Πειραματική διερεύνηση αλληλεπίδρασης ακροβάθρου-επιχώματος ολόσωμων γεφυρών

De Luca F[1], **De Risi R**[2], **Sextos A**[3], **Mylonakis G**[4], **David Williams**[5], **Tony Horseman**[6], **Gabriele Fiorentino**[7], **Sha Luo**[8], **Daniel Boddice**[9], **David Chapman**[10], **Nicole Metje**[11], **Christopher D. F. Rogers**[12], **David Milne**[13], **John Harkness**[14], **Louis Le Pen**[15]

ΠΕΡΙΛΗΨΗ

Στην παρούσα εργασία παρουσιάζονται αποτελέσματα του Βρετανικού ερευνητικού προγράμματος PLEXUS PLUS το οποίο πραγματεύεται τη συμπεριφορά του συστήματος καταστρώματος-ακροβάθρου επιχώματος ολόσωμων γεφυρών. Στην παρούσα σειρά πειραμάτων αξιοποιείται το ενοργανωμένο εδαφικό σκάμμα (Soil Pit) διαστάσεων 6x5x4 m^3 του νέου Εθνικού Εργαστηρίου Αλληλεπίδρασης Εδάφους-Ανωδομής του Η.Β. (UKCRIC Soil-Foundation-Structure-Interaction Laboratory (SoFSI), με σκοπό την καλύτερη κατανόηση του φαινομένου της αλληλεπίδρασης του ακροβάθρου με το επίχωμα μιας ολόσωμης γέφυρας εξαιτίας θερμοκρασιακών μεταβολών, και (β) τη συγκριτική αποτίμηση διαφορετικών μεθόδων ενοργάνωσης του ακροβάθρου και του επιχώματος. Η φόρτιση 120 κύκλων επιβάλλεται με τη χρήση υδραυλικού εμβόλου. Το επίχωμα διαμορφώνεται με περίπου 70t άμμου συγκεκριμένων προδιαγραφών (silica sand) ενώ το ακρόβαθρο ενοργανώνεται με οπτικές ίνες και αισθητήρες μέτρησης μετακινήσεων και πιέσεων. Παράλληλα αξιοποιείται σύστημα μέτρησης της πυκνότητας του εδάφους (Ground Penetrating Radar) σε διάφορες φάσεις του πειράματος και διάταξη επιταχυνσιογράφων μέσω των οποίων εκτιμάται έμμεσα η στιφρότητα του εδάφους υπό δυναμική διέγερση που επιτυγχάνεται με την κίνηση της όμορης σεισμικής τράπεζας 30t, διαστάσεων 6 x 4. Τα αποτελέσματα αποτελούν μια πρότυπη σειρά δεδομένων για το σύστημα ακροβάθρου-επιχώματος σε ελεγχόμενο εργαστηριακό περιβάλλον, και θα χρησιμοποιηθούν για την

[1] University of Bristol, UK, flavia.deluca@bristol.ac.uk
[2] University of Bristol, UK, raffaele.derisi@bristol.ac.uk
[3] University of Bristol, UK, a.sextos@bristol.ac.uk
[4] University of Bristol, UK, g.mylonakis@bristol.ac.uk
[5] University of Bristol, UK, david.l.williams@bristol.ac.uk
[6] University of Bristol, UK, Tony.Horseman@bristol.ac.uk
[7] University of Bristol, UK, gabriele.fiorentino@bristol.ac.uk
[8] University of Birmingham, UK, s.luo@bham.ac.uk
[9] University of Birmingham, UK, d.boddice@bham.ac.uk
[10] University of Birmingham, UK, D.N.CHAPMAN@bham.ac.uk
[11] University of Birmingham, UK, n.metje@bham.ac.uk
[12] University of Birmingham, UK, c.d.f.rogers@bham.ac.uk
[13] University of Southampton, UK, d.milne@soton.ac.uk
[14] University of Southampton, UK, J.Harkness@soton.ac.uk
[15] University of Southampton, UK, louis.lepen@soton.ac.uk

κατανόηση της χρονικά μεταβαλλόμενης μη-γραμμικής συμπεριφοράς και δυσκαμψίας του επιχώματος εξαιτίας θερμοκρασιακών μεταβολών, η οποία αποτελεί σημαντική παράμετρο για την αποτίμηση της, επίσης μεταβαλλόμενης, σεισμικής επιτελεστικότητας του συστήματος κατά τη διάρκεια ζωής του.

Λέξεις Κλειδιά: πειραματική σεισμική μηχανική, ολόσωμες γέφυρες

1 INTRODUCTION

Integral bridges (IBs) have received increasing attention from designers and researchers in the past few decades in many countries. They now constitute a significant part of the transportation infrastructure stock, particularly small- to medium-span highway bridges and overcrossing, with an estimated number in service of over 9,000 in the USA alone [1,2]. Their design varies according to practices and requirements outlined by regional transportation authorities. As an example, in the US each state highway department has its integral abutment with the specification of the American Association of State Highway and Transportation Officials [3] being the most widely accepted IB design guideline in the country, providing performance criteria for IB design. The rationale for the limitations in design codes lies mainly in the uncertainty related to the soil–structure interaction between the backfill and the abutment walls when IB decks expand due to seasonal thermal loads under ambient conditions [4]. In particular, when the bridge expands, substantial force is exerted on the abutment by the soil reaction. Such inherently nonlinear soil action is dependent on the magnitude and distribution (with height) of wall displacements, which encompasses both translational and rotational movements depending on the boundary conditions. In the longer term, as seasons of cyclic expansion and contraction of the bridge decks occur, there can be a build-up of significant lateral earth pressures behind the abutments [5].

This paper presents the results of a large-scale experimental campaign that was conducted in the framework of PLEXUS PLUS project, funded by the UK Collaboratorium for Research on Infrastructure and Cities (UKCRIC). It emerged from the successful experience of collaboration pioneered within the EPSRC project “UKCRIC - PLEXUS - Priming Laboratory experiments on infrastructure and Urban Systems”, a pump-priming project designed to establish the collaboration and practice frameworks needed for long-term, successful, collaborative UKCRIC laboratory environments programme. The PLEXUS PLUS experimental campaign is essentially the third experimental configuration designed and carried out at the University of Bristol to study the problem of soil-embankment interaction at a gradually increasing scale. First, the problem was analysed with the use of a transparent Perspex soil container (Figures 1 and 2). Next, the 3m x 3m, 6DOF, shaking table of the University of Bristol was employed to study the dynamic interaction of integral bridges with their respective backfill and embankment being physically modelled within a 5m long shear stack (dynamic soil box container). The latter configuration permitted the comparative evaluation of the mitigating impact of different EPS (geofoams) (Figure 3).

In the third round of (large-scale) testing that is presented herein, the 6 x 5 x 4 m^3 Soil Pit of the new National Facility for Soil-Foundation-Structure-Interaction Laboratory (SoFSI) is used with the aim to (a) better understand soil-structure-interaction phenomena on the abutment-backfill ensemble of integral bridges due to deck thermal expansion, and (b) employ several monitoring systems necessary to map settlements, strain and pressure characteristics behind the abutment and within the backfill.

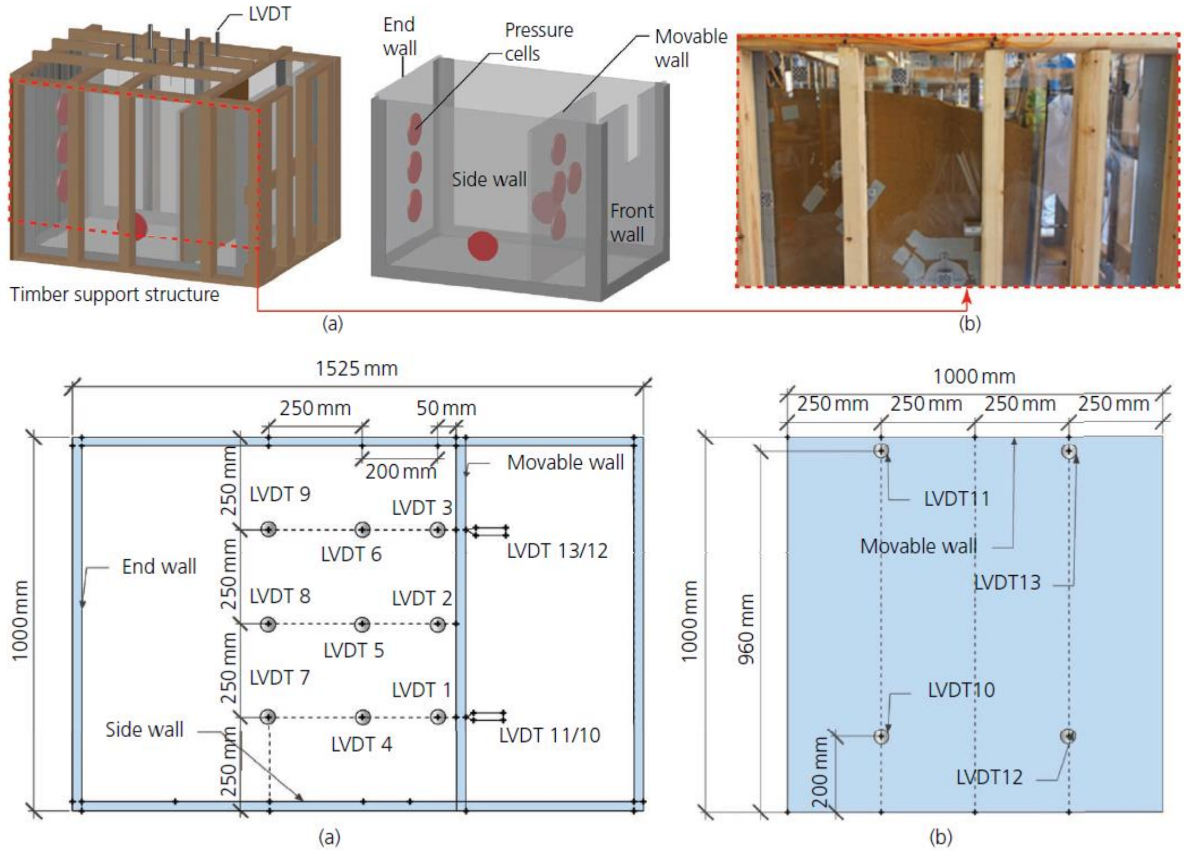

Figure 1: Annotated three-dimensional diagram of the test box; (b) test box filled with LBS (top). Layout of the LVDTs: (a) plan view of the test box; (b) front view of the movable wall (bottom)[6]

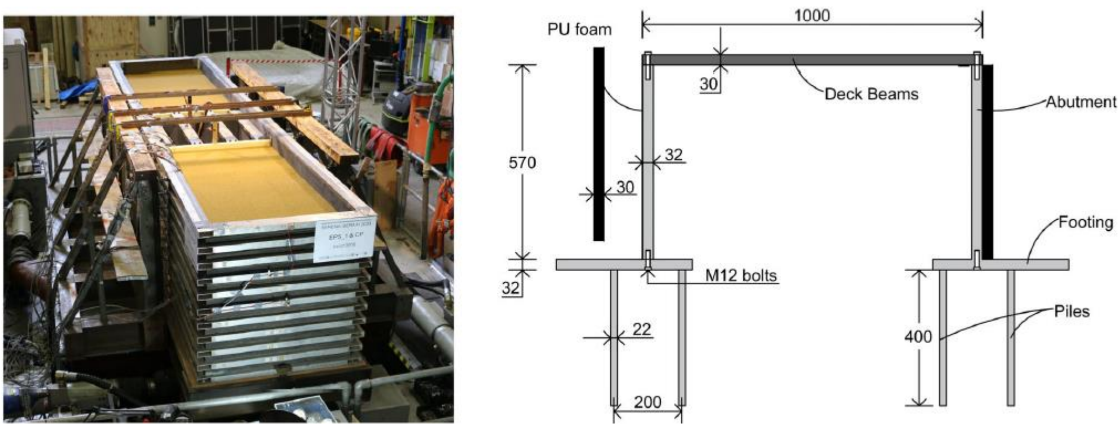

Figure 2: Shear stack configuration containing the scaled integral bridge tested on the 3m x 3m shaking table of the EQUALS Laboratory at the University of Bristol (left) Section of the bridge model (right). All dimensions are in mm. The specific rig was part of the H2020 project SERA [5,7]

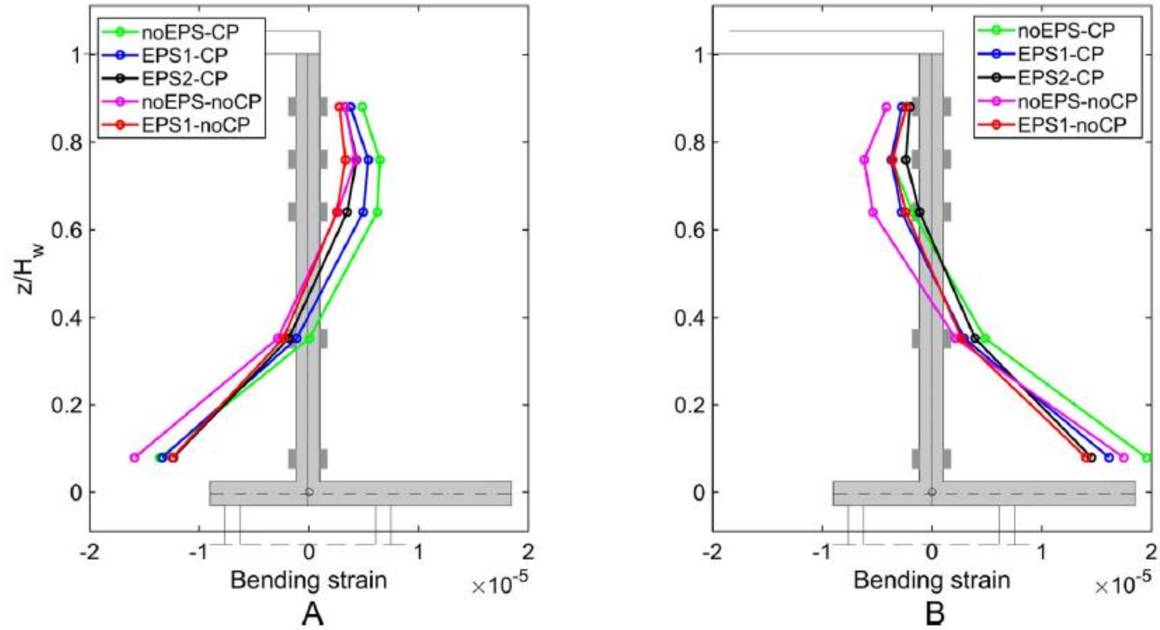

Figure 3: Indicative results of the maximum (left) and minimum (right) bending strain on the abutment wall for different EPS configurations measured as part of the H2020 project SERA in EQUALS Lab [5]

2 TEST RIG

Figure 4 shows an overview of the test rig within the SoFSI Soil Pit right before the initiation of testing. The pit was divided into two sections: an empty chamber facilitating the operation of the actuator and a chamber full of sand that represents the backfill. The two chambers are separated by two robust towers made of concrete Lego Blocks and by a precast reinforced concrete (flap) wall, representing a scaled version of an integral abutment. The wall is supported at the pit floor and is restrained (hinged) at the base by two stoppers preventing translation and allowing only rotation. Approximately 70t of washed and graded high silica sand (code CNSP30) having sub-rounded angularity was used, with a diameter of particles between 0.25 mm and 0.71mm. The friction angle ranges between 31° and 34°, while the density achieved by pluviation varies between 1.55 and 1.66 Mg/m^3. The sand is extracted from the Bent Farm Quarry, Cheshire, UK.

3 INSTRUMENTATION

The wall was monitored using strain gauges, optical fibres, pressure cells, and a digital image correlation. The sand was also instrumented with non-contact LVDT to measure settlements, a Ground Penetrating Radar (GPR) to monitor density throughout the different phases of the test and arrays of accelerometers to measure site conditions based on ambient noise induced by the adjacent 6 x 5 m^2 shaking table.

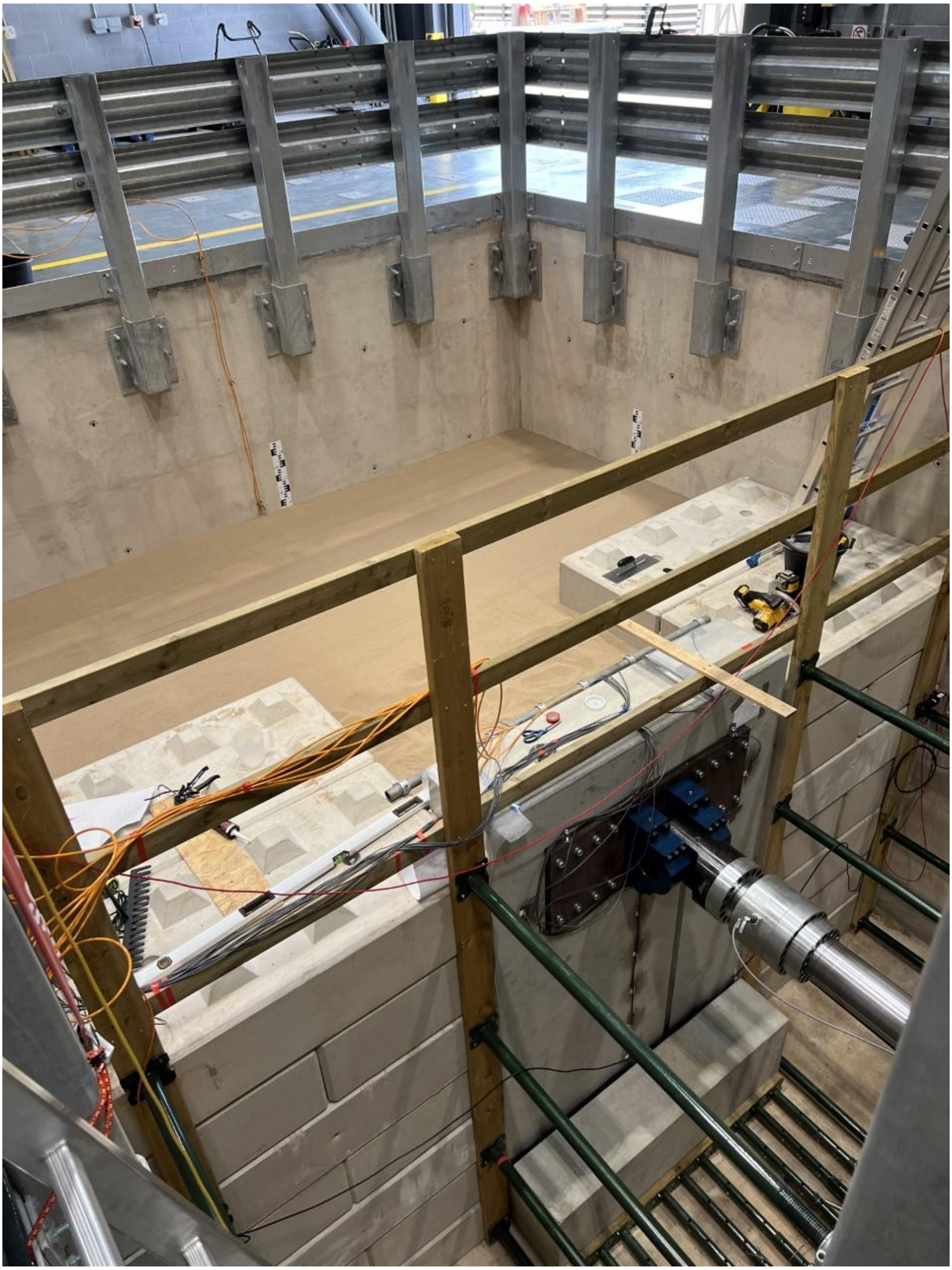

Figure 4: Overview of the SoFSI Soil Pit and the test configuration, including the abutment (flap wall), the hinged base and the loading configuration.

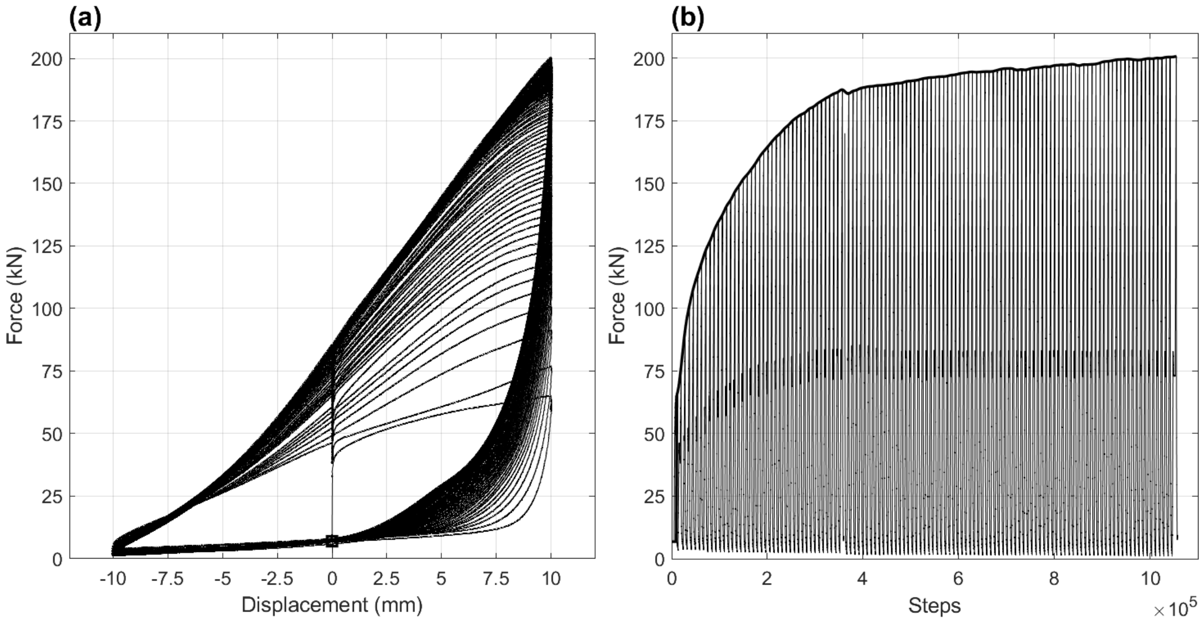

Figure 5: (a) force-displacement hysteretic curves, (b) cyclic loading of increasing amplitude.

4 PRELIMINARY RESULTS AND CONCLUSIONS

The dataset of the results obtained from the test includes measurements of significant settlements (larger than 15 cm – about 6% vertical normal strain) that were observed in the backfill under successive simulations of thermal cyclic loading. This is of importance for actual integral bridges as it may affect the integrity of the approaching slab, particularly in case backfill compaction protocols have not been put in place. Figure 5(a) shows the force-displacement hysteretic curves and the backbone curve of the passive force at the actuator level. It is seen that starting from the rest configuration, the passive force increases quickly to the maximum value (about 200 kN), where it reaches a plateau. Active failure is reached for all cycles, and the force value does not change significantly.

Six pressure cells were installed along the wall height to measure both active and passive pressures for each force cycle. Figure 6 shows the passive and active pressures along the wall at an equivalent (i.e., scaled) time of 10, 60 and 120 years, respectively. It can be observed that the passive pressure reaches a maximum value at 1.5 m from the bottom of the Pit. On the other hand, active pressures are maximized at a height of 1.25 m from the bottom of the pit. Notably, the pressure tends to increase with the number of cycles due to the progressive densification of the sand behind the abutment.

The progressive increase in passive pressures leads to increased internal stresses in the abutment, which implies that serviceability matters (e.g., concrete cracking) may arise with time. Although passive failure is not observed (larger displacements would be needed in this regard), the actuator backbone force is strongly nonlinear, which provides evidence of soil material nonlinearity. The above preliminary results obtained with the experimental campaign are still under processing including comparisons with numerical simulations. The results presented in this paper do confirm the observations made in smaller-scale experiments conducted by the authors [6].

The results at hand do also offer a quality benchmark case within a well-controlled soil-structure interaction environment that can enhance our understanding of the long-term performance of integral bridge abutments, to reduce the epistemic uncertainty associated with the behavior of integral bridges and ultimately reduce unnecessary conservatism margins in design codes.

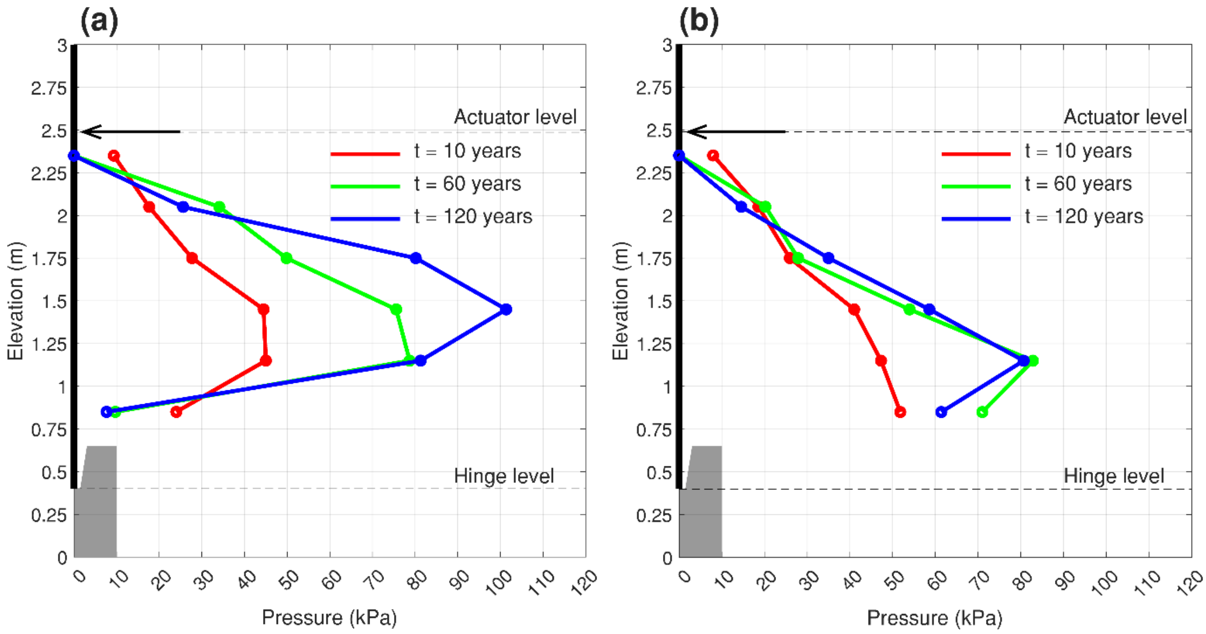

Figure 6: (a) Passive and (b) active pressures along the wall for an equivalent period of 10, 60 and 120 years.

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