APPLICATION OF ACSW STIFFNESS PROFILING DATA TO TRACKBED INVESTIGATION, DESIGN AND VALIDATION

Guidance Note SSGN017

Background

Formation stiffness (E) is a fundamental control for railway track deformation, and hence for the design of trackbed, to maintain track alignment within acceptable tolerances. A further consideration for high-speed rail is critical velocity - the velocity of surface Rayleigh wave propagation (V_r) due to train passage, where V_r should be greater than the maximum design speed to avoid interaction of the train with its bow wave. V_r is a function of formation stiffness.

Advanced Continuous Surface Wave (ACSW) testing provides a method of determining the stiffness profile of the ground rapidly and non-intrusively. Testing is undertaken using a portable vibrating source (shaker) and an array of surface geophones to measure the speed at which surface Rayleigh waves travel through the ground (V_r) over a range of frequencies, controlled by integrated software. This information can then be used to derive a profile of ground stiffness with depth. Values obtained are small-strain stiffness values which can be user-adjusted according to the drainage properties of the ground and operational strain levels to generate design stiffness values.

ACSW testing is increasingly being used in the railway environment for optimisation of foundations for bridge replacement and electrification schemes. ACSW testing has also been successfully used as a rapid and cost-effective alternative to conventional trackbed stiffness testing in that it:

- **Provides accurate, simple-to-use stiffness data - including user editable inputs such as strain softening values**
- **Is non-intrusive, minimising the risk to services**
- **Is rapid - each test taking only around half an hour to complete including move and setup**
- **Does not require specialist track plant**
- **Can be moved along track by rail trolley and moved off track by hand**
- **Does not affect the track and can be undertaken within the 4-foot**
- **Provides a direct measurement of Rayleigh wave velocity (V_r) for high-speed track design**
- **Provides a stiffness with depth profile giving additional information on stratigraphy**
- **Provides data measured at a known strain capable of being used for complex analysis of track deformations or for design of other structures**

This guidance note outlines the applicability of ACSW data to trackbed formation stiffness determination with reference to current Network Rail standards.

See references below, available from info@soilsafe.co.uk , for more information on the ACSW technique.

APPLICATION OF ACSW STIFFNESS PROFILING DATA TO TRACKBED INVESTIGATION, DESIGN AND VALIDATION

Guidance Note SSGN017

Trackbed Stiffness Investigation Methods

A comparison between ACSW and the methods listed in NR/L2/TRK/4239 is shown in Table 1 below.

Table 1: Comparison between common track stiffness measurement techniques and ACSW testing.

Method	Requirements	Observations
Falling Weight Deflectometer (FWD)	• Specialist plant • Unclipping of load sleeper	• Requires information on trackbed thickness to analyse • Strain at measurement not known – assumed to be equivalent to train loading • Can be used to derive critical velocity
Light Weight Deflectometer (LWD)	Excavation of pits to formation level to 1.5 times plate diameter	• Extent of testing limited by plate size (100 to 300mm) • Depth of testing limited by plate size: stiffness measured to depth of nominal 2 times size plate • Cannot be used on gravelly surfaces (maximum particle size limit) • Portable, can be moved manually • Rapid: immediate output
Penetration testing	Intrusive investigation	Relationships between penetration testing and stiffness are often highly inaccurate (*see BS5930*)
Empirical relationships with undrained shear strength of clays (c_u)	Intrusive investigation	Relationships between cu and stiffness are not accurate without site calibration
Advanced Continuous Surface Wave (ACSW) testing	Rail trolley transport along track if no vehicle access	• Provides a stiffness profile to depth without intrusive works, giving additional information on stratigraphy • Stiffness measured at known strain - suitable for complex analyses if required • Representative bulk stiffness over a typical 2-3m test length • Outside of possession 12 to 20 tests typical per shift; in possession 6 to 10 tests per 4hr shift typical • Portable, can be moved manually

Use of ACSW Data for Trackbed Formation Stiffness Evaluation

ACSW data can be adjusted according to drainage conditions (Poisson's ratio) and strains (strain-softening function) to give values which are directly comparable with any other accurate stiffness measurement. Formation stiffness values given by Network Rail trackbed standards are based on values obtained using FWD or other plate bearing-type tests. Loads exerted by rolling stock and plate bearing-type tests are transient, and therefore in fully saturated conditions stiffness moduli for cohesive materials can be anticipated

to be undrained (Poissons' ratio of 0.5). Where drainage conditions are unknown adopting a Poisson's ratio of 0.26 for typical drained conditions will be conservative (i.e. give lower bound stiffnesses). From FE modelling of typical plate load type tests strains can be demonstrated to be of order 0.1%.

ACSW data converted to E using a Poisson's ratio of 0.26 and strain-softened to 0.1% (provided as the SoilSafe default in data outputs but editable by the user) will give stiffnesses equivalent to that obtained by FWD and other plate bearing-type tests. SoilSafe is able to present case studies to demonstrate this for tests such as plate load. The equivalence of ACSW data adjusted using these parameters has also been recently demonstrated as part of trackbed investigations at Blackburn Stabling Depot where ACSW data was compared with LWD data and provided equivalent results.

ACSW data offers considerably more representative data than that provided by LWD testing in that it uses a 2-3m test length and data is not limited by the effects of plate diameter. ACSW data removes the need for reliance on inaccurate relationships between stiffness and undrained shear strength or penetration testing.

Use of ACSW testing provides low-risk stiffness testing data over a test length equivalent to that for FWD data, rapidly and without the need for specialist plant. However, ACSW data is able to characterise the ground stiffness profile to depth, providing additional information on ground conditions – such as the extents of soft layers - which may be relevant for site assessment. Furthermore, whilst FWD data is semi-empirical – it assumes that strains exerted during testing are equivalent to those from rolling stock – ACSW data is measured at a known small-strain and can therefore be used for more complex analyses where actual predictions of deflections are required.

As for any test data, appropriate professional judgement is required in using ACSW data for trackbed design, however SoilSafe provides ACSW outputs as fully editable Excel spreadsheets allowing sensitivity to change in inputs such as Poisson's ratio and strain to be evaluated as part of the design process.