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Sustainable design approach: Integral bridge

F. Arif & M.A. Baig
Al-Falah University, India

ABSTRACT: The world has limited resources which have been exhausting/utilizing by living beings (humans) for centuries. So, it is important to utilize natural resources without compromising ability of future generation to meet their own needs. Being a civil engineer, we should think about sustainable solutions for design and construction. In this paper, we tried to give ideas about the benefits of integral bridges and techniques to optimize reinforcement. Integral bridges are bridges without expansion joints, and fully integral bridges don't have expansion joints and bearings between abutments/piers and deck. As bearings and expansion joints required regular maintenance, so avoiding these elements in bridges help in durability.

1 INTRODUCTION

Bridges are very important part of any country's infrastructure, as it provides connectivity between communities by connecting different cities, village to city, countries etc. by crossing over any obstacle such as river, valley or road. And, proper connectivity is very important for supporting economic activities, development of country and meeting daily needs of people by transporting materials. Bridges enable consumers to travel to shops and malls and visit new cities as tourists. Various forms of bridges have been constructed throughout the world such as masonry arch, steel truss bridge, cable stayed bridge, reinforced concrete integral bridge etc. Deciding form of a bridge for new construction depends on various requirements such as use of bridge (load carrying capacity), span length, type of obstacle and architectural requirement.

Integral bridges perform excellent and a very good alternative to conventional bridges built with bearings and expansion joints. Due to absence of bearings and expansion joints, integral bridges required less maintenance and are more sustainable.

Construction of integral bridges was started in 1930's in USA. Since then many countries have been adopting this concept as a replacement of traditional bridges. Integral bridges are suitable for small span length, maximum up to 40m span.

2 TYPES AND BENEFITS OF INTEGRAL BRIDGES

There are many forms of integral bridges; four basic forms are listed below.

1. Integral bridge with frame abutments.
2. Integral bridge with flexible support abutment.
3. Integral bridge with bank pad abutments.
4. Integral bridge with semi-integral end screen abutments.

In this paper we will present analysis and design results for the Integral Bridge with flexible support abutments (piles). The analysis and design are carried out to validate approach for reinforcement optimization.

3 LITERATURE REVIEW

3.1 *Review of Selected Literature*

The references for the selected journals reviewed are listed in the Table 1.

Table 1. Reviewed literature.

Topic of journals/technical papers	Author	Publication & year
Study of Integral Abutment Bridges with Soil Structure Interaction	Mrs. PritalG.Kalasur	IJAFRSE 2015
Behavior of curved and skewed bridge with integral abutments.	Yaohua Deng-1&Brent M. Phares-2	JCSR 2016
An Exploratory Study on Integral Abutment Bridges	Babitha Elizabeth Philip	IJSRD 2017
The optimal shapes of piles in integral abutment bridges	Cheng Lan-1 &Bruno Briseghella- 2	Science Direct 2017
Integral Abutment Bridge- A review and comparison of the integral bridge and conventional Bridge.	Amit Bamnali-1,P.J. Salunke-2 and Luigi Fenu-3	IRJET 2018
Deck Slab Stress in Integral Abutment Bridges	Shehab Mourad-1&Sami W. Tabsh-2	Research Gate 2019

4 PROPOSED BRIDGE FOR ANALYSIS AND DESIGN

The proposed bridge is a single span integral bridge. The superstructure comprises of 18 no. T3 precast pre-stressed concrete inverted T beams with in-situ concrete infill forming a pseudo slab bridge deck. The deck is casted integral with the reinforced concrete pile capping beam (diaphragm beam). The substructure consists of reinforced concrete piled foundations built integral into the pile capping beam, diameter of each pile is 600mm.

The proposed deck cross-section and the integral connection between deck and piles are shown in the Figure 1 and Figure 2 respectively.

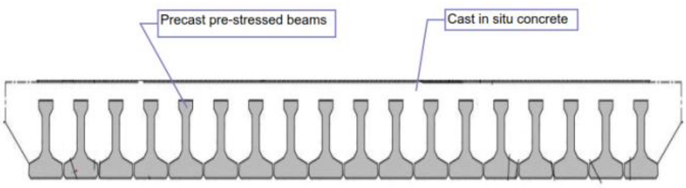

Figure 1. Deck cross section of the proposed bridge.

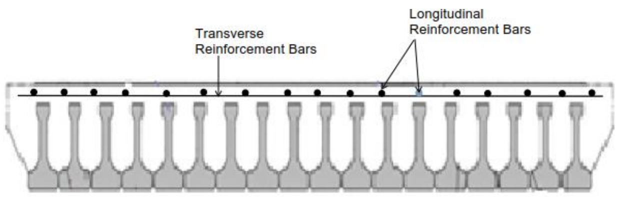

Figure 3. Provide reinforcement in the in-situ concrete.

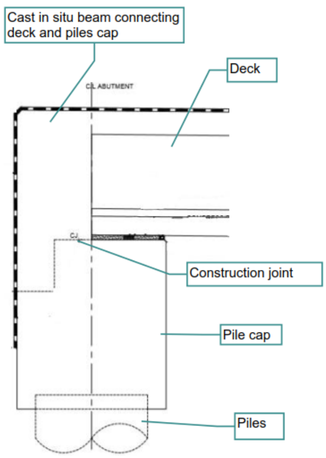

Figure 2. Integral connection between the deck and piles.

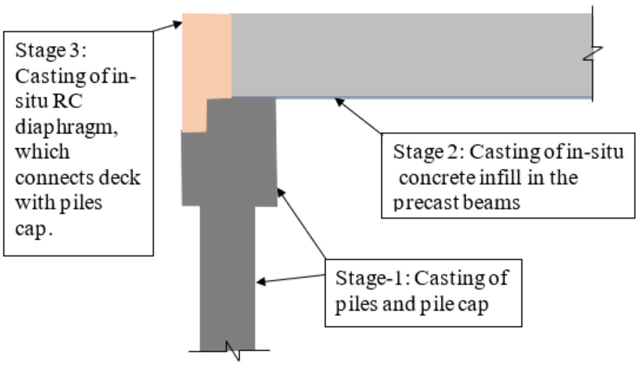

Figure 4. Construction sequence.

5 APPROACHES FOR REINFORCEMENT OPTIMIZATION

5.1 *Reinforcement Optimization in Deck*

The deck is comprised of precast pre-stressed deck concrete inverted T-beams with in-situ infill concrete. Reinforcement is provided in the in-situ concrete for providing sufficient stiffness to the deck and to avoid cracking in the in-situ concrete as shown in the Figure 3.

The quantity of reinforcement depends on various factors such as loading, spacing of precast members and demand of reinforcement to control early thermal cracking (ETC).

Controlling crack width is very important to ensure durability of structure. Design for ETC is carried out in accordance with the CIRIA guide. Numerous factors affect the early thermal behavior of concrete including the following.

- Type of restraint to movement
- Tensile strain capacity of the concrete
- Temperature rise which itself is influenced by:
  - Cement content and type
  - Element thickness
  - Conditions into which the section cast, particularly formwork type

Design Engineer can adjust above conditions to reduce demand of ETC reinforcement. But, any change in condition is subjected to the agreement between design engineer and contractor.

In this paper, variation in the longitudinal reinforcement demand in the infill concrete for controlling ETC is recorded for different cement types. Table 2 presents requirement of longitudinal reinforcement in the in-situ concrete deck for the different cement mixed and with the following considerations.

- Element/slab thickness = 250 mm
- Characteristic (Ch.) compressive strength of concrete = 40 MPa
- Ch. yield strength of steel = 500 MPa
- Nominal cover to the reinforcement = 40 mm
- Formwork type = plywood
- Limiting crack width = 0.3 mm

Table 2. Reinforcement requirement to control early thermal cracks.

Cement type	Cement quantity (kg/m3)	Reinforcement demand for ETC
CEM 1	520	20mm dia. bars @150mm c/c spacing
CEM mixed with 40% fly ash	520	12mm dia. bars @150mm c/c spacing
CEM mixed with 40% ggbs.	520	12mm dia. bars @150mm c/c spacing

5.2 *Reinforcement Optimization in Piles*

Piles are subjected to the following longitudinal forces which are transferred from deck to the piles.

1. Vehicle's braking force.
2. Force due to thermal expansion of deck.
3. Force due to shrinkage and creep effect.

Shrinkage and creep in the concrete causes shortening of deck (strain) which induce lateral force in the piles. Cast in-situ infill concrete in the deck undergoes significant drying shrinkage and autogenous shrinkage. Whereas, substantial part of shrinkage and creep in the precast members have already been occurred before casting of in-situ concrete, as shrinkage and creep depends on the age of concrete.

Force due to shrinkage and creep from the deck to piles could be mitigated by deciding suitable construction sequence. Casting of in-situ concrete in the deck and casting of diaphragm is done in different stages with sufficient time gap (minimum 28 days) to reduce forces in the piles and hence to optimize reinforcement in the construction sequence considered to minimize transfer of shrinkage and creep effects from deck to the piles is presented in the Figure 4.

6 ANALYSIS

6.1 *Global Analysis*

Grillage modeling was done to carry out global analysis of the composite structure. Deck is modeled as integral with piles. As piles are laterally supported by soil, springs of equivalent soil stiffness are modeled. The global model is presented in the Figure 5.

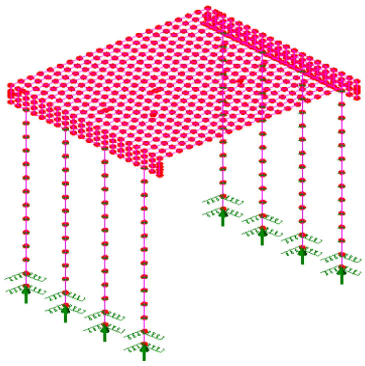

Figure 5. Global grillage model in LUSAS

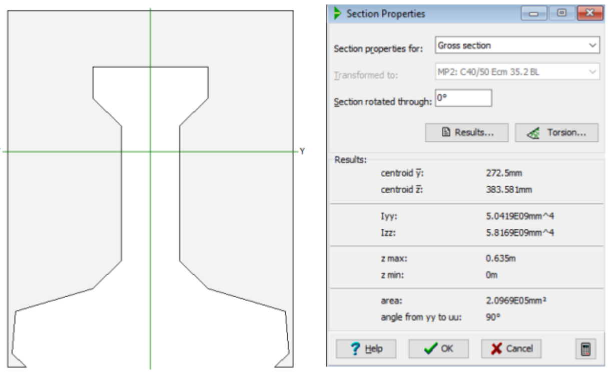

Figure 6. Area of in-situ concrete associated with one beam (ai)

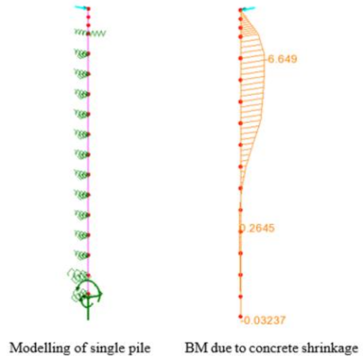

Figure 7. Local analysis of pile carried out in LUSAS for the shrinkage force transferred from the deck

In the above global model, loads are applied in accordance with the Eurocode with UK National Annex. The Force due to shrinkage in the cast in-situ deck is subjected to the cross-sectional area of in-situ deck as calculated below.

Tensile force, $N_{sh} = \varepsilon_{sc} x\ E_c\ x\ A_i$
Where, ε_{sc} is the shrinkage strain in the in-situ concrete deck.
E_c is the short-term modulus of concrete.
$E_c = 22((fck + 8)/10)$^0.3= $22((40 + 8)/10)$^0.3=35.22 MPa
f_{ck} is the characteristic strength of concrete which is considered 40 MPa.
A_i is the area of in-situ concrete deck associated with one pile.

As, $A_i = 5 \text{ x } a_i$
So, $A_i = 5 \text{ x } 2.0969 \text{ x}10$^5 x $10^{\wedge-6} = 1.05 \text{ m}^2$
Force on one pile due to shrinkage of deck concrete (N_{sh}). $N_{sh} = \varepsilon_{sc} \text{ x } E_c \text{ x } A_i = (100\text{x}10^{\wedge-6}) \text{ x } (35.22 \text{ x}1000) \text{ x } 1.05 = 4$ kN

The bridge consists of four number of piles on each side, and total 18 numbers of beams in the deck. So, around 5 beams are associated with one pile. Let us say, area of in-situ concrete associated with one beam is a_i which is determined using the Autodesk Structural Bridge Design Software as shown in the Figure 6.

6.2 *Local Analysis*

A separate analysis of a single pile (local analysis) is carried out by applying force due to shrinkage in the deck which was ignored in the global analysis. Purpose of this separate analysis is to determine actual percentage optimization of analysis of a single pile is carried out for the shrinkage load. Model and analysis results of single pile are presented in the Figure 7.

6.3 *Analysis Results*

The analysis results obtained from the global and local analysis are presented in the Table 3 and Table 4 respectively.

Table 3. Global analysis results for piles (shrinkage force from the deck is excluded).

Load case	Shear Force (kN)	Bending Moment (kNm)
Ultimate limit state loads combination	176	487

Table 4. Local analysis results for pile (for the shrinkage force from the deck).

Load case	Shear Force (kN)	Bending Moment (kNm)
Ultimate limit state loads combination	6	10

6 STRUCTURAL DESIGNS

The design resistance of reinforced concrete sections is determined in accordance with the BS EN 1992-2. The design details of piles for load effects obtained from the global analysis which did not include effect of concrete shrinkage force is summarized in the below Table 5. And, design details of pile for combined effects from the local and global analysis are presented in the Table 6.Although, increase in action values in the Table 6 is not much higher than the values in Table 5, but the provided reinforcement is more than 11% higher in the Table 6. Higher reinforcement may give lesser utilization, but it is required to meet design requirement.

Table 5. Pile design details (for optimized reinforcement in piles)-Designed for global model analysis result.

Actions (ULS load case)	Reinforcement requirement
Bending Moment = 487 kN-m	Long. Reinforcement: 32mm dia., 8 number of bars
Shear Force = 176 kN	Transverse reinforcement: 12mm dia. bars @ 150 mm spacing

Table 6. Pile design details- designed for combined effects from the global model and local model.

Actions (ULS load case)	Reinforcement requirement
Bending Moment = 497 kNm	Long. Reinforcement: 40mm dia., 8 number of bars
Shear Force = 182 kN	Transverse reinforcement: 12mm dia. bars @ 120 mm spacing

7 CONCLUSIONS

The integral bridges are best alternative to the conventional bridges with bearings upto the span length of 40m due to the following reasons.

- More durable/sustainable.
- Required less maintainance.
- Performance is much better.
- Whole Life Cost is lower.

Cost of construction can further be reduced based on right engineering judgement such as considering suitable construction sequence in design which helps in avoiding development of secondary forces in structure. And, using cement mixed with ggbs or fly ash which reduces heat of hydration in concrete and hence minimise the demand of reinforcement to control early thermal cracking. Considering cement mixed with ggbs or fly ash not only reduce cost of construction, but also saves materials (natualresources) for the use of future generation.

8 FURTHER SCOPE

There are the following areas of research which could help in further optimising cost and material in bridge construction.

- Various factors are defined in the section 5 which decide the early thermal cracking behavior of concrete. Effect of factors other than cement type could be verified, as we confimed variation of reinforcement demand for different cement mixes in the Table 2.
- Concrete mixed with steel fibre may be use as in-situ concrete which could reduce requirement of reinforcement to control early thermal cracking, as tensile strength of concrete mixed with steel fibre is more than the normal concrete.
- The main challange in the integarl bridge is cyclic loading due to expansion and contraction which is caused by surrounding temperature variation with time. So, research could be carried out to minimize surrounding temperature effects by isolating bridge, which could be done through introducing some permanent material layer over the whole bridge.

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