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Memorandum

To	Argot Ansons Design Manager CDSJV	From	**Harry Asche**
Copy	Troy Burton, David Oliveira, Mark Percival, Sam Norton, Diane Mather	Reference	**M5N-AJV-MEM-150-500-TR-02017_A**
Date	**14 March 2017**	Pages (including this page)	**9**
Subject	Proposed Changes to Infrastructure approval for SSI 6788; with respect to settlement criteria		

1 Introduction

The construction of the WestConnex New M5 project involves a number of activities which have the potential to cause impact to adjacent infrastructure through ground movements and other associated effects.

The Project activities which have the potential to cause impact to adjacent structures include:

- Mined tunnels
- Shaft excavations
- Decline structures
- Cut and cover structures and trough structures

The project has, in accordance with the SWTC and the Infrastructure approval, undertaken engineering analyses to predict the ground movements and estimate the impacts. In order to establish the actual effects of project activities there are specific instrumentation and monitoring requirements.

The relevant project wide reports include:

- Impact Assessment Report (M5N-AJV-DPK-150-500-TR-1501),
- Ground Movement Assessment (M5N-AJV-DPK-150-500-TR-1505),
- Instrumentation Plan Surface/ Civil (M5N-GOL-DRT-100-200-GT-1530), and
- Instrumentation and Monitoring Strategy (M5N-AJV-TER-150-500-TU-1515).

2 Planning and Environmental Documents

2.1 Conditions of Approval

The conditions of approval are given in the document titled “Infrastructure approval for SSI 6788”.

The purpose of the Infrastructure approval is stated on the title page:

“These conditions are required to:

- prevent, minimise, and/or offset adverse environmental impacts including economic and social impacts;
- set standards and performance measures for acceptable environmental performance;
- ensure regular monitoring and reporting; and
- provide for the ongoing environmental management of the SSI”

The Infrastructure approvals for SSI 6788 are supplied in Schedule 2, Parts A to E.

Part A2 requires that "The Proponent must carry out the SSI in accordance with the conditions of approval and generally in accordance with the:

(a) State significant infrastructure application (SSI 6788);

(b) New M5 Environmental Impact Statement - Volumes 1A, 1B, 1C, 2A, 2B, 2C, 2D, 2E, 2F, 2G and 2H prepared by AECOM Australia, dated November 2015;

(c) New M5 Submissions and Preferred Infrastructure Report - Volumes 1A, 1B and 2 prepared by AECOM Australia, dated March 2016;

(d) WestConnex New M5 Addendum to the Submissions and Preferred Infrastructure Report - Temporary Construction Power Enabling Works prepared by RMS, dated April 2016; and

(e) Supplementary material provided as an addendum to the *New M5 Submissions and Preferred Infrastructure Report*.

Within the Infrastructure approval for SSI 6788, Parts D6, D7, D8 and D9 come under the heading "Settlement". Part D6 requires the preparation of a geotechnical model, to include the proposed excavations and the structures that may be impacted. Part D7 requires that appropriate criteria are set to prevent damage for the properties at risk. Part D8 provides a table (Table 1). If the predictions from the model required by D6 exceed the criteria set in D7, or in the table (whichever is the lower), "the Proponent must identify and implement mitigation measures such as appropriate support and stabilisation structures in consultation with the relevant land and/or infrastructure owners prior to excavation and tunnelling work…" Part D9 discusses utility services and requires consultation with the relevant authorities.

2.2 Environmental Impact Statement (EIS)

The EIS has been written such that (Volume 1A Chapter 1) "In accordance with the EP&A Act, this EIS presents an assessment of all relevant environmental issues identified during the planning and assessment of the project."

Settlement and surface impacts are discussed in EIS Volume 1B, Chapter 13. Chapter 13 describes the two causes of settlement being "volume loss during tunnel excavation", and "groundwater drawdown and subsequent ground consolidation." The same section describes the cause of damage to buildings: "Settlement of the surface can create tensile strains in buildings above and around the settlement."

Details of settlement predictions and detailed commentary are provided in the EIS Volume 1C, Chapter 19. Figures 19-9 to 19-13 provide the predicted vertical settlement contours due to tunnel excavation (volume loss) along the project alignment. Settlement due to groundwater drawdown is discussed on pages 19-62 and 19-63. The discussion includes the following statements:

"Building damage is caused by horizontal and bending movements imposed on the building"

"The predicted magnitude of the groundwater drawdown settlement can be quite high, but the settlement is usually spread over a wide area and is unlikely to cause significant horizontal strain or bending strain in buildings. The settlement that occurs due to groundwater drawdown generally occurs very slowly, possibly over years, and is often indistinguishable from settlement that is already occurring due to groundwater drawdown that might already be occurring and seasonal effects related to swell and shrinkage of the soil."

"Settlement caused by groundwater drawdown can have a significant magnitude, yet not cause damage to buildings."

3 Settlement and Building Damage

Settlement and the potential for building damage due to tunnelling activities has been recognised as a potential risk for a very long time. Notable milestones in the study of settlement due to tunnelling include:

- Work on the Chicago Subway in the 1930s by Terzaghi (Goodman 1998)
- Development of the empirical settlement prediction method by Peck (1969) and Schmidt (1969)
- Suggested criteria for building damage by Burland (1974) and the use of this with respect to tunnelling by Boscardin and Cording (1989)
- Comprehensive statement of the methodology by Mair et al (1996)
- Project description of method and its use and comparison to real case histories in the Jubilee Line Extension (Burland et al 2001)
- Implementation of these methods into a computer code for example Oasys (2016)

The EIS is completely aligned with the results of these well recognised industry methods of settlement analysis. The discussion below mainly follows that of Burland et al (2001).

3.1 Volume loss settlement

Immediately around an advancing tunnel face, the ground is forced to deform and redistribute the insitu stresses. This deformation is largest at the tunnel face and spreads upwards to the surface. Some of the movement occurs slightly ahead of the face, but the majority of the movement occurs at the face and behind. Figure 1 shows the situation in an idealised and exaggerated form:

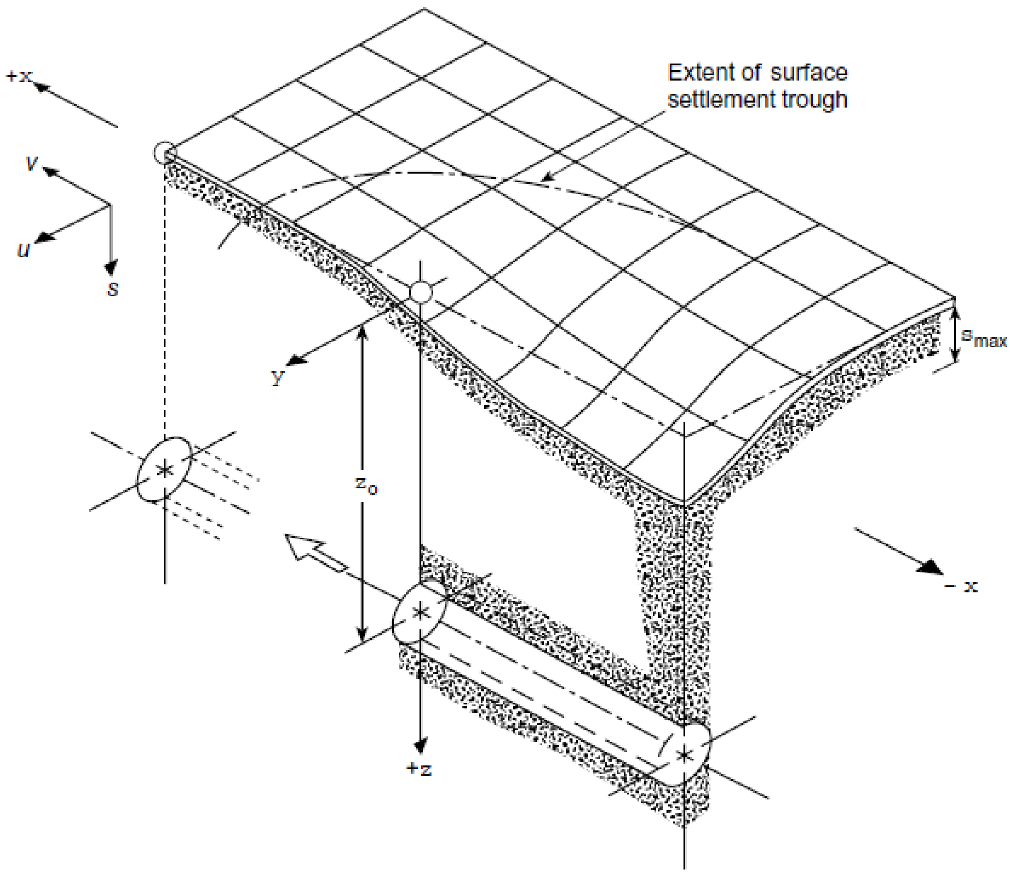

Figure 1 - Surface settlement trough above an advancing tunnel (from Burland et al 2001)

In Figure 1, and as also seen in the EIS Figures 19-9 to 19-13, the horizontal extent of the settlement trough is limited to an area that is approximately equal to twice the depth of the tunnel plus the width of the tunnels themselves.

The movement is not purely vertical; some horizontal movement is also occurring. The empirical method developed in the research described above predicts horizontal and vertical movement as shown in Figure 2:

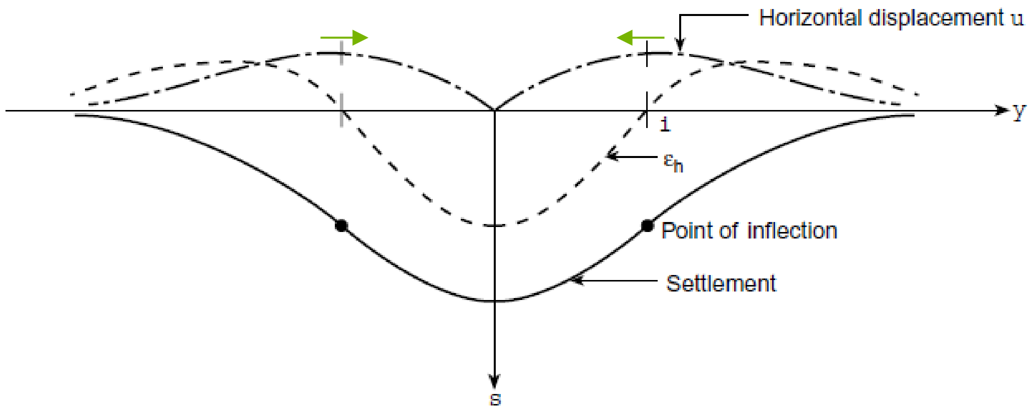

Figure 2 - Transverse settlement trough (from Burland et al 2001). Note that the horizontal movement curve is the absolute value of horizontal movement (which changes direction at the tunnel axis). Note also that the horizontal strain is shown as εh.

3.2 Groundwater consolidation settlement

When a tunnel is excavated beneath the groundwater table, the situation can occur that the groundwater pressures are affected by water draining into the tunnel. The tunnel is said to “underdrain” the sediments above. Settlement then occurs due to consolidation of the overlying soft sediments. This is due to the reduction in ground water pressure that must now be carried by the soil structure itself.

The movement takes place as the water pressure is relieved, a process that is dependent on the rate of flow in the soil itself. Typically, this movement is gradual and can take years to materialise and is sometimes hard to distinguish from other groundwater movements (such as seasonal groundwater fluctuations). The extent of groundwater effects can occur over a wide area beyond the tunnel location.

3.3 Building damage

As discussed in Burland et al (2001), the building is damaged by various effects:

- The building is subjected to direct horizontal strain. If this strain is tensile, cracks can form in the building
- The building is subjected to bending. This bending can create tensile strains which are similar to the direct horizontal strains (see Figure 3(c))
- The bending also causes diagonal tensile strains (see Figure 3(d))

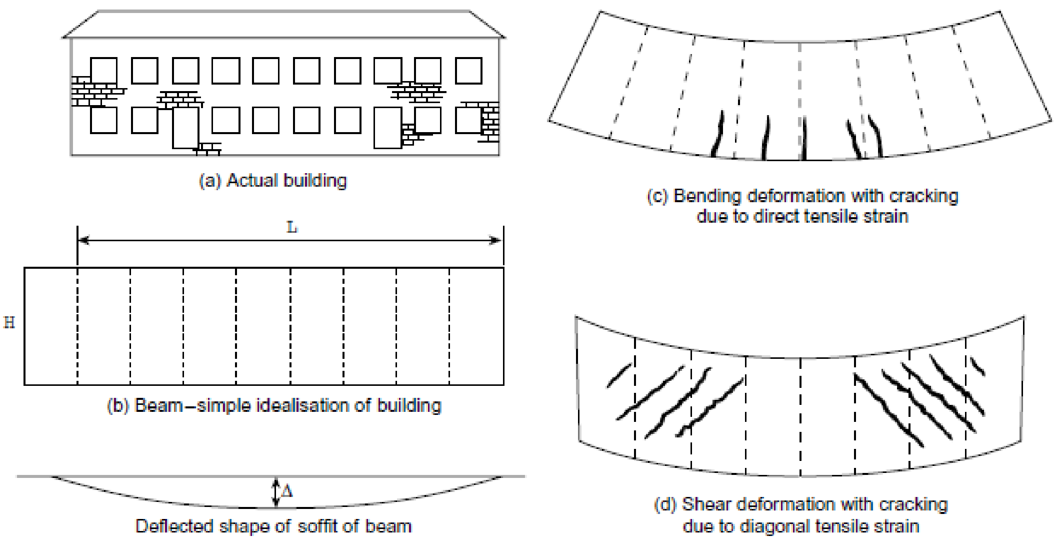

Figure 3 - Cracking of a building due to direct tension, bending and shear (from Burland et al 2001)

3.4 Building damage related to tensile strain

The tensile strain due to bending depends on where the building is located with respect to the settlement curve (Figure 4), and on the shape of the curve itself.

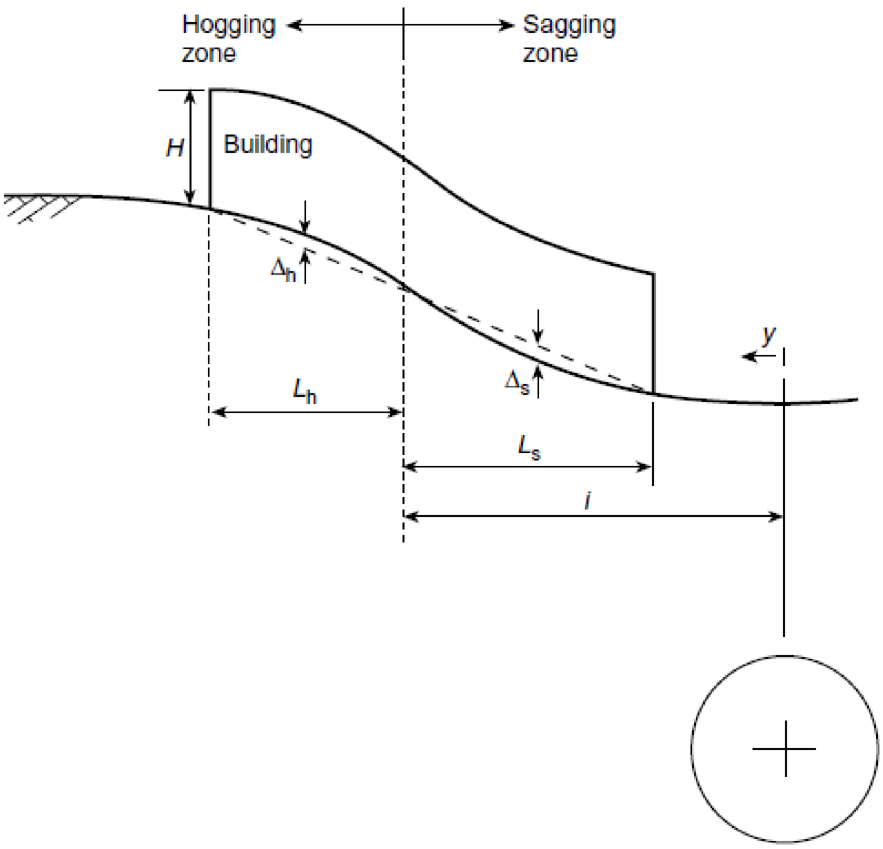

Figure 4 – Assessment of building (from Burland et al 2001)

Figure 4 shows that the buildings are subjected to bending, either in sagging or in hogging. Neither the absolute value of the settlement, nor the slope of the building are actual causes of induced tension. Figure 5 shows the example of similar settlement magnitudes produced by a small shallow tunnel, a deep large tunnel and a wide trough caused by groundwater depressurisation (from tunnelling activity some distance away). These different scenarios are postulated to produce the same absolute value of settlement. The example shows conceptually that the bending of a structure nearby would be expected to be quite different. The shallow smaller tunnel creates the sharpest sagging and hogging, but the zone of influence is relatively small. The deep larger tunnel has less extreme bending effects, but they are spread over a wider area. The very flat and wide trough caused by groundwater induced settlement is different again, with almost no bending and with no horizontal strain.

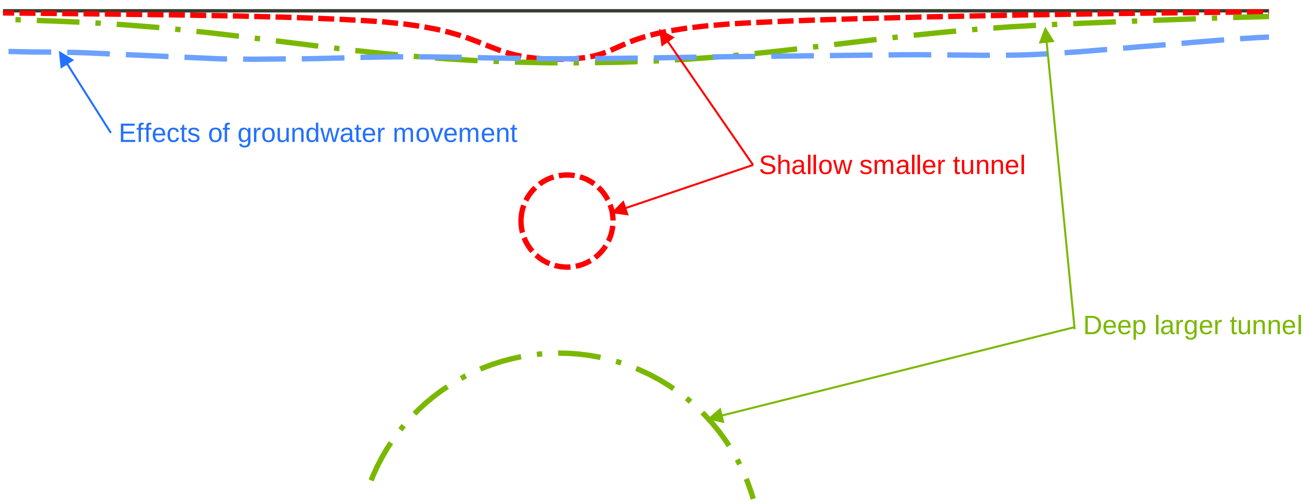

Figure 5 – Settlement of similar magnitude but with different impacts

The buildings are assessed by calculating and adding the tensile strains. Figure 6 shows the strains suggested by Burland et al (2001).

Category of damage	Normal degree of severity	Limiting tensile strain (ε_{lim}) (%)
0	Negligible	0–0.05
1	Very slight	0.05–0.075
2	Slight	0.075–0.15
3	Moderate*	0.15–0.3
4 to 5	Severe to very severe	> 0.3

Figure 6 – Table of risk categories (from Burland et al 2001).

3.5 Building Damage Assessment

Burland et al (2001) describe a methodology of building damage assessment, in three phases. In the preliminary phase, the zone of influence is defined and buildings outside of this zone are assumed to be unaffected.

The second stage uses the methodology described above, where the risk categories are assessed based on limiting tensile strain. Burland et al point out that the results of the second stage are an assessment of *possible* damage, rather than actual damage. There are various reasons for this; the building itself can stiffen the ground and reduce the actual curvature that the building itself experiences.

Where the second stage identifies buildings which are of concern, it is possible to do a third stage assessment, where the actual building structure is modelled. Alternatively, it may be that in-building instrumentation and monitoring is specified, to give an early warning of risk to the building.

4 Predicted effects WCX M5 Project

The packages below describe the predicted ground movement and the estimated impacts to buildings:

- Impact Assessment Report (M5N-AJV-DPK-150-500-TR-1501)
- Ground Movement Assessment (M5N-AJV-DPK-150-500-TR-1505)

These packages fully comply with the requirements of the SWTC and the Infrastructure approval parts D6 and D7. The results shown in these packages are entirely consistent with the statements made in the EIS.

In particular, where settlement is predicted to occur due to the effects of groundwater movement, the buildings are categorised as being within the “negligible” risk level.

5 Conclusions and Proposed way forward

From the Infrastructure approval for SSI 6788, Part D8 contains Table 1, which contains reference to an absolute value of settlement. Applying this Table 1 to the predictions of groundwater drawdown settlement is not in accordance with the descriptive words in the EIS, nor does this effectively protect the building infrastructure against the actual effects that cause building damage.

In order to establish realistic criteria for impacts of settlement, the project seeks to modify Table 1, by addressing the very cause of building damage – induced tensile strain. The proposed amended Table 1 is shown below:

Table 1-Settlement Criteria

Beneath Structure/Facility	Limiting Tensile Strain[1]	Maximum Angular Distortion
Buildings - low or non-sensitive properties (i.e. < 2 levels and carparks)	0.1	1 in 350
Buildings - High or sensitive properties (i.e. > 3 levels and heritage	0.1	1 in 500
Roads and Parking areas	N/A	1 in 250
Parks	N/A	1 in 250

Note 1 – as defined in Burland J. B., Standing J. R. and Jardine F. M. "Building response to tunnelling - Case studies from construction of the Jubilee Line Extension, London", Thomas Telford (2001).

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