Deformation Characteristics and Unloading Time for Passenger-Dedicated Railway Surcharge Preloaded Subgrade

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Abstract

Analytical design of surcharge preloading schemes on soft soils were performed using the deformation characteristics corresponding to several surcharge preloading tests. To ascertain the reliability of this technique, investigative data were collected during the construction of a passenger dedicated railway line in China to deduce the design specifications and control standards. This was done by establishing an unloading time equation based on regression curve fitting method of the measured data; given that different types of settlement deformation gives corresponding unloading time calculations. Specific methods for the calculation of surcharge preloading and unloading time point for passengers dedicated line in the railway sector were also examined. Finally, measured data from the Wuhan-Guangzhou passenger line surcharge preloaded embankment were used to verify the design validity and reliability. The predicted results matched with the settlement deformation trend and the post-construction settlement strictly meet with the control standards.

INTRODUCTION

Historically, structural designs on soft compressible soils (clays) have created problems for civil engineers. Construction work carried out without some sort of soil treatment is usually impractical due to unpredictable long-term settlement. Surcharging is a special condition of pre-compression or a preloading technique for soft ground improvement (Jamiolkowski et al., 1983; Johnson, 1970). The principle of surcharging states that over consolidation in soil is generated after surcharging executions. Hence, the post-construction settlements of structures are thus reduced. Although, there are some unsuccessful surcharging applications around the world (Chang, 1981; Sower, 1964)where surcharge loads are removed too early during primary consolidation; post-construction settlements resulting from both primary consolidation and secondary compression are however still excessive.

Therefore, to ensure a stable subgrade over a long period of traffic use there is need for a proper prediction and assessment of loading induced post-construction settlements. The settlements usually appear quickly but may also continue for a long period of time due to secondary compression. Secondary compression consists of creep processes which can cause the subgrade to reinforce but may also lead to a failure of the subgrade and the loading structure. Consequently, the load has to be placed in stages or, alternatively, the soil must be improved through prior treatment (Wolski, et al. 1988). The choice of the construction method has to be dependent on the type of soil, its initial properties and the height of the embankment and it is necessary to use a technique of build embankments which allows them to reach a safe amount of settlement in a short time.

Designers of embankments on soft ground commonly specify the use of surcharge preloading to eliminate post-construction settlements. The method can be a powerful and economical way to build high embankments on soft ground if properly designed and executed. It certainly represents a much cheaper alternative to solutions that involve constructing a rigid foundation such as a piled slab or stone columns beneath the embankment. However, because there have been many cases where post-construction settlements have continued after completion of surcharge preloaded embankments, confidence in the method becomes questionable. A key issue in surcharge preloading embankment is the determination of the unloading time which is related to the optimal regulation of the design process during preloading and construction organization. For a given set of conditions, the optimum time for the removal of surcharge should be determined based on the desired post-construction performance of the embankment. Removing the surcharge too early will prevent the soft soils from achieving sufficient settlement to compensate for the primary and secondary settlements that would occur under the final load.

Currently, tons of research works has been carried out on unloading time method analysis. A commonly used term in time loading analysis is “foundation treatment manual", which states that in the process of surcharge preloading, the unloading time equals to the time when the degree of consolidation equals the ratio of load to the sum of load and surcharge. Engineering practice explains this as a conservative approach, in which the estimated unloading time exceeds the actual time required. Pan et al. (1991), proposed the use of effective stress ratio method to obtain preloading unloading control, and suggested the effective stress ratio 0.75 as control standard. According to Zhang et al. (1999 & 2007), the ratio of consolidation degree and foundation soil surcharge (based on indoor test) should be optimal before the removal of surcharge. The unloading time settlement rate control method for the establishment of settlement rate and post-construction settlement relation curve were proposed by (Zhong, 2001; Tang et al., 2005). These methods are essentially based on soft soil consolidation theory put forward for railway passenger line on soft soil foundation. The purpose of the surcharge preloading is inclined towards the perspective of deformation control; which further accelerates the compressed foundation soil, reducing the amount of post-construction settlement.

Besides, considering the current railway passenger dedicated line, surcharge preloading control theory method has not been successfully applied. We had opportunity to examine some of the cases where the method of surcharge preloading has failed to arrest post-construction settlements. Some highway embankments have kept settling and have required regular topping up to maintain designed levels and certainly, such topping up have caused more severe settlements. We equally observed that the reason for the ineffectiveness of the method is not in the method itself, but in the improper application of the method caused by a lack of understanding of the fundamentals associated with the technique. More so, it is necessary to draw conclusions from data observed from practical engineering project. In summary, Chow et al. (2004) reported that it is of great importance to understand surcharge preloading embankment deformation development law and analyze unloading time analysis methods critically.

In this paper, huge amount of measured data acquired from the Wuhan-Guangzhou railway passenger dedicated line are employed, and the development process of surcharge preloaded embankment deformation is analyzed. Calculation method for unloading time is established based on regression curve fitting analysis of measured data. Finally, the applicability and effectiveness of the technique is examined through engineering practice.

EMBANKMENT SURCHARGE PRELOADING SETTLEMENT DEFORMATION CHARACTERISTICS

On the Wuhan-Guangzhou passenger dedicated railway embankment, large amount of surcharge preloaded embankment observation data were analyzed. Settlement deformation characteristics showed a similar change law. The settlement deformation development process includes (Figure 1):

Filling stage: Foundation settlement deformation increases with increasing filling height, settlement rate is relatively large. The filling load and loading rate are the main factors controlling the development of settlement deformation at this stage.

Constant load stage: In the constant loading stage, more working point were created and it was ensured that all embankment working point has the same constant load, after the completion of filling. The rate of settlement deformation reduces significantly, amount of settlement deformation shows slow growth trend; in addition the time point of the change in settlement rate and point at which loading is stopped coincide. Settlement rate reduces immediately and finally stop few days after loading, reflecting greater rigidity of the foundation after reinforcement.

Surcharge preloading stage: With the rapid increase in the surcharge load, settlement and deformation rate suddenly increase, deformation curve shows clear point of inflection, the amount of settlement deformation increases gradually after the completion of surcharge filling, in the process of settlement the curve gave a concave curve.

Unloading stage: After unloading, settlement deformation rate is significantly reduced and the settlement quickly stabilize, with no significant rebound deformation. The above changes reflects that surcharge preloading can accelerate the compression of a deformed subgrade soil to reduce late settlement rate, the total settlement amount, post-construction settlement value by regression curve fitting analysis based on the settlement deformation observation data during construction period.

It was observed that after reinforcement of the original base the total amount of settlement observed at the basement was generally small, less than 20mm, although few worksite, have more than 20mm, this is due to their thick soft soil layer, the maximum amount of settlement is about 60mm.

Figure 1 illustrates the key elements of the concept of surcharge preloading to compensate for post-construction settlements. Usually, the aim is to eliminate all the primary consolidation settlement and enough secondary settlement such that the residual settlement is within acceptable performance limits (post construction settlement less than 15mm). The residual settlement for a given length of time after construction can be estimated as the remaining secondary settlement that occurs during the required time after the eliminated equivalent time of secondary compression has elapsed.

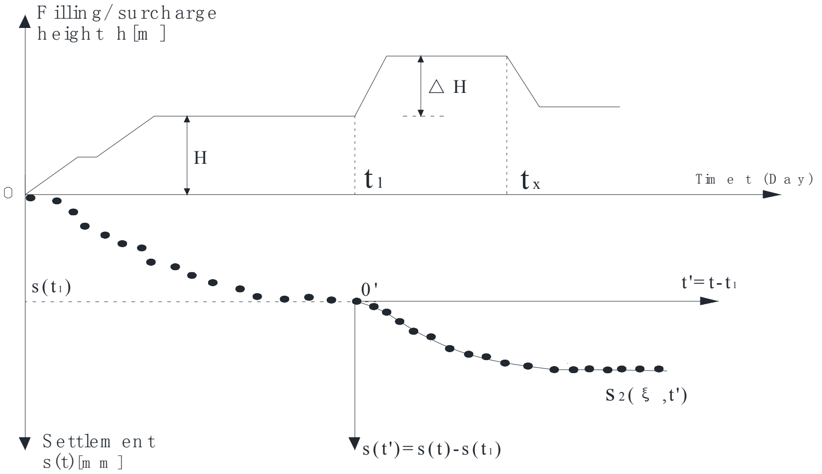

Figure 1. Concept of surcharge preloading to compensate for primary consolidation settlement and secondary compression.

Surcharge preloading section settlement deformation characteristics mainly manifest the following: (1) Significant basement settlement deformation during the filling and surcharge load stage and a high settlementrate; (2) Continuous settlement deformation during surcharge preloading with no significant change in settlement rate; and (3) Significant reduction in settlement rate and gradual stabilization of settlement deformation after unloading.

These features reflect the joint action of the foundation soil embankment and surcharge, they are characterized with a very rapid development of early settlement deformation, and a long period of deformation trend during preloading, although preloading speeds up the basement settlement deformation, but can likely cause the instability and failure of the foundation. After the completion of embankment filling, appropriate surcharge control time and surcharge loading speed, based on the deformation growth and growth rate, is beneficial for the overall stability of the embankment.

UNLOADING TIME DETERMINATION METHOD

Analysis ideas and scheme. The mechanism for surcharge preloaded embankment settlement is not entirely the same as that of soft soil consolidation. For railway passenger dedicated line surcharge preloaded embankment, unloading control method based on consolidation theory has certain limitations. In order to provides a very good reflection of settlement deformation trend some important measures were gathered from regression curve fitting analysis on the settlement deformation observation data obtained during the construction of the Wuhan Guangzhou passengers dedicated line. The measures include: The introduction of post-construction settlement amount control conditions, derivation and establishment of surcharge preloaded embankment unloading time control equation thus determining the unloading time.

Preferred regression curve fitting method. In the process of solving practical problems the criteria of whether the regression curve fitting will or not be able to reflect settlement deformation trend must be ensured. The regression curve fitting method for this research was selected based on the Wuhan-Guangzhou passenger line measured settlement deformation data. General hyperbolic methods widely used in engineering; the Exponential curve method, Three-point method, Asaoka law and Expanded hyperbolic method to verify the system analysis (Wang et al. 2009) were compared, the results showed that three-point method and expanded hyperbolic method can better reflect the settlement deformation trend, higher prediction accuracy, strong adaptability to data fluctuations. Therefore, in the derivation of surcharge preloading section unloading time equation, the expanded hyperbolic and three-point methods were selected for regression curve fitting.

Settlement control standards and requirements. In order to ascertain design parameter embankment surcharge preloaded unloading time determination method follow some specific laid down control standard for the analysis of post-construction settlement and deformation. According to the "Technical Guidelines for assessing ballastless track laying conditions"(2006), the requirements include:

(1) Generally after the laying of ballastless track the post-construction settlement of the embankment must not be greater than 15mm;

(2) Upon embankment completion or after the application of preloading load, there should be a period of 6-18 months for observation and adjustment, i.e. after placing the design load including the surcharge load the constant loading, observation period should not be less than six month.

(3) The final settlement prediction before track layingshould meet the basic requirements of its predictiveaccuracy, that is, the settlement from the embankment filling or after preloading and final settlementprediction value should meet the following condition: $S(t)/S(\infty)\geq 75\%$, where S(t)is the actual settlementfrom subgrade filling or preloading completion,$S(\infty)$is the predicted final settlement from subgradefilling or preloading completion.

(4) Using the regression fitting curve for the prediction of post-construction settlement, correlation coefficient should be greater than 0.92.

The above requirements should be fully considered during the analysis of embankment post-construction settlement surcharge preloading segment.

Unloading time determination method based on curve regression equation. Figure 1 typically shows a schematic representation of surcharge preloaded embankment settlement deformation process. H represents filling height before surcharge; ΔH is the surcharge load height, t_1 is the start time for the application of overload, $s(t_1)$ is the corresponding settlement, t_X is the unload time point. Since surcharge can cause curve to produce significant turning point, surcharge and embankment filling speed are generally different, observed data obtained before surcharge, produce large deviation of fitting. Therefore, observation data used for fitting are generally obtained after the overload is applied.

In accordance with the requirements of post-construction settlement control, during unloading the predicted post-construction settlement S_R should be less than control standard $S_{R,p}$ thus we can have:

$$s_R < s_{R,p} = 15mm \tag{1}$$

For the surcharge preloading embankment, post-construction settlement under design load conditions is the difference between the final settlement deformation predicted value $s_2(\xi_f, \infty)$ and unloading settlement amount $s_2(\xi_{max}, t_x)$,ξ is a ratio of current load to the total load, predicted post-construction settlement is equal to the control standards [SR, p] when the time t_{X1} corresponds to the minimum preloading time.

$$s_R = [s(t_1) + s_2(\xi_f, \infty)] - [s(t_1) + s_2(\xi_{max}, t_x)] \leq [S_{R,p}] \tag{2}$$

Using expanded hyperbolic fitting method, after surcharge, settlement S(t), fitting equation becomes,

$$s_2(\xi, t') = \frac{\xi \cdot t'}{a + b \cdot t'} \tag{3}$$

Where,$t' = t - t_1$, $\xi = \frac{h}{H+\Delta H}$for foundation load level, before surcharge load constant load stage load levels is :

$$\xi = \frac{H}{H+\Delta H} \tag{4}$$

Preloading stage of foundation reach the maximum load level at $\xi max = 1.0$, after the completion of track laying (Design loads) load level becomes;

$$\xi_f = \frac{(H\gamma + p_s)}{[(H+\Delta H) \cdot \gamma]} \tag{5}$$

p_s represent ballastless superstructure track weight, γ represent filling average bulk density.

According to expanded hyperbolic fitting equation, after unloading, the settlement amount equals:

$$s_2(\xi_{max}, t_x) = \frac{\xi_{max} \cdot t_x}{a + b \cdot t_x} \tag{6}$$

Predicted final settlement deformation amount under design load conditions is given as;

$$s_2(\xi_f, \infty) = \frac{\xi_f}{b} \tag{7}$$

By substituting equation (6) and (7) in control conditions (2),we have:

$$\frac{\xi_f}{b} - \frac{\xi_{max} \cdot t_x}{a + b \cdot t_x} < [s_{\mathrm{R,p}}] \tag{8}$$

Leads to:

$$t_x > \frac{a\xi_f - ab[s_{\mathrm{R,p}}]}{\xi_{max} - b\xi_f + b^2[s_{\mathrm{R,p}}]} \tag{9}$$

The above formula is based on Expanded hyperbolic regression fitting unloading time equations (similar result was obtained through the Three-point method as well); substitute $\xi_{\max}$ =1.0, and the post-construction settlement control value $[S_{\mathrm{R,p}}]$= 15mm into equation 9,

$$t_x > \frac{a\xi_f - 15ab}{1 - b\xi_f + 15b^2} \tag{10}$$

As long as fitting after preloading observation data is accurate, fitting parameters "a" and "b" are easily calculated using equation (10), post-construction settlement equal to 15mm, preloading shortest time t_{X1}.

VERIFICATION OF UNLOADING TIME DETERMINATION METHOD

In order to verify the effectiveness of the above methods, the Wuhan-Guangzhou passenger line typical surcharge preloaded sections confirmatory analysis is presented. Different settlement deformation sections were selected and analyzed. The section is characterized with long period of constant load before surcharge, with final settlement amount less than 20mm, representative cross-sections are DK1671 + 440, DK1671 + 518 and DK1672 + 850.

The surcharge preloaded stage observational data were used for the calculation of unloading time point and post-construction settlement amount using the above equations. The actual observation data after unloading were used in carrying out comparative validation.

Unloading Time Analysis. K1671 + 440 and DK1671 + 518 preloading sections lies on the same location, on the January 6, 2008 graded gravel bed filling of the first layer of subgrade bed commenced, preloading started on February 25, 2008.The filling of the first layer of subgrade with graded gravel was done on the DK1672 + 850 section on October 27, 2007, December 11, 2007 starts preloading.

The settlement deformation processes of the three sections are basically the same, there is a constant loading period before heaping, during constant loading stage settlement deformation gradually stabilized as shown in the DK1671 + 440 section surcharge preloading stages settlement curve (Figure 2), but after the application of surcharge load the amount of settlement deformation increases, settlement rate increases, in the process of settling the curve give a concave curve. The calculation results are listed in Table 1.

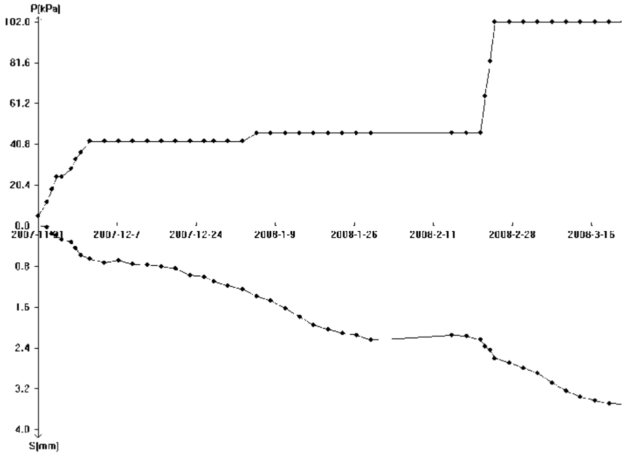

Figure 2. DK1671 + 440 surcharge preloading phase of settlement deformation curve.

As shown in Table 1, the unloading time for DK1671 + 440 and DK1671 + 518 are 26 days and 35 days respectively. Post-construction settlement is fixed as "0" during the calculation, the actual surcharge preloading time took 30 days, that is, the unloading started on March 25, 2008. DK672 + 850 section unloading time is 80 days, the actual control is three months, i.e. it unload on March 11, 2008 .

Table 1. Wuhan-Guangzhou passenger line [DK1671 + 426 ~ DK1672 + 850] surcharge preloading embankment sections permitted unloading time point analysis

Observations section	DK1671 +440	DK1671 +518	DK672 +850
Filling height H (m)	2.30	5.57	3.05
Overload height ΔH (m)	2.77	2.73	3.05
Filling density γ (kN / m3)	20	20	20
Structural layer load *ps* (kPa)	15	15	15
Design load ratio ξf	0.60	0.76	0.62
Preloading stage observed settlement amount s (t) (mm)	3.51	5.81	7.18
Predicted final settlement amount s (ξmax, ∞) (mm)	4.25	6.40	9.02
Post construction settlement S_R (mm)	0.74	0.59	1.84
Unload time point 1: (mm)	26	32	80
Unload time point 2: (mm)	10	35	72
Unloading control time point $t_X = \max(t_{X1}, t_{X2})$	26	35	80

The deformation curves for the settlement of DK1671+440 sections after unloading as shown in Figure 3, showed that settlement rate decreases after unloading, and stabilized quickly. Contrast can be seen in Table 2, after unloading, settlement deformation increment is small, only in the range of 0.1mm~0.3mm,when the observed data after unloading is used to calculate post-construction settlement the result is always less than using the preloading stage observed data to calculate post-construction settlement amount, the post-construction settlement in both cases are less than 1mm, substantially close to zero, this shows that unloading time control conditions are consistent, which proves the effectiveness of the of the unloading time calculation methods.

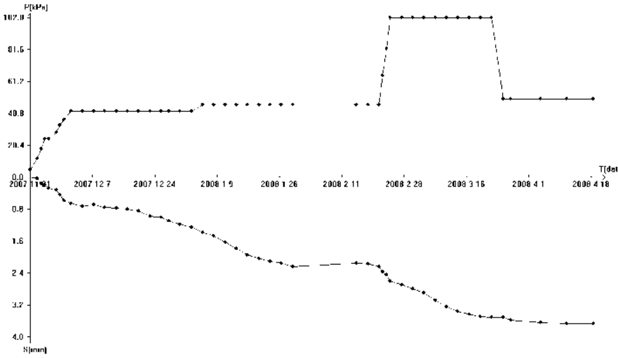

Figure 1. DK1671 + 440 settlement deformation curves of surcharge preloading after unloading.

Table 2. Wuhan-Guangzhou passenger line [DK1671 + 426~DK1672 + 850] surcharge preloading embankment section unloading time validation analysis.

Observations section	**DK1671 +440**	**DK1671 +518**	**DK672 +850**
Observed stable settlement amount s(t) (mm) after unloading	3.64	5.87	7.49
The actual surcharge preloading time t_x(d)	30	30	90
Predictedpost-construction settlement amount S(mm) ($\xi_f \infty$)	0.39	0.48	0.61

CONCLUSION

This paper delves into the actual method of analyses for designing surcharge preloading schemes on soft soils. Considering the current railway passenger dedicated line, surcharge preloading control theory method has not been successfully applied. Some highway embankments kept settling and have required regular topping up to maintain their design levels and of course such topping up have caused more severe settlements. We found that the reason for the ineffectiveness of the method is not in the method itself, but in the improper application of the method caused by a lack of understanding of the fundamentals associated with the method.

Observed measured data obtained during the construction of passenger dedicated Railway line in China were used in the analytical design of surcharge preloading schemes on soft soils. The analysis was performed using the deformation characteristics corresponding to several surcharge preloading tests. To ascertain the reliability of this technique, the investigative data collected during the construction of a passenger dedicated railway line in China to deduce the design specifications and control standards. This was done by establishing an unloading time equation based on regression fitting method of the measured data; given that different types of settlement deformation gives corresponding unloading time calculations. Specific methods for the calculation of surcharge preloading and unloading time point for passengers dedicated line in the railway sector were also examined. Finally, measured data from the Wuhan-Guangzhou passenger line surcharge preloaded embankment were used to verify the design validity and reliability. The predicted results matched with the settlement deformation trend and the post-construction settlement strictly meet with the control standards.

ACKNOWLEDGMENTS

The authors appreciate the support of Chinese Academy of Sciences/The World Academy of sciences scholarship, CAS/TWAS.

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