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AN ALTERNATIVE PROPOSAL FOR A “MOVABLE” ABUTMENT FOR INTEGRAL BRIDGES

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SUMMARY

The present investigation proposes a type of an integral full height abutment which can be implemented in short as also in long integral bridges. The abutment is founded on micropiles which provide flexibility to the abutment and participate to the in-service movement, due to thermal expansion, contraction, creep and shrinkage, abutment’s head. The proposed abutment is an alternative to the nowadays implemented integral abutment in the US namely the stub-type abutments with flexible H-steel piles. The alternative proposal combines on the one hand a full height web, whose thickness is determined from the in service requirements of the deck and on the other hand a foundation of micropiles, which have the ability to contribute to the foundation’s flexibility. The necessary rotational flexibility is provided through the flexibility of the thin abutment’s web and its foundation. Appropriate measures against ratcheting effect were considered. The proposed configuration of the abutment is possible to be implemented also in long integral bridges as the required flexibility is possible to be adjusted through the micropiles foundation and the thickness of the abutment’s web.

1. INTRODUCTION

The construction and the serviceability of integral bridges, which are jointless bridge systems whose deck is monolithically connected to the piers and to the abutments, constitute the current state-of-the-art of bridge engineering. The competition between the States of America gave an advance to USA referring to the construction and to the level of knowledge of the in-service problems of integral bridges. In Europe, integral bridges of total length up to 180m were built the last years, mostly in Germany, which has adopted some basic structural configurations of the American technique, however preserves, in most integral bridges, a conventionally reinforced non-prestressed superstructure. The Sunniberg-Bruecke, the Nesenbachtal-Bruecke and the La Fertre-Steg are a representative sample of integral bridges in Germany.

Despite the fact that integral bridges have explicit aesthetics and earthquake resistance advantages towards the conventional seismically isolated bridges, the implementation of integral systems is restrained due to the in-service problems of creep ($\boldsymbol{c}$), shrinkage ($\boldsymbol{sh}$), thermal actions ($\boldsymbol{\Delta T}$), prestressing ($\boldsymbol{P}$) and differential settlements ($\boldsymbol{\delta P}$) which are distressing the piers, the abutments and the approach embankments, and due to structural methods which discourage the monolithical connection of the deck to the piers (incremental launching). However, integral bridges remain a major structural challenge for Bridge Engineers as they (a) allow the redistribution of action effects due to their hyperstatic systems, (b) take advantage of the ability of the reinforced concrete to dissipate part of the induced seismic energy by hysteretic behaviour and (c) they do not require maintenance and replacement of expendable elements, such as bearings and expansion joints.

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The in-service distress of the piers and of the abutments is possible to be adequately arranged by checking the in-service cracking of those elements according to code's provisions. However, the monolithical connection of the deck with the end piers and the abutments is often inapplicable in bridges of great total lengths. The movable stub-type abutment, Figure 1, which consists of a short wall-like abutment-pile cap and a pile row of H-steel piles, is mainly implemented in integral bridges in the USA, provide a structural solution which can arrange the in-service constraints. The piles of the stub-type abutment are undertaking only the vertical loads of the abutment while they provide horizontal flexibility to the abutment, [Arockiasamy, Butrieng, Sivakumar 2004], as they are driven into pre-drilled holes which are filled with loose sand [Arsoy 2000]. Semi-integral hinged abutments, Figure 1(b), which consist of 2 segments interconnected by a dowel, are suggested for longer integral bridges [Arsoy 2000]. In semi-integral abutments the bending of the piles, due to the temperature-induced cyclic lateral loads, is minimized and as a result the durability of the abutment is ensured. In Europe full height abutments are usually implemented [Tsang, England, Dunstan 2002], whose wall-like abutment is often pinned on a spread foundation, [England, Tsang, Bush 2000].

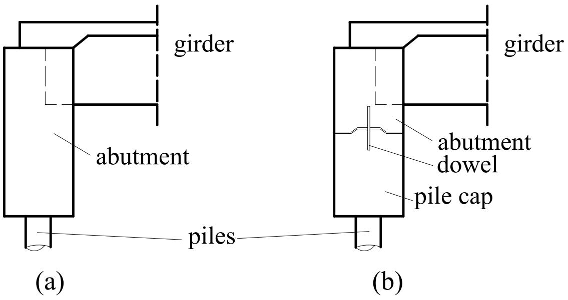


Figure 1: Configuration of the stub-type abutments implemented in the USA: (a) integral and (b) semi-integral.

Apart from the aforementioned in-service and durability problems of integral abutments, the in-service and the seismic response of the approach embankments also constitutes a current field of study. As temperatures change daily and seasonally, the lengths of integral bridges increase and decrease, pushing the abutment against the approach fill and pulling it away. The earth pressures developed "behind" the abutment is depended on a series of factors [Lock, Bolton, Low 2002] and can vary between the active and the passive state. Also the wedging of the soil behind the abutment results in long-time buildup of the soil pressures namely ratcheting effect, [Horvath α,β 1998]. Professor Horvath has proposed a combination of structural techniques in order to minimize the in-service distress of the abutments and its approach fills: (a) on the one hand the approach fills are reinforced by geosynthetic tensile reinforcement to create a mechanically stabilized earth (MSE) and (b) on the other hand a compressible inclusion EPS is interjected between the abutment and the MSE, which plays the role of the desired "expansion joint". The aforementioned techniques have also been reported by the NCHRP [Stark, Arellano, Horvath, Leshchinsky NCHRP 529], [Wu, Le, Helwany, Ketchart 2006]. The response of the aforementioned systems which consists of the reinforced backfill and the compressible inclusion (EPS) was experimentally tested in a full height abutment by Potzl και Naumann, [Potzl και Naumann 2005]. The aforementioned experimental study is considered to be of significant importance as the configuration of the backfill's reinforcement as well as the distribution of the earth pressures behind the abutment is investigated. The experiments, conducted in Germany, also prove the late interest on the construction of integral bridges in the European territory. Apart from the ratcheting effect, also the differential settlements of the approach fill have to be appropriately arranged when an integral abutment is designed, [Briaud, Seo, Ha, Scullion 2003]. Although the traditional approach elements –approach slabs, approach bodies- seem to be efficient for the minimization of the settlement's consequences,-bump at the end of the bridge- there are also investigations which concluded that these approach elements are affecting serviceability, [Hoppe 2005].

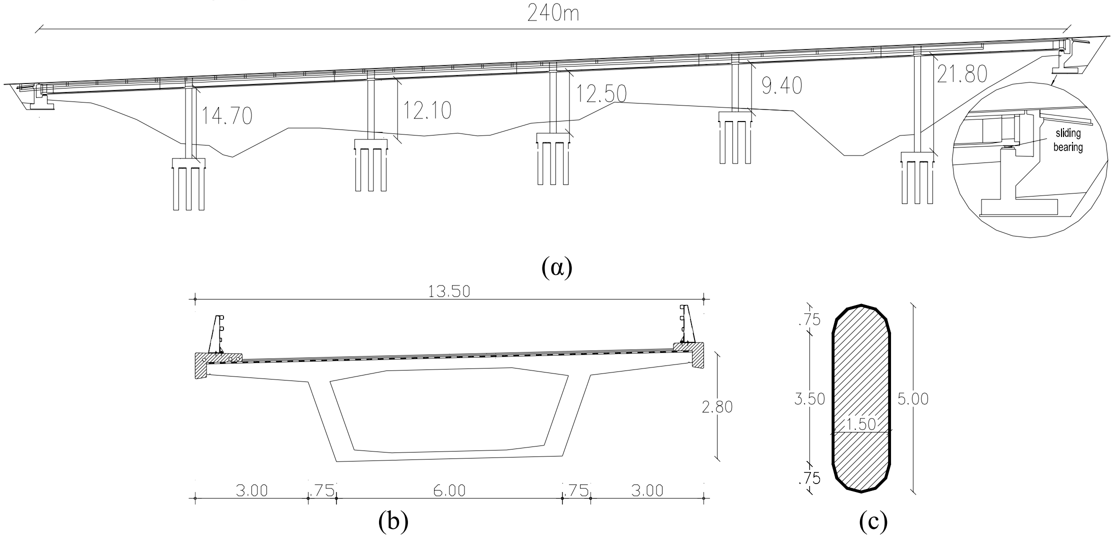
Despite the fact that the aforementioned problems of integral bridges constitute the state-of-the-art of Bridge Engineering more investigation is required in order to elucidate the main parameters of the in-service and the seismic response such a complex interaction problem. For the present, analytical investigations have been conducted and models have been verified through the recorded response of instrumented bridges [Zhang, Makris 2001], [Zhang, Makris 2002], [Goel 1997]. However, the analytical models, which are quantifying the interaction between the abutment and the embankment, resulted from specific conventional abutment-embankment systems, which are in contact, meaning without an EPS layer interjection between them. Up to the present day, no extensive investigation concerning the dynamic interaction of full height abutments with conventional and reinforced embankments have been conducted. Furthermore, the influence of an EPS layer behind the abutment on the seismic response of integral bridges has not been adequately determined. An investigation on the aforementioned complex interaction between full height abutments and their embankments would be practical and efficient as far as the earthquake resistance of integral bridges concerns, as previous studies, [Mitoulis, Tegos 2005], [Tegos, Sextos, Mitoulis, Tsitotas 2005], concluded that the earthquake resistance of such bridge systems can be enhanced by the abutment-embankment seismic participation, leading to a more economical design of the piers an their foundations.

In the present investigation the seismic participation of different approach embankments, whose abutment is either in contact or separated from them by an EPS layer, was studied. The investigation developed a bridge of Egnatia Motorway, which is located in Arahthos-Peristeri territory and which was designed by METESYSM SA, in Thessaloniki. The real bridge was parameterized, including 3 different Seismic Zones of Eurocode 8 Part 1 as well as 3 different total lengths of the deck, and 60 different bridge models were generated. The study comprehended the in-service as well as the earthquake resistant requirements of the 60 integral bridge systems in order to maximize the seismic participation of the abutment-embankment system, while serviceability is appropriately arranged.

2. DESCRIPTION AND RE-DESIGN OF THE REFERENCE BRIDGE

The present parametric investigation can be characterized as “experiments on the paper”. The “reference” bridge, Figures 2(a),(b), has total length of 240m (34.0+4x43.0+34.0m). The deck of the bridge is continuous and monolithically connected to the piers and is supported on the abutments on sliding bearings. The transversal movement of the deck is restrained by stoppers. The box girder superstructure has a total length of B=13.5m. The piers are wall-like columns, Figure 2 (c), and their cross sections are rounded due to aesthetics. The bridge is founded on Ground Type B and the peak ground acceleration (a_g=0.16g) chosen corresponds to Eurocode’s Seismic Zone II. The importance factor adopted equal to γ_I=1.30. The behaviour factors adopted were equal to q_x=3.5 and q_y=2.7 -due to the lower value of the transverse shear ratio α_s of the piers- for the longitudinal and for the transverse direction correspondingly.

In the present investigation different re-design cases, through the reduction of the piers’ width from B_{pier}=1.5m to B_{pier}=1.0m, of the “reference” bridge, were attempted. The aforementioned re-design attempt, which was deemed to be necessary for the present study, does not affect the initial objective of the designer, which was aesthetics. The re-designed bridge is integral-the deck is monolithically connected both to the piers and to the abutments- and developed the abutment which is proposed in the present investigation, Figure 3. The proposed abutment has a wall-like web, which is not connected to the stiff wing-walls, and whose thickness (t_{abut}=0.75m) provide flexibility to the movable abutment. The foundation of the abutment consists of 2x8=16 micropiles, whose diameter is $D_{m\text{-}pile}$=0.30m. The translational and rotational flexibility of the miropiles’ foundation also contributes to the overall flexibility of the movable abutment. It is noted that the seismic action in the transversal direction of the resultant re-designed bridge does not alternate the reinforcement of the re-designed piers as the critical design parameter is the in-service distress of these elements.



(α)

(b)

(c)

Figure 2: The "reference" real bridge located in Arahthos-Peristeri territory (Egnatia Motorway), (a) Longitudinal section, (b) Cross section of the deck, (c) Cross section of the piers.

The proposed abutment of Figure 3, which is considered to be an alternative to the nowadays implemented movable abutments, has explicit advantages comparatively with the currently implemented stub abutments as far as the homogeneity and the explicitness of the dynamic system concerns as also the maximal development of the resistance and damping capacity of the approach fill.

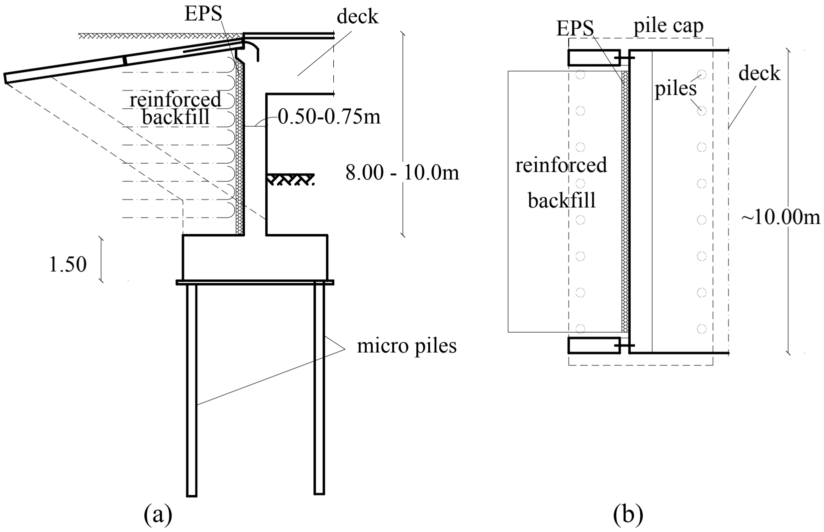


Figure 3: The proposed movable full height abutment separated from the reinforced backfill by an EPS layer: (a) Longitudinal section, (b) Plan view.

3. MODELLING OF THE RE-DESIGNED BRIDGE - PARAMETERS OF THE ANALYTICAL STUDY

In the present study the seismic participation of the full height abutment of Figure 3, which is the alternative proposal to the implemented in the real bridge abutment, was parametrically investigated. The re-design of the "reference" real bridge included the reduction of the piers' widths from B_{pier}=1.5m to B_{pier}=1.0m as well as the monolithical connection of the deck with the proposed abutments. The re-designed bridge, whose model is shown in Figure 4(a), was developed parametrically and different models, Figure 4 (b),(c), were generated. The last two figures correspond to the upgraded bridge systems in which the abutment is either in contact with the embankments, Figure 4(b), or is separated from them by an EPS layer, Figure 4(c). It is noted that conventional embankments, without tensile reinforcement, as well as different total lengths of bridge systems were also analyzed. The seismic displacement restraining effect of the proposed abutment was determined by calculating the percentage reduction of the longitudinal movement of the upgraded bridges' deck of Figures 4(b),(c) comparatively with the movement of the re-designed bridge of Figure 4(a). The selection of the parameters of the present study took into account the in-service as well as the earthquake resistant requirements of the generated bridge systems. Four different parameters were considered:

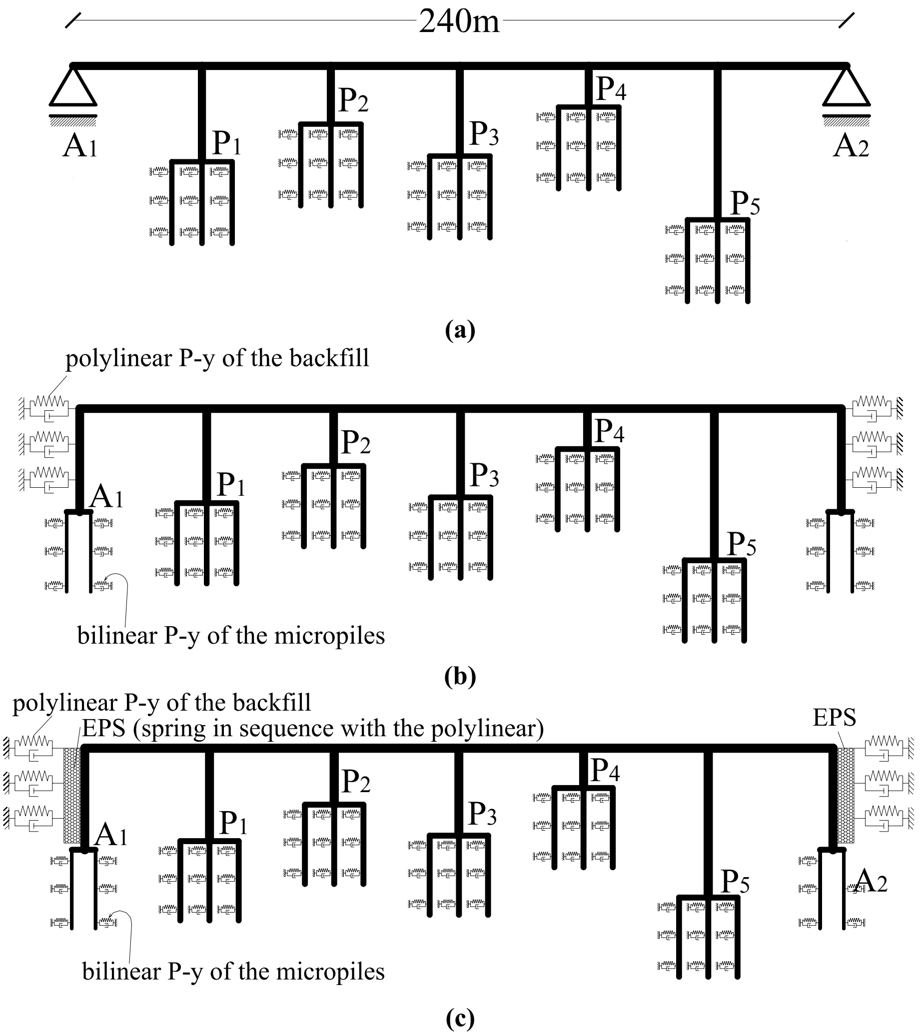


Figure 4: The models of (a) the "reference" bridge, (b) the upgraded integral bridge which develops the proposed abutment in contact with the backfill, (c) the upgraded integral bridge which develops the proposed abutment separated from the backfill by an EPS layer.

1) ***The embankment configuration***: Conventional non-reinforced as well as reinforced embankments were modelled.
2) The ***interjection of an EPS layer between the abutment and the embankment***: Bridge systems, whose abutments were in contact with the backfills or separated from them by an EPS layer, were analyzed. For the second case, the influence of the stiffness of the EPS was examined by modelling 2 different EPS: (a) one relatively stiff, whose modulus of elastisticity had a value equal to $E_{,EPS}$=335KPa, and (b) one more flexible, $E_{,EPS}$=84KPa. The thickness of the EPS layer was determined by the 50% of the in-service expansion of the deck, which means that the EPS could receive a constraint corresponding to an expansion of the deck due to $\Delta T_{exp}/2=+12.5^{o}C$. The aforementioned selection is related to the main objective of the study, which is the maximum seismic participation of the embankment, while the in-service distress of the expanding deck and of the backfills is expected to be reduced after the first 3 years of bridge's service, due to the development of creep and shrinkage.
3) ***The length of the bridge***: Bridges of L=240m (6 spans), L=154m (4 spans) and L=68m (2 spans), of length were analyzed.
4) ***The Seismic Zone***: The aforementioned bridge systems were subjected to the corresponding artificial soil-dependent Eurocode 8 elastic spectrum and 3 different peak ground accelerations a_g=0.16g, a_g=0.24g, a_g=0.36g were considered.

The modelling, meaning the determination of the geometry, the materials and the flexibility of the piers' foundation of the resultant 60 bridge systems, developed the study, which was conducted for the real bridge.
The unilateral visco-elastic response of the embankment of Figure 4(b) was modelled by polylinear spring elements and dashpots. These elements are activated during earthquake when the longitudinal displacement of

the deck is greater than the average gap which exists between the abutment and the embankment at the beginning of the seismic event, Table 1. The aforementioned gaps result from the permanent shortening, due to creep and shrinkage, of the deck. The shortening of the deck was taken into account by equivalent contraction temperatures $\Delta T_{c}=-15^{o}C$ και $\Delta T_{sh}=-20^{o}C$ for the creep and shrinkage correspondingly. The width of these gaps can vary between a maximum value, in case of the maximum thermal contraction of the deck $\Delta T_{con}=-25^{o}C$, and a minimum value, in case of the maximum expansion of the deck $\Delta T_{exp}=+25^{o}C$. The gaps were taken into modelling account by considering its average values given in Table 1.

Table 1: The variance -due to *ΔT*- of the gap existing between the abutment and the backfill, at the beginning of the earthquake, due to the permanent shortening of the bridge deck (*c,sh*) and its average value.

Length of the bridge L (m)	min gap at the beginning of the earthquake minΔ (mm)	max gap at the beginning of the earthquake maxΔ (mm)	Average gap Δ (mm)
240 (6 spans)	12	72	42
154 (4 spans)	8	46	27
68 (2 spans)	3	20	12

In the present investigation an extensive reference research was conducted in order to define the dynamic resistance of the backfill soil, behind the full height abutment, as a function of its deflection, [Eurocode 7], [AASHTO LRFD], [Barker, Duncan, Rojiani, Ooi, Tan, Kim, NCHRP Rep. No. 343], [Lock, Bolton, Low 2002]. The NCHRP's model, which proposes a bilinear model for the resistance of the backfill soil due to its increasing deflection, was implemented or even extended, Figure 5. The resistance of the backfill soil presumes a triangular distribution of horizontal earth pressure, with a resultant reaction force located at *H*/3 above the base of the wall. For the case of a conventional non-reinforced backfill the medium sand of NCHRP was adopted, while the reinforced backfill soil was modelled by considering the NCHRP's dense sand. The passive resistance (Kp=4 and Kp=5.5 corresponding to medium and dense sand) of the aforementioned backfills is developed when its deflection is greater than 5cm and 10cm correspondingly. The modelling procedure, meaning the determination of the stiffness and of the yielding force of the polylinear springs corresponding to the backfill soil was made according to the effective areas of each spring, Faraji, Ting, Crovo, Ernst (2001).

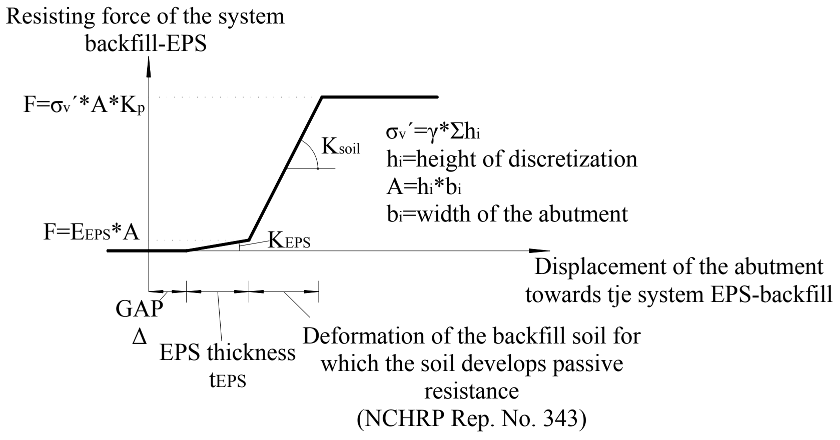


Figure 5: The model used for the total resistance of the system EPS-backfill in depth Σh_i from the ground surface.

For the case that an EPS layer was interjected between the abutment and the approach fill the total resistance of the system EPS-backfill was modelled by dashpots and polylinear springs, Figure 5, which provided two different resisting stiffness levels: (a) one corresponding to the constant resistance of the EPS and (b) the other corresponding to the bilinear elasto-plastic response of the backfill, according to NCHRP's model. It is noted that the deflection of the EPS results in the deflection of the backfill soil and this was taken into account for the determination of the yielding deflection of the backfill. The widths of the EPS layers, which can receive 50% of the expansion constrain, were t_{EPS}=15, 10, 4mm for the bridges of L=240m, L=154m and L=68m of length correspondingly.

The micropiles were modelled with 10 circular frame elements of 1m of length. The diameter of the micropiles was $D_{m\text{-}pile}$=0,30m. The commonly adopted bilinear P-y curve was assumed for these springs. In the elastic range, the discrete soil spring stiffness k was specified according to the in situ geotechnical tests performed at the embankments. The soil is assumed to enter the inelastic range at a deformation D_y = 25 mm, whereas for the second branch of the P-y curve, the soil stiffness is reduced to 25% of the initial stiffness, (Kappos, Sextos 2001), (API 1993). In order to evaluate the effect of the abutment-embankment seismic participation, 60 bridge cases, which develop the proposed integral abutment of Figure 3, were and analyzed. For all the non-linear dynamic time history analysis FE commercial code SAP 2000 was used.

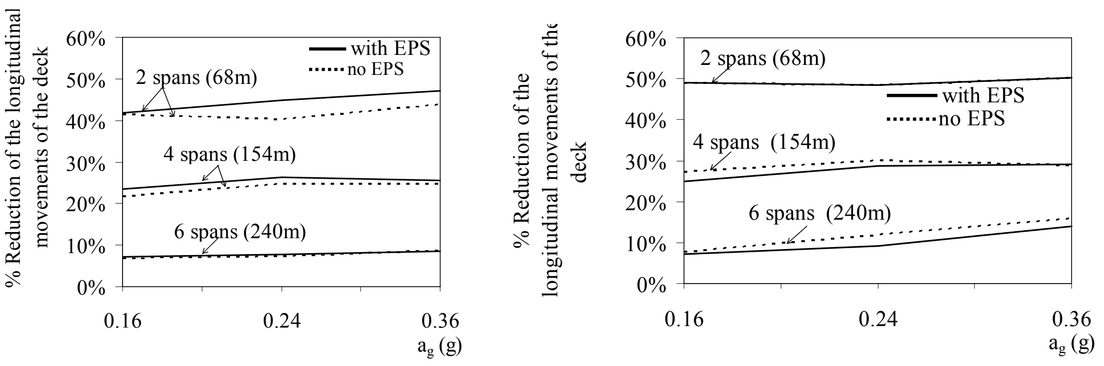
4. RESULTS – QUANTIFICATION OF THE ABUTMENT-EMBANKMENT SEISMIC PARTICIPATION

The results of the present investigation, whose objective was to quantify the seismic participation of the system abutment-embankment, while the serviceability of the bridge systems was appropriately arranged, are given in figures which represent the percentage reduction of the longitudinal displacements of the deck. The aforementioned reduction resulted from the comparison between the longitudinal displacements of the deck of the conventional, Figure 4(a), and the upgraded, Figure 4(b),(c), bridge models.

In Figure 6(a),(b) the percentage reduction of the deck's displacement for the seismic action in the longitudinal direction due to the seismic participation of the (a) conventional or (b) the reinforced backfill, and its abutment is illustrated. The figures refer to the case that the backfill is either separated from the abutment by an EPS layer -continuous line- or is in contact with it -discontinuous line-. It can be extracted that the displacement restraining effect of the proposed system, which consists of the full height integral abutment and its embankment, is increased in shorter bridges, as their displacements are up to 50% reduced comparatively with the conventional re-designed bridge, whose seat type abutment does not participate during earthquake. The longitudinal movements of longer bridges' decks are up to 30% and 10% reduced for bridges of L=154m and L=240m of length correspondingly.

The aforementioned Figure 6(a),(b) also represent the influence of the seismicity to the earthquake resistance efficiency of the integral abutment with its embankment. It is obvious that the seismic participation of the system abutment-embankment is increased when the higher seismicity -higher peak ground acceleration-, is adopted. This conclusion can be interpreted by the higher displacement actions with which the bridge systems respond in regions of higher seismicity. However, the increase of the restraining effect is not following the increase of the peak ground acceleration and this can be attributed to the yielding of the backfill soil after a deflection equal to 5cm or 10cm for the reinforced or the conventional backfill correspondingly.

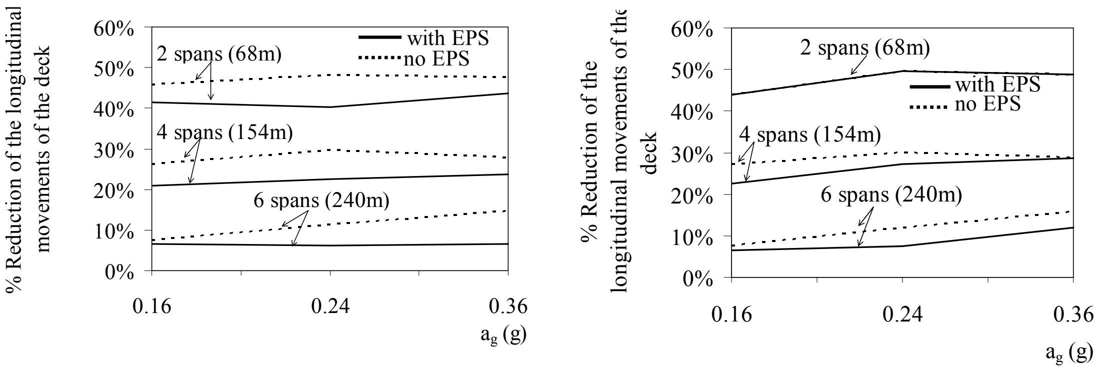
As far as the influence of the EPS layer -continuous line diagrams-, which separates the abutment from the backfill, from Figure 6(a),(b) it can be observed that the EPS layer can either reduce or increase the displacement restraining efficiency of the system abutment-embankment comparatively with the case that the abutment is in contact with the approach fill. Specifically, the selection of a stiff EPS can increase the seismic efficiency of the proposed integral abutment in case of a conventional non-reinforced and relatively flexible embankment, while can reduce its efficiency in case of a stiffer reinforced embankment. The initial objective of the EPS development was to reduce the functional interaction between the abutment and the backfill soil, which is not accomplished for the case of a relatively stiff EPS, ($E_{,EPS}$=335KPa). All the analysis repeated for the flexible EPS, which had a modulus of elasticity equal to $E_{,EPS}$=84KPa and which is more flexible in comparison with the upper part of the conventional embankment, Figure 7(a),(b). From these figures it can be derived that an interjecting layer of a flexible EPS reduces up to 25% the seismic participation of the system abutment-embankment but provides 50% reduction of the in-service distress of the embankment. The aforementioned values of the EPS's modulus of elasticity were determined according to experimental results, [Potzl and Naumann 2005]. It is noted that the in-service distress of the deck had a slight reduction when the flexible EPS was considered and this is attributed to the fact that the distress of the superstructure is mainly determined by the reactions of the in-service deformed piers.



(a) (b)

Figure 6: The percentage reduction of the deck's displacement for the seismic action in the longitudinal direction due to the seismic participation of the (a) conventional or (b) the reinforced backfill, and its abutment, (with stiff EPS or without EPS).

In Figures 6 and 7 the effect of the backfills' reinforcement on the seismic displacement restraining efficiency of the system abutment-embankment is also illustrated. The percentage reduction of the deck's displacement due to the seismic participation of the (***a***) conventional –Figures 6(a),7(a)- or (***b***) the reinforced backfill - 6(b),7(b)-, and its abutment is given for the 3 seismic zones and for the 3 different total lengths of bridges. It can be obtained that the higher earthquake resistance of the reinforced backfill results to a more efficient reduction of the longitudinal movement of the deck comparatively with the conventional non-reinforced backfill. The aforementioned increased efficiency of the reinforced embankment is up to 15% and 35% higher for bridge systems of 2 and 6 spans correspondingly.



(a) (b)

Figure 7: The percentage reduction of the deck's displacement for the seismic action in the longitudinal direction due to the seismic participation of the (a) conventional or (b) the reinforced backfill, and its abutment, (with flexible EPS or without EPS).

5. CONCLUSIONS

The present investigation proposes an innovative full height abutment which is monolithically connected to the deck and whose foundation consists of micropiles with their pile cap. The proposed abutment is an alternative to the nowadays implemented in the US movable abutments and offers some advantages as far as the in-service and the seismic performance of the integral bridge, in which it is implemented, concerns. The investigation developed a bridge of Egnatia Motorway, which is located in Arahthos-Peristeri territory. This "reference" bridge was re-designed and reproduced and the resultant 60 bridge cases were checked in-service. The parametric study, which was conducted in order to identify the abutment-embankment seismic participation, included four parameters namely: (a) the embankment configuration, (b) the interjection of an EPS layer between the abutment and the embankments, (c) the length of the bridge and (d) the Seismic Zone, came up to the following results:

1) The "key point" of the serviceability and the earthquake resistance of bridge systems, which develop the proposed abutment, is the selection of a flexible resisting system in the longitudinal direction. The aforementioned selection is consistent on the one hand with serviceability and on the other hand with the earthquake resistance of bridges as for a given gap between the abutment and the embankment the displacement restraining effect of the backfill is more efficient in systems which respond with large displacements.
2) The displacement restraining effect of the proposed full height abutment with its embankment is increased in short bridges. The longitudinal movements of the deck are up to 10%,30 and 50% reduced for bridges of L=240m, L=154m and L=68m of length.
3) The reinforced self-supporting embankments seem to be more preferable than the conventional ones as the settlements are reduced and the ratcheting effect is minimized, in-service. Furthermore, the displacement restraining effect of the reinforced backfills is up to 35% increased comparatively with the non-reinforced conventional ones.
4) The seismic participation of the system abutment-embankment is increased when the higher seismicity -higher peak ground acceleration-, is adopted. This conclusion can be interpreted by the higher displacement actions with which the bridge systems respond in regions of higher seismicity.

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