Global Journal of Researches in Engineering: E
Civil And Structural Engineering
Volume 15 Issue 3 Version 1.0 Year 2015
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Effect of Temperature Variation and Type of Embankment Soil on Integral Abutment Bridges in Sudan

By Eltayeb Hassan Onsa, Anwar Adam Ahmed & Ahmed Gasim Mahmoud

Omuramn Islamic University, Sudan

Abstract- The integral-abutment bridge (IAB) concept was developed at least as far back as the 1930s to solve long-term structural problems that can occur with conventional bridge designs. Due to limited funding sources for bridge maintenance, it is desirable to establish strategies for eliminating joints as much as possible and converting/retrofitting bridges with troublesome joints to jointless design.

IABs or jointless bridges have many advantages over full height abutment. They eliminate expansion joints in bridge superstructures and simplify design, detailing, and construction. Despite the recognized benefits, the behavior of such structures is not yet fully understood, and nationally adopted design criteria are still lacking.

Keywords: integral abutment bridges, jointless bridges, semi-integral bridge, temperature variation, embankment soil, bridge total length.

GJRE-E Classification : *FOR Code: 090502*

EFFECTOFTEMPERATUREVARIATIONANDTYPEOFEMBANKMENTSOILONINTEGRALABUTMENTBRIDGESINSUDAN

Strictly as per the compliance and regulations of :

Effect of Temperature Variation and Type of Embankment Soil on Integral Abutment Bridges in Sudan

Eltayeb Hassan Onsa [α], Anwar Adam Ahmed [σ] & Ahmed Gasim Mahmoud [ρ]

Abstract- The integral-abutment bridge (IAB) concept was developed at least as far back as the 1930s to solve long-term structural problems that can occur with conventional bridge designs. Due to limited funding sources for bridge maintenance, it is desirable to establish strategies for eliminating joints as much as possible and converting/retrofitting bridges with troublesome joints to jointless design.

IABs or jointless bridges have many advantages over full height abutment. They eliminate expansion joints in bridge superstructures and simplify design, detailing, and construction. Despite the recognized benefits, the behavior of such structures is not yet fully understood, and nationally adopted design criteria are still lacking.

This paper presents results of finite element analysis of four IABs at Kassala State, the four bridges are considered one of the first fully integral bridges designed and constructed in Sudan. The structural system adopted for these bridges is: RC walls on single row of piles at abutments and piers; hollow-core RC slab at deck. The temperature change is varied between 10°C and 50°C and three types of locally available soil are applied behind the abutments. The effects of varying temperature and embankment soil type in the deflection, maximum bending moments, and maximum shear forces are presented and discussed.

The effect of temperature change and bridge length in the bridge forces is also presented; useful comments on the optimum IAB length to be locally adopted are suggested.

Keywords: integral abutment bridges, jointless bridges, semi-integral bridge, temperature variation, embankment soil, bridge total length.

I. INTRODUCTION

Integral Abutment Bridges (IABs) possess a number of unique design details that make them desirable in many applications. These bridges are constructed without expansion joints, within the superstructure of the bridge, nor elastomeric bearings at the supports, i.e. the superstructure is constructed integrally with the abutments and piers [13, 16].

IABs eliminate the use of move-able joints and the expensive maintenance or replacement costs that go with them. The overall design of IABs is simpler than that of their non-integral counterparts; the simplicity of these bridges allows for rapid construction. IABs have proven themselves in earthquakes and performance studies. The advantages of IABs make them the preferred choice for many design and construction engineers in Sudan and worldwide.

Despite the significant advantages of integral bridges, there are some problems and uncertainties associated with them. These include the following, [10]:

- Temperature-induced movements of the abutment cause settlement of the approach fill, resulting in a void near the abutment if the bridge has approach slabs.
- Secondary forces (due to shrinkage, creep, settlement, temperature and earth pressure) can cause cracks in concrete bridge abutments.This problem can be eliminated by using approach slabs.

a) Soil – structure interaction at IAB embankments

Although the IAB concept has proven to be economical in initial construction for a wide range of span lengths as well as technically successful in eliminating expansion joint/bearing problems, but is not problem-free overall in service. Because of the increased use of IABs, there is now greater awareness of and interest in their post-construction, in-service problems. Because of the continuity between superstructure and substructure of IABs, there is a significant interaction with surrounding soil and backfill behind abutments, especially during thermal expansion as the structure is pushed into the soil of the backfill, see Figure 1. The soil is usually represented as an elastic-plastic material whose properties affect internal forces in the integral bridge, [8, 10, 12]. Therefore, it is necessary to consider the influence of embankment soil in the integral bridge design. This is,apparently, seems one of the main problems in the analysis of IABs in practice.

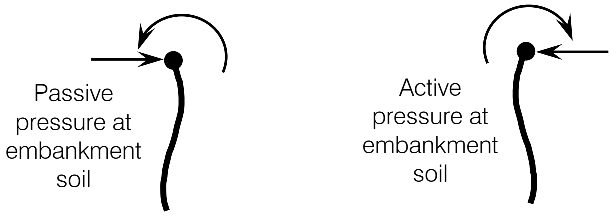
Fundamentally, these problems are due to a complex soil-structure interaction mechanism involving relative movement between the bridge abutments and adjacent retained soil. Although such problems turnout to be primarily geotechnical in their cause, they can result in significant damage to structural components of the bridge. Overall, these post-construction problems,

---

Author α σ ρ : Faculty of Engineering Sciences, Omdurman Islamic University, Sudan. e-mail: anwarsudan@gmail.com

and the maintenance and/or remedial costs they generate, inflate the true life-cycle cost of an IAB.

As the bridge superstructure goes through its seasonal length changes, it causes the structurally connected abutments to move away from the soil they retain in the winter and into the soil during the summer. The mode of abutment movement is primarily rotation about their bottom although there is a component of translation (horizontal displacement) as well. The total horizontal displacements are greatest at the top of each abutment and can have a maximum magnitude of the order of several centimeters [8, 12, 13].



1. Forces on pile-cap during deck expansion (Load Combination 3)
2. Forces on pile-cap during deck contraction

Figure 1 : Abutment piles: deformed shape and forces at pile head

II. Case Study: four iabs in Sudan

Four IABs at Karakon – Hameshkoreib road in Kassala State at east of Sudan are presented in this paper as case study. Table 1 shows the bridges main data and Figures2 to 4 illustrate the general views regarding Bridge #2; the other three bridges differ from Bridge #2 in the number of spans and totallengths.

Studying the effects of longitudinal bridge movement on the forces at the four subject bridges was a major focus of the paper. A bridge will expand and contract from seasonal and diurnal variations in temperature and will contract with concrete creep and shrinkage strains. Piers and abutments must be designed to accommodate this movement, and the superstructure must be capable of carrying the forces induced by the stiffness of the piers and abutments.

Table 1 : Main geometric data of four IABs

Bridge	No. of spans	Span (m)	Width (m)	Total length (m)
Bridge #1	3	17.0	12.0	51.0
Bridge #2	2	16.0	12.0	32.0
Bridge #3	4	17.0	12.0	68.0
Bridge #4	5	17.0	12.0	85.0

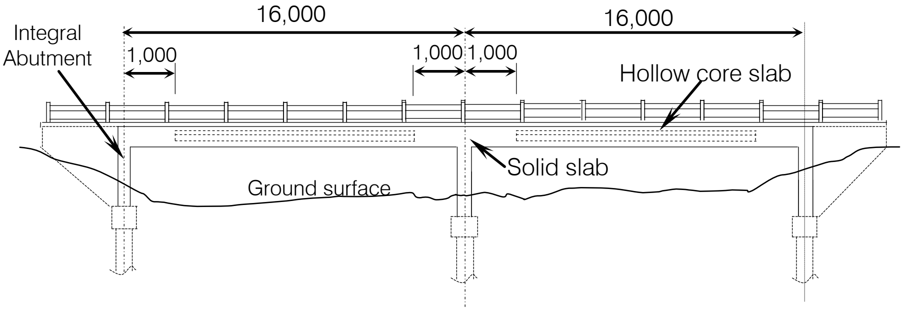


Figure 2 : Elevation at Bridge #2

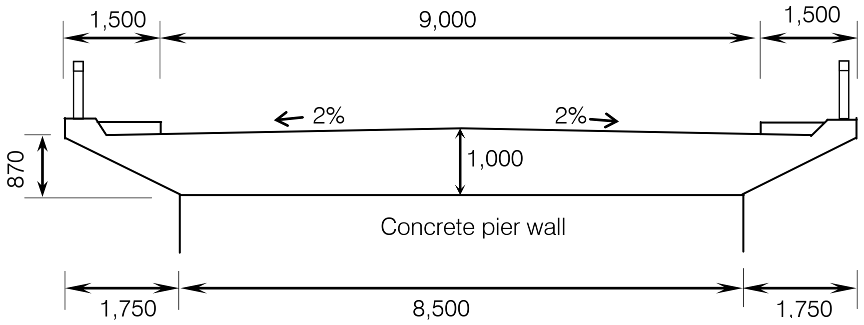


Figure 3 : Cross section at solid part of the deck slab

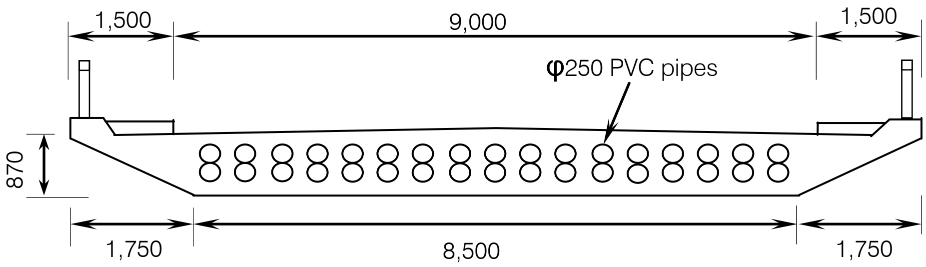


Figure 4 : Cross section at hollow core part of the deck slab

a) *Materials and design data*

The following sections present the material, geometric and design data adopted for the analysis and design of the four bridges; see also Tables 2 and 3 and Figures 2 to 6.

Table 2 : Abutment properties

Unit	Moment of initial, *I* (m^4/m)	Modules of elasticity *E*, (kN/m^2)	Rigidity *EI*, (kN/m^2)
Abutment wall	0.018	1.40×10^7	2.52×10^5
Pile cap	0.630	1.40×10^7	2.28×10^6
Pile (equivalent for 1m)	0.003	1.40×10^7	2.52×10^4

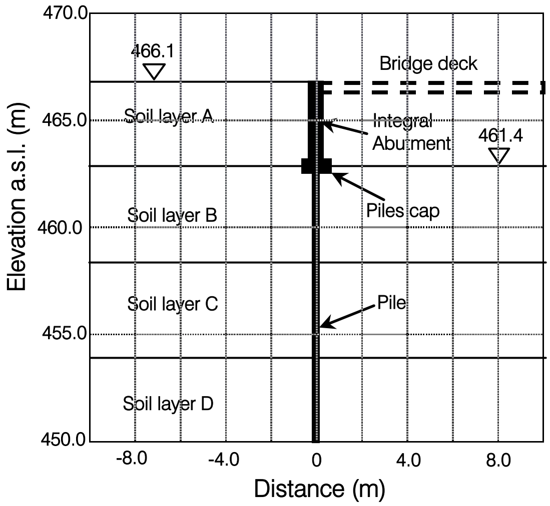


Figure 5 : Soil layers used in the model

.

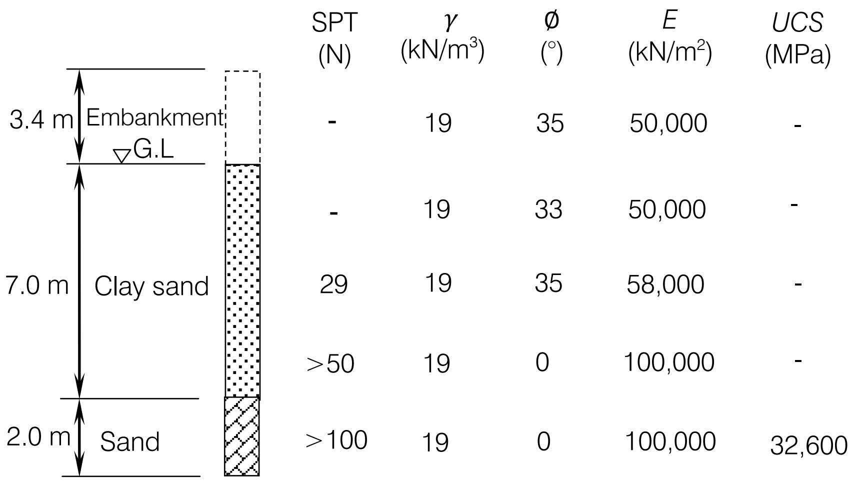


Figure 6 : Soil profile at Bridge # 4

Table 3 : Soil properties

Soil layer	Soil type		Unit weight, γ_s (kN/m³)	Modules of elasticity, *E* (kN/m²)	Angle of friction, ϕ (°)
A	Embankment	soil 1: Fine sand	18.0	40,000	25
		soil 2: Gravely sand	19.0	50,000	35
		soil 3: Gravel	18.0	100,000	0
B	sand		18.0	50,000	25
C	Sandy clay		18.0	58,000	29
D	Sand stone		19.0	100,000	0

Temperature effect is calculated assuming the following:

- Thermal expansion, $\Delta_L = L \times \Delta T \times \alpha$ .... (1)

  Where L = length of the bridge, ΔT = the temperature range between temperature at time of setting of bridge concrete to the maximum and minimum temperature extremes.
- Max. air temperature = 65°C.
- Min. air temperature = 10°C.
- Temperature at time of setting assumed = 25 °C.
- Thermal coefficient of expansion, $\alpha = 12\times10^{-6}$ mm/mm/°C
- The bridge deck Type 3, according to [3].

Effective Temperature Change, ΔT:

The effective temperature is the temperature that governs the overall longitudinal movement of the bridge superstructure. Determination of the effective temperature is a complex problem influenced by shade temperature, solar radiation, wind speed, material properties, surface characteristics and section property [11].

The following equations are sometimes used to calculate the effective temperature change, [4]:

$$\Delta T = T_1 - T_2 + \frac{T_3 - T_1}{3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where,

T_1 = air temperature at dawn on the hottest day,
T_2 = air temperature at dawn on the coldest day,
T_3 = Maximum air temperature on the hottest day,

However, temperature calculated using Equation 1 does not seem to be suitable for the case of IABs in Sudan since it gives too low temperature changes. Hence, in the absence of approved temperature contours in Sudan, the Authors used maximum and minimum temperatures corresponding to the nearest metrological station at Kassala Town (100km to South from Bridge #2).Calculation of temperature effects are performed using the procedure shown in reference [3].

The effective temperature change also depends on the air temperature at concrete setting: assumed here = 25 °C. However, to illustrate the extended effect of temperature change on the forces exerted on the IABs the temperature change is varied between 10°C and 50°C.

Analysis steps:

Longitudinal capacity:

Calculate the active earth pressure coefficient, K_a needed to resist braking and traction forces, applying $\gamma_m = 0.5$ to K_a Check that sufficient horizontal capacity is available from the earth behind the abutment to resist the longitudinal forces, and check the magnitude of the horizontal movement required to mobilize the required earth pressure.

- Check horizontal movement.
- Check capacity of soil to resist horizontal forces.

Analysis of deck, piers, and abutments:

The whole bridge structure is modeled and all bridge load combinations are applied. Linear elastic foundation model based on actual soil parameters is applied at piles and abutment wall.

The abutment piles are designed such that their diameters are much smaller than abutment wall thickness to insure negligible restraint to rotation (pinned ends) at abutment/pile interface [5, 15]. Hogging due to creep is therefore also unrestrained, but can be ignored. Maximum thermal expansion and Load Combination 3 are applied [1, 2,3] wheremaximum earth pressure on abutment walls is based on lateral earth pressure coefficientK* calculated as if expansion is unrestrained, $K_o + (d/0.03H)^{0.6}K_p$, where d = longitudinal defection at top of abutment, K_o,K_p = coefficients of at rest and passive earth pressure, respectively,[clause 3.5.5 in [2])

Maximum thermal contraction, together with minimum bridge loads and active earth pressures are applied as loads. The effects of long term creep and positive differential temperature loading are included. Load Combination 3 is applied to deck expansion, considering passive earth pressure and rotation at pile heads, i.e.Piles are designed for bending. Thermal movement, creep rotation and rotation due to differential temperature loads are applied to pile heads, resulting in reverse bending in piles.

b) *Results of analysis*

The interaction of abutment wall and piles with soil layers are modeled using finite elements concepts. The results of longitudinal defection, bending moment and shear force at abutment/deck joint for the four bridges are presented in Figures 7, 8 and 9, respectively.

It is worthwhile mentioning that for the 4 bridges the negative moment and shear force at abutment governed the design. Design sagging moments within spans and negative moments at piers are governed by Load Combination 3 (permanent loads, primary live loads, and temperature loads)

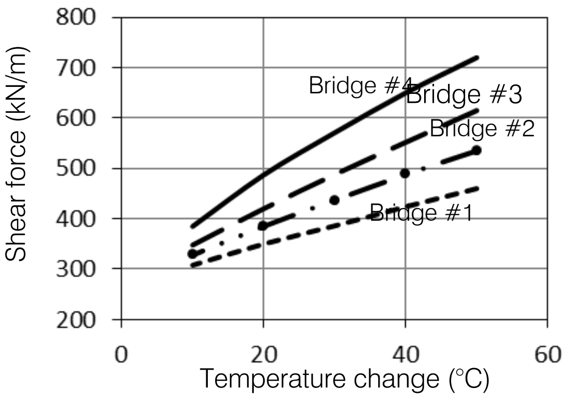


Figure 9 : Effect of temperature change in the shear force at abutment/deck joint

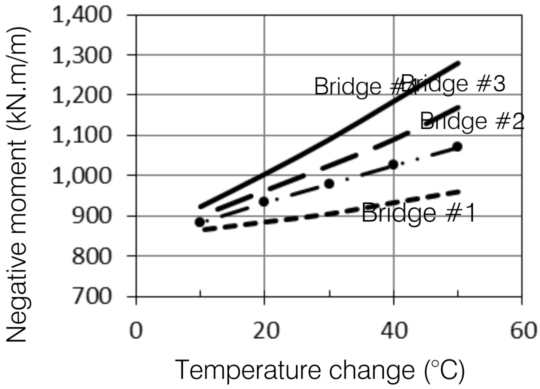


Figure 8 : Effect of temperature change in the moment at abutment/deck joint

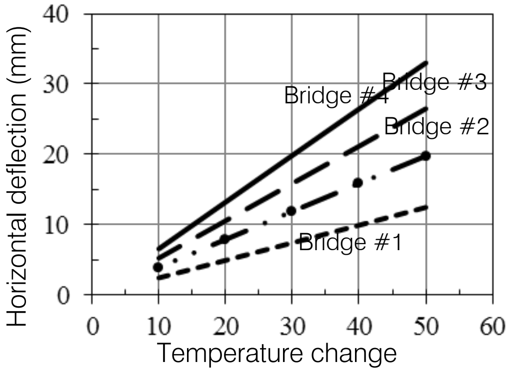


Figure 7 : Effect of temperature change in the horizontal deflection at top of abutment

In this paper three types of soil are tried at embankments behind the abutments, Table 2 shows the physical properties of the three embankment soils.

Effect of temperature and bridge total length:

Although it was advised to adopt IABs up to 60 meters, [2, 8], many countries experiences much longer IABs [10,13]. In this study the longest IAB is 85m long. Also note that 3 of the 4 subject bridges have same span but differ in total length, the effect of temperature change showed 9.6% average increase in negative bending moment, at abutment/deck joint, due to 10°C increase in temperature change e.g. in Bridge #4 (85m long). Figure 10presents the effect of temperature and bridge total length the maximum negative moment at top of abutment walls of the 4 bridges.

It is noticed from Figure 10 that for IABs longer than 65m the forces at abutment/deck slab joint start to increase rapidly at temperature change = 50°C (the temperature change normally experiences in Sudan) resulting in non-economical cross sections; this probably explains the advice of given in [2]. Therefore, it is recommended at present time to adopt alternativebridge setup e.g. for bridges with total length exceeding 100m semi-integral bridges are more appropriate where bridge deck is placed on sliding bearings over the abutment front wall.

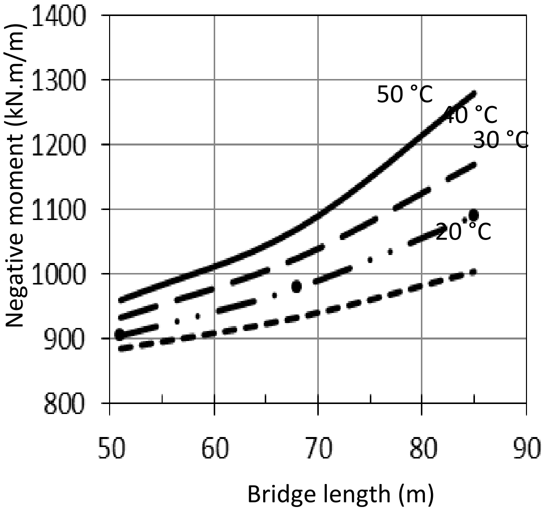


Figure 10 : Effect of temperature and bridge length in the moment at abutment/deck joint

However, the literature review and field inspections indicate that the maximum lengths of integral abutment bridges have not been reached [7, 10]. Jointless bridges over 180 meters in total length have been built and have performed satisfactorily in USA [6].

Table 4 : Analysis results: Effects of embankment soil, Bridge #4, temperature change = 40°C

Type of embankment soil	Analysis Results at Abutment/desk joint		
	Moment (kN.m/m)	Shear (kN/m)	Horizontal deflection (mm)
soil 1: Fine sand	1185	554	26.48
soil 2: Gravely sand	1185	543	26.42
soil 3: Gravel	1185	560	26.45

III. Conclusions

The following conclusions are drawn from this paper:

Changing the soil properties behind the abutment and around the piles does not affect significantly the performance of deck slab in terms of bending moment, shear force and horizontal deflection.

The bending moment, shear force, and deflection in deck slab tend to increase linearly with increase in temperature.

As expected, the variation in soil type at embankment behind the abutment wall has negligible effect in the deformation and forces at wall to deck joint, see Table 4.

The restraint provided by abutment wall backfill is usually considered ineffective in reducing the free thermal expansion of the superstructure this is attributed to the fact that the superstructure to abutment in the direction the bridge is high, and the reactive soil pressure at top of abutment wall is often considered low.

The bending moment and deflection in deck slab increases linearly with increase in temperature.

The internal forces in the abutments are found to be functions of the thermal-induced displacements of the bridge deck, properties of the pile and stiffness of the foundation soil. Similar to conclusion was reported in [9, 14].

For countries experiencing high temperature changes, like Sudan, and until further verifications are reached, the maximum total length of IAB shall be carefully controlled.it is recommended at present time to adopt alternative bridge setup e.g. semi-integral bridges for bridges with total length exceeding 100m.

References Références Referencias

1. BD 37/01, (2001) Loads for Highways Bridges. Volume 1, Section 3, Part 14.

2. BA 42/96, (2003) Design Manual for Roads and Bridges: The Design of Integral Bridges. Volume 1, Section 3, Part 12.
3. BS EN 1991-1-5:2003. Eurocode 1: Actions on structures - Part 1-5: General actions -Thermal Actions.
4. Conner D. H. Uffake (2013) Behavior and Analysis of an Integral Abutment Bridge. MSc Thesis, Utah State University, Logan, Utah, USA.http://digitalcommons.usu.edu/etd/1718
5. D. D. Girton, T. R. Hawkinson& L. F. Greimann (1999) Validation of Design Recommendations for Integral – Abutment Piles. Journal of Structural Engineering, ASCE, Vol 117, No.7 .July 1991.
6. Edward P. Wasserman (2005) Integral Abutment Practices in the United States" Indian Concrete Journal, Vol 79, No.9, pp. 56-65.
7. Hoppe, E. J. and Gomez, J. P. (1996) Field study of an integral back-wall bridge, Virginia Transportation Research Council, VTRC 97-R7: 47 - 60.
8. Murat Dicleli, Suhail M. Albhaisi (2003) Maximum Length of Integral Bridges Supported on Steel H-Piles Driven in Sand. Engineering Structures, Volume 25, Issue 12, pp. 1491-1504.
9. Murat Dicleli, Suhail M. Albhaisi (2004) Performance of Abutment Backfill System under Thermal Variations in Integral Bridges Built on Clay. Engineering Structures, Vol 26, pp. 949 - 962.
10. Olli Kerokoski (2005) Soil-Structure Interaction of long Jointless Bridges with Integral Abutments.Doctor of Technology Thesis, Publication 605, Tampere University of Technology, Finland.
11. Ralph G. Oesterle, and Jeffery S. Volz (2005) Effective Temperature and Longitudinal Movement in Integral Abutment Bridges. Proceedings of the 2005 – FHWA Conference. Integral Abutment and Jointless Bridges, Baltimore, Maryland, USA: 302 – 311.
12. Shreedhar R., VinodHosur, and IftikarChappu (2012) Behavior of Integral Abutment Bridge with and without Soil Interaction. International Journal of Scientific & Engineering Research, Volume 3, Issue 11: 1 – 9.
13. Sami Arsoy, Richard M. Barker, and J. Michael Duncan (1999) The Behavior of Integral Abutment. Report submitted to Virginia Transportation Research Council, Virginia, USA.
14. ShehabMourad& Sami W. Tabsh (1999) Deck Slab Stresses In Integral Abutment Bridges. Journal of Bridge Engineering, ASCE, Vol.4 No.2.
15. Susan Faraji, John M. Ting, Daniel S. Crovo and Helmut Ernst, "Nonlinear Analysis of Integral Bridges: Finite Element Model" Journal of Geotechnical & Geo environmental Engg, ASCE, Vol 127, No 5, May 2001.
16. Vasant C. Mistry (2005) Integral Abutment and Jointless Bridges. Proceedings of the 2005 – FHWA Conference. Integral Abutment and Jointless Bridges, Baltimore, Maryland, USA: 3 - 11.

This page is intentionally left blank