Process of Preload and Surcharge Release for Embankments Constructed Over Soft Soils

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ABSTRACT: The Gerringong Upgrade (GU) will provide 7.5 km of upgraded highway, which traverses two flood plains with soft soils extending up to 10 m depth. Preload and surcharge are adopted to meet the stringent total and differential settlement criteria. The use of surchargeover-consolidates the soft soiland reduces long-term creep settlement. The process of preload release involves a review of the instrumentation and monitoring data (including fill-settlement history and piezometric data). Back analysis is carried out to match field measurements with numerical predictions by adjusting relevant geotechnical parameters and construction sequence. Once a match is achieved, the calibrated geotechnical model is used for the prediction of long-term settlement. The removal of preload and surcharge fill is only allowed via the release of a Hold Point, when the predicted long term settlement satisfies the design criteria.

1 INTRODUCTION

Roads and Maritime Services (RMS) of New South Wales (NSW), Australiaplans to upgrade the Princes Highway between Mount Pleasant and Toolijooa Road, which is known as the Gerringong Upgrade (GU).The GU will provide approximately 7.5 kilometres of minimum four lane divided carriageway, providing increased road safety and traffic efficiency to the south coast region.

Some sections of the road traverse low lying areas which are underlain by up to 10 m of soft soils. Preloading and surcharging are required to speed up the consolidation process and reduce long term creep settlement. In order to confirm that the soft ground has been suitably treated and the targeted soil properties have been achieved, a process of preload and surcharge release was developed and implemented during construction, which ensures that the predicted long term embankment performance meets the project design criteria.

2 EMBANKMENT DESIGN CRITERIA

The RMS has imposed stringent embankment design criteria to ensure that the upgrade highway meets its performance standards, and to provide road users with safe and comfortable ride quality. The following design criteria were specified:

- A maximum total settlement of 100 mm in 40 years following the construction of the pavement, except under bridge approach slabs where a maximum total settlement of 18 mm in 40 years is applicable.
- A maximum differential settlement, measured as a “change in grade” in all directions, of 0.3% over 40 years following the construction of the pavement.

3 CONSOLIDATION AND CREEP SETTLEMENT

3.1 *Consolidation settlement*

When a compressive load (such as that from embankment construction) is applied to a saturated soil, the pore water pressure will increase. Dissipation of this pore pressure will reduce the volume of voids as the water content of the soil decreases, resulting in settlement of the soil layers. Since clayey soils have relatively low permeability, the dissipation of excess pore pressure takes time. This time-dependent process is known as consolidation settlement.

The stress history plays an important role in the consolidation settlement behaviour. The maximum effective stress the soil has been subjected to is called pre-consolidation pressure (σ_p’). As shown in Fig. 1, up to σ_p’, any increase in applied effective stress from its initial value (σ_0, with corresponding initial void ratio e_0) results in a reduction of void ratio proportional to the recompression index C_r and the soil is described as being over-consolidated. Above σ_p’ (with corresponding void ratio e_p), the reduction in void ratio becomes proportional to the compression index C_c, and the soil is described as being normally consolidated. It is important to know what the current effective stress (σ_0’) is in the soil compared to σ_p’ in order to determine the consolidation settlement. This is described by the over-consolidation ratio (OCR), which is defined as σ_p’/σ_0’.

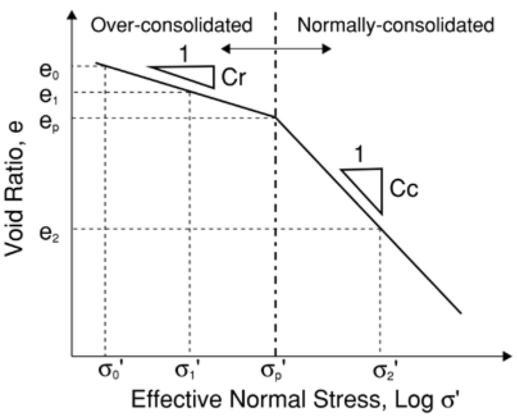

Fig.1 Settlement behaviour in relation to pre-consolidation pressure

Consolidation occurs as pore water is squeezed from the soil matrix. Settlement can take considerable time if the water lacks an easy path to leave the soil. The rate of consolidation is controlled by the coefficient of consolidation (C_v in vertical direction and $C_h$in horizontal direction) which in turn depends upon the square of the distance the water must travel to exit the soil.

3.2 *Creep settlement*

Consolidation theory implies that a change in void ratio is due to a change in effective stress brought by the dissipation of excess pore water pressure, with permeability governing the time dependency process. However, experimental results show that compression continues at a gradually decreasing rate under constant effective stress after all excess pore water pressure has dissipated. This process is known as creep settlement and is due to the readjustment of the clay particles into a more stable configuration.

It is well recognized that when soft soil is surcharged, the coefficient of secondary compression (C_α) will reduce depending on the OCR achieved (e.g. Stewart et al. 1994).

The starting time of creep settlement (t_s) depends on the degree of over-consolidation as shown in Fig. 2. However, for conservative reasons, creep settlement is assumed to start from the time when the primary consolidation settlement is complete and continue indefinitely under constant loading.

The reduced value of coefficient of secondary compression (C_α') due to surcharging can be assessed using Fig. 3. The degree of over-consolidation after surcharge removal is used to estimate the creep reduction (C_α'/C_α), which is then used to estimate the creep settlement.

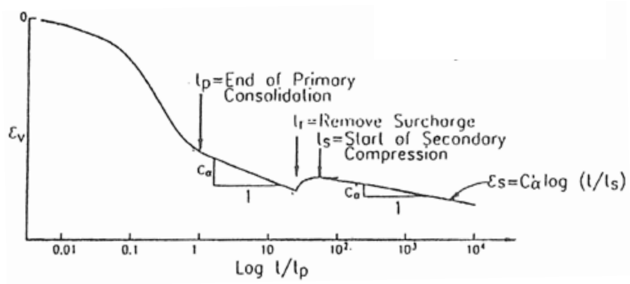

Fig. 2 Effect of surcharge on secondary compression (after Stewart et al. 1994).

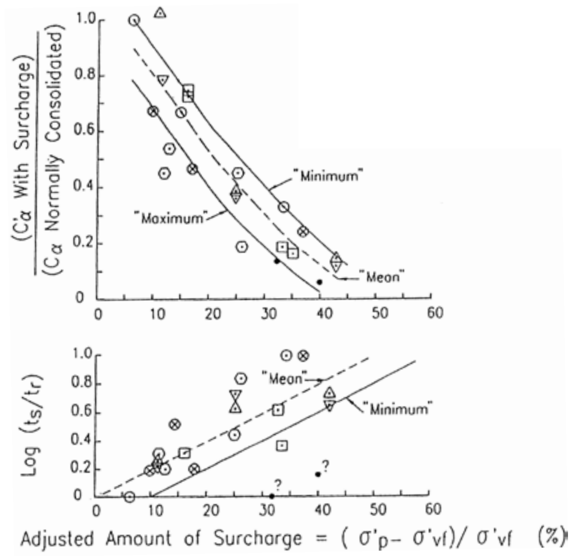

Fig. 3 Reduction in rate of secondary compression due to surcharging (after Stewart et al. 1994).

4 PRELOAD AND SURCHARGE

Ground improvement using preload and surcharge consists of the installation of prefabricated vertical drains (PVDs) and staged embankment construction (preloading with or without surcharge) to accelerate consolidation settlement and reduce post construction settlement.

Preloading generally refers to the process of compressing the soil under applied vertical stress prior to construction and placement of the final construction load.It reduces primary consolidation settlement if the applied load during preloading is less than the long-term design load, or it can eliminate can eliminate the primary consolidation settlement if the applied preload is equal to or greater than the future load.

Surcharging involves embankment construction to a level above the design level, and waiting for a nominated period of time before pavement construction. After the surcharging period, the fill above the design level is excavated. Due to the reduction in stress, the ground is over-consolidated under the design load. Since the ground has been subjected to a higher stress than it has previously experienced, the creep settlement is reduced.

PVDs can be installed into the soft materials to accelerate the discharge of excess pore pressure by providing shortened drainage paths for the water to exit the soil.

5 INSTRUMENTATION AND MONITORING

Geotechnical design is based on the interpretation of available geotechnical information. However, actual ground conditions may vary from design assumptions. Instrumentation and monitoring are required to provide information to reflect actual ground behaviourand confirm theperformance of the design. The collected data and information allow the following:

- Continuously re-evaluate design assumptions and predictions
- Record embankment performance during construction and provide early indications of excessive settlement, slope instability or potential impacts on surrounding structures
- Assist in the safe completion of construction by implementing an observational approach and indicating if/when contingency measures are to be implemented
- Verify that performance requirements are being met

The instruments proposed for the embankment fills will depend on the actual site conditions, geometry of the embankment and the presence of existing infrastructure. For the GU project, settlement plates and piezometers were specified to assist in the assessment of the performance of preload and surcharge treatment methods. Inclinometers were also installed for confirmation of embankment stability during construction. However, their monitoring data are not required for preload release assessment.

6 BACK ANALYSIS AND PRELOAD RELEASE ASSESSMENT

6.1 *Back analysis of monitoring data*

The scope of works for the GU project mandates that pavement construction above compressible foundation materials must not commence until the a Hold Point has been released by the nominated verifier, certifying that the validated predicted total and differential settlements in both the transverse and longitudinal directions satisfy the design criteria. The process of back analysis and preload release assessment is used to demonstrate this.

The results of the back analysis are used to justify the duration of preload period and to ensure that the long term performance of the embankment is not compromised. The process of back analysis involves:

- Obtain the actual fill height and construction history from monitoring data.
- Carry out settlement analysis using the original geotechnical model. If the time settlement curve does not agree with field measurements, refine the model by adjusting soil parameters related the stress history (e.g. OCR), compressibility (e.g. C_c, C_r, and e_0) or rate of consolidation (C_v and C_h) until the two time-settlement curves are in reasonable agreement with each other.
- Compare the total primary settlement predicted by the refined model with that predicted by the Asaoka (1978) method, which is a simple graphical procedure for extrapolating field settlement observation by using earlier observations to predict the end of consolidation settlement.
- Revise long term creep settlement predictions by re-calculating the creep reduction ratio based on the actual final effective stress after the preloading and surcharging.
- Examine the pore pressure response recorded by the piezometer and ascertain whether the excess pore water pressure under fill construction has dissipated.

6.2 *Case study*

The ground treatment zones for the GU Project have been divided into discreet areas based on fill heights and thickness of soft clays. An example has been chosen as a case study to demonstrate the process of back analysis and preload release assessment. The example area is along the northbound carriageway of the Princes Highway, with the following design details:

- Approximate plan area: 20 x 50 m
- Design fill height = 4.9 m
- Ground treatment: Preload for 3 months with PVDs (9.6 m length at 1.2 m triangular spacing) and 1.6 m surcharge
- Design prediction of primary settlement at surcharge removal: 0.6 m

Fill settlement history obtained from monitoring data did not agree with the original settlement predictions. At approximately 1.5 months after the surcharge height has been reached, the total primary settlement is approximately 0.3m (around 50% less than originally predicted). This smaller settlement and faster rate of consolidation could be attributed to smaller compressibility and/or the presence of local sandy lenses which reduces the drainage path for pore pressure dissipation.

Back analysis was undertaken by varying the compressibility and coefficient of consolidation until the predicted settlement using numerical means agree well with the recorded settlement. The approach allowed any local variability in soft soil thickness to be taken into account. The original and refined geotechnical models are summarised in Table 1 below.

Table 1. Original and refined geotechnical model

Depth (m)	S_u (kPa)	C_v^* (m^2/yr)	C_c	C_r	OCR	C_α
0.0 -1.0	30	5 *(30)*	0.725*(0.55)*	0.0725 *(0.0145)*	37.3 *(1.5)*	0.010 *(0.001)*
1.0 -3.6	10	5 *(30)*	0.725*(0.55)*	0.0725 *(0.0145)*	3.4 *(1.3)*	0.012 *(0.004)*
3.6 -4.3	50 *(60)*	5 *(30)*	0.725*(0.55)*	0.0725 *(0.0145)*	10.6 *(2.4)*	0.012 *(0.004)*
4.3 -7.0	100 *(120)*	5 *(30)*	0.375	0.0375*(0.0125)*	13.2 *(4.2)*	0
7.0 -9.0	50	5 *(30)*	0.375	0.0375 *(0.0145)*	3.5 *(1.5)*	0.005 *(0.0005)*
9.0 -12.8	50	50 *(30)*	0.375	0.0375*(0.0145)*	2.6	0.005 *(0.0005)*

(Italics) = Refined geotechnical parameters from back analysis
$^*C_h = 2\ C_v$(in m^2/year)

The back analysed fill history and settlement curve are shown in Fig. 4. The total primary settlement predicted above was compared with the value obtained using the Asoaka (1978) method, as shown in Fig. 5.

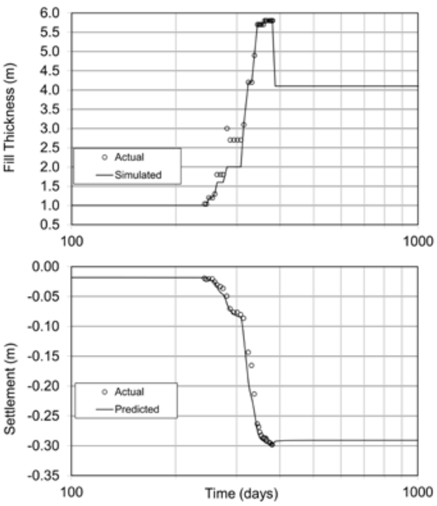

Fig. 4 Back analysed fill history (above) and settlement curve (below) for preload release assessment

The final OCR was determined by dividing the effective stress under the surcharge height by the final effective stress after surcharge removal. This was then used to calculate the revised creep reduction ratio to predict the long term (creep settlement. This was assessed to be approximately 25 mm over 40 years, which was less than the design criteria of 100 mm. Hence it was assessed that the long term performance criteria for the embankment will be met, which allowed the preload and surcharge to be released.

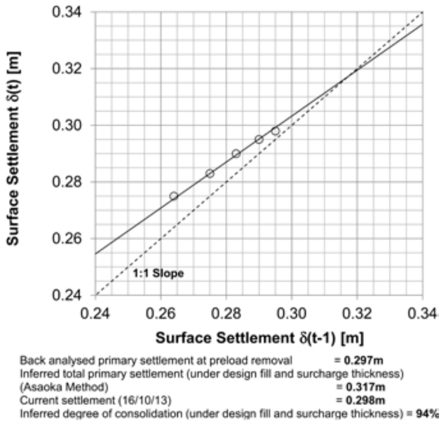

Fig. 5 Asoaka plot for settlement recorded by settlement plate

The excess pore water pressure measured by the piezometers showed little to no response to increasing fill height. This could be because the piezometers were installed close to the PVDs. Hence, they have not been used to assist in the preload release assessment.

7 CONCLUSIONS

Preload and surcharge was used as the ground treatment for fill embankments constructed over soft soils to meet the stringent total and differential settlement criteria. The use of surcharge over-consolidates the soft soil and reduces long termcreep settlement. Back analysis was undertaken to match field measurements with numerical predictions by adjusting the relevant geotechnical parameters and construction sequence. The calibrated geotechnical model was then used to predict the long term settlement to demonstrate that the long term performance criteria over the design life of the embankment will be met.

REFERENCES

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