-For-Sale

Baars, S. v. (2012). Foundation Engineering. Luxembourg.

Beuker kunststof leidingsystemen. (2019). Infiltratiekratten. Opgehaald van Beuker kunststof leidingsystemen: www.beuker-bkl.com/producten/infiltratie/infiltratiekratten/

Daga, S. (2016, August 31). Strengthening Semarang's Climate Change Solutions: Collaboration, key to enhance resilience. Opgehaald van Thomson reuters foundation news: http://news.trust.org//item/20160831024839-pdg54/

Deltares systems. (2016). D-Settlement User Manual. Delft: Deltares.

Google. (2019). Opgehaald van Google Maps: http://www.maps.google.nl/

PlasticRoad. (2019). Opgehaald van PlasticRoad: https://www.plasticroad.eu/

Rochim, A. (2017). Soil consolidation. Rotterdam.

Sewnath, P. (2018). De ontwikkeling van een digitale trainer voor de Koppejan Methode in Maple TA. Rotterdam: TUDelft.

Tuindomein.nl. (2019). Lavasteen natuursteen 40-80mm Big-bag 750 kilo. Opgehaald van Tuindomein.nl: https://www.tuindomein.nl/lavasteen-natuursteen-40-80mm-big-bag-750-kilo

Wahyudi, S., Adi, H., & Lekkerkerk, J. (sd). Handling Solution Tidal Flood in Kaligawe Area by Polder System Drainage .