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Long-Term Response Prediction of Skewed Integral Bridges under Creep Effects

Akilu Muhammad[1], Redzuan Abdullah[2], Ibrahim Ogiri Hassan[3]
[1,2]Faculty of Civil Engineering,Universiti Teknologi Malaysia, 81310,Skudai, Johor Bahru Malaysia
[3]Department of Building Technology,Federal University of Technology Minna, Nigeria
Corresponding Author: amty72@yahoo.com

Abstract— A research was carried out to assess the effect of concrete creep on long-term performance of skewed Integral Abutment Bridge. Time-history transient analysis was conducted using Finite Element method for 75-year period. Parametric study was conducted in LUSAS to assess the effect of bridge total length (60m,90m,150m), skew angles (0^0,10^0,20^0,30^0,40^0), backfill soil stiffness (dense sand, loose sand) on the behaviour of the bridge measured by girder and abutment displacement, moment and shears. Three dimensional nonlinear thick beam element with CEP-FIP 1990 creep material properties was used to model bridge girders. Other structural members were modelled using three dimensional thick beam element. Bridge total span and skew angle were found to have predominant effect on behaviour of skewed IABs than backfill soil stiffness. Loose sandy backfill soil results in higher values of deformations in comparison to dense sandy soils. Most of the deformations are regular from zero to 20^0 skew, variations in deformation mostly occurred after 20^0 skew.

Keywords— Integral Abutment bridge; Skew angle; creep; soil-structure interaction

Introduction

Integral Abutment Bridge (IAB) also called Joint-less bridge is a bridge having no expansion joint and bearing. It has structural continuity between bridge deck and structural support systems [1]; superstructure is rigidly connected to the abutment. IABs have recently generated much interest due to their functional and economic advantages. Integral connection of superstructure and substructure simplifies the construction procedure and provides additional redundancy to the structure thereby enhancing its structural performance especially during seismic loading. Maintenance of expansion joints and bearings that constitutes 70% of bridge maintenance budget [2] are avoided in IABs.

There are concerns on the long-term performance of IABs under thermal and creep loading due to absence of joints that usually serve as release mechanism. Research has shown that creep has adverse effect on long-term performance of concrete structures [3],[4],[5] it leads to changes in rheological and material properties of concrete which results in straining of concrete structures. Deflection due to concrete creep was found to equal displacement due to instantaneous loading [6].

Much of the research works carried out on behaviour of IABs gave emphasis on non-skewed IABs; little work was done on skewed IABs. There is need to understand the superstructure and substructure response to backfill-abutment interaction at various vertical skew angles. In this research, a parametric study is carried out to obtain the effect of concrete creep on long-term response prediction of skewed IABs. The parameters considered are bridge total length (varied between 60m, 90m and 150m), vertical skew angles (varied between 0^0,10^0,20^0,30^0, and 40^0) and backfill soil stiffness (varied between dense and loose sandy soils). Time-history transient analysis is carried out using Finite Element method to study the effect of creep on the behaviour of the bridge over 75- year period in line with 75-year bridge life span by American Association of State Highway and Transport Officials (AASTHO)[7].

II. FE Bridge Model

Hypothetical Finite Element models of slab on T-beam IABs of varied lengths were developed in LUSAS. Width of the bridge is 13.9m; eleven equally spaced Post-tensioned girders of 30m length were seated on pier heads that were supported by piers (Fig.1). A three dimensional nonlinear thick beam element in LUSAS (BTS3) having CEP-FIP 1990 creep material properties [20] was used to model girders. The remaining structural elements are modelled using three dimensional beam elements (BMS3 element in LUSAS). Geometric and material properties of bridge members are as in Table 1 and Table 2 respectively. Line mesh was applied for the entire structure (Fig 2). Prestressing tendon and beam are modelled as beam element using presstress definition shown in Table 3. Prestressing effect of tendon on beam is achieved by calculating equivalent prestressing force from tendon and applying it to the beam at nodal points.

The bridge was loaded with self-weight, imposed load (HA, HA+HB 45) in line with BD37/01 design manual of roads and bridges [8]. Numerical analysis was carried out using modified Newton Raphson iteration method. It is a solution procedure that predicts the response of the structure as the load is increased. With each load increment, an incremental-iterative or predictor-corrector method is performed where a linear prediction of the nonlinear response is made and iterative corrections are performed to maintain equilibrium and remove the residual forces with reference to various convergence criteria

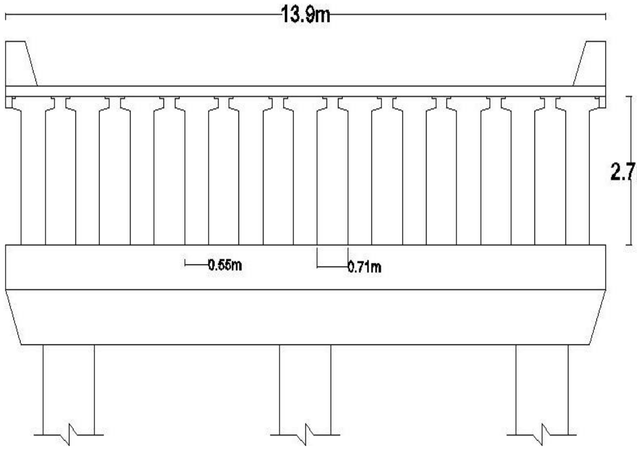


Fig. 1.Section of the superstructure of the Integral Bridge

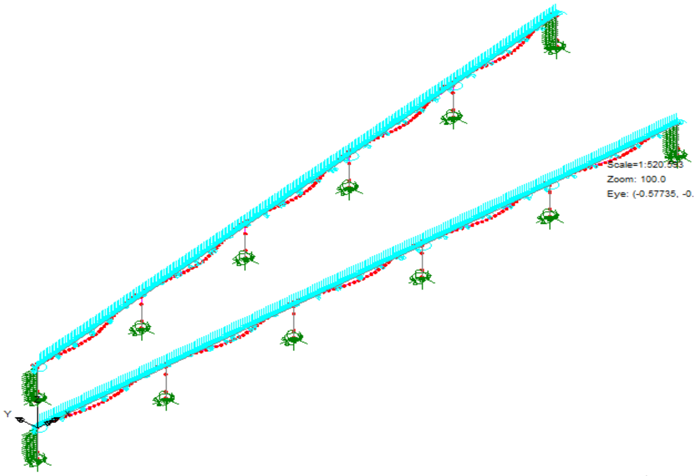


FIG. 2. Finite element models of 150m IABs skewed at 0^0 and 10^0 skew angles.

III Soil-structure interaction

Due to the absence of joints and bearings in IABs, soil-structure interaction becomes the only means of accommodation of superstructure movement and has been identified as the major factor affecting the bridge behaviour [9], [10], [11], [12], [13], [4]. Linear spring supports were provided behind bridge abutment to approximate backfill soils behaviour. Implementation of linear springs in assessing effect of substructure stiffness on the behaviour of IABs under thermal loads was done with good level of accuracy [14]. The concern of this research is on backfill abutment interaction. Horizontal load on foundation can be resisted by friction and passive soil resistance [15]. Estimation of horizontal spring stiffness Es behind bridge abutment of height H and length L is approximated in equation (1) [16].

$$k_{horz} = \frac{(4/\pi)E_S}{(L/H)^{0.6}H} KN/m/m^2 \qquad (1)$$

E_s was approximated [17] to be:

$$E_s = 150000\frac{(2.17-e)^2}{(1+e)}\left(\frac{p'}{p_{atm}}\right)^{0.5}\left(\frac{0.0001}{\gamma}\right)^{0.4} KN/m^2$$

(2)

Dry density of soil ρ_d, used in specifying the degree of compaction of backfill, is related to the void ratio in equation (16) which is used in obtaining void ratio of soil.

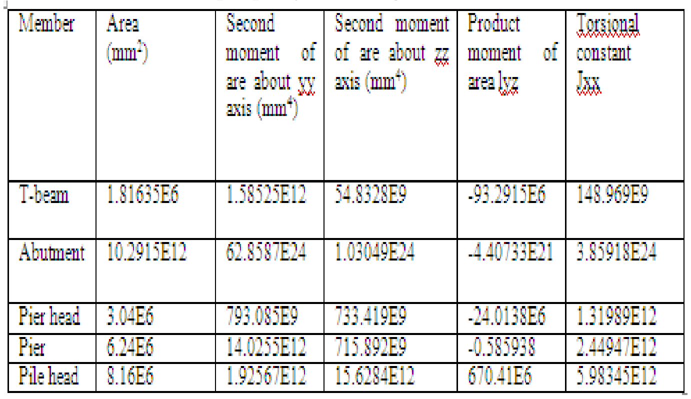
$$\rho_d = \frac{G_s\rho_w}{(1+e)} \qquad (3)$$

Where G_s and ρ_w are the specific gravity of soil and density of water respectively, e is the void ratio of soil, P' is the mean confining stress less pore water pressure in the soil, P_{atm} the atmospheric pressure (100kN/m^2), γ is the shear strain taken to have a range of 50×10^{-6} to 0.01. Properties of the backfill soil types used in the analysis are as shown in Table 4.

IV Results and discussion

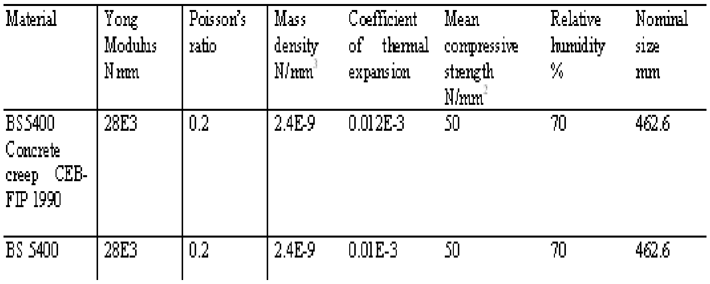
From the time-ependent finite element analyses carried out to predict the effect of creep on skewed IABs over a period of 75-years, results have shown that skew alignment has profound effect on response of IABs. Girder moment increased significantly as the skew angle is increased (Fig. 3). Girder moment increased as the length of the bridge is increased and there are higher deflections when the backfill is made of loose sandy soil than when it is dense sandy soil. There is however decrease in abutment moment, girder axial load and abutment shears as a result of increase in skew angles (Figs 4,8 and 9). Girder displacement had steady increase when the skew angle was increased from 0^0 to 10^0, there was no appreciable increase when the skew angles was increased from 10^0 to 40^0. Girder displacement is more affected by bridge length than by backfill soil stiffness and skew angle (Fig. 5). Abutment displacement increased as skew angle is increased but had a decrease when the skew was increased from 30^0 to 40^0 (Fig. 6). The peak increase occurred mostly at 20^0 skew angle which is 25 times the value at zero skew angle. Girder shears increased by 25-30% when the bridge is skewed to 40^0 skew

Table 1. Geometric property of Bridge members.



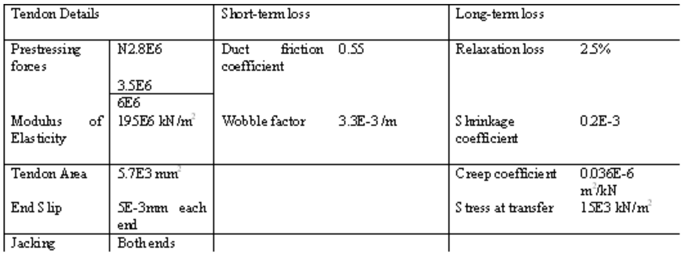
Member	Area (mm^2)	Second moment of are about yy axis (mm^4)	Second moment of are about zz axis (mm^4)	Product moment of area Iyz	Torsional constant Jxx
T-beam	1.81635E6	1.58525E12	54.8328E9	-93.2915E6	148.969E9
Abutment	10.2915E12	62.8587E24	1.03049E24	-4.40733E21	3.85918E24
Pier head	3.04E6	793.085E9	733.419E9	-24.0138E6	1.31989E12
Pier	6.24E6	14.0255E12	715.892E9	-0.585938	2.44947E12
Pile head	8.16E6	1.92567E12	15.6284E12	670.41E6	5.98345E12

Table 2. Material Properties of bridge girders



Material	Yong Modulus N mm	Poisson's ratio	Mass density N/mm^3	Coefficient of thermal expansion	Mean compressive strength N/mm^2	Relative humidity %	Nominal size mm
BS5400 Concrete creep CEB-FIP 1990	28E3	0.2	2.4E-9	0.012E-3	50	70	462.6
BS 5400	28E3	0.2	2.4E-9	0.01E-3	50	70	462.6

Table 3. Prestress definition to BS5400



Tendon Details		Short-term loss		Long-term loss	
Prestressing forces	N2.8E6 3.5E6	Duct friction coefficient	0.55	Relaxation loss	2.5%
Modulus of Elasticity	6E6 195E6 kN/m^2	Wobble factor	3.3E-3 /m	Shrinkage coefficient	0.2E-3
Tendon Area	5.7E3 mm^2			Creep coefficient	0.036E-6 m^2/kN
End Slip	5E-3mm each end			Stress at transfer	15E3 kN/m^2
Jacking	Both ends				

Table 4. Varying soil properties used in the Model [18],[19].

Soil type	Density (wet) kN/m^3	Void ratio of soil (e)	Average shear strain (γ) m	Soil Stiffness kN/m^2	Horizontal Spring Stiffness kN/m/m^2
Dense sandy soil	22	1.0	0.0002	375771.8	6991.4
Loose sandy soil	16	1.38	0.0002	186562.6	2695.9

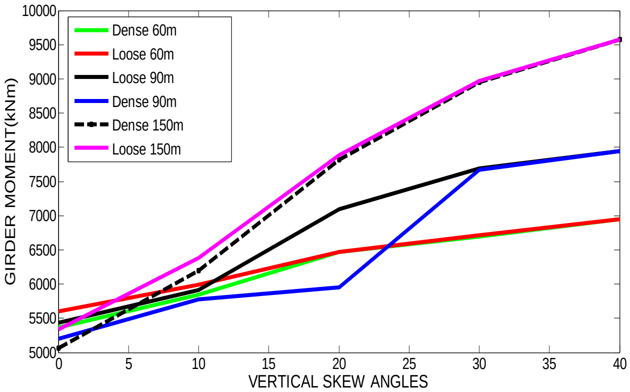


Fig. 3.0 Variation in girder moment after 75years

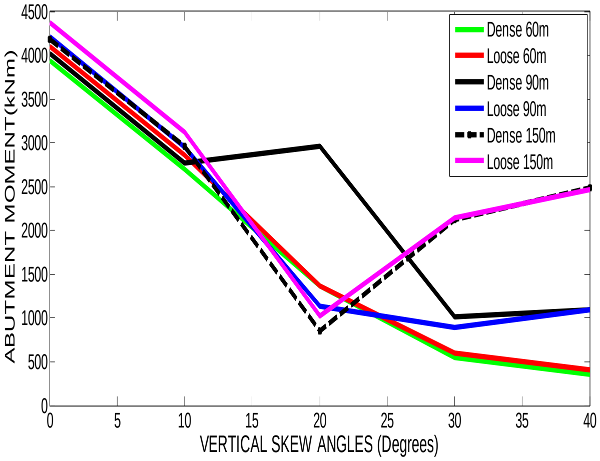


Fig. 4.0 Variation in Abutment moment after 75years

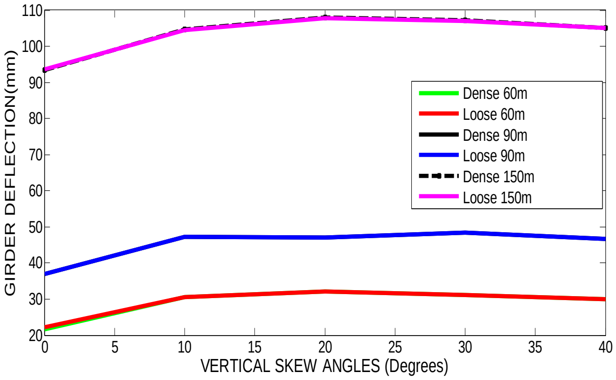


Fig. 5.0 Variation in girder deflection after 75years

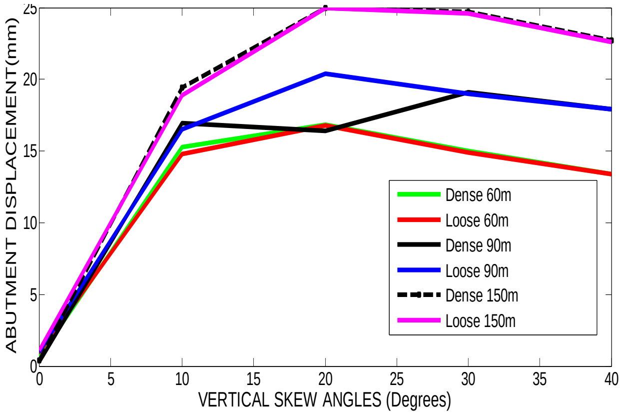


Fig. 6.0 Variation in Abutment displacement after 75years

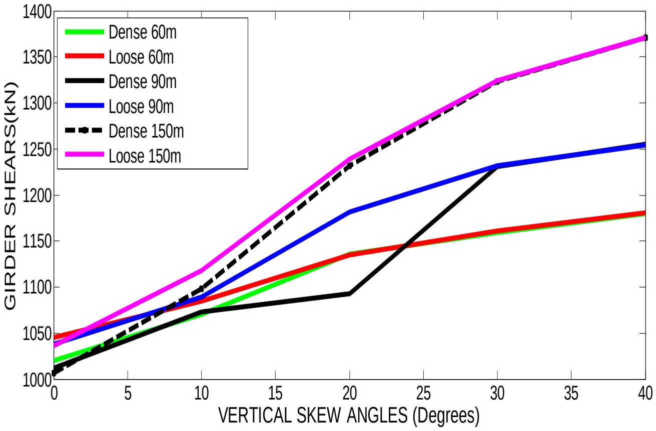


Fig. 7.0 Variation in Girder shears after 75years

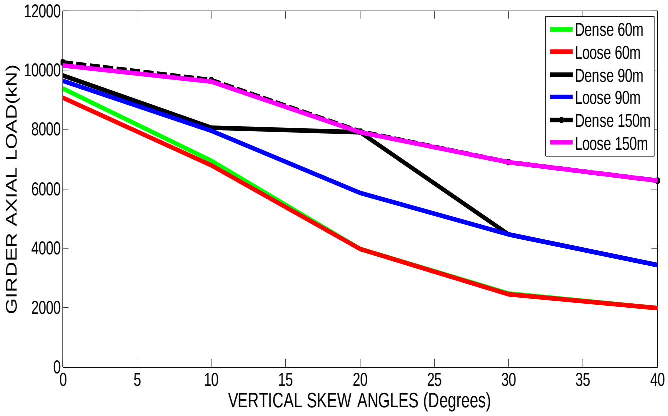


Fig. 8.0 Variation in Girder Axial load after 75years

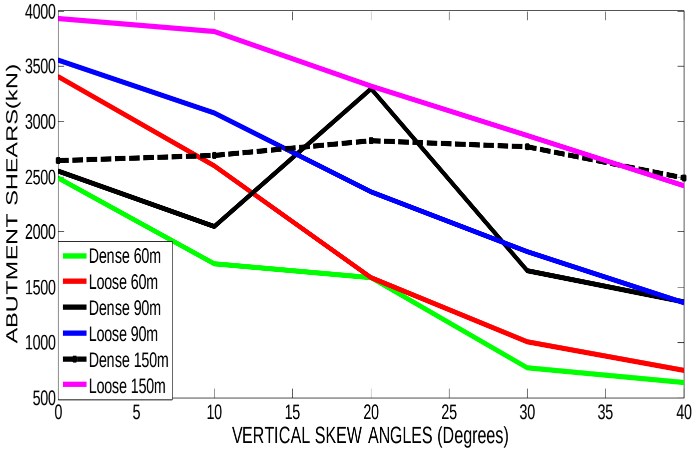


Fig. 9.0 Variation in Abutment shears after 75years

with maximum values obtained at 150m with loose sandy backfill (Fig 7).

V Conclusion

The research has found that bridge span and skew angle have predominant influence on behaviour o skewed IABs than backfill soil stiffness. They should therefore be given great attention when designing skewed IABs. Loose sandy backfill soil results in higher values of deformations in comparison to dense sandy soils. Most of the deformations are regular from zero to 20^0 skew, variations in deformation mostly occur after 20^0 skew.

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