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Performance of Bridge Approach Slabs in Bridge Construction: A Case Study

Aurora Cerri, Niko Pullojani

Abstract**—**Long-term differential settlement between the bridge structure and the bridge embankment typically results in an abrupt grade change, causing driver discomfort, impairing driver safety, and exerting a potentially excessive impact traffic loading on the abutment. This paper has analysed a case of study showing the effect of an approaching slab realized in a bridge constructed at Tirane-Elbasan Motorway. The layer thickness under the slab is modeled as homogenous, the slab is a reinforced concrete structure and over that the asphaltic layers take place. Analysis indicates that reinforced concrete approaching slab distributes the stresses quite uniformly into the road fill layers and settlements varies in a range less than 2.50 cm in the total slab length of 6.00 m with a maximum slope of 1/240. Results taken from analytical analysis are compared with topographic measurements done on field and they carry great similarities.

Keywords—Approach slab, bridge, road pavement, differential settlement.

I. Introduction

IT is frequently observed that passengers feel uncomfortable when they drive through the end of bridge or as called "bump" zone. This has been attributed to differential settlements between abutment on the pile and pavement on the natural foundation. In turn, the bump has been said to cause differential settlement by increased impact loads on the bridge deck [1]. To minimize the effect of differential settlement approach, slabs are constructed and their primary purpose is to provide a smooth ride at the transition region of the bridge and pavement [2]. Different studies indicate that more than 25% of bridge approach slabs have significant differential movement which may cause serious maintenance problem and also uncomfortable driving [3], [4]. To evaluate the performance of bridge approach slabs, some criteria have been established which suggest a settlement less than 50 to 75 mm or a slope less than 1/200 although the allowable slope of approach slab should be determined considering running speed of vehicles and length of slab [4], [5]. Recent studies have shown that reinforced concrete bridges in Albania are in poor or very poor physical conditions [6], especially the connection point between bridge structure and back fill has great differential settlements which cause abnormal noise and punch the vehicles while passing through. Also, these settlements have caused serious damage in expansion joints. Many researchers have studied cause of settlement at bridge approach slabs and identified the causes of bridge approach settlement [7], and this case study has analysed the effect of an approaching slab constructed in a bridge part of Tirane-Elbasan motorway. The settlements of soil itself and the approaching slab together with it are widely studied but the aim of this work is to integrate and then analyse the previous works with local parameters of soil and local quality of workmanship.

Aurora Cerri is with the "Tirane-Elbasan" Road Project QA/QC Department, Aktor s.a, Tirana, Albania (e-mail: cerriaurora@yahoo.com).
Niko Pullojani is with the "Tirane-Elbasan" Road Project QA/QC Department, Aktor s.a, Tirana, Albania.

II. Bridge and Approach Slab Description

The typical cross section of the bridge, approaching slab, fill and asphalt layers is shown in Fig. 1. The reinforced concrete bridge is designed as box culvert with total height of 8.40 m and it is constructed in a part of existing Tirane-Elbasan national highway. In order to obtain the required construction area, the existing fills are excavated by 3:2 (H:V). The excavated area is back filled by gravel taken from a nearby river bed and compacted with vibrating 120 kN rollers, and each layer had a maximum thickness of 45 cm. The total road width is 10.70 m which is covered by two identical approach slabs of width 5.30 m and length 6.40 m. The approaching slab has a thickness of 40.00 cm and is double reinforced in longitudinal direction by 14 mm in diameter steel bars 7 pieces/meter, and the steel bars used in transversal direction are 10 mm in diameter and 6 pieces/meter. The compacted thicknesses of sub base and base layer are respectively 30.00 cm and 20.00 cm. Bitouminous asphalt layer is composed by base course, binder and wearing course respectively 10.00 cm, 6.00 cm, and 4.00 cm.

III. Analysing Methodology

The gravel back fill is compacted with vibrating rollers of weight 120 kN, and each layer had a maximum thickness of 45 cm, the measured compaction has always reached values over 98% with an average unit weight of 20.65 kN/m^3 and angle of internal friction of 35^0, and its modulus of subgrade reaction is tested to be approximately between the values of 24.000,00 kN/m^3 and 32.000,00 kN/m^3. The gravel back filled is designed as continuous elastic support along the approaching slab. Reinforced concrete approaching slab is designed as an elastic beam, with the specific reinforced amount given in technical drawings, of width 1.00 m and is settled over gravel back fill layer. The traffic load is taken calculation as acting forces. This is derived from AASHTO specification about loading which comprises a load of 9.34 kN/m/lane. Design truck is HL93 with axle loads of 40 kN & 160 kN respectively and design tandem with axle loads of 125 kN. The weight of asphalt and road fill layer over the approaching slab is neglected.

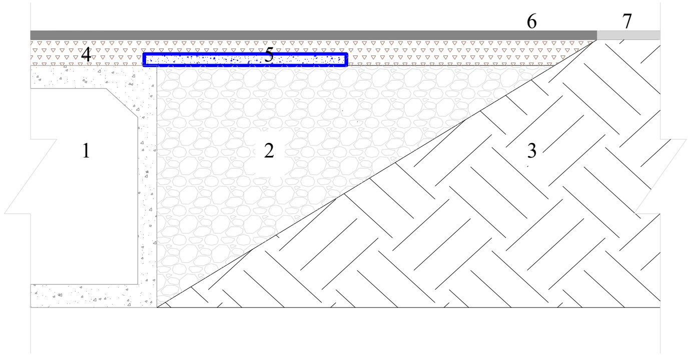

Fig. 1 Cross section of the bridge, approaching slab, fill and asphalt layers

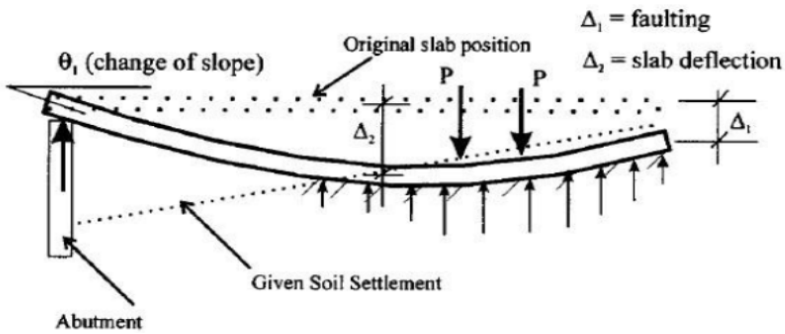

Fig. 2 The model of bridge approaching slab under given embankment settlement [8]

To analyse the performance of bridge approach slab considering the partial soil support under given embankment settlement, Cai et al. [8] developed a three-dimensional finite element model shown in Fig. 2. Differential settlement at the pavement end of approach slab is assumed along with the linear settlement of embankment. The model used in this study states that road fill settlement causes concrete approach slabs of bridges to lose their contact and support from the soil and then the slab will bend in a concave manner that causes a sudden change in slope grade near its ends. SAP2000 [9], [10] is employed to analyse the model of this work basically using the analogy of the structure shown in Fig. 2. The model of the approaching slab is shown in Fig. 3. The slab is subjected to dead load which is equally distributed ***(q),*** which is the summation result of slab self-weight, sub base and base fill weight and asphalt layer weight an concentrated ***(F)*** forces are the loads of design truck and design tandem. The soil spring stiffness $\boldsymbol{k}$ is calculated by (1), where $\boldsymbol{k_s}$ is the subgrade modulus of backfill, and $\boldsymbol{A}$ is approaching slab acting area, which is 0.50 m^2 as the result of 0.50 m x 1.00 m (distance between two springs x design beam width). The approach slab settlements are calculated only per longitudinal direction for this reason the slab is considered as a beam, and its unit width is taken as 1.00 m and the settlements in the transverse direction are neglected.

$$\mathbf{k} = \mathbf{k_s} \cdot \mathbf{A} \qquad (1)$$

As it is mentioned above, the first part of the slab will lose the contact with backfill so the first segment, 1.00 meter in length, of the approaching slab is designed unsupported. The second segment 2.00 meter in length will have partial contact with the backfill so this was done under the assumption that the first 1.00 meter of the segment will have 1/3 and the second 1.00 meter of the segment will have 2/3 of the value soil spring stiffness $\boldsymbol{k}$, calculated in (1), the other part of the slab has the value soil spring stiffness $\boldsymbol{k}$ calculated in (1).

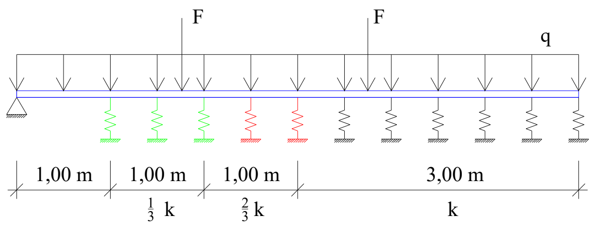

Fig. 3 Model of approaching slab settled on continuous elastic support subjected to equally distributed dead load (q) and concentrated (F) forces

IV. Topographic Field Measurements

In order to compare the analytical results with the real behaviour of approaching slab and its back fill, regular topographic field measurements are done on right and left abutments approaching slab as shown in Fig. 4. There is a total of 12 benchmarks installed 1 as reference point and 11 as measurement targets in both lines of the road, so totally we have 4 x 12 = 48 benchmarks.

Fig. 4 Topographic field measurements

The reference point is located just over the bridge abutment, where the approaching slab starts, and the 11 as measurement targets are located one per half meter. The topographic measurements are done with Topcon QS3M total station measuring accuracy of ± (1.50 mm + 2 ppm), for our research propose this values are very small and they are neglected. Per each line, there are done one measurement per week for a time period of three months, and the maximum value achieved is recorded as monthly value.

V. Results

Analytically calculated approaching slab settlements are presented in Fig. 5 and Table I, the calculations are done per tow boundary values of backfill soil subgrade reaction. Maximum settlement in both cases is reached in 5^{th} meter respectively 3.69 cm when soil subgrade reaction is taken 24.000,00 kN/m^3 and 2.58 when soil subgrade reaction is taken 32.000,00 kN/m^3. The approaching slab slope in the first case is 1/135 and for the second case it is 1/235, the second case satisfies the literature limits which states that bridge approaching slab slope must be less than 1/200.

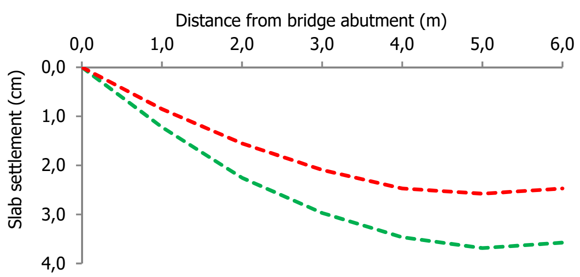

Fig. 5 Settlements calculate analytically, Green line shows the settlement when soil subgrade reaction is taken 24.000 kN/m^3, Red line shows the settlement when soil subgrade reaction is taken 32.000 kN/m^3

Measured approaching slab settlements are presented in Fig. 6 and Table I, the measurements are done for every line in right and left abutments, totally there are four lines, two per each abutment. Maximum settlement in left abutment is measured to be in left line and has a value of 2.50 cm, maximum settlement in right abutment is measured to be in left line and has a value of 2.15 cm. The approaching slab slope in the left abutment is 1/240 and in the right abutment is 1/280, in both abutments the measured slope satisfies the literature limits which states that bridge approaching slab slope must be less than 1/200. As it is shown in Figs. 5 and 6, the mid span deflection of reinforced concrete approaching slab is so small.

TABLE I
Analytically Calculated and Measured Approaching Slab Settlements

		Settlements (cm)						
		0	1	2	3	4	5	6
Analytically	k_s = 24.000 kN/m^3	0.00	1.22	2.26	2.97	3.47	3.69	3.58
	k_s = 32.000 kN/m^3	0.00	0.85	1.55	2.09	2.47	2.58	2.47
Topographic measurements	Left abutment Left Line	0.00	0.68	1.40	2.00	2.30	2.48	2.50
	Left abutment Right Line	0.00	0.67	1.32	1.80	2.10	2.20	2.32
	Right abutment Left Line	0.00	0.65	1.34	1.87	2.10	2.12	2.15
	Right abutment Right Line	0.00	0.62	1.20	1.65	1.90	2.05	2.05

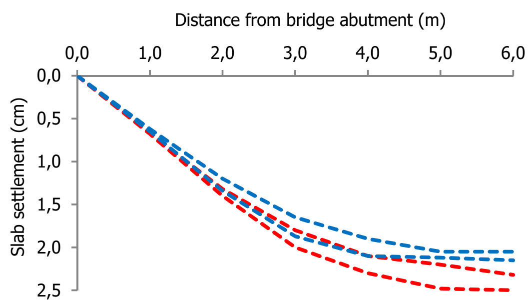

Fig. 6 Measured Settlements, Red lines shows the settlements in the right abutment, Blue lines shows the settlements in the left abutment

VI. Conclusions

Long term topographic measurements indicate that settlements of approaching slab carries great similarities with the ones obtained from analytical results. Maximum settlement obtained from analytical results when soil subgrade reaction is taken 32.000,00 kN/m^3 is 2.58 cm and maximum measured settlement is 2.50 cm, similarly calculated approaching slab slope is 1/235 an measured approaching slab slope is 1/240. Maximum approaching slab settlement and maximum approaching slab slope satisfies the literature criteria. Mid span deflection of reinforced concrete approaching slab is so small so there is no need to increase the amount of steel bars above the required one. Well compacted back fills increase the value of soil subgrade reaction coefficient thus it decreases the settlement, right abutment was beater compacted, for this reason the settlements measured there are smaller. The settlements and deflection of approaching lab have not caused any defect or distress in wearing asphalt layer.

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