Assessment of Tunnel-Induced Damage to Masonry Buildings at King’s Cross

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King’s Cross Development Project (2002)
- Construction of underground ticket halls and tunnels connecting to existing tube lines.
- New Piccadilly Line access tunnel constructed beneath Western Range Buildings.
- These buildings are grade 1 listed.

Tunnel-Induced Settlements
- Excavating a tunnel causes the soil above to settle.
- Without a building, the ground surface will form a Gauss curve transverse to the tunnel, where:

\[ S_v = S_{\text{max}} e^{-\frac{y^2}{2z^2}} \]

- \( S_v \) is the vertical settlement,
- \( S_{\text{max}} \) the maximum settlement,
- \( y \) distance from centreline,
- \( K \) trough width parameter,
- \( z \) tunnel depth.
- These are known as ‘greenfield settlements’.
- Settlements create potentially damaging strains in buildings above.

Surface settlement trough, Attewell et al. 1986.

Finite Element Analysis
- Two models were used. (A) had plain walls, (B) included windows.
- A gap was able to form between the foundation and the soil, creating a more realistic model.
- The soil surface is at the base of the foundation.

Computed West Façade Settlements
- Settlemets were measured along the base of the façade.
- The stiffness of the building reduces the settlement.
- This means the damage to the building is less than a greenfield analysis would predict.

West Façade Structural Damage
- Strains can be read directly from the finite element results.
- These strain contour plots show that tensile strains of the order of 0.015% develop at the base of the façade for both models.
- These strains correlate well with those estimated from the computed settlements.

Comparison to Conventional Methods
- Conventional design methods ignore interactions between the building and the soil. This leads to an overestimate of the likely damage.
- In this project, conventional design methods predicted ‘moderate’ damage to the building. The finite element method predicted ‘negligible’ damage, which is consistent with field observations.
- Damage predictions influence legal agreements between building owners and infrastructure developers. Therefore, it is important that they are as accurate as possible.

Specification of Analysis
- This project looked at the effect of tunnelling on the Western Range building, particularly the west façade.
- A finite element model was created in Abaqus CAE. The results of which were processed using Matlab.
- Predicted greenfield settlements were imposed on the soil at the base of the footing, eliminating the need to model the tunnel itself. This analysis procedure is a new idea being developed in this project.

Problem configuration

Acknowledgements
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Potential Structural Damage
- Masonry is weak in tension and will crack at low strains.
- Small cracks may lead to redecoration, whereas large ones limit the serviceability of the building.
- The tensile strain provides a link between deformation estimates and possible severity of damage

<table>
<thead>
<tr>
<th>Damage Category</th>
<th>Degree of Severity</th>
<th>Limiting Tensile Strain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Negligible</td>
<td>0-0.05</td>
</tr>
<tr>
<td>1</td>
<td>Very Slight</td>
<td>0.05-0.075</td>
</tr>
<tr>
<td>2</td>
<td>Slight</td>
<td>0.075-0.15</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>0.15-0.3</td>
</tr>
<tr>
<td>4 to 5</td>
<td>Severe to Very Severe</td>
<td>&gt;0.3</td>
</tr>
</tbody>
</table>

Relation between damage category and limiting strain, Boscardin et Cording 1989.

Acknowledgements