METHOD FOR ASSESSING DAMAGE INDUCED IN UTILITIES DUE TO GROUND MOVEMENTS FROM MAJOR INFRASTRUCTURE PROJECTS

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ABSTRACT

Geotechnical Engineers are faced with huge challenges in predicting the movements caused by tunnelling and excavations and their impacts on utilities. Furthermore the number of parties involved in infrastructure projects often requires multiple iterations to come to a common solution, making the analyses very labour intensive, locking resources and budget from other parts the project. The ground movement induced in utilities due to major infrastructure projects is to be assessed by means of the Oasys software Xdisp. The stakeholders comprise various utilities providers, each with unique criteria and a variety of asset dimensions to be assessed. Ground movements generated by three phases of works (demolition of buildings, installation of temporary and permanent retaining walls, excavation behind the walls and tunnelling) are calculated using a combination of Oasys Pdisp and Xdisp. Displacements are calculated for each phase and imported in the subsequent phase, for the utility assessment to be undertaken. Asset information provided in GIS format, which included the geo-referenced position of the asset, function, dimensions and material in order to identify the limiting criteria to be applied. Due to the number of assets and expected iteration typical of this kind of analysis a fluid solution consisting of tailoring the software XDisp to adapt it to the requirements of the different asset holders is adopted. The output can then be manipulated with a relatively sophisticated geospatial process for direct input in GIS for improved settlement visualisation based on strain and displacement set criteria. It is estimated the process can save up to 60% of the computing time, based on size of the project, compared to standard methods of calculation using the same software.

Keywords:

INTRODUCTION
Background

For large infrastructure projects, it is common to use a phased methodology to for assessing the utilities affected by ground movement from works. A three-phased process is proposed. Phase 1 considers the magnitude of likely ground movements only. Phase 2 determines the potential utility strain, pull-out and joint rotation assuming the utilities follow the ground movement (i.e. the utilities have negligible structural stiffness). Reduction factors can be used to consider axial slip between the grounds and pipe as appropriate. Phase 3 consists of a more detailed analysis in which the assumption made in Phases 1 & 2 are re-assessed and more complex methods like Finite Elements that consider soil-structure interaction are used.

Recent developments

This paper describes the proposed methodology used and implemented in Xdisp for assessing damage induced in utilities due to ground movements arising from major infrastructure projects. Given the number of utilities required to be assessed this paper presents further developments that have been achieved using database and GIS based system to semi-automate the process (Devriendt, et al. 2012).

GROUND MOVEMENTS
Loading and unloading

Oasys Pdisp, in combination with Oasys Xdisp, was used to predict settlements due to loading and unloading near buildings and utilities. Within the program, the Boussinesq method was utilised.

The method has the advantage that it gives a report of stresses in the ground in addition to displacement. The software uses integrated forms of the well-known equations derived by Boussinesq (1885). Strains are calculated within the strata. Displacements are then defined by integrating vertical strains. However, the method is not able to calculate horizontal displacements.

The program was also enhanced to consider polygonal loads, where previously only rectangular and circular loads could be inputted. The Polygon Wizard within the program is used to fit rectangles to the load's polygon

In order to generate rectangles from a polygon the polygon is first expanded into trapezoids. Each trapezoid is then expanded into one or more rectangles. The rectangle Tolerance is defined as the total "overlap" and "underlap" of rectangles within each trapezoid, as a proportion of the total area of that trapezoid. Due to the methodology used, trapezoids with greater differences in length of their parallel edges will generate more rectangles than those of lesser difference - even though those with lesser difference may have larger areas.

Retaining wall installation and box excavation

Retaining wall installation and excavation are calculated in accordance with Ciria Guide C580, now updated to C760. Movements at corners are calculated using the methodology outlined in Fuentes R. and Devriendt M. (2010).

Tunnels

Greenfield ground movements due to the excavation of a tunnel can be predicted assuming the transverse settlement trough approximated by a normal Gaussian curve and the longitudinal trough corresponding to a cumulative probability curve as described by Atterwell & Woodman (1982) and O'Reilly & New (1982).

The geometry of the settlement trough is defined by the volume loss due to tunnel excavation, which is the order of 2% of tunnel diameter for tunnels in London Clay, and the depth of the tunnel relative to the level at which displacements are to be measured.

Pipe Strains

The initial assumptions made in Oasys Xdisp were the same as the ones described by Bracegirdle et al. (1996). Bending strains along the pipe are calculated assuming the pipe follows the ground movements; the horizontal strain consider the soil-pipe interaction by decreasing the strain on the pipe by a reduction factor. This methodology does not allow for slip at soil-pipe interface and can be quite conservative.

Welded pipes can be treated as a continuum therefore not allowing for stress concentration at joints. Consequently, the strain calculations for welded pipes remained the same. For jointed pipes, the analysis assumed all rotation to happen at the joint between adjacent pipe segments. The envelope of flexural strains deriving from the worst combination of joints location relative to the tunnel axis should therefore be considered. Axial strains should be considered in terms of pullout at axis level between two consecutive segments. This is done by considering the resultant of strains along the pipe segment as in Figure 1. Different pullout combinations should be considered as in Figure 2.

$PO = P_{length} \times \Sigma_{\varepsilon axial}$

Where:

PO = pullout

P_{length} = length of pipe segment

$\Sigma\varepsilon_{axial}$ = sum of axial strain along pipe segment

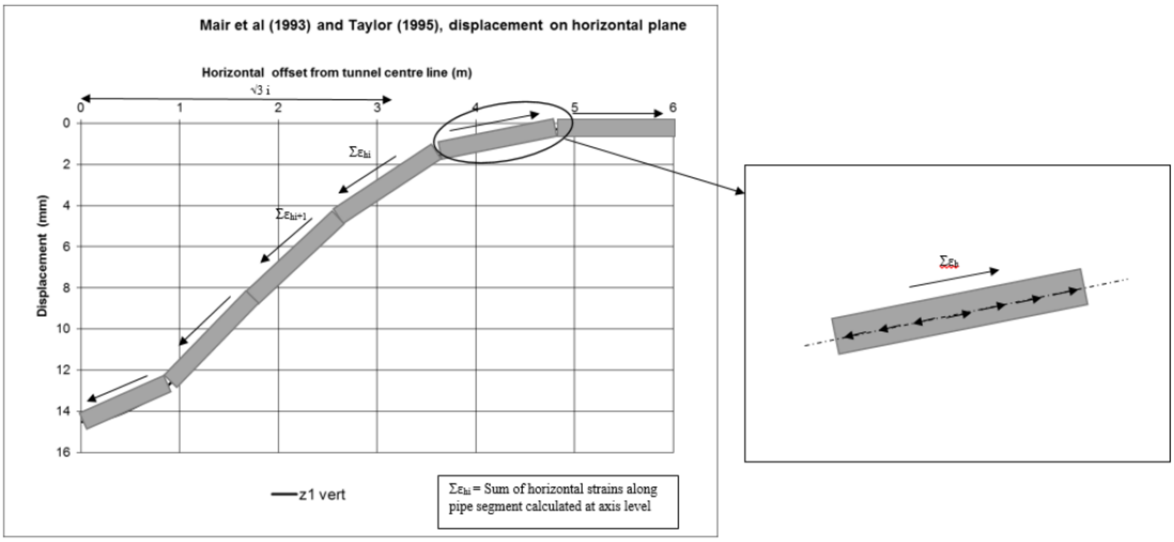

Fig. 1 - Example of strain distribution along pipe segment

The pullout for a segment is then be added to the pullout from adjacent segment to a joint to obtain the total pullout for that joint (Figure 2). No friction between pipes or interlocking due to flexion at joint are considered.

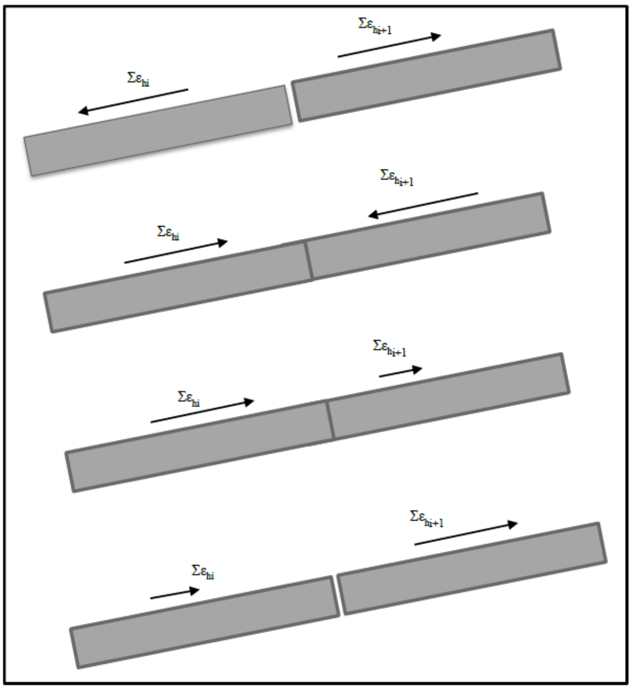

Fig. 2 – Pullout at joints

The maximum strain at the joint is the combined action of axial and flexural strain. These are added together according to the sign convention stated above.

THREE PHASE ASSESSMENT
Phase 1: Asset screening assessment

Phase 1 determines the magnitude of settlement and maximum ground slopes only based on the greenfield surface settlement contours. This phase identifies the zone of influence (i.e. 1mm settlement contour). This is used to identify the utilities that are at negligible risk of damage and therefore screened out of from further assessment. Those utilities considered to be flexible are also screened out at this phase of the assessment.

Phase 2: Assessment of buried assets

Oasys Xdisp software automates the calculation of the ground movements and carries out utilities damage impact assessments according to the methodology proposed by Bracegirdle et al. (1996). Figure 3 shows a snapshot of the Xdisp model used for the utilities assessment.

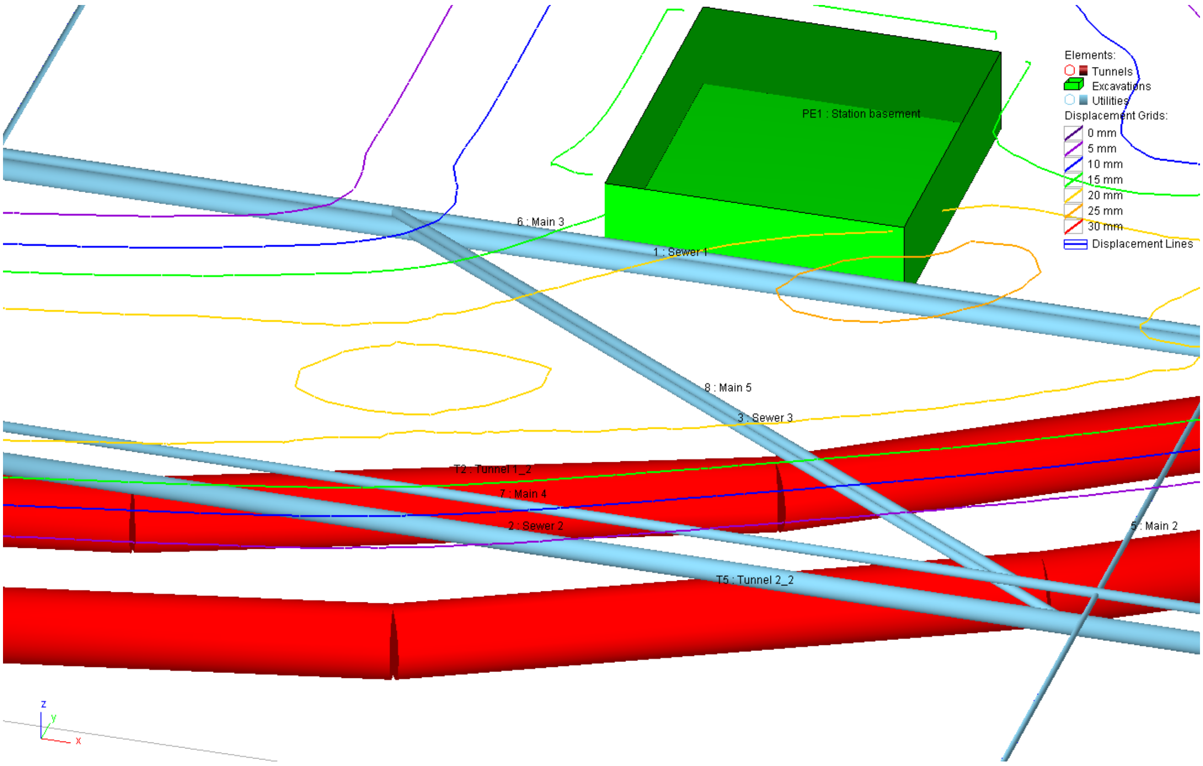

Fig 3. Snapshot of Xdisp model with ground movement contours

Phase 3: Re-assessment of Phase 2 hypothesis or more complex analysis and mitigation measures

Conservative parameters like the volume loss or ground settlement calculation method can be adjusted in order to adopt a more realistic approach. Other methods like Finite Element analysis that account for soil-structure interaction could be used to refine the results if needed.

If the potential for damage induced to the utility is considered to be unacceptably high, engineering judgement must be made to understand whether mitigation is possible and appropriate. When considering the mitigation, account must also be taken for the potential negative impact it may have. (i.e. ground movements arising from the installation of Tubes-a-Manchette (TAMs) could influence ground movements) and result in greater damage to the utility.

USE OF DATABASE AND GIS BASED SYSTEMS FOR AUTOMATION

Given the number of utilities required to be assessed on large infrastructure projects, the use of database and GIS based systems for automating the process linked with specifically designed ground movement impact assessment software such as Oasys Xdisp and Pdisp, enables time and cost savings to be made.

FME (Feature Manipulation Engine) can transform or translate sets of data from one format to another. The results of the assessment are incorporated into the GIS database, reports and graphs along the asset chainage to show axial and flexural strains, combined tensile and compressive strains, and the displacements along and perpendicular to the utility can be automatically generated. In Figure 5 there is a snapshot of the FME workflow used for the generation of output results.

Moreover, utilities companies are now using contents of the GIS database, producing utilities drawings with associated information such as material, diameter, age, etc. Designers can therefore take advantage of the pool of information provided to automate the calculation process by pre-setting different software to exchange information directly, without the need to enter items manually. The same process can then be utilised once the calculations are complete to update drawings providing the client with an even greater pool of information, it being the output of the analyses. The typical output consists of drawings including settlement contours, showing the utilities labelled with “exceeding” or “not exceeding” the agreed criteria.

Figure 4 summarises the process of GIS database automation linked with Oasys geotechnical software. A semi-automatic process was achieved to generate the visual assessment output as shown in Figure 5 using combination of Pdisp for demolition heave and Xdisp for excavations and tunnels together with digital tools like GIS and FME.

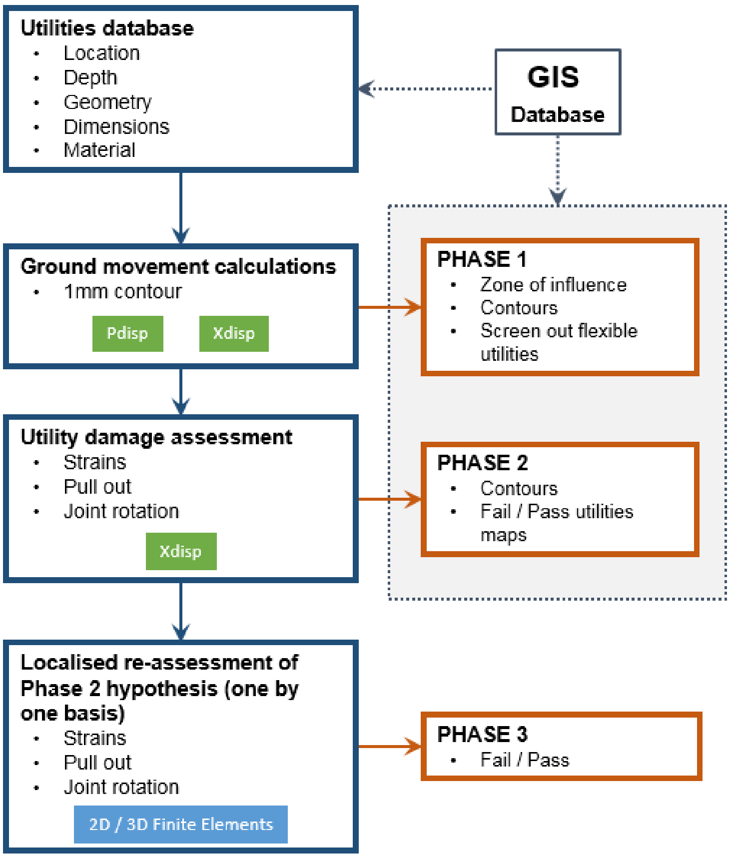

Fig. 4. Diagrammatic process of database and GIS automation linked with Oasys Pdisp and Xdisp

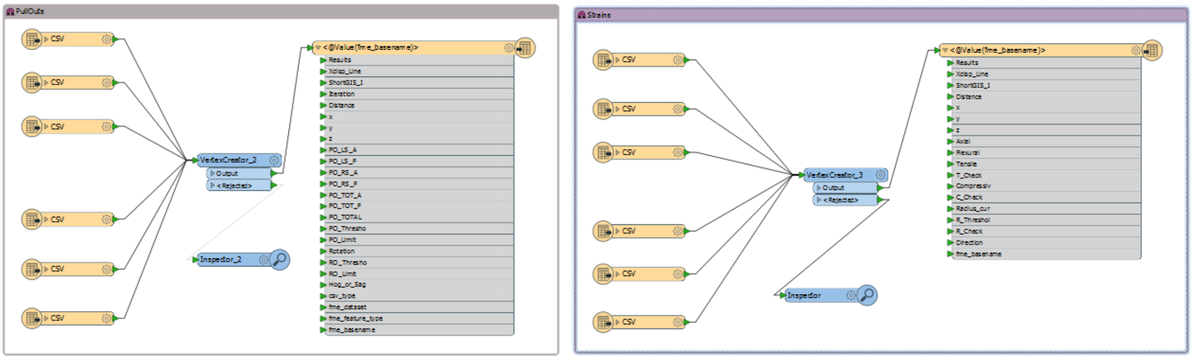

Fig. 5. Automation of the output generation using FME.

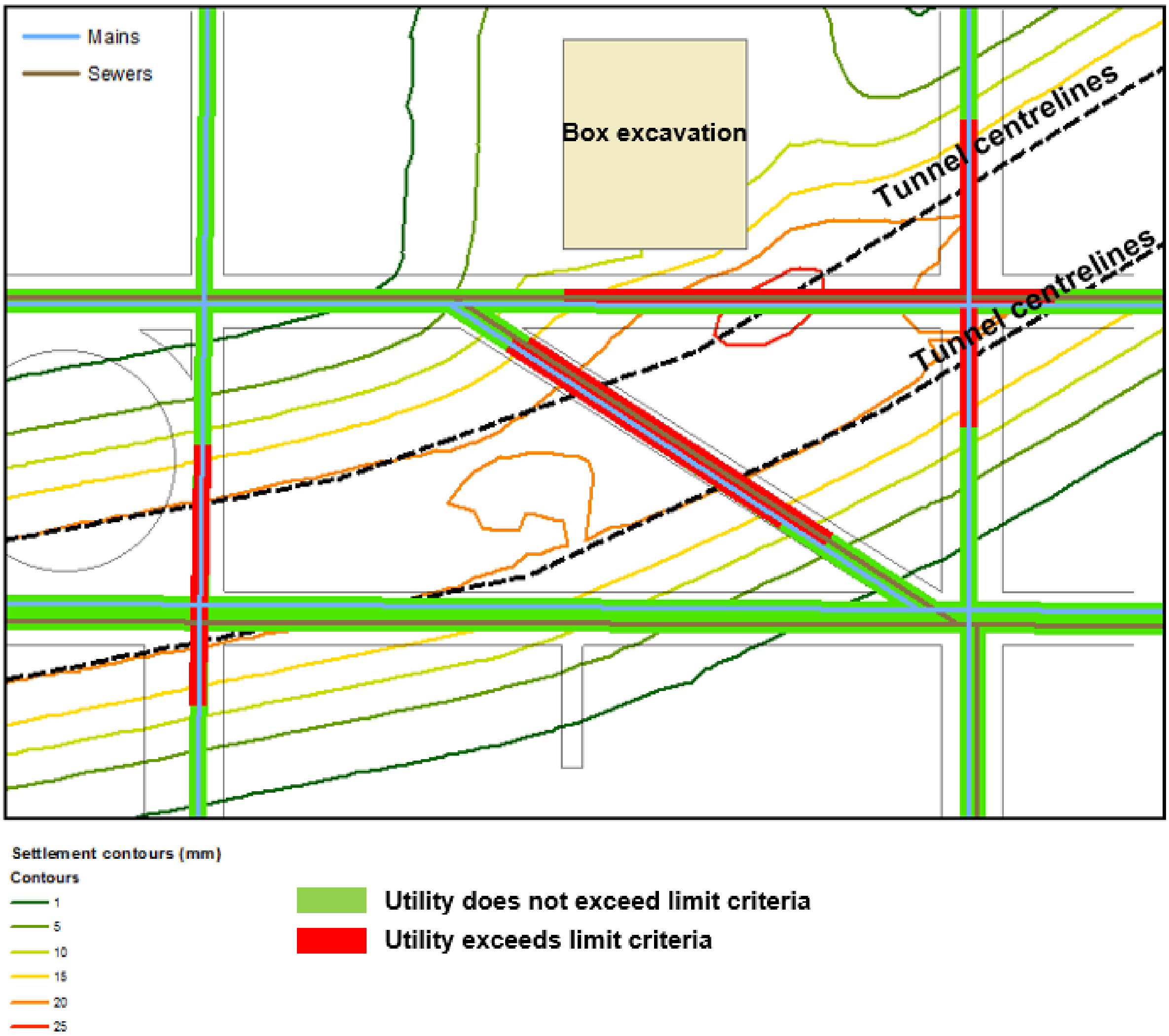

Fig. 5. ArcMap assessment output example with settlement contours and pass/fail criteria

CONCLUSIONS

Time and cost savings

The automation of processes described in this paper not only allows evident time savings connected with direct input of data from one software to another, but reduces the risk of committing mistakes and omitting information which are typical of jobs involving manipulation of big amount of data.

Time savings has been estimated to the number of iterations needed to complete the project. It is typical in projects with many stakeholders to reach upwards of ten iterations by Phase 2. The time saved, also allows the Engineer to add value by providing the Client with alternative scenarios, for example dealing with different Volume losses hypothesis, different retaining wall movements, etc.

Further Work

This particular development allows analysis results to be reviewed in GIS by all parties, which could then be connected to a Common Data Environment. As the project advances through its life cycle, it would be hoped that site readings and actual settlements could be compared to the calculated limits. This would give engineers the ability to respond quickly to any excessive settlements near sensitive infrastructure.

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