Observational Method for More Reliable Settlement Prediction for Reclamation on the Holocene Marine Clay Deposit in Jakarta Bay

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Abstract. Construction of the 276 and 312 ha reclamation on the Holocene marine clay deposit in Jakarta Bay is on-going. Settlement has been measured during the construction in order to satisfy the requirement of residual settlement. This paper briefly discusses limitation of accuracy of settlement prediction based on purely parameters derived from laboratory and in situ testing, in particular the Holocene marine clay. A reliable 'observational' method which makes full use of the monitoring data is described and estimates reliable residual settlement. More accurate settlement method is then also briefly described taken into account complex loading history. Finally, the factors, which are source of inaccurate settlement predictions and its implications, are included in the discussion.

1 Introduction

1.1 Geological setting

Jakarta bay is defined by the capes of Tanjung Krawang to the east and T. Jawa to the west. The central sector of the bay is the place for discharge area of several fluvial systems (Sungai Angke, S. Sunter, S. Ciliwung, S. Bekasi and S. Cikarang). The other two larger systems (S. Cisadane and S. Citarum) discharge peripherally from T. Krawang and T. Jawa [1]. The coastal plain of the bay is widely represented by river channel [2] and beach deposits [3]. This delta flanking Jakarta Bay, like other places in north Java, consists largely of clays - their sand content is small [4]. These deposits were formed during the Holocene. The Holocene is the most recent geological age corresponding to the current interglacial period extending from about 12,000 years ago up to now. This upper part of Holocene marine clay (HMC) is underline with the lower part of marine clay, which was formed about 120,000 years ago. These clay formations are likely found in low-laying coastal area in Indonesia [5].

The properties of this upper HMC are varying from place to place. However, it has high water content and void ratio. It is generally classified as very soft to soft, is close to normally consolidated and has high compressibility and well know lateral extent. Typical range of cone resistance for UMC is 0.1 to 0.2 MPA with mean effective stress of 350 kPa. Normally, when performing Standard Penetration Test (SPT), it will result in a normalized SPT blow count (N-SPT) of 0 to 2. As can be seen from Figure 1, variation of water content and its saturated weight of soil are shown in four different places in North Java.

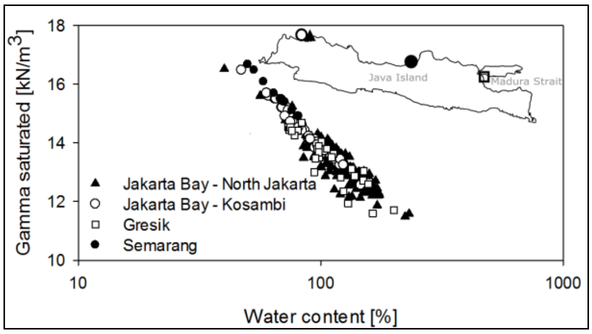

Fig. 1. Saturated weight and water content of Holocene soft clay in different locations in north part of Java (N-SPT=0-2).

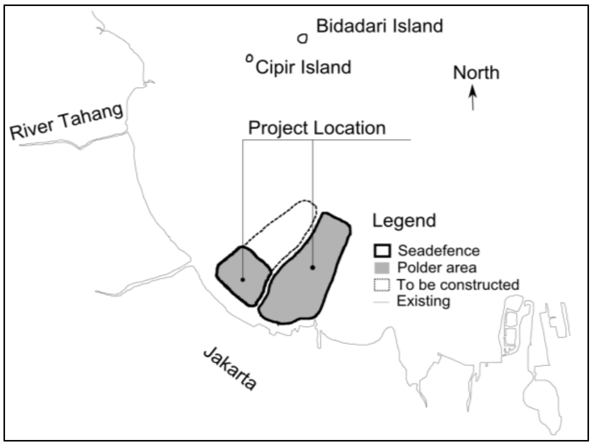

Fig. 2. Location of the two reclamation islands (Island 2A and 2B with part to be constructed in the future) for a polder system on the Jakarta Bay.

1.2 Reclamation islands

Construction of the two artificial islands on Jakarta Bay was started in 2012 and is still on-going. Their final

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shape for a polder system has almost reached as shown in Figure 2. The system consists of outer sea defence (a dike for protection) and inner polder area for canal, drainage systems, pumping house and other infrastructure and buildings.

The reclamation islands on the low laying coastal area are underlay by the more than 10-metres-thick-layer of very soft to soft clays as shown in Figure 3. The soft clays are underlay clayey sand from the river mouth, and followed by tuffaceous sediments consisted of silty clay and silt ranging from soft to very stiff and hard. Tuffaceous sands with consistency of dense to very dense (cemented and none cemented) are also found in between the sediments. Table 1 provides an overview of the soil profile and properties respectively. This was derived based on results of several in situ tests consisting of boring and Standard Penetration Test (SPT) and some of the classification parameters.

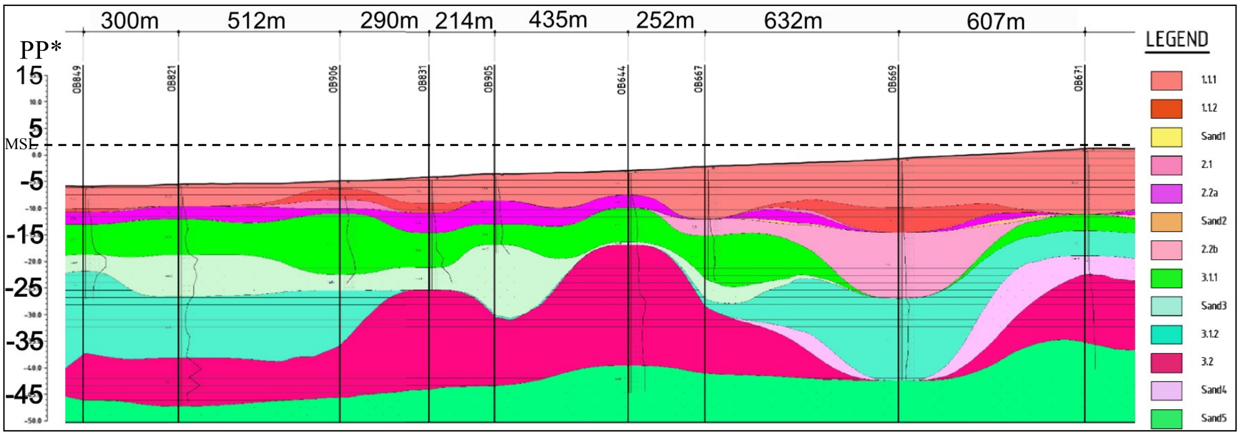

Fig. 3. A cross section showing soil layers along the north (left) and south (right) part between the two islands where the mean sea level (MSL) at +1.2 m from the project reference level, PP*.

Table 1. Soil profile and parameters with a lower characteristic value.

Unit [-]	Soil Description [-]	Unit weight [kN/m^3]	Water content [%]	N-SPT blow counts
1.1.1	Silty CLAY, very soft	13.6	122	0-2
1.1.2	Silty CLAY, soft	14.0	116	0-2
Sand-1 from river mouth	Clayey SAND	17.0	45	10-30
2.1	Tuffaceous Silty CLAY, soft to medium stiff	15.5	73	2-6
2.2	Tuffaceous Silty CLAY, medium stiff to stiff	15.6	68	6-15
Sand-2 and -3 lenses between 2.2. to 3.2	Tuffaceous SAND, dense to very dense, cemented and non cemented	15.7 to 17.2	43-47	30-40
3.1.1	Tuffaceous SILT, medium stiff to stiff	15.2	61	15-30
3.1.2	Tuffaceous Silty CLAY, stiff to very stiff	15.6	59	>30
3.2	Tuffaceous Silty CLAY, hard	15.8	49	>30
Sand lense 4-5	TUFFACEOUS SAND, very dense, cemented	15.7-17.2	34-42	50-80

1.3 Fill stages and requirement

This paragraph described in general how the islands are constructed. However, the description was limited to aspects related to settlement prediction for polder area. Some definitions for this paragraph are given based on Figure 4 [6] and will be used more often for the coming chapters.

In the first stage of fill period, sand was sprayed and submerged to the bottom of the sea. In this earlier stage no soil improvement was carried out yet. Therefore, a required thickness, shape and certain waiting period were foreseen in order to avoid instability. Once, the sand was already above the water level, monitoring instrument was installed. Improvement works for the clay layers were also carried out to accelerate consolidation and gain strength in the soft clay layers during waiting period. In some area, a temporary fill excavation was carried out during the waiting period. This was due to a levelling area for accessibility road. A Prefabricated Vertical Drains (PVD) with a triangular grid and a centre-to-centre distance of 1.2 m was penetrated reaching layer with a N-SPT blow count of

15. Deep penetration of the PVD was varying from 15-20 m over the entire two islands. A settlement during construction time (termed here as surcharge) occurred, adding required total fill material during the construction time or so called bruto fill – so netto fill and the surcharge. In most of the fill area, it was also required to have additional surcharge to reach requirements with shorter waiting period. The requirements are in terms of a residual settlement after a handover time and design level. The residual settlement of 0.30 m for the polder area has been chosen for period of 50 years of service time. This is started after the handover time. Since most of the building on the island will be constructed on pile, therefore, the handover time is started in the end of construction fill time. It is expected that after removal of the applied additional surcharge, limited residual settlement might reach the requirements. After service life of 50 years, the polder is expected to be at a design level, which was determined not only regarding end settlement but also adding a predicted land subsidence in the vicinity of the islands that was assumed to be constant with a rate of 2 cm/year (so 1.0 m in 50 years). Other aspects related in determining the design level are water management and coastal engineering. However, they are out of scope of this paper, focusing only on geotechnical aspect.

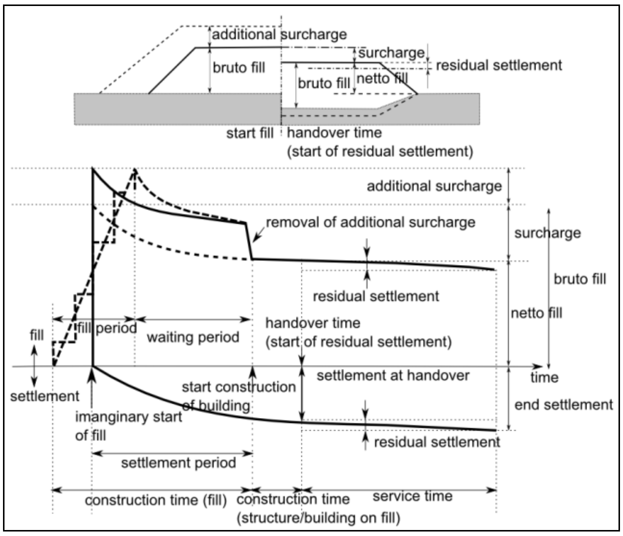

Fig. 4. Scheme (top) and terminology (bottom) fill-settlement-time diagram according to CROW 204 definition [6].

1.2 Problem definition and structure of the paper

Significant consolidation of the upper HMC with a depth of 20-50 m below the surface will occur during the placed fill material, giving the greatest portion of the total settlement. The soft clays with very low permeability imply two big consequences: very low consolidation and high creep rate. The increasing water pressure due to the fill has to be released in order to avoid instability until the end of the construction time. Very low consolidation process in the clays will be an obstacle to apply another fill material – larger interval within fill or longer waiting period per fill. This waiting period, however, is influenced with application of vertical drainage. This method in accelerates consolidation period to gain sufficient strength of the sub soil and also to reach the required residual settlement with shorter waiting period. The second geotechnical consequence is related to creep, which takes place also in the upper young deposit layers. Consolidation and creep occur also in a deeper layer (deeper than 20-50 m) due to stress increasing (deep ground water extraction). These last two components were treated as the land subsidence and were not covered within the regular settlement prediction. However, these were already considered when determining design levels of the islands, as described previously. This paper discusses all of these aspects and elaborates them with any geotechnical consequences, which might occur when dealing with the reclamation project underlain the very soft soil. Importance of an observational method through a monitoring program to reduce/avoid risk is also part of the discussion as proven to give accurate settlement prediction to approve the construction when the required residual settlement is achieved.

2 Observational method

In this project, two observational methods were carried out in terms of monitoring stations including instrumentations and also additional soil investigation and its supervision.

2.1 Monitoring stations

Monitoring station consisted of several monitoring instruments. Coupling of monitoring data gave essential insight on the behaviour of the subsoil towards the construction activity in the fill period. Instruments like, settlement plate, piezometer, stand pipe and, if necessary, inclinometer, were included in monitoring station. A settlement plate covers a grid which equals to an area of 100-by-100 square meters. In total there are almost 400 settlement plates have been placed. In most of the sea defence, piezometer and inclinometer were also installed. Whereas, some stand pipes were installed to cover evenly for both the islands. In general all the instrumentation installed and measured as soon as sand fills were above the water. The amount of settlement before the plate in placed was estimated by having CPTu. By using of this information and also the previous soil investigation (prior construction), the bottom level of sand can be determined. Moreover, the settlement can be determined by subtracting the different of the level. This was used to re-construct the data gap before the measurements become available. Earlier stage of settlement measurements was considered as valuable data to verify the parameter sets used in the design phase.

2.2 Additional soil investigation and supervision

During the design work it posed a lot of uncertainties. The soft marine clays have water content that is higher than the liquid limit, indicating that the undisturbed soil samplings are difficult to guarantee. Therefore, in the earlier stage of construction, additional soil investigations with a supervision program have been planned in order to verify the soil parameters based on the previous soil investigation during the design process. The CPTu has been also used to determine the actual soil profile when sand fill was already above the water. Changing the soil profile due to fill process can effect also the settlement prediction.

3 Ground uncertainty and risk

Risk ground engineering that influences accuracy of the settlement prediction related the following major aspects: the subsoil parameters. The most critical parameters for this aspect are the compression indices and the pre-consolidation pressure. Another important aspect is consolidation which its parameter was the coefficient of consolidation. This is, actually, not related to the soil parameter but a ‘process’ parameter since permeability and stiffness response during consolidation [6]. Chosen consolidation and settlement model will also influence the accuracy. Other aspects were related to fill sequence, groundwater fluctuation during construction, quality of fill material (that leads to efficiency of PVD) and possible changing of the actual soil profile during filling period. All of these aspects are given in Figure 5.

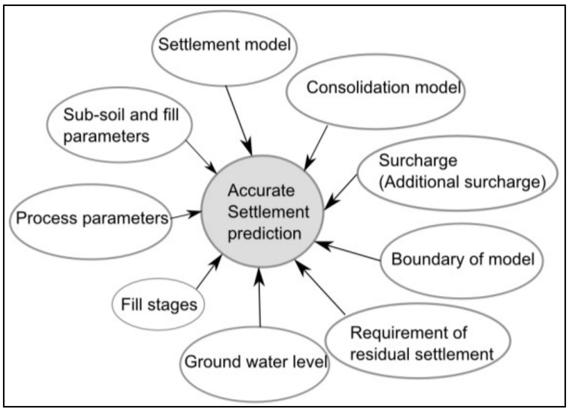

Fig. 5. Aspects related to input parameters for accurate settlement prediction.

Deviation in any settlement prediction (inaccurate) might occur due to the fact that the risk ground engineering does always exist. The risk is associated to uncertainty as an absence of information about parts of a system under consideration, which is always present [7]. This uncertainty was embedded in input parameters for settlement prediction. For each aspect of settlement prediction, risk was defined. Consequence of risk associated to settlement prediction is then briefly described in the following sub-chapters. Advantage of having observational approach is also elaborated here to reduce or even avoid the risks.

3.1 Calculation models

3.1.1 Settlement model

The NEN-Bjerrum isotache model supports the common linear strain parameters C_r, C_c and C_α. The reloading/swelling index C_r describes the elastic stiffness during unloading and reloading (below preconsolidation pressure). The primary compression index C_c and the coefficient of secondary compression C_α describe respectively the idealized elasto-plastic deformation and the viscous creep rate during virgin loading. These parameters can be determined from the oedometer tests which was previously described in Dutch Norms NEN 5118 [8] and 6740 [9]. The interrelation ship with Bjerrum (1967) is the reason behind the name of the model. Den Haan [10] has developed the full mathematical formulation by application of the small strain limits derived from the a,b,c isotache natural strain model. The parameters C_r and C_c are in fact related to changes in void ratio: becoming

$$RR = C_r \,/\, (1+e_0) \qquad (1)$$

$$CR = C_c \,/\, (1+e_0) \qquad (2)$$

respectively. Cα is however directly related to changes in linear strain. Please note that this definition of the Cα complies with common practice, but differs from the original definition by Mesri [11].The shared isotache formulation implies that all inelastic compression results from visco-plastic creep. The NEN-Bjerrum model, therefore, assumes that creep rate will reduce with increasing overconsolidation and that overconsolidation will grow by unloading and by ageing. Bjerrum’s name is attached to this model, because he was the first to notice that creep rate depends on both overconsolidation ratio and age. The NEN-Bjerrum model is suited for cases with un- and reloading, by using a rate-type visco-plastic isotache formulation (all plastic compression results from creep). This model solves the problem of any simplified interpolation model, such as Koppejan [12], that tends to underestimate the creep time considering a complex fill/load stage that involving also re-loading [13].

The creep effect is taken into account in the settlement prediction when the stress is higher than the pre-consolidation stress [13]. In Figure 6 a typical result of settlement prediction with ($C_\alpha \neq 0$) and without the effect of the creep ($C_\alpha=0$) in a 5 m thick of layer 1.1.1 with the NEN-Bjerrum settlement model. For the sake of simplicity no PVD effect has been taken into account in the models. As can be seen from both graphs in Figure 6, the creep already occurs at low stress level, and significantly starts at date around 100 days.

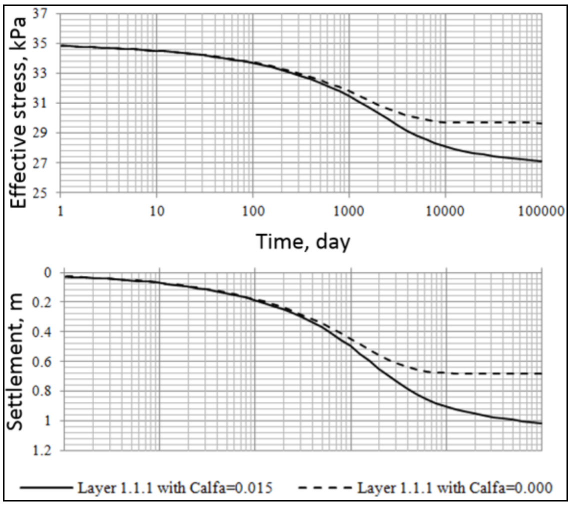

Fig. 6. Creep effect in NEN-Bjerrum settlement model, a simplified case with a 5 m thickness of layer 1.1.1 underlay none-compressible sand layer.

3.1.2 Consolidation model

Due to a surcharge, excess water in cohesive soil will occur. Consolidation is estimated by how much water flows out from the soil. Without any PVD the excess water will only flows out vertically. By introducing PVD, the water will also flows out horizontally through strips. In the latter case, consolidation will accelerate and faster than the former case. In the classic Terzaghi [14] method, effect of the PVD is estimated by adjusting coefficient of vertical consolidation. Barron [15] solved the former solution to estimate the effect in radial direction. Carillo [16] combined both solution by Terzaghi and Barron and. The method is so called Terzaghi-Barron-Carillo method and has been widely applied in the practice. Another alternative is to consider Darcy method. The main different between both methods is that Terzaghi method does not take into account effect of creep in the consolidation process, in the other hand, Darcy method does take into account creep effect in the consolidation. However, both methods will be equal considering a case with a single soil layer with a constant stiffness and ground water table where no creep is applied.

The used approach is combined use of NEN-Bjerrum for settlement model with a linear rek and Darcy solution for consolidation model for the case with PVD and additional (temporary) surcharge. These models are available in the commercial D-series program version 14.1 developed by Deltares. The settlement prediction is estimated by means of the software.

3.2 Soil and process parameters

3.2.1 Compressibility indices and process parameter

Ground sampling in very soft soil always is difficult in a good way and always results in sample disturbance. Sampling breaks the contact between soil particles causing stress reduction [10]. Therefore, 'undisturbed samples' often mentioned simply do not exist. These give significant contribution of risk when these samples are tested, then to derive parameters.

The soil parameters in the design phase were based on soil data obtained in several soil surveys consisting of boreholes, SPT's and laboratory tests. During monitoring settlement, it was observed that the compressibility derived from the laboratory test was found to be higher than it was expected. Based on the investigation it can be concluded that the classification tests, description of soil profile and units (Table 1) were consistent based on such quite simple tests such as SPT, bore-logging, Atterberg limits. However, for more complex parameters such as compressibility, it was not the case. As shown in the Figure 7, a widely spread of the results of *CR* in relation to the water content was observed giving a very big spreading with a margin of up to 30%, which was unexpected.

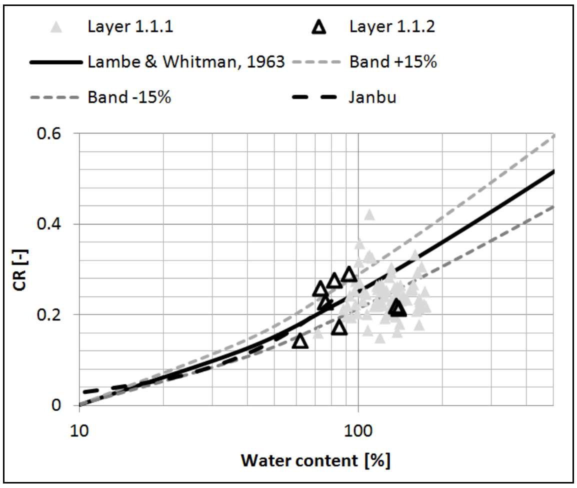

Fig. 7. Correlation of *CR* based on the result of several consolidation tests of layer 1.1.1 and 1.1.2 and its corresponding water content.

As consequence, the soil behaviour based on the soil parameter from the consolidation tests differed significantly from the prediction, as can be seen in Figure 8. During further investigation, this was found out due to in proper handling of the soft soil samples for such a long period causing significant disturbance in the sampling before consolidation tests.

3.2.2 Earlier stage of fitting

During the earlier stage of fitting, the parameter were updated accordingly based on correlation such as Lambe & Whitman [17] and Janbu [18] to determine the compressibility parameters *CR*, *RR* and C_α with index properties (water content and Atterberg limits) including Liquid Limit (*LL*), Plastic Limit (*PL*) and Plasticity Index (*PI*). The ratio of *CR*/*RR*=6.0 was considered for all layers. For the update of parameters, the typical ratio for soft clay and stiff clay is *CR*/*RR*=5.0 and 8.0 respectively. Similar procedure in determining C_α, it was used the typical ratio of C_α/*CR* from 0.06 for soft clay until 0.02 for stiff clay. The update of the parameters was including also the process parameters with a constant C_h/C_v=1.5. The C_v value for the first two layers was found to be varied and, therefore, divided into three zones covering the north, centre and south part of Island 2A. The pre-overbourden pressure (*POP*) of the soils was reduced for layer 1.1.1 and 1.1.2 with respect to the result of the laboratory test, while the other layers are not. Table 2 provides the complete parameters after adjustment based on the earlier stage of fitting.

Table 2 Adjusted NEN-Bjerrum compressibility parameters after an earlier stage of settlement-fits.

Unit [-]	*CR* [-]	*RR* [-]	C_α [-]	*POP* [kPa]	C_v [m²/s]	C_h/C_v [-]
1.1.1	0.26	0.050	0.015	5.0	2.0-6.0 10^{-8}	1.5
1.1.2	0.25	0.050	0.014	5.0	4.0-8.0 10^{-8}	1.5
2.1	0.20	0.035	0.008	41.5	5.0 10^{-7}	1.5
2.2	0.19	0.030	0.007	43.5	5.0 10^{-7}	1.5
3.1.1	0.18	0.025	0.006	63.3	2.34 10^{-6}	1.5
3.1.2	0.18	0.025	0.006	68.3	1.89 10^{-6}	1.5
3.2	0.16	0.020	0.005	90.4	2.82 10^{-6}	1.5

These updated parameters provided a good match with the field results as shown in Figure 8 and were used also for the fitting process of Island 2B as well.

3.2.3 Next stage of fitting

More data has been available in Island 2A after the earlier stage of the fitting process that was used for validating the soil and process parameters. At least two CPTu data were also available to verify the amount of settlement before the monitoring data available. The last CPTu data was to check the recent soil profile as this more relevant for long term prediction. Based on the fitting, predicted settlement were in-line with measured settlement, and therefore, were still consistent as shown in Figure 9. After the removal of the additional surcharge, the residual settlement meets the requirement in 50 years.

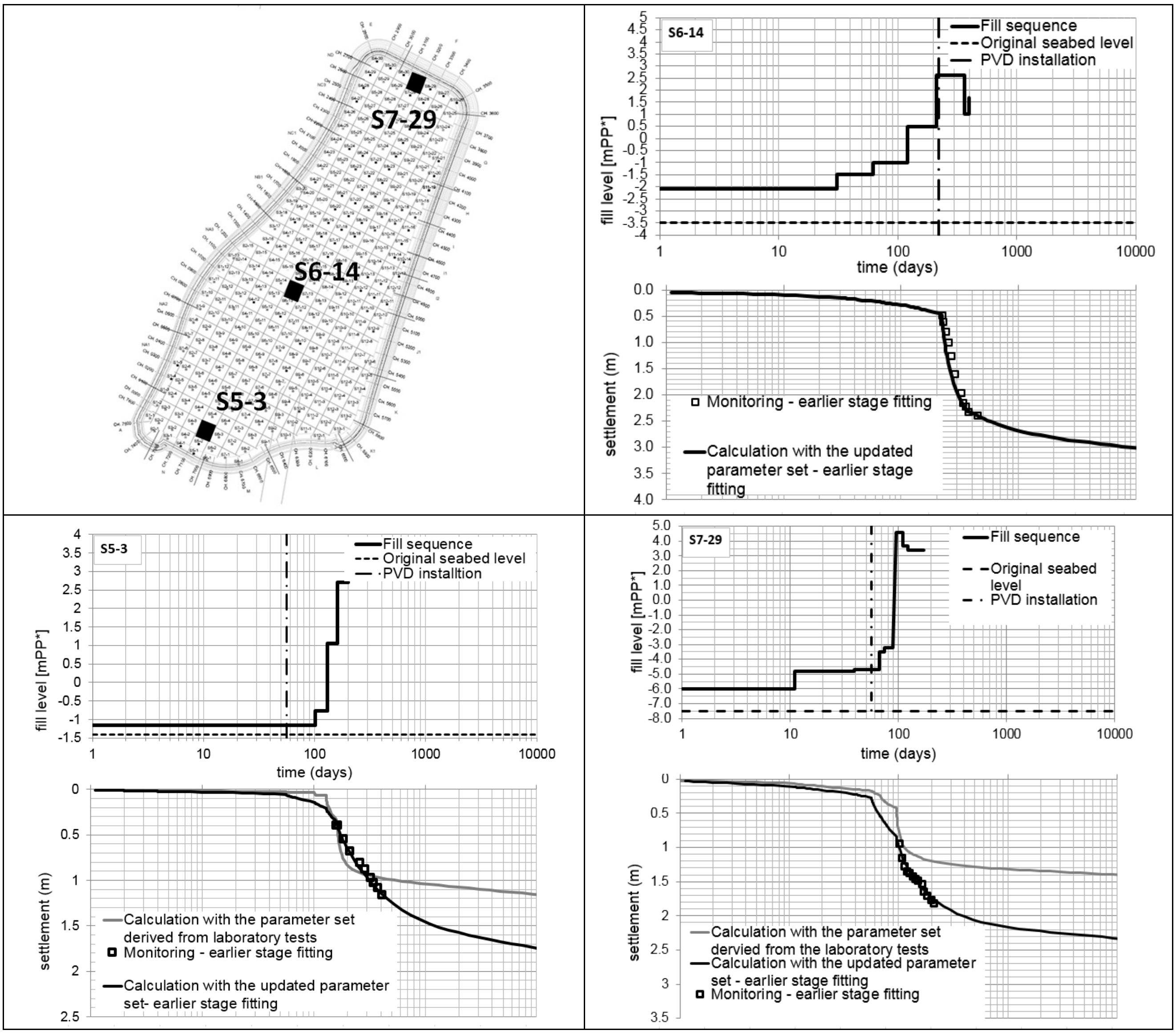

Fig. 8. Typical earlier stage of settlement fits in the north, middle and south part of Island 2A with the design and adjusted soil parameters.

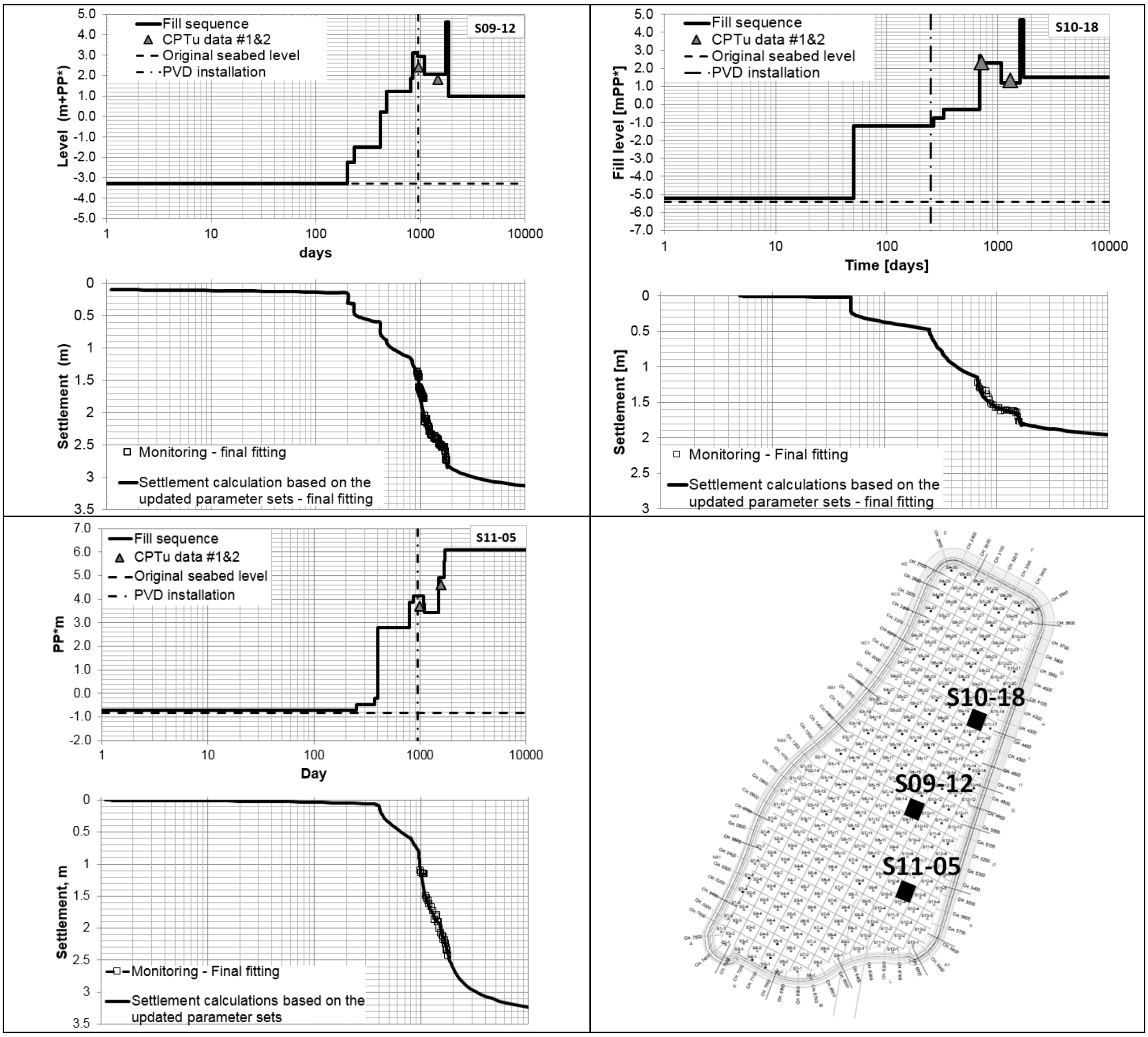

Fig. 9. Typical settlement fit Island 2A in the final phase of the fill stage - with the adjusted soil parameters and location of the measurement.

3.3 Other aspects

During the next stage of fitting in Island 2B, it was found that there were deviation between the prediction and measurement, although the parameter sets were already adjusted. There were two important factors that caused the deviation. One of the aspects was the quality of the fill material that might affect the consolidation process. This related to quite high fine content embedded in the sand fill, which was found to be higher than 15% giving low friction with high friction ratio in comparison to those of typically clean sand. The second aspect was due to the temporary water pumping during compaction works in a quite long period during the earlier stage of PVD installation. Based on the example of the fittings shown in Figure 10, an adjustment of process parameter C_v is necessary to have good fit. In addition, fluctuation of ground water level during the period of temporary pumping was also taken into account to provide better results. Having pore pressure measurement into the fitting made this possible. Based on the results of the fitting, the consolidation occurs slowly than expected and leads to quite high residual settlement, with an adjustment of total C_v with factor of 1.2-3.0. The settlement period of Island 2B is still on-going before the end of the construction time or starting of the hand over. However, additional surcharge can still be planned with certain waiting period in order to achieve the required residual settlement; otherwise longer waiting period can also be an option to achieve depending on the construction planning of the island.

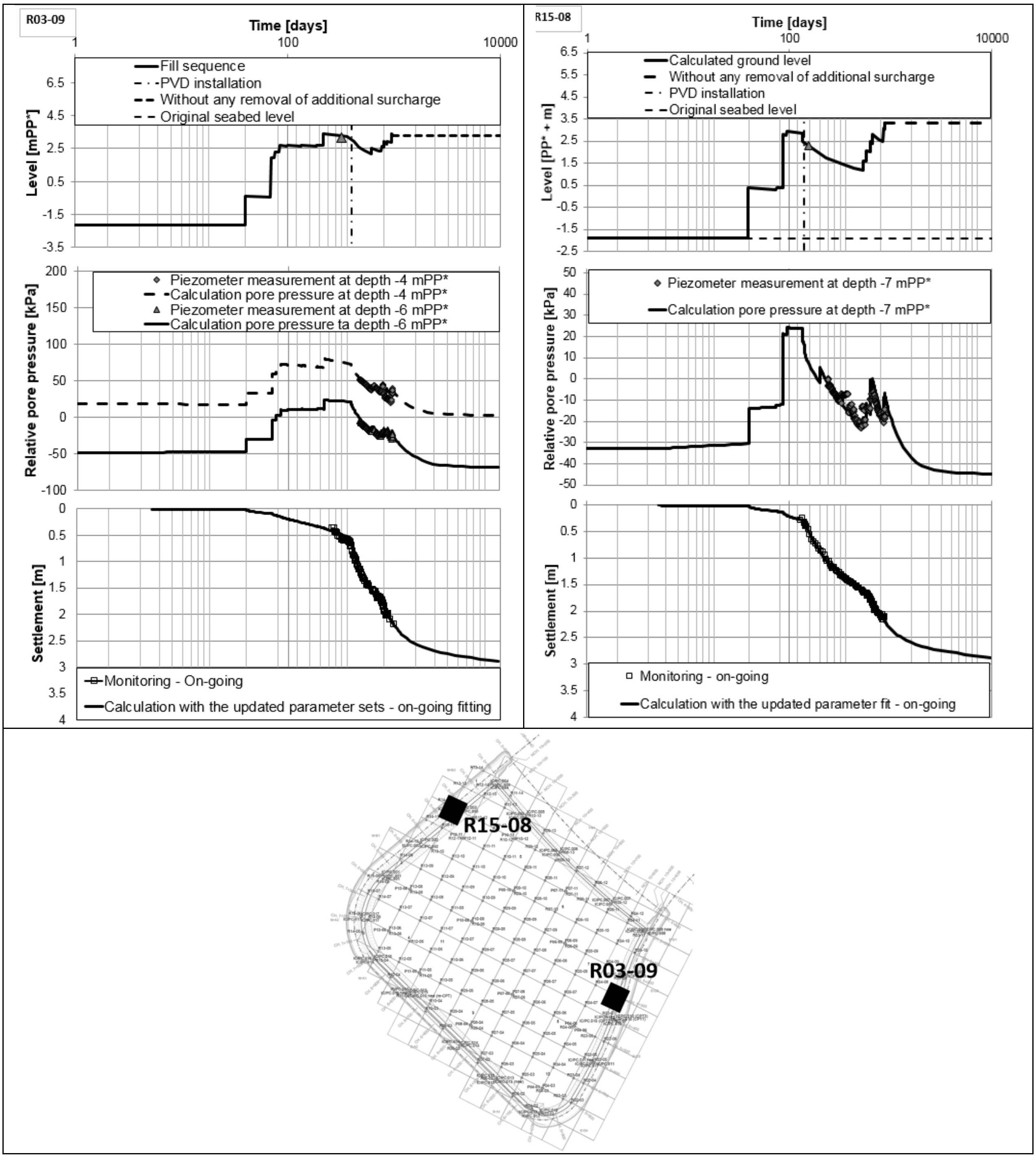

Fig. 10. Typical settlement and pore pressure fits Island 2B during the phase of the fill - with the adjusted soil parameters and further adjustment on C_v and water level fluctuation and location of the measurement.

4 Conclusion and recommendation

Risk associated to ground engineering, in this particular case related to settlement prediction was pre-defined prior to the start-up of the reclamation islands on Jakarta Bay. Each aspects of the risk were registered and were anticipated within the project phases: from the earlier stage towards the completion of the projects through the monitoring programs. The observational program, which was part of the construction phase, has been proved to be a powerful approach to calibrate the sub-soil soils parameter and the process parameters related to the PVD application. These two parameters were the main source of uncertainty in the settlement prediction. With proper settlement and consolidation models dealing with such complex loading history, the approach resulted in more reliable parameters that lead to better settlement prediction. The settlement results were not only successively predicted the immediate settlement due to fill with very complex loading history but also the effect of creep as the used method consider it. The application of the additional surcharge along with the PVD with certain waiting period was able to limit the residual settlement. This was also the good measure to successively achieve the strict residual settlement requirement of 30 cm within 50 years design lift time for the polder islands. Other important aspects were related to the quality of fill material and ground water fluctuation that were affecting the consolidation process. As the settlement period is still on-going measure can still be proposed based on the actual condition based on the fitting.

Although, the full set of parameters were already validated with the settlement measurements including the creep effect, however, a long-term measurement has been placed in Island 2A (will be also followed in Island 2B) to closely monitor the creep. In this case, settlement plates have been placed in the area where the surcharge already removed to the desired hand over level. Natural rek models such as *a*-*b*-*c* isotache or finite element models, such as Soft Soil Creep model, could be also an approach for settlement model considering higher rek cases. These two subjects are not covered yet within this paper, and will be kept for the future research.

Nomenclature

a, b	=	Stiffness parameters of soil
c	=	Creep parameter of soil
C_c	=	Primary compression index
C_h	=	Horizontal consolidation coefficient
C_r	=	Elastic stiffness during unloading and reloading (below preconsolidation pressure)
CR	=	Compression ratio
CPTu	=	Cone Penetration Test with pore pressure (*u*) measurement
C_v	=	Vertical consolidation coefficient
C_α	=	Secondary compression index. Similar to the common Ca.
e_0	=	Initial void ratio
HMC	=	Holocene Marine Clay
LL	=	Liquid Limit
NSPT	=	Normalized Standard Penetration Test
SPT	=	Standard Penetration Test
PI	=	Plasticity Index
POP	=	Pre Overburden Pressure
PL	=	Plastic Limit
PVD	=	Pre-fabricated Drains
RR	=	Reloading/swelling ratio
SPT	=	Standard Penetration Test

References

1. T.M., Williams, J. Rees, & D. Setiapermana, *Land-derived contaminant influx to Jakarta Bay, Indonesia. Volume **1**: Geochemestry of marine water and sediment*, Technical Report WC/97/19 Overseas Geology Series, Natural Environment Research Council (1997)
2. R.w. van Bemmelen, *The geology of Indonesia - General Geology of Indonesia and Adjacent Archipelagoes*, ***IA**,* Government Printing Office (1949)
3. C.R. Meinardi, *Hydrogeological considerations with regard to drinking water supply and land improvement in Desa Totoran (Kab. Indramayu)*, OTA-33 **9** (year?)
4. J.H.J. Terwijndt , P.G.E.F. Augustinus, J. R. Boermsa, and P. Hoekstra, *Mud-discharge, dispersion, and deposition in a mansoon-dominated coastal environment*, Proceedings International Conference Coastal Sediment, Coastal Sediments **87** (1987)
5. M. Dobbie, *Site investigation of the Holocene Marine Clay of Southeast Asia using the CPT*, Proceeding of Soft Soils (2014)
6. CROW **204**, *"Betrouwbaarheid van zettingsprognoses"*, in Dutch, (2004)
7. Smallman, *Crisis and Risk Management*, NIMBAS University (2000)
8. NEN **5118**, *"Bepaling een-dimensionel samendrukkingseigenschappen van de grond",* in Dutch (1991)
9. NEN **6740**, "*Basis eisen en belastingen"* ,in Dutch (2006)
10. E.J. den Haan, J.B. Sellmeijer, *Calculation of Soft Ground Settlement with an Isotache Model,* Proceedings Soft Ground Technology Conference, ASCE Geotechnical nr. **112**, 94-104 (2000)
11. M.A. Mesri, *Coefficient of Secondary Compression*, Journal of Soil Mechanics and Foundations Division, **277**, pages 123–137 (1973)
12. W.A. Koppejan, *A formula combining the Terzaghi load compression relationship and the Buisman secular time effect,* Proc. 2nd Int. Conf. Soil Mech. and Fnd. Eng., **272**, 32–37 (1948)
13. E.J. den Haan, *"Het a,b,c-isotachenmodel: hoeksteen van een nieuwe aanpak voor zettingsberekeningen"*, Geotechniek (**4**), p 28-35, in Dutch (2003)
14. K. Terzaghi, & R.B. Peck, *Soil Mechanics in Engineering Practice* (1967)
15. R.A. Barron, *Consolidation of fine-grained soils by drainwells*, Trans ASCE **113**, 718-742 (1948)
16. N. Carillo, *Simple two and three-dimensional cases in the theory of consolidation of soils*, Journal of Math. Phys. **21**, 1-5 (1942)
17. T. Lambe and R.V. Whitman, *Soil Mechanics*, John Willey and Sons, 553 p (1969)
18. N. Janbu, *Soil Compressibility as Determined by Oedometer & Triaxial Tests*, Proceedings, 3rd European Conference on Soil Mech. And Found. Eng., Vol. **1**, p 19-25 (1963)