Relative stiffness effects on the strain ratcheting behind integral bridge abutments

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Background

Ratcheting of the soil behind integral abutments causes cracking and settlement concerns.

Integral bridges are a **low-maintenance form of bridge construction** without the bearings and expansion joints which trouble conventional bridges. Hence, they have become the **first choice for short & medium span structures**.

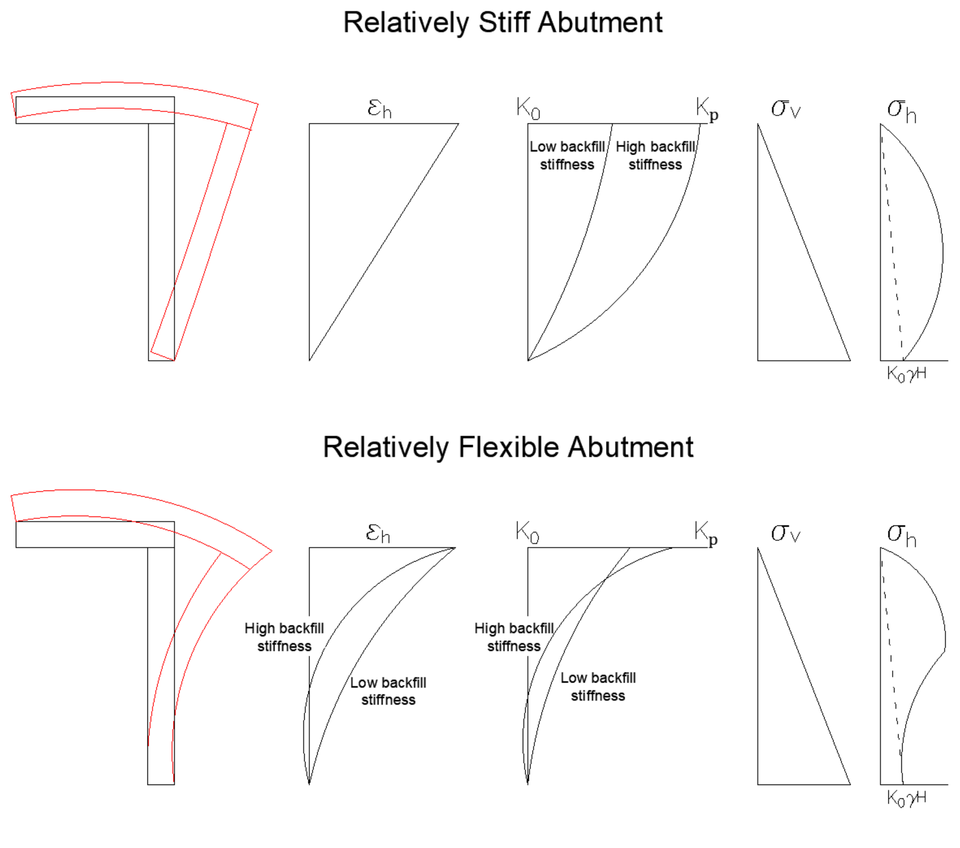
Figure 1. Common bridge problems: joint corrosion, cracking and approach settlement.

However, since they have no joints, **thermal movements of the bridge deck** thrust the abutments into and away from the retained backfill in daily and seasonal cycles. Over many years this brings about **pressure ratcheting and approach slab settlement**, both attracting their own maintenance concerns.

U.K. integral bridges are often designed to the LE method in PD 6694-1. This limits **movements to +/- 20 mm (typically a 60 m span)** due to uncertainty in the post-ratcheting pressure distribution acting on the abutments. This distribution neglects the **relative stiffness of soil and structure** (Sandberg et al., 2020).

Research aim: investigate relative stiffness effects

Explore the significance of soil-structure stiffness on backfill strain ratcheting and the resulting pressure distribution down the abutment.



The LE method in U.K. design specifies an earth pressure distribution that **does not account for the deflected shape of the abutment,** and hence lateral straining of the soil. This shape varies based upon the relative stiffness of soil and structure.

An abutment that is **stiff compared to the soil will rotate rigidly** about its toe and hence cause soil straining down its full height. Whereas a **flexible wall may bend at some point above the base** due to soil restraint, reducing the strains and hence pressure build-up (Wood, 2004).

Figure 2. Influence of abutment deflection on earth pressure distribution.

References

Sandberg, J., Magnino, L., Nowak, P., Wiechecki, M., & Thusyanthan, I. (2020). The integral bridge design concept for the third runway at Heathrow, UK. Proceedings of the Institution of Civil Engineers: Bridge Engineering, 173(2), 112–120.

Wood, D. M. (2004). Geotechnical Modelling. Abingdon: Spon Press.

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Methodology

Centrifuge modelling was used to simulate the 120-year design life of an integral bridge, with thermal cycles imposed using a mechanical actuation system.

Actuation System

- An actuator was designed to simulate **daily and annual thermal cycles** of the deck.
- Continuous sensor feedback allowed **displacement or force control** up to a load of 12 kN and displacement of +/- 0.02 mm.

Integral Abutment Model

- A **9 m RC** integral bridge abutment on a **spread footing** was scaled for a 60g centrifuge flight.
- Four configurations of backfill-structure stiffness were tested using **1 m and 0.4 m thick abutment walls.**
- Sensors captured abutment displacement, deck force, abutment bending moments, lateral earth pressures and soil straining during the test.

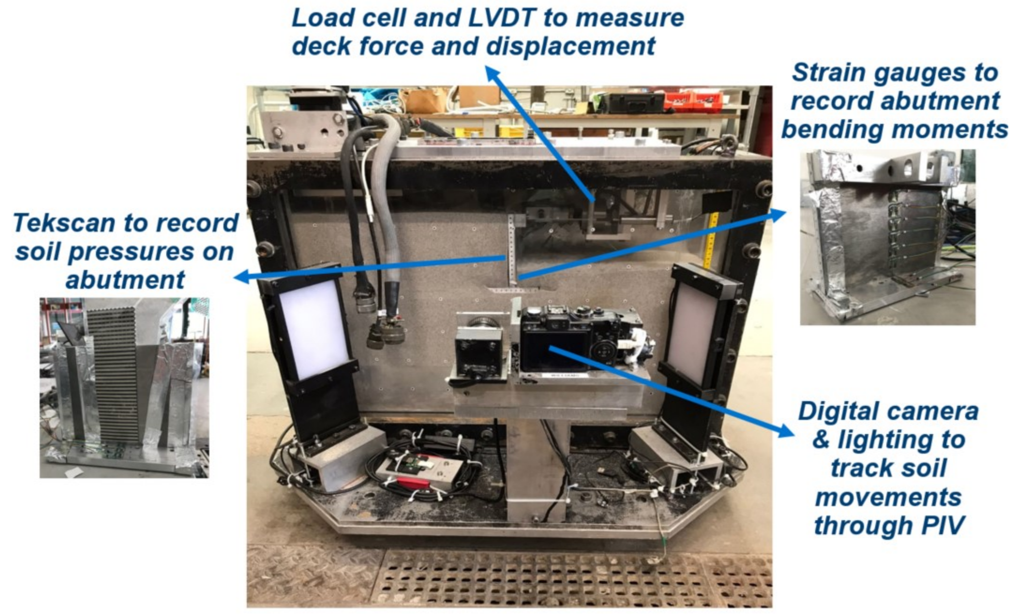

Figure 3. Centrifuge model assembly.

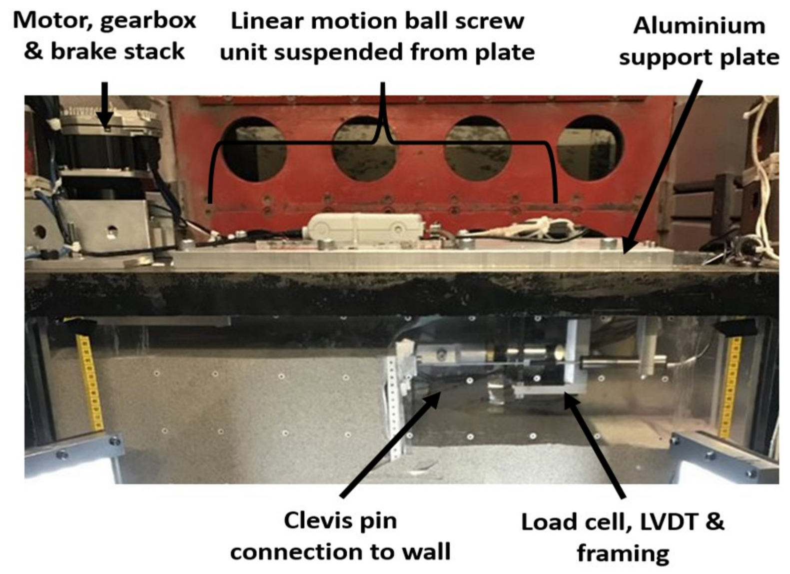

Figure 4. Actuator mounted on the model.

Results

A selection of figures show the influence of relative soil-structure stiffness on ratcheting response, with implications for integral abutment, foundation and deck design.

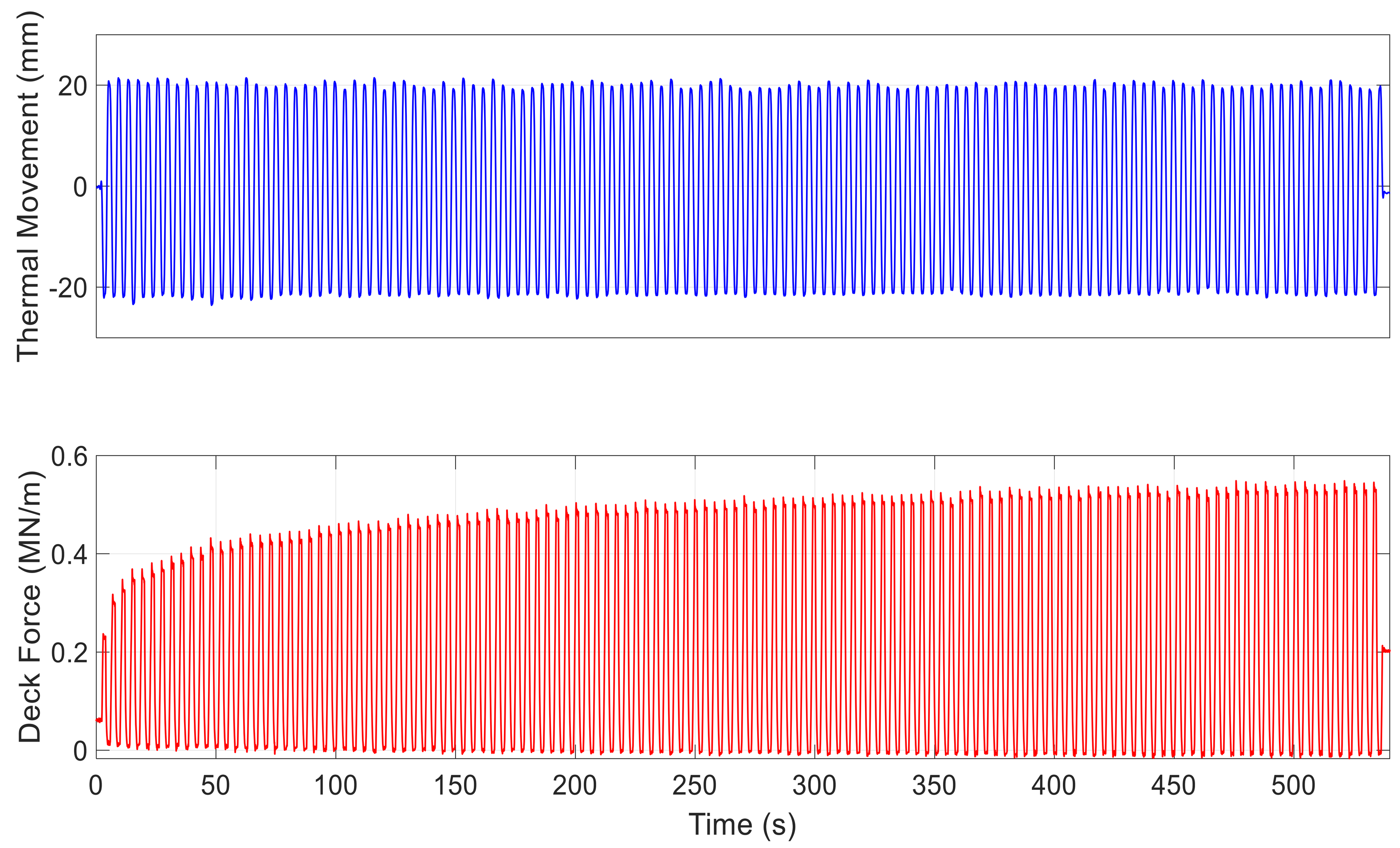

Figure 5. Displacements maintained while deck force increases due to soil strain ratcheting.

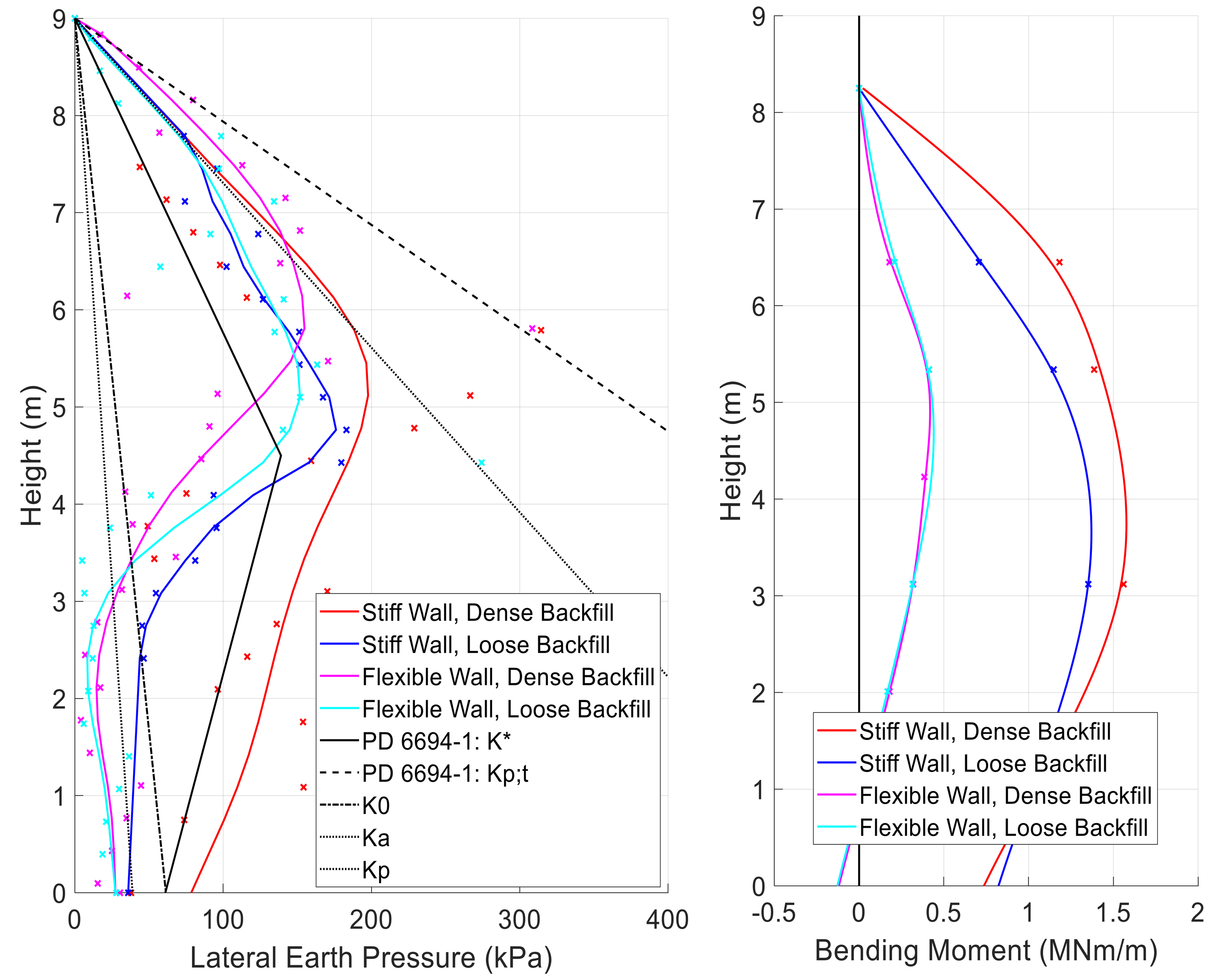

Figure 6 a) Peak earth pressure and b) bending moment distribution after 120 years.

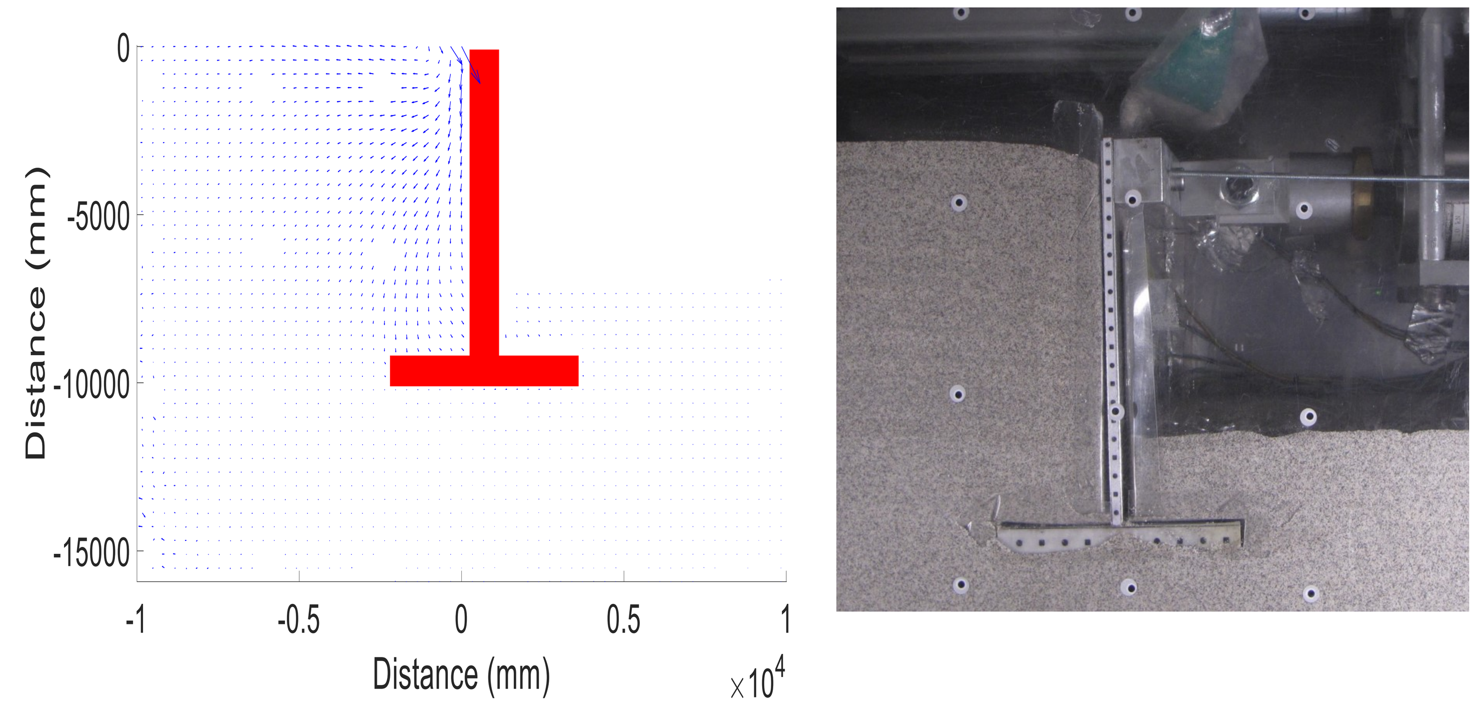

Figure 7. Typical soil vectors (left) and settlement (right) observed at the bridge approach following cycles.

Conclusions

Soil-structure stiffness was shown to significantly affect the strain ratcheting of soil behind integral bridge abutments.

1. **Ratcheting occurs over the entire bridge design life**, most dramatically in the first five years (*Figure 5*) .
2. The LE method in the U.K. design code PD 6694-1 **underpredicts the height and magnitude** of peak earth pressures acting on the abutment (*Figure 6a*).
3. **Abutment bending moments were reduced by around 70 %** with a flexible abutment (*Figure 6b*).
4. **Soil settlement at the bridge approach occurred in all tests**, being larger with loose backfill (*Figure 7*).