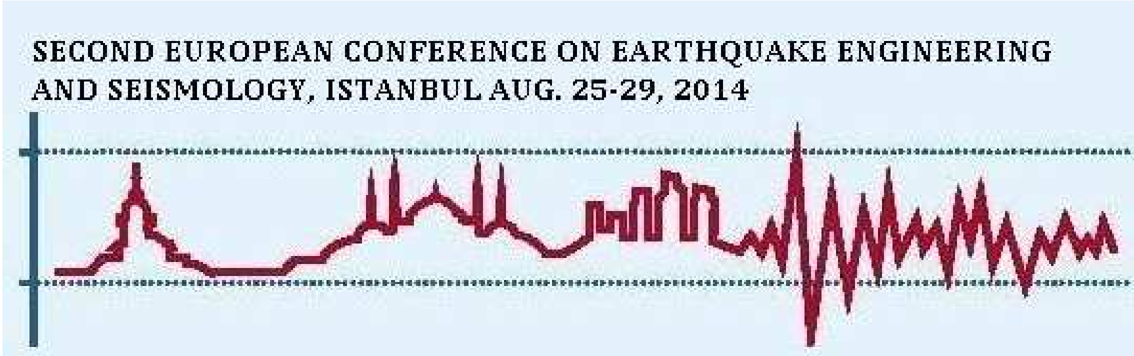

GREEN RUBBERISED COMPRESSIBLE INCLUSIONS TO ENHANCE THE LONGEVITY OF INTEGRAL ABUTMENT BRIDGES

Stergios MITOULIS[1] Sotiris ARGYROUDIS[2] and Kyriazis PITILAKIS[3]

ABSTRACT

Integral abutment bridges (IABs) are jointless bridges supporting the “get-in, get-out stay-out” philosophy of sustainable, maintenance-free and resilient structures. A wide field of study is open to abutment and backfill design innovation, as no unified procedures are available in current codes for the design and construction of IABs. At the same time waste tyres are banned from landfills according to the recent European and UK Landfill directives. Large amounts of recycled tyre shreds are expected to be absorbed in the near future in the structural sector, i.e. in foundations, abutments and backfills. In light of this wide field of study, a compressible inclusion (CI) of tyre derived aggregates (TDAs) is introduced between the abutment and the backfill soil. The use of this CI is a smart design alternative, with clear and straightforward benefits: (a) **Environmental benefit**: by making use of recycled materials into real structures the use of recycled materials is maximised; (b) **Structural benefits**: the bridge response and long-term performance and resilience is significantly improved, since many problems related to the bridge-embankment interaction of bridges are tackled by making use of engineered CIs: (i) the SSI effects between the abutment and the backfill are controlled; (ii) the bump-at-the end-of-the-bridge due to the backfill settlements; (ii) the ratcheting effect and the increasing in time passive pressures towards the abutment and (iii) the additional stresses induced to the prestressed deck that may induce cracking and long-term deterioration of the deck. (c) **Cost-effectiveness:** reduced cost is achieved, compared to the cost of conventional backfilling. In this framework, the use of CIs is to be studied as means to provide remediation of the frequent serviceability and seismic problems of IABs in an effort to increase the length limits of IABs, whilst supporting a smart earthquake resistant and environmental friendly design concept. In doing so, this research will evaluate the modification in the seismic response and the long-term performance (serviceability) of a full-height integral abutment when CIs are used for an IAB of 240 meters long.

INTRODUCTION

Bridges are important structures that are extremely expensive to construct and maintain. Integral Abutment Bridges (IABs) became rapidly popular lately (INTAB 2010, IABSE 2011) due to their low need for maintenance and robustness (Mistry 2005). Extending the length limits of IABs, to cover the majority of contemporary bridges, is a critical step towards maintenance-free bridges and this has always been a challenge (Burke 1993).

It is now well established that most of the critical design issues of IABs are related to the known bridge-abutment-backfill interaction, which is twofold, as it concerns primarily the serviceability and also the dynamic response of medium to long-span highway bridges (Burke 1993). Structural

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measures, such as the use of loose backfill soil, have been introduced by researchers aiming at enhancing the resilience of the abutment's pile foundation against serviceability under cyclic loading (Arsoy et al., 2004) The in-service interaction between the abutment web and the backfill soil is minimized by the use of substitute expansion joints with compressible materials, such as expanded polystyrene (EPS) (Horvath 2000 and 2004) or tyre shreds (Humphrey, 2003 and 2011) combined with a mechanically stabilized earth (MSE). Apart from stub type abutments with piles, also full-height integral abutments are introduced in the European literature. England et al. (2001), Xu et al. (2007) Clayton et al. (2006), Bloodworth et al., 2012 have studied the response of full height integral abutments with extended laboratoy tests. Its web is either rigidly connected to or pinned on a spread foundation (Darley et al 1998). In the latter case, the minimization of its in-service loading is aimed. Potzl et al. (2005) have also employed EPS layers behind full height abutments. However, the seismic performance of IABs, i.e. with abutments rigidly connected to the deck, can be significantly improved when utilizing the backfill soil, reinforced or conventional, to the earthquake resisting system (ERS) of the bridge. This has been established by now in bridges with either conventional seat-type abutments (Mitoulis 2012; England & Tsang 2001) or unconventional abutment configurations (Mitoulis et al., 2011). Hence, it seems that the design of integral abutments is an open field of study attracting new concepts and innovation (Arockiasamy et al., 2005) aiming to utilize the prospective seismic interaction with the backfill in IABs.

In this framework, smart and eco-friendly designs of the backfill soil with recycled elastic aggregates (TDAs) are investigated as means to overcome frequent problems of long-span IABs, such as the settlements, the poor drainage, the excessive pressures towards the abutment and the long-term deterioration of the approach area. The typical backfilling solutions are compared with innovative compressible inclusions (CI) that are interjected between the backfill soil and the abutment. The objective of the ongoing research is to identify whether the CIs are able to to minimise the pressures towards the abutment and the loading of the abutment during the bridge service and under seismic loads. This novel design offers a new solution towards minimising the environmental impact of stockpiled tyres, saving valuable landfill space, reducing fire and health hazards and conserving natural aggregate resources. The study started with experimental research. Oedometer tests conducted at the University of Surrey to define the properties of the CIs. The results were compared with triaxial tests conducted in Aristotle University of Thessaloniki. Subsequently, numerical models were developed and analyzed using 2D nonlinear FE model in Plaxis. Modeling of two different abutment configurations were attempted: (a) abutment-CI-backfill and (b) typical abutment in contact with thebackfill. The analyses accounted for the construction stages of the abutment and the backfill soil, which modify the initial stresses in the soil and on the abutment. A step-by-step analysis-validation procedure was followed, starting from simple static to complex non-linear dynamic models (Argyroudis et al., 2013). The properties of the backfill employed in the analyses are based on typical design cases and literature. Representative input loading that correspods to typical serviceability and seismic loading was selected. Serviceability and dynamic SSI effects were analysed and evaluated on the basis of settlements of the backfill soil, pressures towards the abutment and loading of the abutment. The above results are directly related to the long-term performance and condition of: (a) the backfill and the prospected bump-at-the-end-of-the-bridge; (b) the abutment and its loading; (c) the prestressed deck and its additional stresses that affect the prestressing needs.

DESCRIPTION OF THE PROBLEM IN IABs

Because of natural, daily and seasonal variations in air temperature, the bridge superstructure will change in temperature, as shown in Figure 1 and tends to change dimensions in its longitudinal direction. This causes constraint movements of the abutments top as shown in Figure 2.

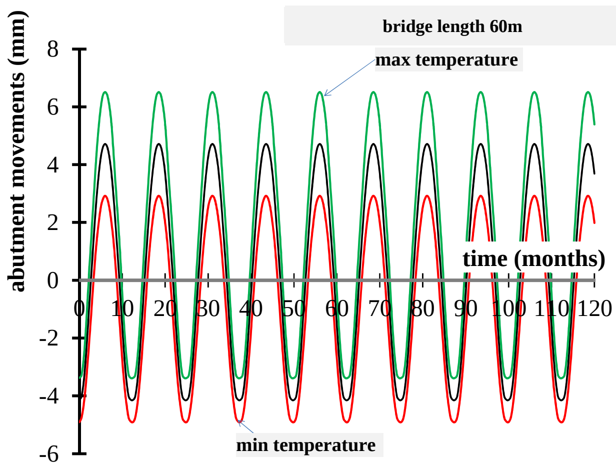

Figure 1. The movements of the abutment due to the thermal expansion and contraction of the deck (annual movements are indicatively shown for the max, average and min temperatures for a bridge of 60 meters long).

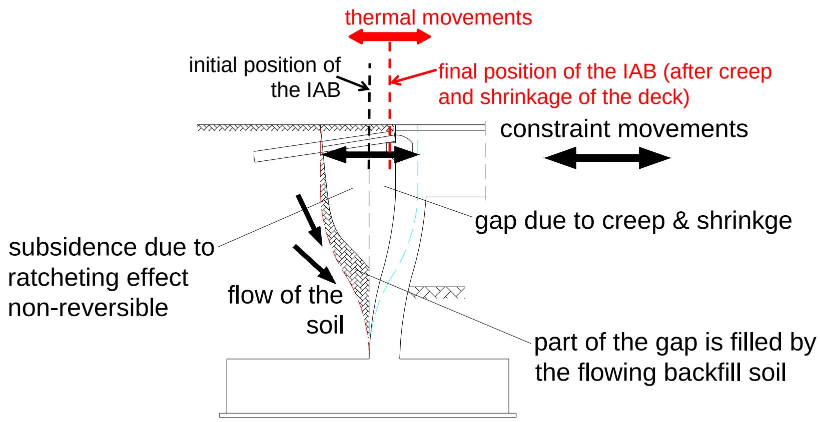

Figure 2. Schematic diagram of interaction between the IAB and backfill soil.

The problem had been understood in 1990s. Research has indicated that this seasonal increase in lateral earth pressures may actually be a bigger problem than initially thought. The reason is related to the net movement of the abutments away from the retained soil as shown in Figure 3 (bottom left). The explanation of the cause of this net movement, in addition to any post-construction superstructure permanent contraction due to creep, elastic shortening due to prestress and shrinkage effects, begins with the fact that a wedge-shaped portion of the retained soil moves toward each abutment foot during the annual winter contraction of the bridge superstructure and concomitant movement of an abutment away from the soil. When the superstructure expands towards its next summer maximum expansion, this soil wedge does not return to its original position. This is due to the inherent non-linear behaviour of soil and can thus occur with any type of soil and no matter how properly it was placed or compacted during the original construction (Horvath 2000).

In any event, as a result of this soil movement the summer lateral earth pressures tend to increase over time as the soil immediately adjacent to each abutment becomes increasingly wedged in. Because each summer lateral earth pressures are somewhat greater in magnitude than those from the preceding year it means that structural failure may take years to develop, a phenomenon that has been observed in practice for other types of earth retaining structures where thermally induced cyclic movements and soil wedging also occurs. Overall, this phenomenon of soil wedging and long-term build-up of lateral earth pressures is referred to as ratcheting. Given the relatively long (over 100 years) design life of IABs, ratcheting behaviour represents a potentially serious long-term source of IAB problems and a primary structural failure of the abutments. Ratcheting flow pattern (England & Tsang 2001), wedging and densification of the soil behind the abutment, indicatively shown in Figure 3, cause the long-term increase of pressures, which eventually approach passive earth pressure conditions (Bloodworth et al 2012). Figure 3 describes in a simplified way the phases of the in-service complex abutment-backfill interaction effect.

Compressible inclusions have been introduced in international literature by Horvath (2000) as means to overcome frequent SSI-related problems of IABs. Potzl et al. (2005) have also employed the use of EPS in full height abutments, whilst Athanasopoulos-Zekkos (2012) made use of EPS to reduce the earthquake effects on yielding earth retaining structures. Humphrey (2011) has reported extensively the application of tyre derived aggregates (TDAs) in real structures. The use of tyre streds to create a compressible inclusion behind integral abutments was introduced for the first time on Topsham-Brunswick By-Pass project constructed in 1996,. However, the application of recycled tyres in that case was made to a short span bridge. This paper studies the application of CIs in demanding long-span IABs, which exhibit large seismic and serviceability movements.

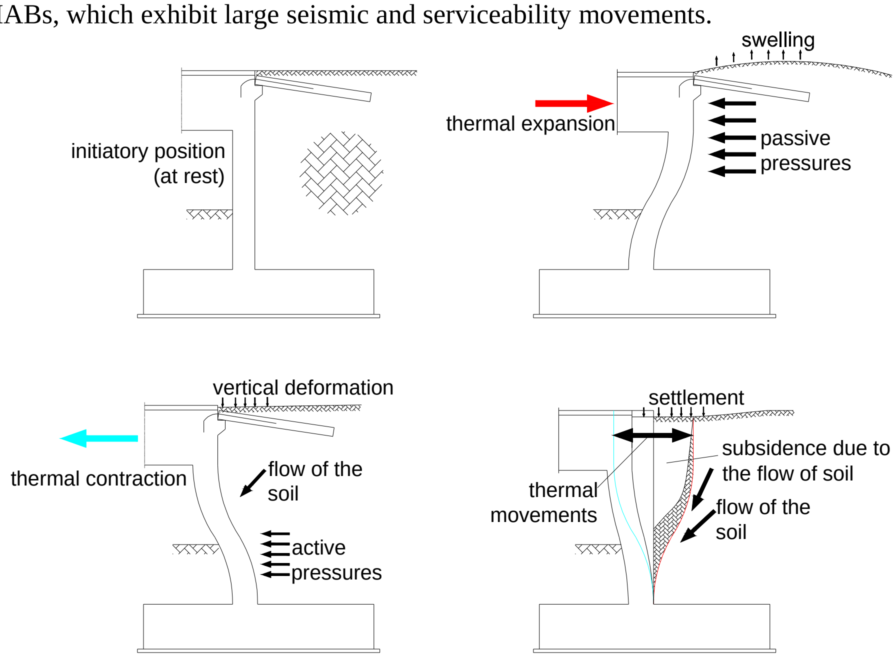

Figure 3. Top left: the initial position of the abutment; top right: the position of the abutment when the deck expands and the corresponding swelling of the backfill soil; bottom left: at bridge contraction and verical deformation of the flowing balckfill soil; bottom right: the flow of the soil, the subsidence “behind” the abutment and the prospected settlements.

OEDOMETER TESTS AND DESIGN OF THE COMPRESSIBLE INCLUSION

The compressible inclusion (CI), which is placed behind the abutment, is loaded by pressures when the abutment moves towards the backfill soil, i.e. when the deck of the bridge expands. This loading can be adequately modelled by one-dimension pressure of the layer. Hence, oedometer tests were considered to be adequate for obtaining the stress-strain curve and the Young’s Modulus and the oedometer modulus of the CI under compression. In the framework of the experimental study, oedometer tests were conducted for compressible inclusions having 25%, 50%, 75% and 100% tyre derived aggregates (TDAs). The rest of the material, i.e. the 75%, 50% and 25% of the CI was sand that is used in conventional backfills.

The design of the CI described in this paper took into account only the case that 100% TDAs were used. The stress-strain curve of the oedometer tests for the specimen of 100% TDAs is given in Figure 4. The objective of the design was to maintain the elastic behaviour of the CI under the maximum movement of the abutment, aiming to minimise the permanent deformatıons of the CI. This design minimises the creation of potential subsidences behind the abutment, which would allow the flow and ratcheting of the soil material behind the wall and the consequent build-up of pressures. To minimise the potential permanent deformations of the CI, i.e. the CI is expected to respond in an elastic manner, the oedometer tests were used to identify the maximum allowable strain of the CI.

Having found that the CI responds in an elastic manner for axial strains up to 30% the Young's modulus of the CI was obtained. For a CI with 100% TDAs and an upper limit for an axial pressure equal to 100kPa the axial strains of the CI were calculated equal to 30%. The target displacement that the CI is required to undertake whilst responding in an elastic manner was 30mm. This movement of the abutment corresponds to the demanding case of an integral abutment bridge of 240 meters long with continuous deck. A simplified calculation of the movement is given with equation 1.The maximum movement of the abutment Δ_{ab} due to the maximum thermal expansion of the deck is:

$$\Delta_{ab}=a \cdot L \cdot \Delta T/2 \quad (1)$$

where a is the coefficient of thermal expansion of the concrete, taken equal to $10^{-5}/^{o}C$, L is the length of the bridge, i.e. 240 meters, and ΔT the uniform temperature change of the bridge deck, i.e. $\pm 25^{o}C$ according to Eurocode 1-5 (2005). The total contraction of the deck was divided by 2 to obtain the constraint movement of the abutment Δ_{ab}. Based on equation 1, Δ_{ab} is calculated equal to 30mm. In order to maintain the CI elastic for the maximum expansion of the deck, i.e. to obtain a maximum allowable strain smaller than 30%, the required thickness of the CI is 30mm/0.30=100mm.

The above design parameters were used for the analysis conducted with the finite element code PLAXIS (see next section). For a strain equal to 30% that corresponds to a stress equal to 100kPa, the Young's modulus is E=100/0.3=333.33kN/m^2. The laboratory triaxial tests of Senetakis et al. (2012) and Anastasiadis et al. (2012) concluded that the Young's modulus of 100% rubber is 960 kPa for a σ_3=100kPa, that is almost three times larger than the value obtained by the oedometer tests. However, the results obtained by the triaxial tests preassummed a confining pressure of the rubber material to model its response when used as a backfilling material. The CI does not receive credible vertical loads by traffic, since an approach slab, shown in Figure 5 receives the vertical traffic loads and transfer them on the bridge and on the backfill soil. Hence, the value of the Young's Modulus equal to 333.33kPa was considerd to be more accurate under the predefined loading of the CI. This modulus was then multiplied by the factor 1.5 to account for the long-term hardening of the rubber material that is recognised by Eurocode 8-2 (2005). This value is on the side of safety as it increases the axial stiffness of the CI and hence increases the undesirable pressures towards the abutment for a given movement of the wall towards the balckfill soil. Hence, analyses were considered a Young's modulus equal to 500kPa for the CI and a thickness equal to 100mm.

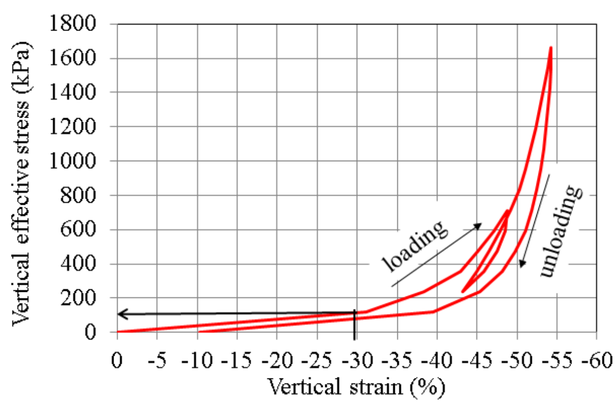

Figure 4. Stress-strain curves obtained by the oedometer tests for a CI of 100% recycled tyres.

DESCRIPTION OF THE ANALYSED INTEGRAL ABUTMENT

GEOMETRY

The abutment was a full-height integral abutment, as shown in Figure 5. The height was 7 meters and the depths of the web and the spread foundation were both 1 meter. The foundation was extended 1 meter towards the centre of the bridge and 3 meters towards the backfill soil. The depth of the footing was considered to be 2 meters below the surface. The wing-walls and the approach slab shown in Figure 5 were not taken into account in the numerical model. These elements are expected to restrain the movements of the abutment and, as such, to influence the loading of the abutment, the CI and the backfill soil. The C30/37 concrete strength was considered for both the abutment and its footing. The concrete has cubic and cylindrical strength equal to 30 Mpa and 37 Mpa respectively.

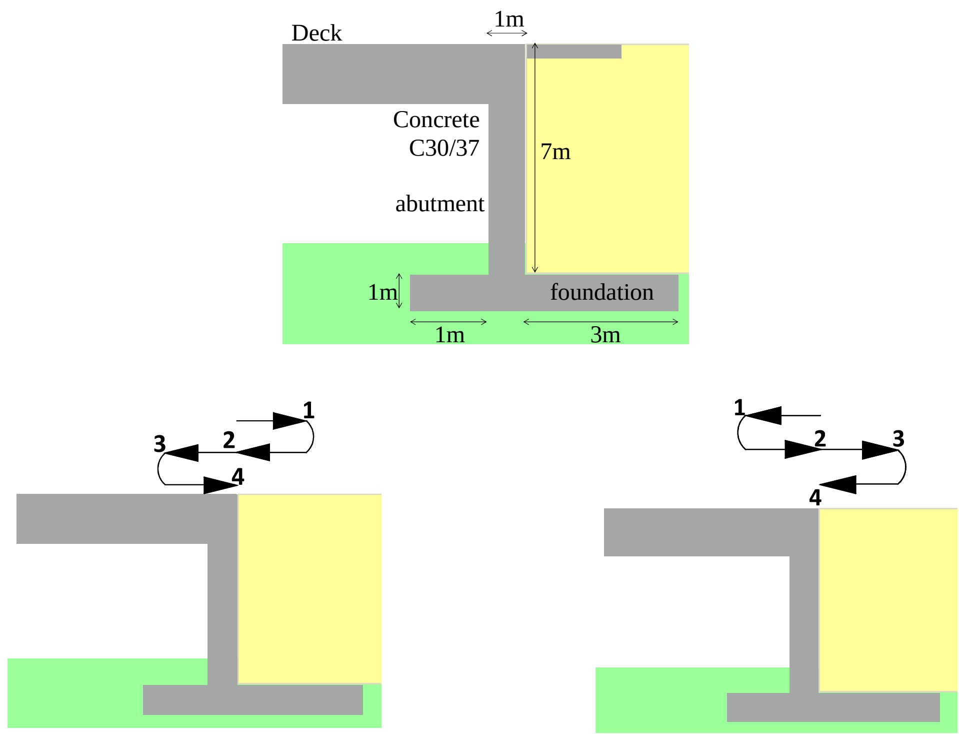

Figure 5. Top figure: the geometry of the integral abutment that was analysed, bottom left: loading 1, expansion and contraction, bottom right figure: loading 2, contraction and expansion.

STAGED CONSTRUCTION AND ASSUMPTIONS

The abutment was considered to be constructed in stages, as described in Figure 5, while it was considered to be restrained by the bridge deck at the average bridge temperature, i.e. 10^{o}C. This study did not take into account different loading scenarios due to potential different seasonal average temperatures, i.e. restraint of the abutment during the summer or during the winter. However, construction and restrain of the abutment during the warm summer or cold winter seasons would cause the maximum movement of the abutment towards the centre of the bridge or towards the backfill soil correspondingly. The time of the restraint of the abutment can potentially change the response of the abutment and the backfill soil, as the initiatory position of the abutment would be different for temperatures higher or lower than 10^{o}C. In the first case, the movement of the abutment towards the centre of the bridge would create a subsidence behind it that would change the response of the system abutment-backfill and the prospected SSI effects. Similarly, the response of the system abutment-CI-backfill would be different, if the abutment had a large movement towards the backfill, due to its restraint during the winter.

The construction of the abutment and the backfill soil that were modelled with PLAXIS was considered as follows (Figure 7): *Phase 1*: The abutment is constructed, *Phase 2*: Installation of the CI, i.e. placement of the TDA geogrid sacks and attachment of the sacks on the abutment; *Phase 3*: construction of the layers of the backfill soil and use of horizontal geogrid reinforcements. A total of 14 layers of sand having a thickness equal to 500mm and 8 meters long geogrid reinforcements were used. *Phase 4*: The construction of the backfill is completed and the approach slab is constructed to undertake potential settlements of the backfill soil during the bridge service; *Phase 5*: Restraint of the abutment, i.e. connection of the continuous bridge deck with the integral abutment. After the completion of the backfill, the soil was compacted. Compaction was provided by applying vertical pressure to the backfill equal to 30kPa. The abutment was then subjected to thermal serviceability movements, shown in Figure 1. Full cycles of maximum expansion and contraction of the deck were considered, and the system abutment-CI-backfill was subjected to a maximum movement of ±30mm. To obtain potential different responses of the abutment-CI-backfill soil, the abutment was subjected to either expansion-contraction cycles and to contraction-expansion cycles as the bridge might expand or contract after its connection with the abutment. The average temperature of the bridge was considered along the ten-years period whilst daily changes in bridge temperature were not taken into account.

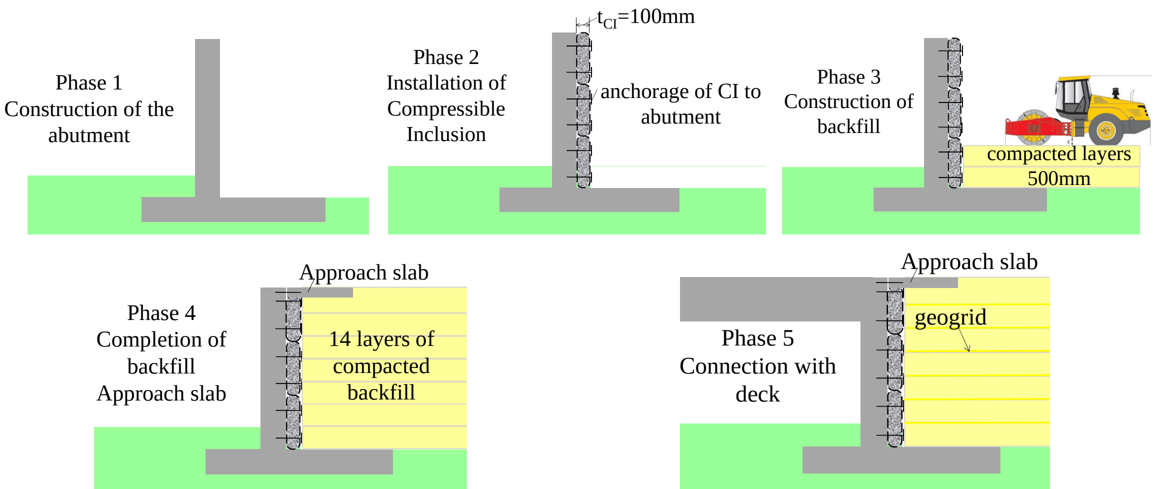

Figure 6. The construction stages of the abutment with the CI and the compacted sand backfill.

MODELING IN PLAXIS

The integral abutment described before is modelled with the 2D (plane strain) finite element code PLAXIS (Figure 7). The coupled soil-wall interaction analyses were performed for two cases with the compressible inclusion and without it (conventional backfill soil). The width of the model, 120 meters, was properly selected to minimise boundary effects. A set of initial analyses is performed to simulate initial geostatic stresses as well as the staged construction of the wall, the backfill and the compressible inclusion (as shown in Figure 6). Then, the displacements due to the uniform temperature effects are applied at the stem of the abutment. Two cases of one cycle of loading (±30mm) are considered: load 1 (expansion-contraction) and load 2 (contraction-expansion of deck).

The behaviour of the foundation soil and the backfill material was considered as elasto-plastic described by the Mohr-Coulomb criterion. Interface elements having a friction coefficient R_{inter}=0.70 were used to model the interface behavior between the backfill and foundation soil with the wall as well as between the compressible inclusion, the wall and the backfill, allowing the relative movement between the soil/rubber and the abutment/rubber. The abutment is modeled with linear elastic beam elements having E=30 Gpa. In case of the model with the CI, geogrid elements are placed between the backfill layers as well as the backfill and the CI, as it is described in the previous section, with length equal to 8.0 m and EA= $1 \cdot 10^5$ kN/m.

The abutment was founded on soil with volumetric weight γ=19 kN/m^3, c=100 kN/m^2, Young's modulus E= $1.5 \cdot 10^5$ kN/m^2 and Poisson ratio v= 0.35. The backfill soil behind the integral abutment had volumetric weight γ=18kN/m^3, phi=36^0, Young's modulus E=$3.3 \cdot 10^4$ kN/m^2 and Poisson's ratio v=0.30. The CI material (TDA) follows elastic behaviour, has volumetric weight γ=6.1 kN/m^3, and Young's modulus E=57 kN/m^2, which corresponds to Oedometer modulus E_{oed}=500 kN/m^2 and Poisson ratio v= 0.48. A sensitivity analysis showed that the results are strongly influenced by the Poisson ratio of the CI. For smaller values of v, deflections of the backfill soil were found to be increased, whilst for values of v close to 0.5 the deflections of the backfill soil are rapidly reduced.

Hence, the design of the CI should target to values of v close to 0.5, which are also described in the literature (Senetakis et al. 2012).

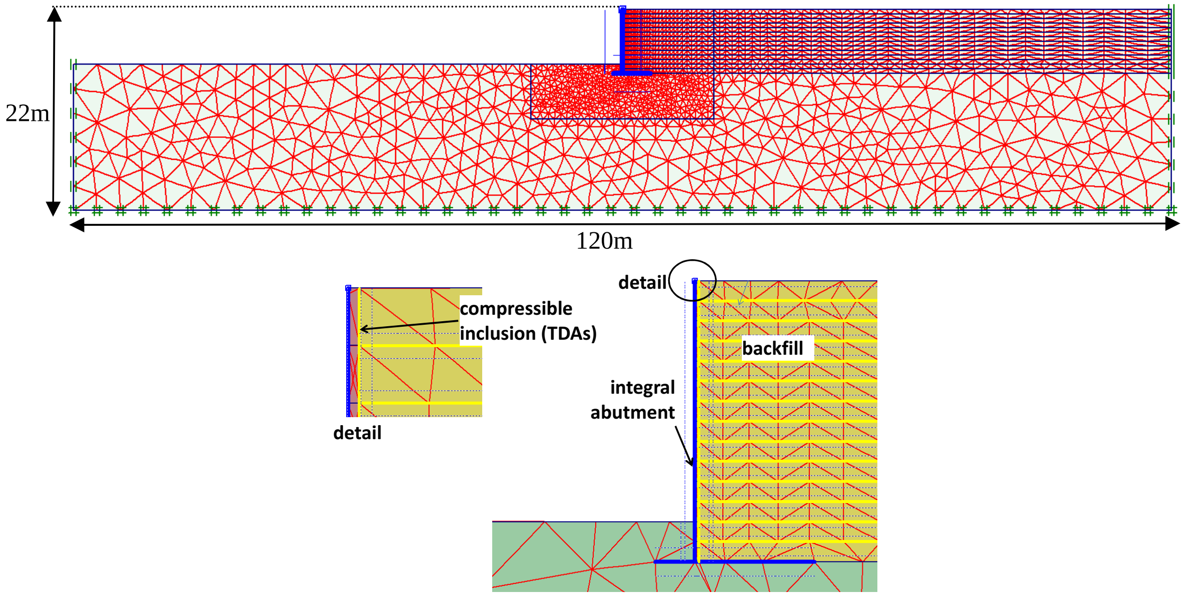

Figure 7. Top: The model of the integral abutment with the backfill soil bottom: detail of the modeling in the vicinity of the integral abutment, the compressible inclusion and the backfill soil in PLAXIS.

Additional dynamic analyses were performed for the two models (with and without CI) under seismic loading conditions. The objective of these analyses was to obtain a preliminary view of the effect of the CI in the seismic response of the abutment-backfill system. A synthetic seismic ground motion that corresponds to stiff soil conditions (soil class B according to EC8) with PGA = 0.19g and duration 20s was applied uniformly at the basis of the model. Simultaneously, a deck-to-abutment pounding time history is applied on the top of the abutment wall, corresponding to the response of numerical results obtained for a real 240 meters long integral bridge. The total width and the depth of the model are now extended to 200 m and 37 m, to avoid boundary effects. The soil material damping is introduced numerically in the form of Rayleigh damping (see Argyroudis et al.2013 for more details of the modeling).

RESULTS

Figures 8 to 10 show the results of the study, i.e. the effective pressures on the abutment, the horizontal displacements of the backfill soil and the settlements of the backfill soil after one cycle of loading cases 1 and 2 (described in Figure 5). The comparisons of the two figures on the top shows that the pressures applied at the abutment are different when the sequence of loading differs, i.e. expansion first and then contraction (load 1) or contraction first and then expansion (load 2). In the first case (load 1) the maximum pressure on the abutment 150kPa was found to be developed at the abutment stem. The final residual stresses (curve number 4 of the figure) on the abutment were found to be almost equal to the ones developed during the expansion of the deck, i.e. when the abutment moves towards the backfill soil.

The results differ significantly from the described ones when the contraction of the deck occurs first (load 2), followed by the expansion. Figure 8b on the top right shows that the maximum stress is at 5.5 meters from the abutment foundation, whilst the maximum stresses on the abutment are of the order of 230kPa, i.e. much larger than the ones measured at load 1. The last value corresponds to values of the coefficient of passive earth pressures of the order of K_p=8. The max residual stresses (curve number 4 of the figure 8b) are of the order of 110kPa, whilst their distribution along the height of the abutment is similar to the one measured when the maximum movement of the abutment towards the backfill soil occurred (curve number 3 of the figure).

The use of the CI reduced rapidly the pressures applied at the abutment. It seems that the backfill soil creates a maximum pressure towards the abutment of the order of 42kPa at the bottom of the abutment, Figure 8c. These pressures correspond to the active earth pressures, i.e. to a K_o=0.4. The pressures were slightly increased when the abutment moves towards the backfill soil, see curves with number 1 in figure 8c curve number 3. However, the shape of the stresses along the height of the abutment does not change for the different positions of the abutment, due to the expansion and contraction of the deck. Similarly, the loading of the abutment is slightly influence by the sequence of loading described in Figure 5.

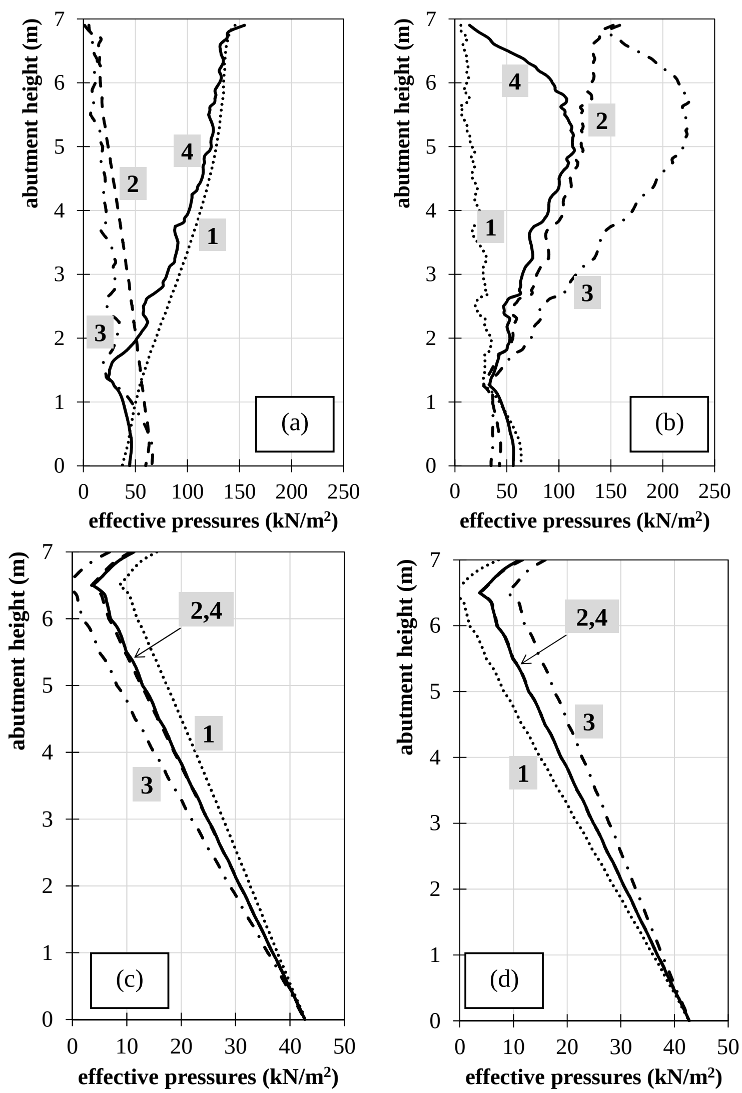

Figure 8. Pressures on the abutment (a) when the backfill is in contact with the abutment for load 1 (expansion-contraction); (b) load 2 (contraction-expansion); (c) when a compressible inclusion (CI) is used for load 1 and (d) load 2. Loading steps (1, 2, 3, 4) are described in Figure 5.

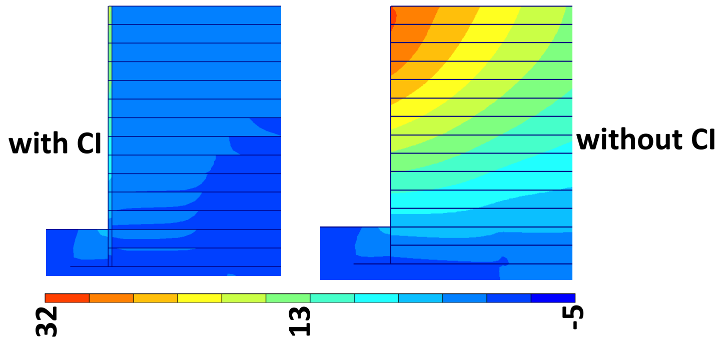

Figure 9. Horizontal deflections of the backfill and the CI (displacements in mm).

The results are illustrated in Figure 9 for load case 1. The figure shows that the CI is able to absorb the total movement of the abutment, and to minimise the disturbance, i.e. the horizontal deflections, of the backfill soil. The opposite is valid when no CI was used (see figure on the right).

For the settlements, Figure 10 shows the permanent vertical deflections of the backfill soil for the two load cases described in Figure 5. These settlements were found in the past to be responsible for the well-known problem bump-at-the-end-of-the-bridge. The figures show than for both loading patterns the settlements are negligible when the CI is employed. The maximum value of the measured settlement was of the order of 5mm and this settlement was found to affect a small length of the backfill soil, i.e. roughly 1.5 meters after the abutment, which can be easily covered by an approach slab. The settlements were found to be much larger when the conventional backfill soil was employed, i.e. without the CI. The maximum settlement was of the order of 25mm, whilst this settlement was found to affect a large length along the approach area of the bridge, i.e. 7 meters behind the abutment.

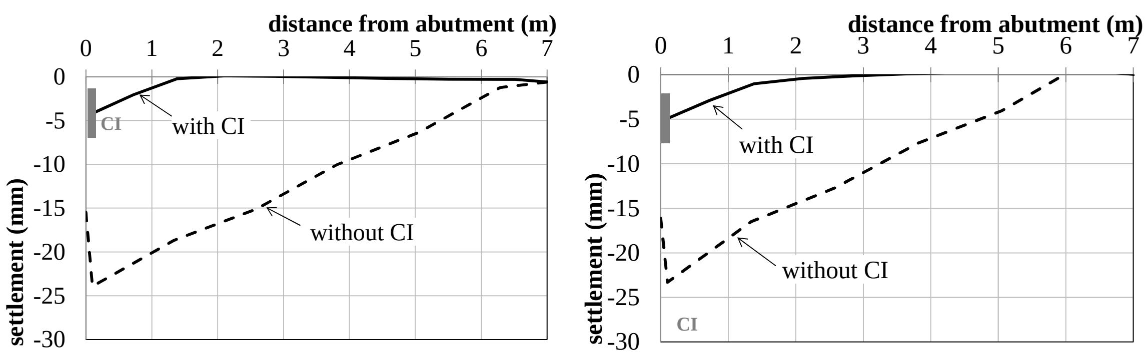

Figure 10. The settlements of the backfill soil after 1 cycle of loading. On the left loading due to expansion and contraction of the deck and on the right contraction and expansion of the deck.

The results for the seismic loading showed a beneficial effect of the CI . As shown in Figure 11, the effective pressures on the abutment at the end of the seismic loading are reduced from 107kPa to 46kPa. A considerable reduction is also observed in the permanent deformation of backfill soil, i.e. the settlements from 317mm to 112mm. Similarly, the permanent horizontal movements of the backfill soil were reduced from 155mm to 137mm when measured along the length of 7.0m behind the abutment. The developed loading in the abutment wall is also reduced when the CI is applied. The maximum bending moment during the seismic excitation is reduced from 4930kNm to 3070kNm and the maximum shear force from 1610kN to 650kN.

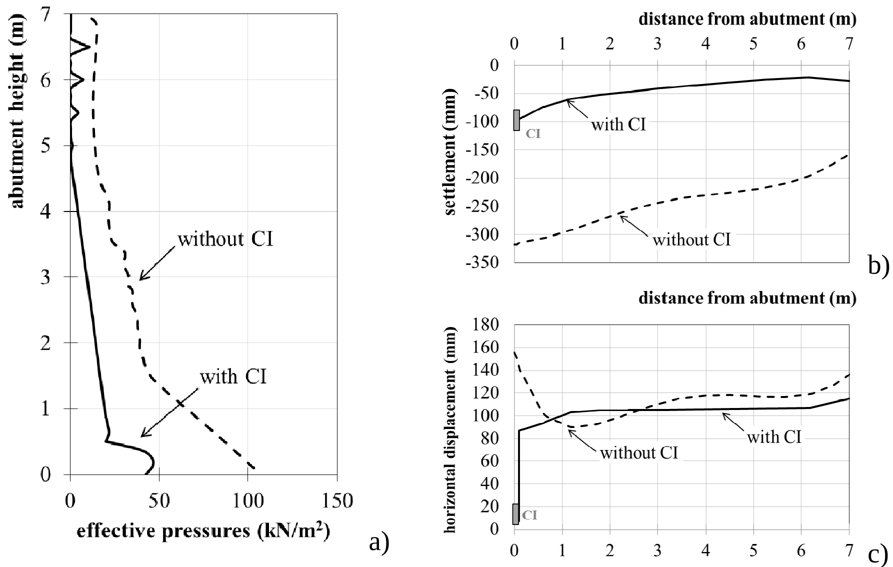

Figure 11. a) Pressures on the abutment, b) settlements and c) horizontal displacements of the backfil behind the abutment, with and without the use of a compressible inclusion (CI) under seismic shaking.

CONCLUSIONS

A compressible inclusion (CI) of tyre derived aggregates (TDAs) was experimentally tested in the Laboratory of Strength of Materials at the University of Surrey and analysed with numerical models in Aristotle University. The use of CI is a smart design alternative for integral abutment bridges (IABs), with clear and straightforward environmental, structural and cost benefits. It is believed that the use of tuned CIs can help when bridge engineers face with the most frequent problems of IABs, i.e. the ratcheting effect, the build-up of passive pressures towards the abutment and the additional stresses induced to the prestressed deck that may induce cracking and long-term deterioration of the deck.

Oedometer tests were conducted and compared with laboratory tests available in the international literature for the characterisation of the CI. The Young's modulus, the stress-strain curve and the design of the CI was performed assuming that the CI remains elastic under the maximum thermal movement of a 240 meters long bridge. The successful design of the CI showed that a thickness of 100mm is adequate to absorb the 30mm movement of the expanding deck in the elastic range, whilst remaining elastic.

Five construction phases were taken into account for the abutment-CI-backfill modelled with the 2D finite element PLAXIS. Subsequently, the abutment was subjected to movements corresponding to serviceability movements due to uniform temperature changes of the deck. The analyses showed that both the residual movements and the bending moments of the abutment were effectively reduced when the abutment with the CI was employed, indicating that not only the residual stresses induced at the deck, but also the additional bending moments that affect the prestressing needs of the deck, are drastically reduced. Preliminary analyses for seismic loading have also shown similar benefits of using rubber material in the form of compressible inclusion between the bridge abutment and the backfill.

To obtain the prospected benefits of the CI, i.e. to reduce the pressures towards the abutment and to reduce the loading of the abutment, a mechanically stabilised backfill (MSB) is required. The use of CIs at integral abutments without a MSB cannot reduce the flow and the ratcheting of the soil behind the abutment, when the abutment moves towards the centre of the bridge.

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