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A22.1 Summary of Utilities Settlement Analysis Study

Contents

1. Introduction

This summary report presents the findings of a utility settlement analysis study. The study will inform the design team and appointed contractor(s) for the MetroLink project.

The assumptions made for the settlement analysis are based on the soft ground geology described in the geotechnical and design reports completed for the proposed Project.

Tunnelling in overburden will cause ground losses which can lead to negative impacts on surface and underground utilities. The tunnel design process includes assessment of all impacts to determine if mitigation measures are required. There were in the region of 50,000 utilities identified within the project boundaries potentially impacted by the tunnelling. Employing a conservative approach, the assessment of tunnelling impact to the utilities is discussed in six technical memoranda as follows:

- Utility Impact Assessment for Dublin Airport;
- Utility Impact Assessment for Electrical;
- Utility Impact Assessment for Telecom;
- Utility Impact Assessment for Gas;
- Utility Impact Assessment for Water; and
- Utility Impact Assessment for Sanitary (Foul).

2. Settlement Methodology and Theory

Ground loss during tunnelling is the difference between the actual excavation volume and the theoretical excavation volume. It is a function of the ground conditions as well as the contractor's design, workmanship and means and methods. Ground loss that occurs from the tunnel excavation will generate horizontal and vertical movements of the ground above the tunnel. The ground movement is referred to as a settlement trough. An innovative solution was adapted to automatically solve the repetitive calculations with various inputs along the tunnel alignments, creating settlement contours at the surface above the tunnel. The approach included the use of AutoDesk Civil 3D and Dynamo, Microsoft Excel and Python.

The method described by O'Reilly and New (1982) was adopted where the transverse distance to the point of inflection of the settlement trough is assumed to be linear with the tunnel depth. The simplified form assumes $i = KZ$, where Z is the depth from the ground surface to the tunnel axis and K is a trough width parameter that varies between 0.4 and 0.7 for cohesive soils and between 0.2 and 0.3 for granular soils. Lower values of the trough width parameter will result in narrow troughs with a greater settlement at the tunnel centre line, whereas higher values will result in wider troughs with less settlement at the tunnel centre line.

The variables that impact the tunnel induced settlements include the size of the tunnel, the volume loss percentage, the depth of the tunnel, the tunnel type and the ground conditions. The topography was directly referenced in the analysis to determine the tunnel depth. The remaining variables were parameters input to the configuration of the analysis based on the dimensions and assumptions from the Settlement Study and have been summarised in Table 2.1 below.

Table 2.1: Settlement Analysis Input Parameters by Tunnel Section

Alignment Name	Excavation Diameter (m)	K trough parameter	Percentage ground loss (%)
Main Tunnel TBM	9.5	0.5	1
Non TBM Drive 1	5.9	0.5	1.5
Non TBM Drive 2	6.9	0.5	1.5

The percent of ground loss was determined by the design team based on knowledge of the ground conditions and local experience with tunnelling. Ground movements caused by large excavations were estimated using empirical relationships of ground settlement and depth of excavation as described by New and Bowers (1994). The lateral displacement will result in displacement of the ground surface around the excavations which will follow a parabolic distribution. The settlement becomes zero at a distance from the shaft equal to the depth and increases as the square of the distance from the undisturbed ground toward the shaft wall. The parameters below are based on empirical relationships and methods described in CIRIA C760 (CIRIA, 2017).

Table 2.2: Station and Portal Input Parameters

Drawing Layer	Vertical Alpha (%)	Horizontal Alpha (%)	Vertical N ratio	Horizontal N ratio
Station Excavation	0.55	0.15	1	1
Portal Excavation	0.55	0.15	1	1
Shaft Excavation	0.55	0.15	1	1

The settlement for each tunnel section and station/portal excavation along the alignment was solved using the empirical relationships and methods described above. The combined ground movement was determined and applied to the utilities impact assessment.

3. Utility Impact Analysis

The utility locations were obtained using the data collection methods described in Section 22.3.3 of Chapter 22 (Infrastructure and Utilities) of the EIAR and those utilities within the zone of influence analysed to estimate if they were impacted. The 'zone of influence' is the area which is bounded by the 1mm settlement contour caused by the construction works.

The pipelines and masonry sewers were assumed to follow the ground movement which is a conservative assumption as the pipes will likely undergo less movement than the surrounding soils. Due to the large quantity of utilities that are within the settlement trough, utilities located within ground subject to 1 mm or less of vertical movement were excluded from further assessment considering the potential impact will be negligible.

The utility assessment criteria analysed included the strain of the pipes, the joint rotations and the joint pullout which were calculated using the methods described by Bracegirdle et al. (1996). The joint rotation for pipes are conservatively estimated assuming a configuration that is located transverse to the tunnel as determined by the expression:

$$\theta = 2tan^{-1}(\frac{S_{v\,max}}{\sqrt{2\pi i}})$$

The joint rotation for pipes that are located parallel to the tunnel is determined by the expression:

$$\theta = tan^{-1}(0.4\frac{S_{v\,max}}{i})$$

Where Sv max is the maximum vertical ground movement.

The joint pullout of the pipe is conservatively estimated by assuming the maximum horizontal ground displacement for both longitudinal and transverse directions will directly equate to the joint pullout.

The strain is measured for both tensile and compressive deformations of the pipe. The tensile strain is a result of both the bending strain in the pipe caused by curvature and the axial strain. The strain is calculated as the change in length of the pipe due to the movement of the ground over the initial pipe length and this is determined for the bending and axial direction. A reduction factor was applied to consider further soil-pipe interaction based on Attewell et al. (1986) using the graphs below.

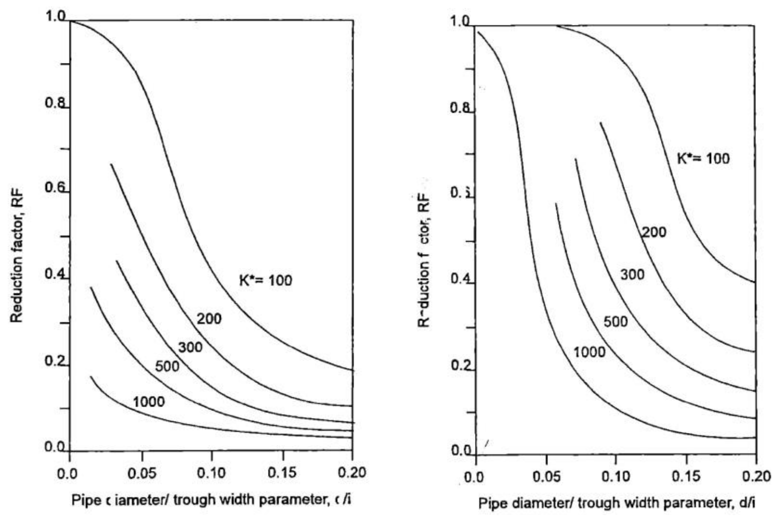

Figure 3-1: Reduction Factor for Transverse Pipes (Left) and Longitudinal Pipes (Right)

Based on the methods described above, the analysis for each individual pipe was completed and the results were estimated for the following criteria; settlement, rotation, curvature, axial strain, bending strain, total strain and pullout. The assessment was calculated at set intervals of 1m for the entire length of each pipe. Pipes that were less than 1m in length were excluded from the assessment. An output was generated for the results of all pipes and the values that were shown in the summary output consist of the maximum calculated values along the pipe length.

The maximum values were compared to threshold criteria to estimate whether the impact would have a significant effect on the performance and structural integrity of the pipe. The threshold criteria were established based on literature and experience with similar pipes in terms of age and structural condition found in the United Kingdom. The criteria published by Thames Water PLC for water pipeline and sewer assets were adopted for comparison.

Table 3.1: Established Deformation Threshold Criteria for Utility Impact Assessment

Description	Elastic Modulus (MPa)	Poisson Ratio	Max Allowable Strain (μ)		Max Pullout (mm)	Max Rotation (deg)	Reduction Factor		Is Compression Only
			Tension	Compression			Tension	Compression	
Unreinforced Concrete	50,000	0.175	400	400	12.5	2	1	0	Yes
Concrete	50,000	0.175	400	400	12.5	2	0.2	0.2	No
Brick Sewer (Red/Yellow)	5,200	0.11	500	700	12.5	2	1	0	Yes
Brick Sewer (Blue)	15,600	0.16	500	700	12.5	2	1	0	Yes
Cast Iron (Pre-1914)	80,000	0.26	100	1,200	15	0.1	0.2	0.2	No
Cast Iron (Spun)	100,000	0.26	100	1,200	15	0.1	0.2	0.2	No
Ductile Iron (Lead-yarn)	174,000	0.275	500	700	25	1.5	0.2	0.2	No
Ductile Iron (Rubber)	174,000	0.275	500	700	25	2	0.2	0.2	No
Steel	205,000	0.26	450	450	25	1.5	0.2	0.2	No
Vitrified Clay	50,000	0.175	80	400	7.5	0.5	0.2	0.2	No
Plastic	4,000	0.46	2000	2,000	12.5	10	0.2	0.2	No

3.1 Assumptions

The analysis conservatively assumes the entire alignment is in soft ground. An assumption that the ground will follow a “greenfield” settlement trough is made in the analysis which assumes there is only native soil above the tunnel. This assumption can be conservative if the presence of other pipes or sub-structures mitigate ground movement and/or if the madeground performs better than assumed or rock is encountered. The analysis also assumes that the pipes will follow the ground movement which can be conservative as the pipes will likely take more stress to span local differential settlements.

Other assumptions that have been made in the analysis to complete the assessment are as follows:

- All utilities shorter than 1 m in length have not been included in the assessment.
- All utilities with 1 mm or less settlement have not been included in the assessment.
- All utilities assumed to be at 2 m depth below surface, unless noted otherwise.

- Where a single utility line underwent an acute angle (less than 90 degrees) change in alignment, the utility was split into two and assessed as individual utilities.

- All gas, electric and telecom services have been assumed to be 300mm diameter plastic pipework with 25mm thick walls. (Any non-plastic and larger diameter plastic pipes will need to be confirmed by the utility provider and subsequently reassessed.)

- All water mains have been assumed to be 250mm diameter cast iron pipework with 20mm thick walls. (Any non-CI and larger diameter CI pipes will need to be confirmed by the utility provider and subsequently reassessed.)

- This assessment covers distribution mains only.

4. Output Assessment

Table 4.1 below shows a summary of the output from the six reports on the 50,000 utilities analysed. It conservatively confirms that there are 397 cases of pipes exceeding the assessment criteria.

- 16 of these utilities clash with the proposed Project alignment and are scheduled to be diverted away from the alignment.
- 120 of the pipes exceed the assessment criteria at maximum settlement values of less than 20mm which is unexpected and suggests that there are issues with the utility provider input data . (From experience it is very unusual for a pipe to 'fail' at this level unless there is some pre-existing condition). These will need further investigation and refinement of the analysis . It is anticipated that all of these will be downgraded to negligible damage on further assessment.

The remaining 261 pipes represent a 0.5% criteria exceedance rate (for the 50,000 assessed).

Table 4.1: Summary of Utilities Settlement Analysis Results

	Foul & Storm	Gas	Telecoms	Electric	Water	Total
Fail	84	2	1	16	294	397
Clash with alignment – to be diverted	5	0	1	0	10	16
Low (<20mm) settlement failure result	20	0	0	5	95	120

The settlement analysis uses a number of conservative assumptions, and it is anticipated that the number of predicated cases of pipe failure due to settlement will be reduced on further assessment. Further information will be required from the utility providers to enable the contractor(s) to carry out a detailed analysis.

If, after further analysis, pipes remain in the 'severe' to 'extremely severe' impacted category, these may require additional structural measures, as detailed in Section 5 below.

The extent and nature of the protection required will be determined in conjunction with the asset owner and undertaken utilising the providers existing powers.

5. Protective Measures

Protective measures will be undertaken to keep settlement to a minimum. It is intended that the primary form of mitigation will be to use good tunnelling practice, including continuous working, erecting linings immediately after excavation and providing tight control of the tunnelling process to reduce the magnitude of settlement. For the majority of utilities, they would be monitored, inspected on completion of the works and any damage repaired. Where this approach is deemed insufficient to mitigate the risk of damage to utilities, then intrusive mitigation measures will need to be considered in conjunction with the utility owner. These may include direct works on the utilities and possibly ground treatment around and beneath. These three categories are described in more detail below.

At-source Measures

These include all actions taken from within the tunnel, requiring no additional land take:

- during its construction to reduce the magnitude of ground movements generated at source such as TBM closed head operation; and
- increased tunnel face pressure, etc.

Ground Treatment Measures

These comprise methods of reducing or modifying the ground movements generated by tunnelling/ shaft/box excavation by improving or changing the engineering response of the ground at source. Categories of ground treatment include:

- permeation or jet grouting which involves the creation of stiffer ground to reduce settlement; and
- control of ground water to avoid changes which could potentially cause ground movement.

These measures would be undertaken from the proposed construction worksite areas, as detailed in Chapter 5 (Construction Phase) of the EIAR.

Structural Measures

These methods reduce the impact of ground movements by increasing the capacity of a utility to resist movement. Available measures would include:

- support,
- repairs,
- isolation from the moving ground,
- relining; and
- replacement or diversion (in the most significant cases).

These measures would require works to the utility similar to those regular undertaken by utility providers to maintain or upgrade existing assets. They would be undertaken either by the utility provider or by MetroLink contractors in conjunction with the utility provider under their existing powers. The approach to intrusive mitigation measures will be further developed during the detailed design process in cooperation with the contractor.