Back Analysis to Estimate Resilient Modulus of Soft Clay

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ABSTRACT: Selection of an appropriate resilient modulus for soft clay subgrade is important in the assessment of formation (sub-ballast) thickness and dynamic deflection of rail tracks. When no site specific laboratory cyclic triaxial tests or field measurements are available, published data can be used for the selection of resilient modulus. Sometimes, adopting a resilient modulus from the published data leads to a conservative design, leading to an increase in formation thickness and construction cost. This paper presents abackanalysis carried out to estimate the resilient modulus of soft clay based on field measurements for a rail project at Hexham, New South Wales, Australia. The back analysis results indicated that are silent modulus of 600 to 700 times the undrained shear strength of soft clay can be adopted for the design.

1 INTRODUCTION

1.1 *Project Background*

Hexham Relief Roadsproject (HRR), commissioned by the Australian Rail Track Corporation (ARTC),involved construction of five Relief Roads (tracks), a down coal track and associated infrastructures at Hexham in the NSW Hunter Valley, approximately 160km north of Sydney. The alignment of the HRRwas located over the low lying floodplain of the Hexham Swamp that comprised Quaternary Aged sediments (soft clay) overlying the Permian aged Tomago Coal Measures. Soft clay thickness varied between 12 m and 25 m within the project corridor. The length of each rail track varies up to 3.2 km.

1.2 *Design Criteria*

The formation design for the HRR project was carried out adopting two design criteria summarized below fora rail track configuration shown in Fig. 1.

Strength Criterion:
The formation thickness should be sufficient enough to reduce the risk of subgrade failure due to static and repeated train loadings.

Operational Criterion:
Dynamic deflection of the tracks should be less than the allowable limits (allowable limits for turn outs and plain tracks were 10 mm and 17 mm, respectively for the HRR project). In this step, dynamic deflection was predicted adopting the formation thickness assessed from Strength Criterion above to check whether it is within the allowable limit. If not, formation thickness was increased until the deflections are within the limit.

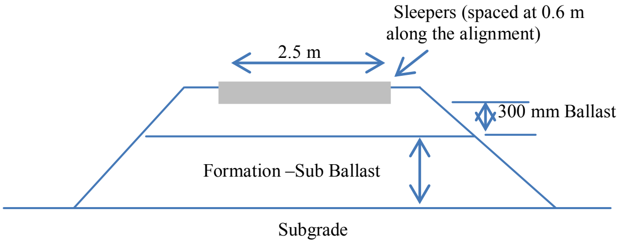

Fig. 1 Components of a Rail Track - HRR Project

Any small increase in formation thickness will increase construction cost significantly considering the amount of material required to construct formation for six rail tracks over a length of 3.2 km. Therefore, formation design should consider appropriate resilient modulus for soft subgrade to develop an economical design. This paper summarizes a back-analysis conducted to assess the resilient modulus of soft clay from field measurements.

2 RESILIENT MODULUS OF SOFT CLAY

Assite specific laboratory cyclic triaxial tests were not carried out on the soft clay during the site investigation for the HRR project, published data was used for the estimation of resilient modulus for the initial design purposes. From a wide range of resilient modulus values available from published data, a resilient modulus of 500 times the undrained strength of the soft claywas adopted for the initial design (Sukumaran, *et.al*. 2002, Abdullah, *et.al*. 2012, Loh, B.H. 2011).

Formation thickness was initially assessed adopting the strength criterion and then it was used to assess dynamic deflection of the tracks. The assessed dynamic deflections exceeded the allowable limits, leading to an increase in formation thickness and construction cost. Recognizing the fact that the adopted resilient modulus of 500 times the undrained shear strength for soft clay is relatively low, the HRR project team decided to measure dynamic deflection of an operating rail track located closer to the project corridor for the purpose of back calculating the resilient modulus. Adopted methodology to measure dynamic deflection and back analysis approach to assess the resilient modulus are summarized in the following sections.

3 PILE DRIVING MONITOR SURVEY

Pile Driving Monitor (PDM) survey technique was used to record the dynamic deflection of an operatingrail track located close to the HRR project corridor. Originally developed for pile driving procedures, the PDM can also be used to measure the deflection of rail roads, bridges and highways under repetitive wheel loadings.

A PDM was set up outside the rail corridor in a stable platform. A target was then set up on the sleeper where deflection is to be measured. Initially, a baseline reading was taken to assess the stability of the PDM and it indicated that the PDM settled by 0.4mm to 0.8mm when there is no trains on tracks. Then the dynamic deflection was recorded when train was passing. Recorded maximum dynamic deflection of the track was approximately 6.5 mm when a train was passing (Fig. 2). Therefore, the total dynamic deflection as assessed using the PDM readings can be in the range of 6.9mm to 7.3mm.

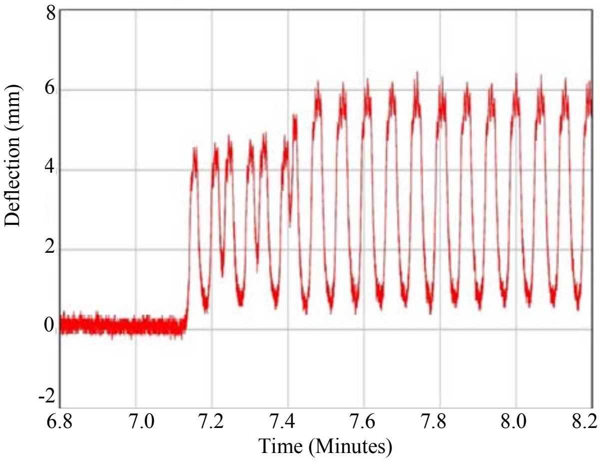

Fig. 2 PDM Monitoring Data with Train

4 GEOTECHNICAL MODEL

A geotechnical model was developed for the analysis based on the available cone penetration test and test pit results near the measurement location. The adopted material parameters and resilient modulus for each material is summarized in Table 1.

Table 1. Adopted Geotechnical Model

Material	**Thickness (m)**	**Undrained Shear Strength(kPa)**	**Resilient Modulus,(MPa)**
Ballast	0.7	-	150
Fill	0.3	-	100
Stiff Clay	0.6	75	
Firm Clay	0.3	45	
Very Stiff	1	150	600 to 700timesundrained shear strength of Soft/Firm and Stiff Clay
Soft Clay	0.7	25	
Stiff Clay	0.5	50	
Soft Clay	1	14	
Sand	1	-	
	1.5	16	
Soft to Firm Clay	20	Increases from 16 at a rate of 1.2 kPa/m	

5 TRAIN LOADINGS

The PDM readings were recorded when a train with four 30Tonne axles (refer Fig. 3)was passing measurement point at a speed of 15 km/h.A dynamic load allowance factor (F_d) was assessed based on the relationship reported by Li and Selig (1998) to predict the dynamic loads (Eq. 1).

$$F_d = \left[1 + 0.0052 \frac{V}{D_w} \right] \qquad (1)$$

Where, V (km/h) is the train speed and D_w (m) is the diameter of wheel.The wheel diameter was assumed to be 0.95 m.

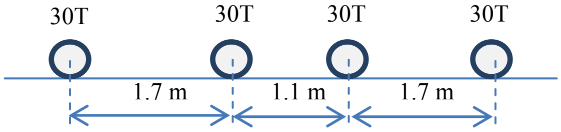

Fig.3 Axle Configuration Considered for the Study (As per AS5100.2 – 2004, excluding simulated locomotive)

6 BACK ANALYSIS METHODOLOGY

Ballast and formation fill will distribute train loads in both longitudinal and transverse directions to the alignment of the rail track. Commercially available computer software, Plaxis3D, was used in the back analysis to model the load distribution. The PLAXIS 3Dfinite element modeling has been carried out simulating the axle loads shown in Fig. 3. Adopted sleeper/rail configuration is presented in Fig. 4.

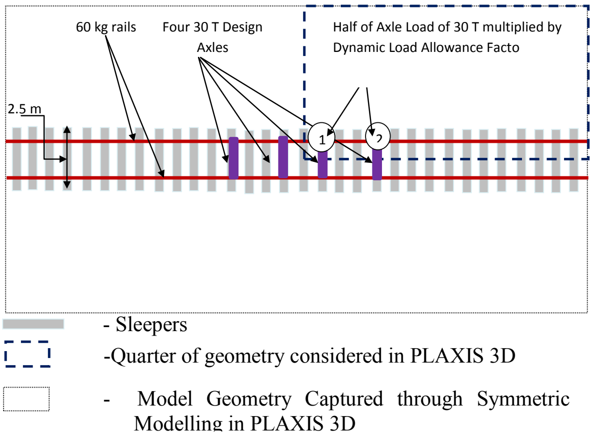

Fig. 4 PLAXIS 3D Modeling Geometry

Considering the symmetric nature of the model geometry shown in Fig. 4, a quarter of the model geometry has been adopted in PLAXIS 3D modeling (refer Fig. 5 below). Symmetric modeling adopting a quarter of the model geometry will capture the effect of loading from four design axles.The load applied on the rail is 162kN at each axle location, which is the half of the design axle load of 300 kN multiplied by a dynamic load allowance factor of 1.08.

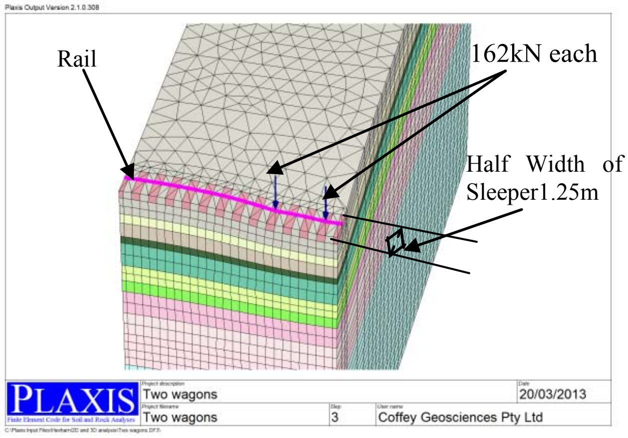

Fig. 5Adopted in PLAXIS 3D Mesh - Symmetric Modeling

In general, the following construction stages were considered for this study:

1. Initial condition – K_0 procedure
2. Apply repeated train loadings – Plastic analysis.

For all stages prior to applying repeated wheel loadings, formation fill, ballast and existing fill were modeled using a Mohr-Coulomb model while aSoft Soil model was adopted for the soft soil layers. When the repeated wheel loadings were applied, all materials were switched to drained linear elastic material with appropriate resilient modulus provided in Table 1. The Poisson's ratio for the soft soil layers during the repeated train loadings stage was assumed to be 0.49 considering undrained conditions.

A beam element was adopted to model the 60 kg rail in PLAXIS 3D with the following sectional parameters (As per ARTC code of practice Section 1: Rail - 2011 and AS1085.1-2002):

1. Cross sectional area = 7,725 mm^2
2. Second moment of area = 29.3x107mm^4 about horizontal axis of rail cross section
3. Second moment of area = 4.9 x106mm^4about vertical axis of rail cross section

An elastic modulus of 200 GPawas adopted for the rail. Resilient modulus of soft clay has been increased until the dynamic deflection assessed from PLAXIS 3Dmodelling matched with the PDM measurement. Resilient modulus of ballast and existing fill were not adjusted for the back analysis purposes.

7 RESULTS

The measured dynamic deflection using PDM technology at the selected location was in the range of 6.9mm to 7.3mm for a train with 30 T axles. Adopting resilient moduli of 600 and 700 times of the undrained shear strength for soft clay resulted in a dynamic deflection of 7.2mm and 6.5mm, respectively. These findings from this case study have been used to optimize the formation thickness for the HRR project.

8 CONCLUSIONS

Resilient modulus of soft clay is important parameter in the assessment of formation thickness and dynamic deflection of train tracks constructed over soft clay subgrade. Resilient modulus assessed from published data led to increased formation thickness and construction cost in the HRR project. Back-analysis of field dynamic deflection measurements demonstrated that the resilient modulus of 600 to 700 times the undrained shear strength can be adopted for the soft clay presents in Hexham Swamp area.The findings from this case study have been applied to optimize the formation thickness and thereby to reduce the construction cost of the HRR project. The HRR project has been successfully completed in 2014 and opened to traffic.

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