INTRODUCTION
Leaning walls are quite common in UK, but few are actively monitored. Movement of a leaning wall frequently goes unnoticed until a severe level is reached, when the wall is at risk of collapse. This study focusses on a historic church boundary wall in Rainham, Essex which shows clear signs of leaning and ongoing movement. Potential causes of wall lean were assessed and thermal expansion of a curved section identified as the primary cause. Geometrical modelling was used to predict this expansion.

MONITORING SETUP
The Rainham wall rotates about its base, thus it is a rigid-body movement, and translational movements are likely to be small. The wall lean i.e. tilt is measured by positioning an inclinometer stick on monitoring points installed on the wall.

MONITORING RESULTS

CAUSES OF WALL TILT
Inward movement
• Likely caused by removal of a tree behind the wall, as surcharge is removed and lateral force on the wall reduces.

Outward movement
• Likely caused by a combination of cyclic moisture and thermal effects, which are not fully reversible. The wall expands when temperature rises, but does not contract to its original size when temperature falls because of restraints at foundation level and contact with retained ground. Tilt is exacerbated by fact that upper part of wall is affected by solar radiation.
• Earth pressure exerted on the wall is computed to be small, and unlikely to be the cause of outward tilt.

Local fluctuation
• Seasonal variation in moisture extraction of trees alters the pore pressures in the backfill.

BROMPTON ORATORY BOUNDARY WALL
Another leaning curved boundary wall at Brompton Oratory was identified and measurements provide additional validation to the hypotheses.

GEOMETRICAL MODELLING
The curved section of the Rainham wall is modelled as a hyperbola. Using measured tilt readings as input, the wall is ‘stretched’ and elongation of the wall computed. The Oratory wall was also modelled but using a quadrant.

MODELLING RESULTS

REMEDIAL ACTIONS
Remedial actions include using duckbill anchors or a combination of anchors and steel walers to tie the tilting wall back. Introducing movement joints is viable as the main driver of tilt is thermal expansion. Rebuilding the wall remains an option, but could be prohibitively expensive.

CONCLUSIONS
• Outward tilt of the wall is primarily driven by thermal expansion of the curved section itself.
• For unmonitored walls, it may be possible to estimate wall tilt using the geometrical model, based on the input of wall age, shape, length and surrounding temperatures. Tilt monitoring data from other walls with curved sections are needed to further validate results from the geometrical model.
• The inclinometer is a simple yet effective method for tilt monitoring.

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