Civil Engineering Design Standard

PART 7
GROUND MOVEMENT PREDICTION

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Custodian
Standards Manager

Please notify the Custodian of all errors, omissions and suggestions for improvement.

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1.0 – 3.0						Civil Engineering Design Manual (CEDM)

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7 GROUND MOVEMENT PREDICTION

7.1 Introduction

This design standard forms part of the Civil Engineering Design Standard (CEDS) and shall be used in conjunction with Part 1 document number CR-STD-303-1 Part 1: Introduction and General Requirements.

Part 7 of the CEDS describes the formulae and calculation methods that shall be used to calculate ground movements.

Part 8 describes the process that shall be followed to complete the assessment process and where necessary design mitigation works.

This Standards sets out methods to be used for determining short-term ground movements. The Designer shall however establish the magnitude and extent of long term ground movement (including consolidation settlement) and determine any increase in differential settlement and structural damage that results.

Within this Standard the Designer is permitted to propose alternative assessment methods for agreement with CRL. Should the Designer be of the opinion that the methods proposed in this Standard are not sufficiently conservative they shall propose alternative methods. However, for an alternative method to be accepted it shall either have been published and subject to sufficient peer review, or otherwise verified (for example by field data or case histories).

7.2 Deliverables

Structures within the zone of influence of ground movements caused by the construction of Crossrail shall be assessed and the following documents prepared where appropriate:

a) Conceptual Design Statement

b) Calculations and Drawings

c) Mitigation design and implementation proposals

d) Process for implementing mitigation measures

e) Contingency Plans

f) Monitoring Plans including trigger levels for settlement and movement monitoring.

g) Emergency Preparedness Plans (EPP's)

h) Compliance Statement

7.3 Assessment Phases

The assessment Phases used to evaluate the impact of ground movement on existing structures are covered in Part 8 of this standard.

During Phase 1, Phase 2 and Phase 3 (Iteration 1), empirical methods should be adopted for the prediction of ground movements. However, where required in this Standard they shall be verified by comparison with the structural and geotechnical analyses being undertaken for the design of the new structures.

Beyond Phase 3 (Iteration 2) numerical modelling may be necessary. The Designer shall propose analysis methods for agreement with CRL.

7.4 Empirical Ground Movement Prediction

7.4.1 Surface Movements from Bored Tunnels

Vertical movements (both transverse to the tunnel and longitudinal) shall be derived using the following methods:

a) O'Reilly and New (1982) or New and O'Reilly (1991). This is appropriate for predicting surface movements where the ground cover is greater than one tunnel diameter above the crown of the tunnel.

b) New and Bowers (1994) which replaces a point sink approach with a ribbon sink. This is appropriate for predicting surface and sub surface movements which are within one diameter of the crown of the tunnel.

Horizontal movements shall be derived assuming no change in volume of the ground (i.e. undrained conditions) and that the ground movement vectors are directed at either a point sink or a ribbon sink in the vicinity of the tunnel.

7.4.2 Subsurface Movements from Bored Tunnels

Short-term subsurface movements from bored tunnelling shall be initially predicted using empirical methods. The preferred method is to use New and Bowers (1994) which proposes a ribbon sink as the source of movement. This is appropriate for a range of ground conditions.

Alternatively Mair et al (1993) may be used but is only appropriate for tunnels in stiff clays.

7.4.3 Segmental, SCL and Caisson Shafts

London Underground Manual of Good Practice, number G-058 Issue A10 July 2009 (or later version) shall be used as the basis for the prediction of ground movements due to shafts being constructed using the following methods:

a) Segmental linings either sunk as caissons or by underpinning.

b) Caissons.

c) Sprayed Concrete Linings.

d) Any combination of the above.

This refers to the model proposed by New and Bowers. However, as noted in the London Underground Manual of Good Practice G-058 the New and Bowers method does not take account of shaft diameter and does not cover the prediction of horizontal movements. The Designer shall propose a suitable correction for shaft diameter and a method for predicting horizontal movements for CRL agreement. The Designer's proposal shall be based on a robust engineering theory validated by either: back-analysis of suitable field data; a reliable programme of laboratory testing; or numerical modelling.

7.4.4 Embedded Retaining Walls, Shafts and Box Structures

This section applies to all types of embedded retaining wall (e.g. piled walls, diaphragm walls) and shafts or box structures constructed using embedded retaining walls as ground support. The Designer shall propose the methods to be used for calculation of ground movements (vertical and horizontal) but due cognisance shall be given to the methods in both:

a) CIRIA Report C580 Embedded Retaining Walls: Guidance for Economic Design.

b) London Underground Manual of Good Practice G-058 Issue A10 July 2009 (or later version)

In particular, London Underground Manual of Good Practice G-058 provides guidance on predicting movements due to short lengths of embedded walls and on making allowance for corner effects.

Movement predictions arising from embedded wall construction methods shall be verified by comparison with the geotechnical and structural analyses undertaken as part of the design of the structures. These analyses shall allow for the wall stiffness, propping and excavation sequence, propping and excavation levels, prop and waling stiffness etc.

7.4.5 Dewatering

The Designer shall make allowance for ground movements due to dewatering.

7.5 Numerical Modelling

Where numerical models are required beyond Phase 3 (Iteration 1) the Designer shall select appropriate methods and propose these for CRL agreement. All numerical modelling methods shall be:

a) Calibrated by reference to back-analysis of previous excavations and monitoring data.

b) Verified by comparison with alterative calculation methods.

Where the designer considers that the above methods and precedent experience is insufficient to justify his design he may propose model tests such as centrifuge testing to calibrate his analysis.

7.6 Parameters

7.6.1 Volume Loss

In order to estimate the ground movements resulting from a tunnel excavation it is necessary to determine an appropriate volume loss. Table 7.1 sets out appropriate volume loss parameters to be used for assessment.

The conservative values for Set (i) in Table 7.1 are those used for the settlement assessments used in support of the Parliamentary Process for the Crossrail Bill. The Figures are historic and are based on open-faced tunnelling in London Clay. They shall be used as a coarse upper bound filter to eliminate properties not at risk of damage from tunnel settlement.

The moderately conservative values for Set (ii) in Table 7.1 are based on the proposed construction methodology and should be the starting value for assessment of third party assets. For single tunnels these figures should be readily achievable using standard good practice in construction.

The best estimate values for Set (iii) in Table 7.1 are considered to be reliably achievable in uniform ground conditions provided that industry best practice construction and monitoring procedures are adopted. If the designer considers that there is a significant risk of damage where these volume losses are exceeded (up to the values in Set (ii)) then this must trigger an action to develop mitigation measures in the compliance documentation.

Tunnel Type	Set (i) Conservative (Used for the Hybrid Bill)	Set (ii) Moderately Conservative	Set (iii) Best Estimate
Segmental lined closed face EPBM driven tunnels	1.7%	1.0%	0.5%
Segmental lined slurry TBM driven tunnels	1.7%	1.0%	0.7%
Platform enlargements from a TBM Pilot tunnel	2.0%	1.25%	1.0%
Concourse & platform tunnels without TBM pilot	2.0%	1.5%	1.0%
Inclined escalator tunnels, cross passages & adits	2.0%	1.5%	1.0%

<u>Notes</u>

1. The designer may propose alternative volume loss figures to those proposed where justified by specific site circumstances.
2. Volume losses are based on experiences in competent London Clay and the formations below.
3. Special consideration shall be given to the selection of parameters for tunnels in the superficial deposits, made ground or sands close to the surface.
4. With the exception of segmental lined tunnels the above volume loss figures are based on SCL. Ground losses for hand excavation, square works and junctions shall be separately assessed.
5. Figures shall be used for the prediction of short term ground movements only.

Table 7.1: Volume Losses to be used for Assessment Purposes

7.6.2 The trough width parameter, K

The trough width parameter to be used for the empirical prediction of ground movements are as follows, unless the Designer proposes alternative parameters with justification which are agreed with CRL:

a) Cohesive soils (e.g. London Clay) K= 0.5

b) Granular material (e.g. Terrace Gravel) K = 0.35

c) Thanet Sands (which is a very stiff cemented sand) K = 0.5

Experience in London indicates that the trough width parameter is rarely less than 0.4 and where modern TBM tunnelling methods result in low volume losses (<1.0%) there is evidence that a wider trough width parameter with K>0.5 is appropriate.

Where the above analysis identifies structures that are on the border/within the moderate damage category a sensitivity analysis should be undertaken to assess the impact of variations in trough width parameter on the risk damage category. This is particularly important for establishing the horizontal extent of the monitoring scheme.

7.7 Reference Documents

1) CIRIA Report C580 (2003), Embedded Retaining Walls: Guidance for Economic Design.

2) Mair et al. (1993), Subsurface settlement profiles above tunnels in clay, Geotechnique, Vol 43. No 2, pp315-320.

3) New and O'Reilly (1991), Tunnelling induced ground movements : predicting their magnitude and effects, Invited review paper to4th International Conference on Ground Movements and Structures, Cardiff, Pentech Press, London.

4) New and Bowers (1994), Ground movement model validation at the Heathrow Express Trial Tunnel. Tunnelling 94. Institution of Mining and Metallurgy, London. Pp 301 – 329.

5) O'Reilly and New (1982), Settlements above tunnels in the United Kingdom – their magnitude and prediction, Tunnelling 82. Institution of Mining and Metallurgy. London pp 173 -181.

6) London Underground, Manual of Good Practice, Number G-058 Issue A10 July 2009 Civil Engineering - Technical Advice Notes