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A Comparative Study of Precast Pre-Stressed U-Girder Integral and Continuous Bridges

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ABSTRACT

Integral bridges are gaining popularity due to enhanced durability achieved because of a reduction in numbers of movement joints and bearings. Consequently, these provide smooth traffic movement than continuous bridges. Further, the horizontal loads are better distributed. Deformation pattern of a precast pre-stressed girder under primarily loads gets modified and this indeterminate system is affected by several factors such as: pre-stressing type (pre-tensioning/post-tensioning), amount of prestress, process of making the structure composite (girder-slab connection), variations in earth pressure and temperature, construction sequence, creep, shrinkage, and differential settlement. It is found that consideration of secondary forces in the design of these bridges plays a vital role. A comparison of primary, secondary and design forces in Integral and Continuous bridges with open foundation constructed using U- type precast pre-stressed girders is presented in this paper.

Keywords: Primary; Secondary; Earth pressure; Creep.

INTRODUCTION

Continuous and integral bridges, nowadays, are being constructed round the globe because of their structural advantages and aesthetics. Because of the inherent problem of continuous bridges like expansion joints that lead to ingress of water and de-icing salts in bridge deck and sub-structure, designers often prefer Integral bridges. The bridge decks up to 60 metres in length and skews not exceeding 30o are generally made integral with their supports [1]. These are called Integral Bridge. Since movements are restrained in integral bridge, secondary stresses are developed, which may be of the order of primary stresses and therefore of concern. Moreover, secondary effects may even cause stress reversal and if not accounted for may lead to collapse. Besides primary loads, following secondary loads and their effects considered in the design of integral bridges are type of pre-stress and amount; Process of making the girder-slab connection; Variation in earth pressure; Differential settlement; Daily and seasonal temperature variations at the site, Creep and Shrinkage; and Sequence of construction. A brief description of these effects has been discussed [2].

ANALYSIS

Integral and Continuous bridges display a complex structural behaviour. The modeling and design of these bridges encompasses appropriate structural modeling for the estimation of rigidity for the continuity connections among structural elements, soil properties and appropriate modeling of the soil-structure interaction, effects of daily and seasonal temperature fluctuations on the structure, determination of the redistribution of time-dependent deformation of creep and shrinkage and effects of construction sequence on the distribution of primary and secondary forces.

For modeling three dimensional effects of lateral loads on the piers, abutments, and wing walls, 3-D model is used for analysis. The gravity loads, earth pressure and effects of temperature variation are considered for the design of the deck-abutment and deck-pier joints. The correlation between the temperature variation and the effects of earth pressure is modeled to allow for the soil-structure interaction. A very small displacement of

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the abutment away from the backfill soil creates active earth pressure behind the abutment [3]. Further, depending upon the amount and direction of displacement, the coefficient of earth pressure K may change between K_o, K_a and $K_p$where K_o is the coefficient of earth pressure at rest, K_a is the coefficient of active earth pressure, and K_p is the coefficient of passive earth pressure. Integral bridges are generally designed with stiffness and flexibility spread throughout the structure-soil system so that all the supports accommodate the effects of thermal and braking loads. The foundations are designed so as to behave flexible and less restraint to longitudinal movement of the bridge deck to minimize the effects of forces parallel to the bridge in longitudinal direction.

The bending and shear forces in the bridge elements are affected by the construction sequence of Integral/Continuous bridges and are accounted for in the design. At each of the construction stage the stresses are assessed with the final moments and shears. Since the statical system of a bridge is changed during construction, creep of the concrete modifies the as-built forces. This change will depend on the creep factor(ϕ) [4]. In case of a sudden change to the statical system like connection of precast girder to deck slab, the moments are modified in accordance with the following equation

$$M_{final} = M_s + (1-e^{-\Phi})(M_c - M_s)$$

Where, M_{final} is final design moment, M_c is moments if structure is constructed in one go, and M_s is simply supported moment.

The construction sequences followed in the present work for the analysis of superstructure of Integral and Continuous bridges are shown in Fig 1.

For 3-D modeling of the bridges the deck and girders have been modeled using beam element, and the abutments and foundation with plate using 4-noded element. The 3-D models of Integral and Continuous bridges are shown in Figs. 2 and 3, respectively [2]. The earth pressure behind abutments is applied using spring stiffness [5, 6]. The parameters and their stipulated values considered in the present work are differential settlement (5mm), temperature fluctuation (± 31℃), differential shrinkage strain ($100x10^{-6}$), long term creep coefficient ϕ (1.62), creep coefficient when girder made continuous (1.2) and shrinkage strain (130×10^{-6}). The superstructure was considered to be made up of precast pre-stressed members. The loads and different effects considered were as per the British Standard. The live load considered were HA + KEL for class 1 design and HA + HB-45 for class 2 design [7, 8].

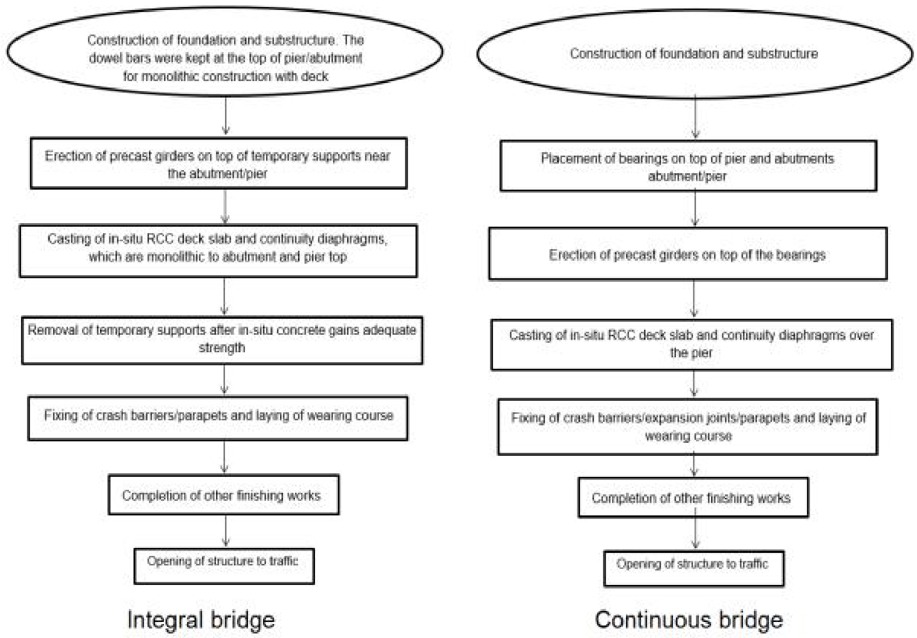

Fig 1: Flow chart of construction sequence

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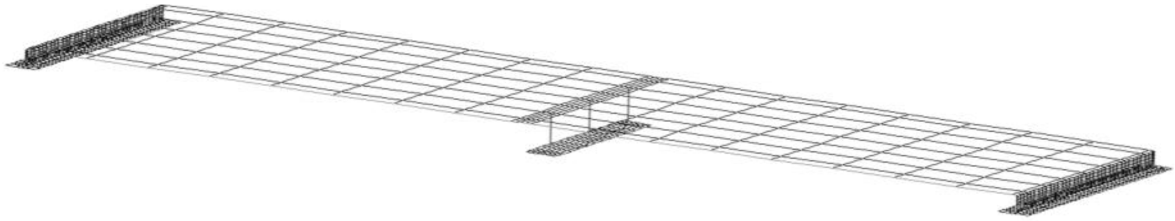

Fig 2: 3-D Model of Integral bridge

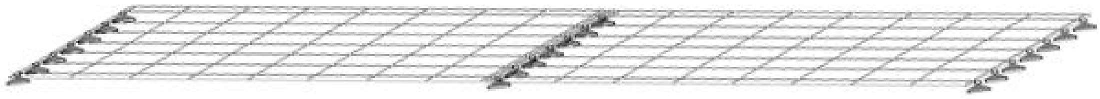

Fig 3: 3-D Model of Continuous bridge

MODELLING AND DESIGN

A two span six lane bridge of width 24.4 m was considered for the comparison. Both the Continuous and Integral bridges were modelled using U-girders (Figs. 2 to 5). The member sections used were obtained after three cycle analysis and design iterations. Then these were used for the final analysis and design. Following stipulations were made:

Thickness of deck slab = 200 mm;

Number of girders and spacing = 7 at 3.4 m centre to centre.

Span (depth) of girders considered for Integral bridge were as follows.

20m (1600mm), 30m (2100mm), 40m (2900mm), 50m (3600mm)

Span (depth) of girders considered for Continuous bridges were as under.

20m (1200mm), 30m (1800mm), 40m (2600mm), 50m (3300mm)

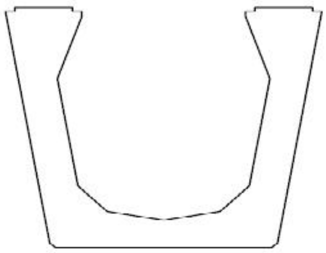

Fig 4: U Type Girder

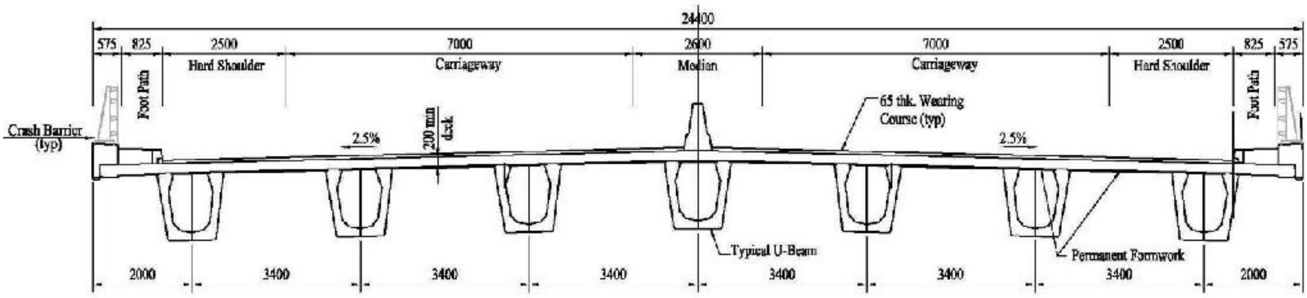

Fig 5: Typical Cross Section of Bridge Deck

The properties of construction materials used in the present work are given in Table 1.

Table 1. Properties of construction materials

Pre-stressing strand	Characteristic strength = 279 kN/strand
	Modulus of elasticity = 200 GPa.
	Area of strand = 150 mm^2
Concrete	Characteristic strength of deck slab concrete = 50 MPa
	Characteristic strength of girder concrete = 70 MPa
	Density of concrete, γ_c = 25 kN/m^3
	Modulus of elasticity of deck slab = 34 GPa
	Modulus of elasticity of girder = 37 GPa
	Age of Girder (at the continuity being established) = 21 days.

RESULTS AND DISCUSSION

Fig 6 to 10 show the primary, secondary and design results obtained from the analysis of Integral and Continuous bridges. The notations Ip, Is, Id, Idn, Idp, Cp, Cs, Cd ,Cdn and Cdp in the figures designate integral primary, integral secondary, integral design, integral design negative, integral design positive, continuous primary, continuous secondary, continuous design, continuous design negative and continuous design positive values respectively. The sagging moments are considered positive and hogging moments as negative. The design values were calculated considering the worst simultaneous occurrence of primary and secondary effects.

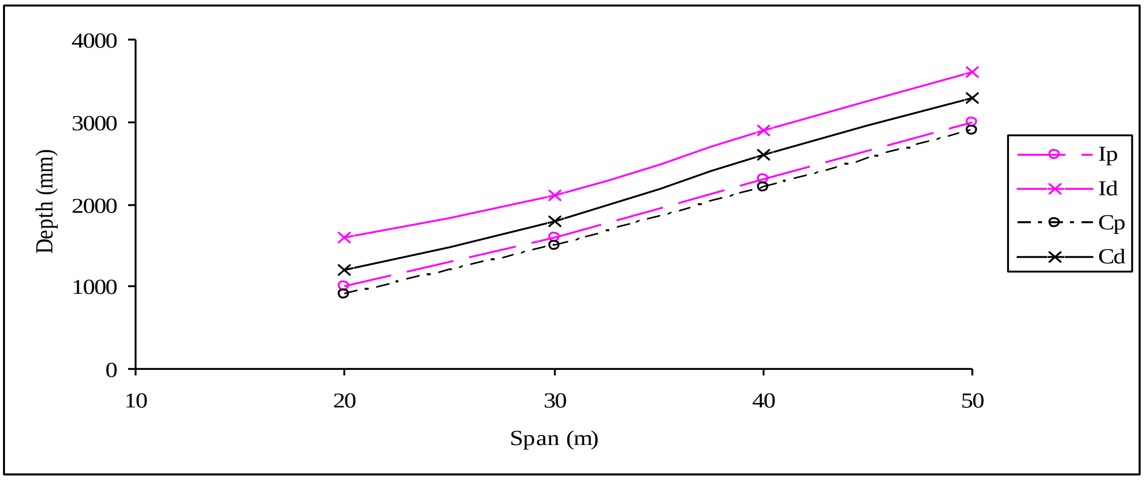

Fig 6: Variation of Girder Depth for Primary and Design BM with Span

Fig 6 shows the variations in girder depth required for primary and design BMs with span for Integral and Continuous bridges. It can be seen from the figure that the difference between girder depths in case of primary BMs for both the Integral and Continuous bridges are not appreciable. However, when design BMs are considered depth of the girder will be higher for the Integral bridges than that for the Continuous bridges. The depths of girder required from design BM consideration are on an average 34 and 21% more than those required from primary BM consideration for Integral and Continuous bridges, respectively.

The variations of deck weight, required for primary and design BMs with span for Integral and Continuous bridges are shown in Fig7. When the primary BMs are considered, thedifference in weight of concrete is insignificant for Integral and Continuous bridges. But with regards to design BMs, the concrete weight for

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Integral bridge is higher than that of Continuous bridge. The concrete weights required from design BM consideration are on an average 18 and 11% higher than those required from primary BM consideration both for Integral and Continuous bridges, respectively.

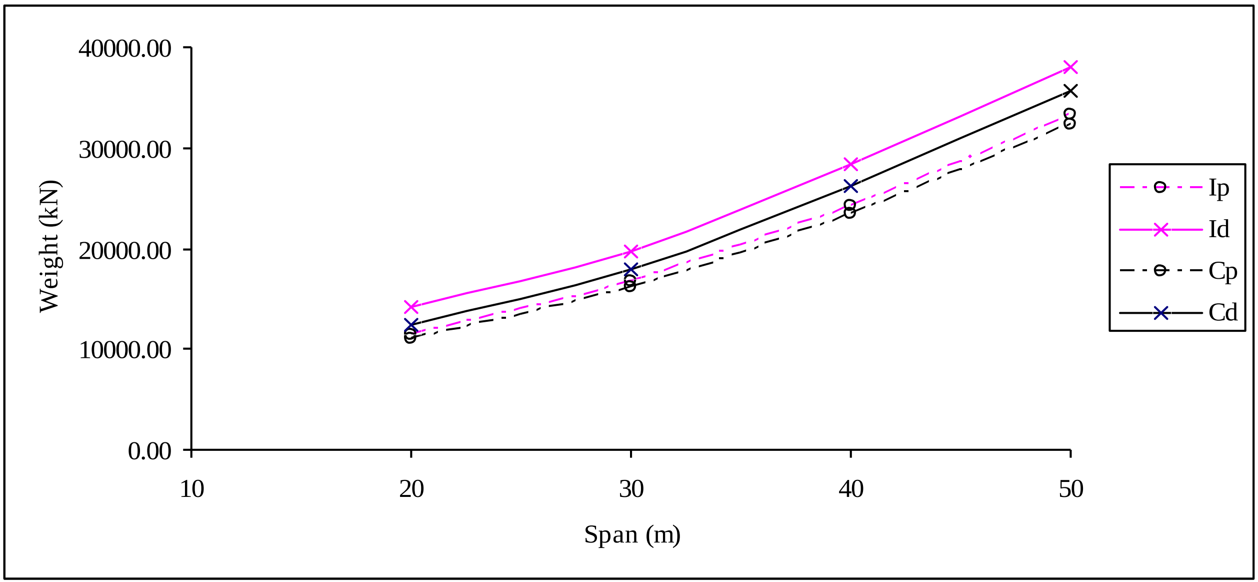

Fig 7: Variation of Deck Weight for Primary and Design BM with Span

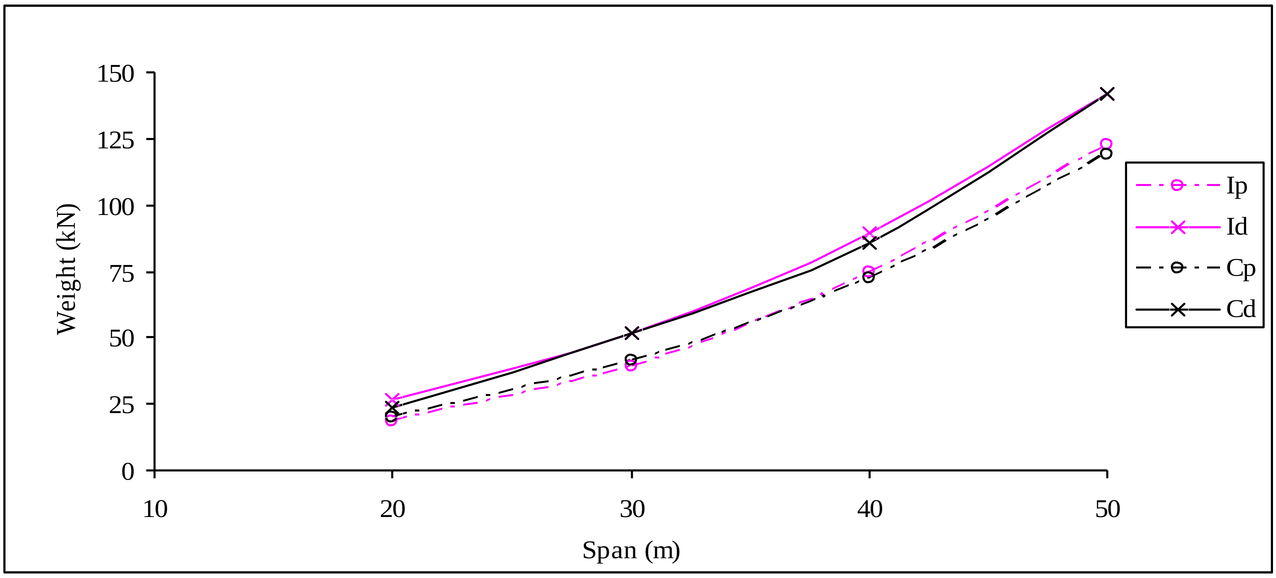

Fig 8: Variation of Girder Strand Weight for Primary and Design BM with Span

Fig 8 shows variations of girder strand weight, required for primary and design BMs with span for Integral and Continuous bridges. In case of primary and design BMs the difference in strand weights required for both the Integral and Continuous bridge is not appreciable. When design BMs are considered, the strand weight is marginally higher in case of integral bridge. The strand weights required from design BM consideration are on an average 28 and 20% higher than those required from primary BM consideration for Integral and Continuous bridges, respectively.

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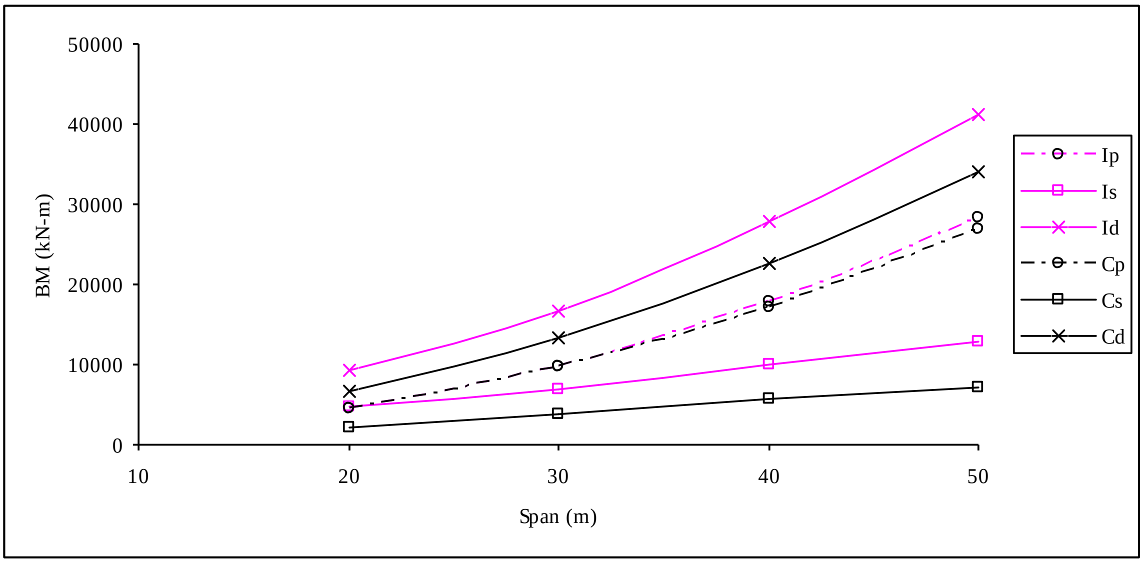

Fig 9: Variation of Primary, Secondary and Design BM with Span at Mid-Span

The variations of primary, secondary and design BMs (at mid-span) with span for Integral and Continuous bridges are shown in Fig. 9. It reveals that the difference between primary BMs for Integral and Continuous bridges isinsignificant. The secondary BMs are on an average 69 and 37% of primary BMs for Integral and Continuous bridges, respectively. The design BMs are on an average 69and 37% higher thanthat of primary BMs for Integral and Continuous bridges, respectively.

Fig. 10 shows the variations of primary, secondary and design BMs (at pier support) with span for Integral and Continuous bridges. The difference between primary BMs for Integral and Continuous bridges is not appreciable. The secondary negative BMs are on an average 81 and 22% of primary BMs for Integral and Continuous bridges, respectively. There is a stress reversal at this location and the positive design BMs developed are on an average 1.54 times of primary BMs in case of Integral bridge. This positive BM varies from 2.46 to 1.15 times of primary BM when span is increased from 20 to 50 m. Further, it is observed that the BMs at pier location change sign in case of Continuous bridge. The average positive BMs developed are 0.79 times of primary BMs. The positive BMs range from 0.99 to 0.53 times of primary BMs when span is increased from 20 to 50 m. The difference between the secondary positive BMs of integral and continuous bridges is not appreciable.

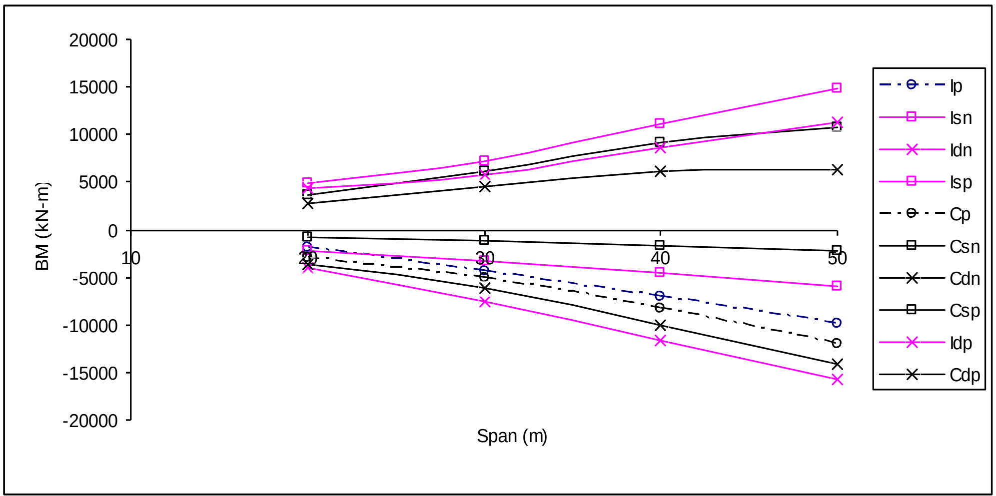

Fig 10: Variation of Primary, Secondary and Design BM with Span at Pier

CONCLUSION

Although the girder depths required for Integral and Continuous bridges based on primary BM consideration are almost same, but the design BMs are larger in case of Integral bridges than those in Continuous bridges, the weight of concrete required for Integral bridge is more than that of Continuous bridge, and when design BMs are considered, the Integral bridge requires more depth than the Continuous bridge.

Since the primary and secondary BMs, in general, for large spans and small girder spacing are larger in case of Integral bridges than those in Continuous bridges, it is recommended that U-type girders for Integral bridges may be provided for spans up to 30 m with a girder spacing up to 3.0 m only.

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