RPA
Railway Procurement Agency

METRO NORTH
ORAL HEARING
PROOF OF EVIDENCE

Geoff Featherstone

Ground Movement

Thursday 23rd April 2009

Metro North Oral Hearing

Proof of Evidence

Ground Movement Additional Evidence

Geoffrey Featherstone

Ground Movement Additional Evidence

In response to a request made by the Inspector's technical adviser this evidence sets out further details in relation to the derivation of ground movement predictions and in particular in relation to the cumulative impacts induced by face loss from tunnelling, groundwater lowering and vibration.

1 Overview

It is firstly important to note the stage within the design process at which the project currently stands. Tenderers design proposals are currently being evaluated. That evaluation will be followed by detailed discussions on the tenderers designs throughout the subsequent procurement process through to financial close.

Professor John Burland has explained the current stage that the designs are at in relation to the four stage process in his evidence under the section "*Methodology for Assessing Settlement Impacts*". He has explained that the Stage 1 and Stage 2A assessments carried out by RPA are to be fully validated by the Contractor taking "account of the detailed design and actual construction methods to be used". He has also noted that where it is considered to be appropriate indicative Stage 3 assessments have been carried out.

Stuart Cowan has provided an explanation in his evidence of the Reference Ground Conditions Report and other geological/geotechnical data available.

This validation process has in effect commenced in relation to the tender submissions received. Details concerning, *inter alia*, ground movement predictions, building response and a review of the Reference Ground Conditions Report have been received and are under evaluation. Because these details have been provided as part of the competitive tendering process they are confidential.

The predictions carried out by RPA are entirely suitable for this stage in the process and the current status is now described in more detail in the following

2 Predicted Ground Movement Assessment

In his evidence Professor Burland set out details of volume loss during tunnelling at item 3.2 and at item 5.1 he set out details of the Stage 1 preliminary greenfield settlement impacts. Following this evidence, at the request of the Inspector's technical adviser, RPA has provided copies of its report entitled "*Stage 1 Predicted Ground Movement Assessment*". This report clearly sets out all the settlements predicted to be induced along the alignment from the effects of tunnelling and stop box construction. Settlement contour maps are provided along the entire underground route within this document.

A request has now been made by the Inspector's technical adviser for a briefing note on the software used by RPA's engineering consultants for the prediction of settlement; RPA notes that the fully validated in house program TunDISP was used to estimate settlements arising from bored tunnelling and the methodology used by the program is clearly set out in Section 6.2.1, Predicting Ground Movement of the report entitled "*Design Input Statement for Predicting Ground Movement and the Response of Overlying Property to Underground Excavation*", which has also been provided to the Inspector. It is considered that this should be suitable information in this regard.

3 Groundwater Lowering

Professor Burland dealt with the issue of groundwater lowering within his evidence at item 3.5.

In amplification of that evidence it is noted that the construction contract requires that all underground structures are designed as undrained (watertight structures). The water tightness criteria are extremely onerous; therefore there will be no significant drawdown of the groundwater.

The criteria included in the Construction and Maintenance Requirements (contract specification) follow:

Tunnels

> 13.1.1 The tunnels, shafts and underground structures shall be constructed such that they are watertight. Infiltration rates shall meet Class 3 dampness characteristics as described by the STUVA (Studiengesellschaft fur Unterirdische Verkerhsanlagen e.V) recommendations for allowable water seepage into tunnels. Groundwater leakage rate shall not exceed a general value of 100 millilitres/sq metre of lining area/day. For any continuous 10 metre length of tunnel the leakage rate shall not exceed 200 millilitres/sq. metre/day. The inflow shall be measured for sections of tunnel during construction to demonstrate that the seepage criteria are being met.

Below Grade Stops

> 9.1.2 Groundwater leakage rates shall not exceed a general value of 50 millilitres/sq. metre of external structure (only including that area of structure exposed to groundwater) per day. For any 100 square metres of external structure the leakage rate shall not exceed 100 millilitres/sq. metre/day.

During construction, including temporary works, the Contractor is obligated to ensure that groundwater drawdown does not exceed the allowable impact on property permitted by the contract.

The Reference Design and associated construction planning achieves this in the following way:

- Ground water cut off to boxes achieved by diaphragm walls or piles supported by ground treatment as required.
- Ground treatment of the base of excavations as required.
- Fissure grouting of the limestone bedrock as required – both for stop and tunnel excavation.
- Ground treatment of tunnels excavations in soft ground where required.
- Construction of the majority of the bored running tunnels using a TBM with ability to pressurise the face above the natural hydrostatic pressure of the ground and installation of a watertight segmental tunnel lining.

As previously explained by Stuart Cowan, it is known from the expected ground conditions that water during tunnelling will for the most part not present a serious issue. The Glacial Till has a very low permeability while the limestone in most cases will be predominately dry. For non-TBM tunnelling, where required, ground treatment and fissure grouting will be employed for the soft and hard ground respectively.

In the case of the tunnels to be excavated by tunnel boring machine no separate allowance has been made in the settlement predictions for the effects of groundwater lowering

In the case of the stop box excavations an appropriate allowance for groundwater drawdown has been provided in the evaluations and generally drawdown of one metre has been inferred.

4 Vibration Induced Settlement

As has been explained by Stuart Cowan, the materials overlying the limestone are generally densely packed and are not susceptible to vibrations arising from the excavation methods that are proposed to be used.

However by way of example the following is put forward in the case of excavation by tunnel boring machine.

1. The question has been raised as to whether vibration from the tunnelling operation could induce settlement.

2. It has been estimated that the maximum vibratory induced strain in the ground adjacent to the tunnel boring machine would be about 1.2×10^{-5}.

3. In his book “Soil Behaviour in Earthquake Geotechnics” (published by Oxford Science Publications) Professor Kenji Ishihara, who is very highly regarded internationally, devotes Chapter 7 to the topic of Strain Dependency of Modulus and Damping. In this chapter he presents the results of many laboratory and field studies of the influence of the amplitude of shear strain on the shear modulus G and damping ratio D for a variety of soils. (D is proportional to the ratio of dissipated energy over the stored energy for a closed cycle of stress).

4. At low levels of strain (less than about 10^{-5}) the response of the soil tends to be approximately elastic such that the shear modulus G is close to the small strain value G_0 (i.e G/G_0 is close to unity). Also the damping ratio D is usually less than 0.05. Both the modulus ratio G/G_0 and the damping ratio are related to the amount of plastic, or irrecoverable, strain that occurs in a closed cycle of stress.

5. Professor Ishihara shows that, for a wide range of soil types, a strain of 10^{-4} or less will give values of G/G_0 greater than 0.85 and values of D less than 0.05. Moreover the effects of high confining pressures (which are likely to occur around a 30m deep tunnel) result in even higher values of G/G_0 and lower values of D for a given magnitude of strain. Since the maximum value of strain quoted is about an order of magnitude less than the above value, the

magnitude of any irrecoverable plastic strains likely to induce settlement will be negligible.

In the case of the cut and cover stops these will be constructed using diaphragm walling or bored piling techniques. Diaphragm walls will be excavated in the soft ground using a 'clam shell' to grab the soft ground and remove it from the excavation. This operation will not generate significant groundborne vibration. Alternatively a hydrofraise or milling machine may be used. This is generally used just to excavate rock, but could also be utilised through the overlying soft ground. Analysis has been undertaken to predict the groundborne vibrations generated from using a hydrofraise. This work has concluded that groundborne vibrations will be substantially less than that predicted for the TBM, and therefore RPA's vibration and geotechnical specialists do not consider that surface settlements of significance will result from vibration generated by diaphragm wall installation. Bored piling is ideally suited to sites where vibration and noise needs to be minimised and is why bored piles are preferred to other piling methods that involve soil displacement rather than soil replacement. The magnitude of vibration generated is small and therefore vibration generated ground movements are not considered to be of concern by RPA's vibration and geotechnical specialists.

In the case of excavation by blasting this would only be acceptable if there were no risk of settlement and the Contractor would have to be able to demonstrate to RPA and its experts that the blasting will not result in damage in excess of that permitted by the Construction and Maintenance Requirements. In any case it would be expected that very low charge weights would be required to meet other environmental criteria (noise and vibration)

As such, no separate allowance has been made in the settlement predictions for the effects of vibrations generated by the proposed methods of excavation

5 Summary

In summary, RPA has effectively considered the cumulative impacts on ground movement due to face loss by tunnelling, groundwater drawdown and vibration for the reasons set out in the foregoing.

There are appropriate safeguards built into the contract specification that require the Contractor to assess correctly each and every condition that may give rise to ground movement based on the detailed design and actual construction methods to be used.

Further evidence is provided in relation to movement monitoring and risk management that may be considered in conjunction with this evidence.

Railway Procurement Agency
Ghníomaireacht um Fháil Iarnród
Parkgate Business Centre,
Parkgate Street, Dublin 8, Ireland
Phone +353 1 646 3400
Fax +353 1 646 3401
www.rpa.ie

Responsible for

LUAS METRO Integrated Ticketing System

With funding and support from

transport21 progress in motion

NDP National Development Plan 2007 - 2013

EUROPEAN REGIONAL DEVELOPMENT FUND