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Research Paper

SECONDARY EFFECTS IN PRECAST PRE-STRESSED W-GIRDER INTEGRAL AND CONTINUOUS BRIDGES

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Movement joints and bearings in concrete bridges can cause severe maintenance issues during the service life of a structure. A recent trend in bridge design has been towards integral type structures. Durability of such bridges is greatly improved by removing or minimizing the movement joints and bearings. Further, these structures offer better riding quality and a better distribution of horizontal loads. A simply supported pre-stressed girder deforms due to primary loads. However, secondary effects further affect the geometry, when these girders are made continuous over the supports or made integral with the supports. It is found that the secondary forces are important and must be considered in the design. This paper presents a comparison of primary, secondary and design forces in Integral and continuous bridges with open foundation, constructed using W- type precast pre-stressed girders.

Keywords: Primary, Secondary, Design, Earth pressure, Creep, Shrinkage, Temperature

INTRODUCTION

The Continuous and Integral bridges are viable and economical alternatives to most of the bridges, if suitable foundation is available. Severe durability problems may emerge due to penetration of water or/and de-icing salts (cold climates) in the expansion joints of decks of continuous bridge and its substructure. These problems can be overcome by making the bridge decks of < 60 m span and with skews < 30^0 integral with their supports (BA 42/96, Amendment No. 1) , and are referred to as Integral bridge or rigid frame bridge. This construction leads to reduced forces and deformation in the various components of the whole bridge system comprising of superstructure, substructure and foundation. Due to the movement restraints, the additional stresses developed (referred to as secondary effects) may sometimes be comparable to the primary effects due to Dead Load (DL), Super Imposed Dead Load (SIDL), Live Load (LL), and Impact Load (IL), etc. The secondary effects may also cause the stress reversals

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leading to the failure of the structure, if not accounted for in the design. For the analysis and design of Integral bridges, the different loads and their effects that need a consideration, besides the primary loads, are: (i) Prestressing type (pre-tensioning/post-tensioning); (ii) Amount of prestress; (iii) Process of making the structure composite (girder-slab connection); (iv) Earth pressure variation; (v) Differential settlement; (vi) Daily and seasonal temperature variations on the structures, (vii) Time dependent deformation of creep and shrinkage; and (viii) Sequence of construction. A brief description of these effects follows.

The earth pressure is dependent on abutment height and longitudinal deck movement and is highly dependent on the friction coefficient. The abutments may bodily slide (in case of bank seat) or may tilt (in case of tall wall). The variable temperature effects force the structurally connected abutments to move outwards/inwards during expansion/ contraction of the bridge deck. The creep and shrinkage effects force the structurally connected abutments to move inwards. The modes of abutment movement are primarily rotation about its bottom and horizontal translation displacement. During expansion, large lateral earth pressure develops on the back of abutment, which may approach the theoretical passive value. Further, the net inward movement of the abutments may cause after a number of cycles of temperature changes a wedge slump in the adjacent soil. The upward/downward deflection and the camber of a simple unloaded pre-stressed pre-tensioned beam depends upon the magnitude of pre-stressing force and its self weight, which are modified by the Creep, Shrinkage and Relaxation with time. When two adjacent beams are made continuous with a rigid connection, a sagging restrained bending may develop over the supports. The full continuity may be reduced due to development of tension in cross heads, which may crack under action of the time dependent effects. Due to the load combinations, material and structural properties, and the sequences of construction, the levels of the hogging/sagging restraint moment and their significance require lengthy calculation for each combination.

Since bridge engineers are divided over the importance of secondary effects and their inclusion in the design, a proper study of such effects is required in the analysis and the design of integral and continuous bridges. In view of the above, the primary, secondary and design forces were calculated in case of continuous and Integral bridges with open foundation using W-type precast pre-stressed girders to establish the importance and inclusion of secondary effects in the design.

Analysis

The overall behavior of integral and continuous bridges is very complex as it depends on several parameters. The general problems that require attention with regards to the modeling and design of these bridges are as follows: (i) Appropriate structural modeling of continuity connections among structural members for estimating rigidity. (ii) Estimation of soil properties and appropriate modeling of the soil-structure interaction; (iii) Estimation of the effects of daily and seasonal temperature fluctuations on the structure; (iv) Determination of the redistribution of time-dependent deformation of creep and shrinkage; and (v) Effects of construction sequence on the distribution of primary and secondary forces.

The three dimensional effects of lateral loads on the piers, abutments, and wing walls is not reflected by two dimensional modeling of the Integral bridge. This requires a three dimensional (3-D) model to analyze the structure for the effect of lateral loads. The weight of slab, girder, diaphragm, superimposed loads, live loads, earth pressure and effects of temperature variation need a consideration for the design of the deck-abutment and deck-pier joints. Further, for the soil-structure interaction correlation between the temperature variation and the effects of earth pressure need a modeling. The earth pressure coefficient is a function of the displacement of the earth retaining structure. Active earth pressure behind the abutment (Dicleli, 2000) is created even due to its meager displacement away from the backfill soil. The coefficient of earth pressure K may change between K_o (rest), K_a (active) and K_p (passive). Its value depends upon the direction and displacement suffered.

Integral bridges are generally designed with stiffness and flexibility spread throughout the structure-soil system. This results in all the supports to accommodate the effects of thermal and braking loads. The abutments and their foundations are so designed that they are flexible and less restraint to longitudinal movement of the bridge deck. This minimizes the effects of forces parallel to the bridge in longitudinal direction.

The construction sequence of Integral/ Continuous bridge affects the moments and shears generated in the bridge elements and this needs to be fully taken into account during the design. Stresses must be assessed at each stage of construction with the final moments and shears derived to reflect the construction sequence. When the statical system of a concrete structure is changed during construction, creep of the concrete will modify the as-built bending moments and shear forces towards the instantaneous moment and shear distribution. The amount of the change is dependent on the creep factor ϕ (Ryal, 2000). Where the change to the statistical system is sudden, such as connection of precast girder to deck slab creating continuity, the modification to the moments is through the following equation

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

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 following construction sequences were adopted for the analysis of superstructure of Integral and Continuous bridges.

Integral Bridge: (i) Construction of foundation and substructure. The dowel bars were kept at the top of pier/abutment for monolithic construction with deck; (ii) Erection of precast girders on top of temporary supports near the abutment/pier; (iii) Casting of in-situ RCC deck slab and continuity diaphragms, which are monolithic to abutment and pier top; (iv) Removal of temporary supports after in-situ concrete gains adequate strength; (v) Fixing of crash barriers/parapets and laying of wearing course; (vi) Completion of other finishing works; and (vii) Opening of structure to traffic.

Continuous bridge (diaphragm continuity): (i) Construction of foundation and substructure; (ii) Placement of bearings on top of pier and abutments; (iii) Erection of precast girders on top of the bearings; (iv) Casting of in-situ RCC deck slab and continuity diaphragms over the pier supports; (v) Fixing of crash barriers/ expansion joints/parapets and laying of wearing course; (vi) Completion of other finishing works; and (vii) Opening of structure to traffic.

In the present work, the bridges were modeled as 3-D structure. The deck and girders were modeled using beam element. The abutments and foundation were modeled as plate using 4-noded element. The 3-D models of Integral and Continuous bridges are shown in Figures 1 and 2, respectively. The earth pressure behind abutments is applied using spring stiffness (Hambly, 1991 and Nicholson, 1998). The stipulated values of the parameters considered in the present investigation are: differential settlement- 5 mm; temperature fluctuation- +31^{0}C; 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 assumed to be made up of precast pre-stressed members. The loads and different effects considered were as given in British Standard. The live load considered were HA + KEL for class 1 design and HA + HB-45 (BD 37/01, 2001) for class 2 design (BS 5400 Part 4, 1990).

MODELLING AND DESIGN

For comparison, a two span six lane bridge of width 24.4 m was considered. Both the Continuous and Integral bridges were modelled by using W-girders (Figures 1 to 4). The sections used were obtained after three cycle analysis and design iterations and 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 center to center.

Figure 1: 3-D Model of Integral Bridge

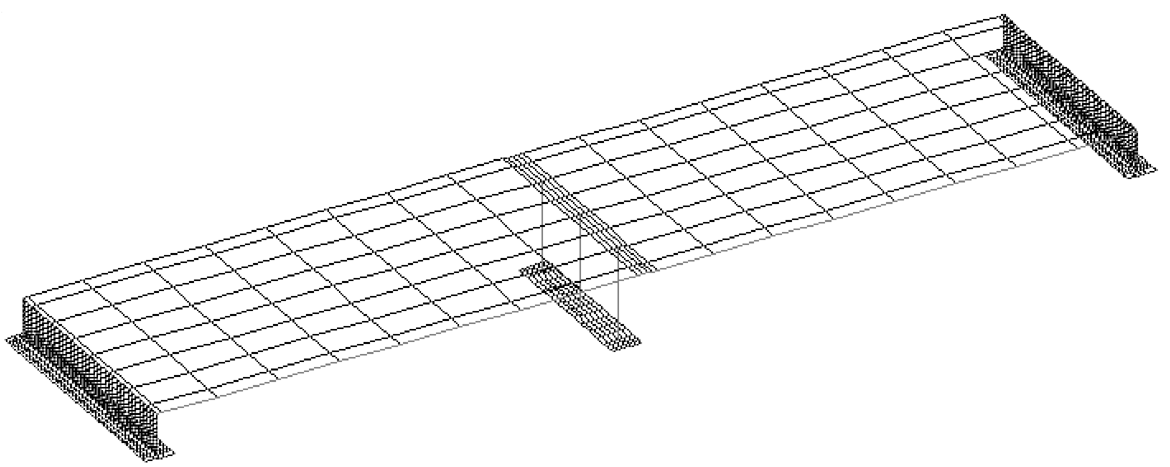


Figure 2: 3-D Model of Integral Bridge

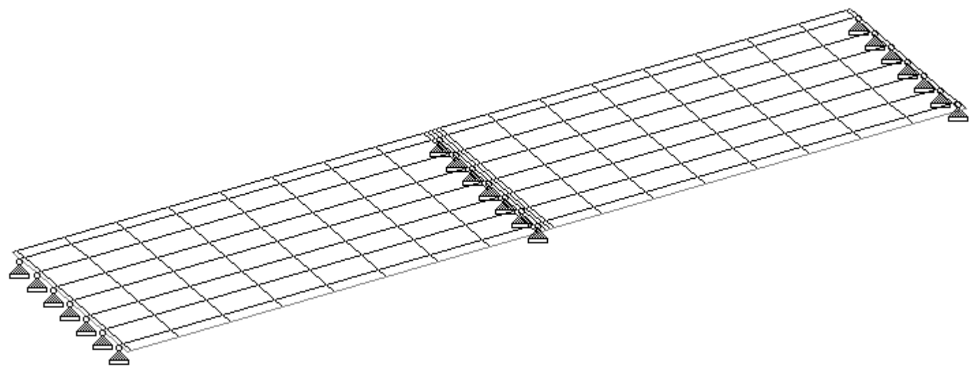


Figure 3: W Type Girder

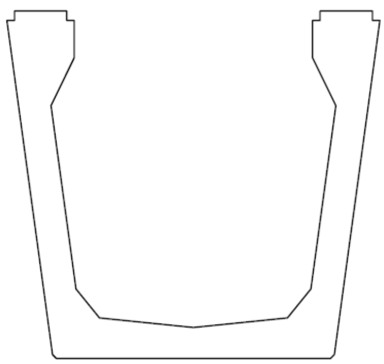
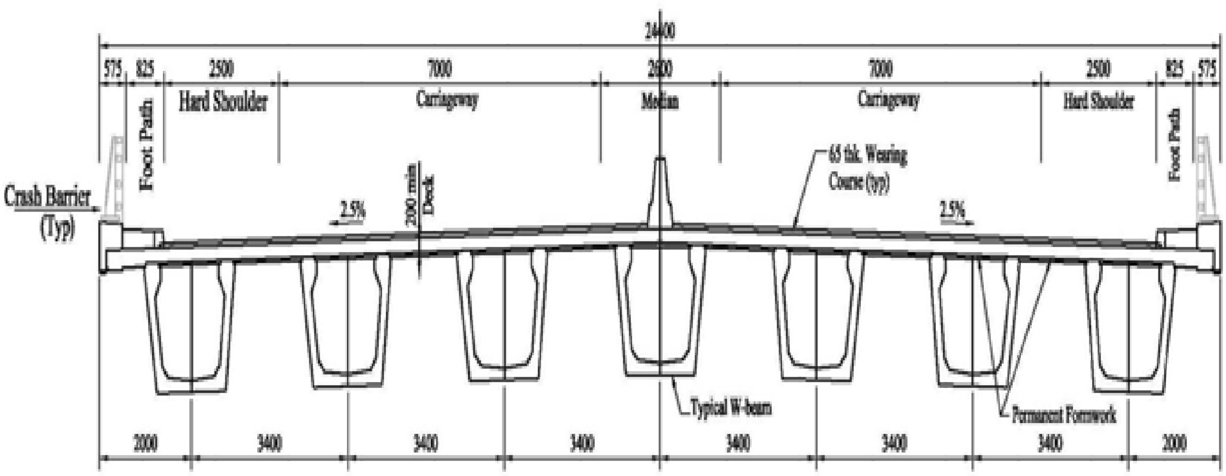


Figure 4: Typical Cross Section of Bridge Deck



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

20 m (1200 mm), 30 m (1800 mm), 40 m (2400 mm), 50 m (3100 mm)

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

20 m (1000 mm), 30 m (1600 mm), 40 m (2200 mm), 50 m (2900 mm)

The properties of different materials used in the present investigation were as under.

Concrete: (i) Characteristic strength of deck slab concrete = 50 MPa; (ii) Characteristic strength of girder concrete = 70 MPa; (iii) Density of concrete, γ_c = 25 kN/m^3; (iv) Modulus of elasticity of deck slab = 34 GPa; (v) Modulus of elasticity of girder = 37 GPa; (vi) Age of Girder (at the continuity being established) = 21 days.

Pre-stressing strand: (i) Characteristic strength = 279 kN/strand; (ii) Area of strand = 150 mm^2; (iii) Modulus of elasticity = 200 GPa.

RESULTS AND DISCUSSION

The primary, secondary and design results obtained from the analysis of Integral and Continuous bridges are presented in Figures 5 to 9. 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 treated as positive and hogging moments are treated as negative.

The variations of girder depth, required for primary and design BMs with span for Integral and Continuous bridges are shown in Figure 5. From the figure, it is seen that when the primary BMs are considered both the Integral and Continuous bridges require similar depths. When design BMs are considered the Integral bridges require higher depths than the Continuous bridges. The depths of girder required from design BM consideration are on an average 31 and 17% higher 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 Figure 6. From the figure, it is seen that when the primary BMs are considered the weights of concrete for both Integral and Continuous bridges are similar. When design BMs are considered, the concrete weight for Integral bridge is higher than that of Continuous bridge. The concrete weights required from design BM consideration are on an average 17 and 9% higher than those required from primary BM consideration, for Integral and Continuous bridges respectively.

The variations of girder strand weight, required for primary and design BMs, with span for Integral and Continuous bridges are shown in Figure 7. From the figure, it is seen that when the primary BMs are considered more strand weight is required in case of Continuous bridge. However, when design BMs are considered the strand weight is higher in case of integral bridge. The strand weights required from design BM consideration are on an average 39 and 12% higher than those required from primary BM

Figure 5: Variation of Girder Depth for Primary and Design BM with Span

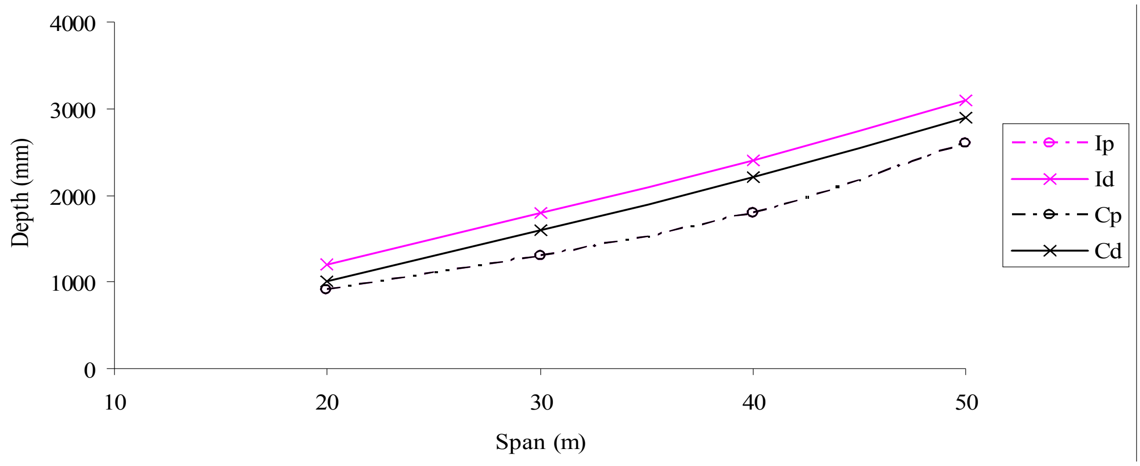


Figure 6: Variation of Deck Weight for Primary and Design BM with Span

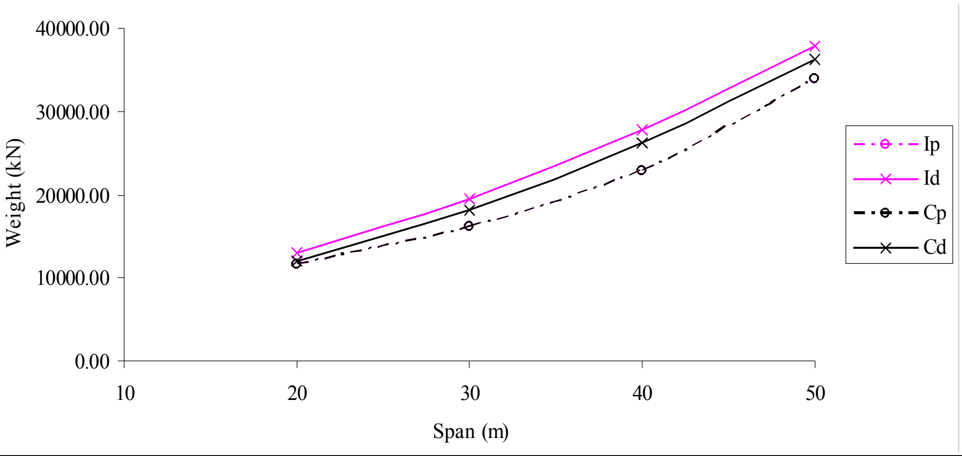


Figure 7: Variation of Girder Strand Weight for Primary and Design BM with Span

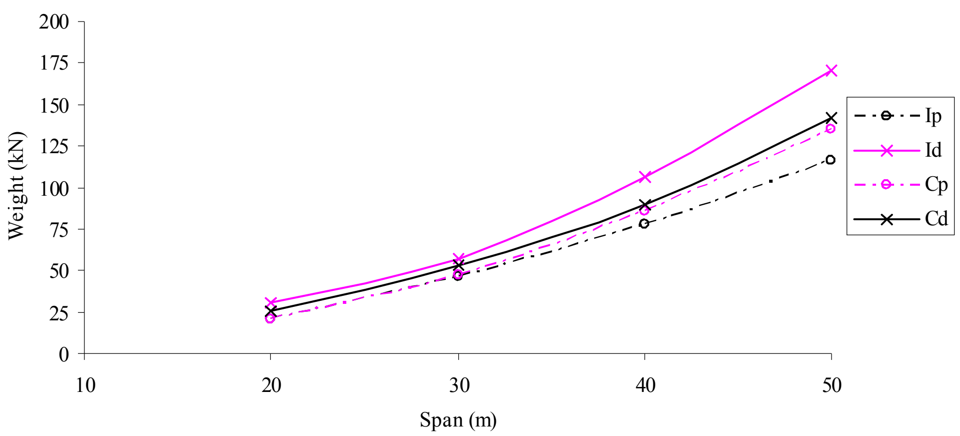


Figure 8: Variation of Primary, Secondary and Design BM with Span at Mid-Span

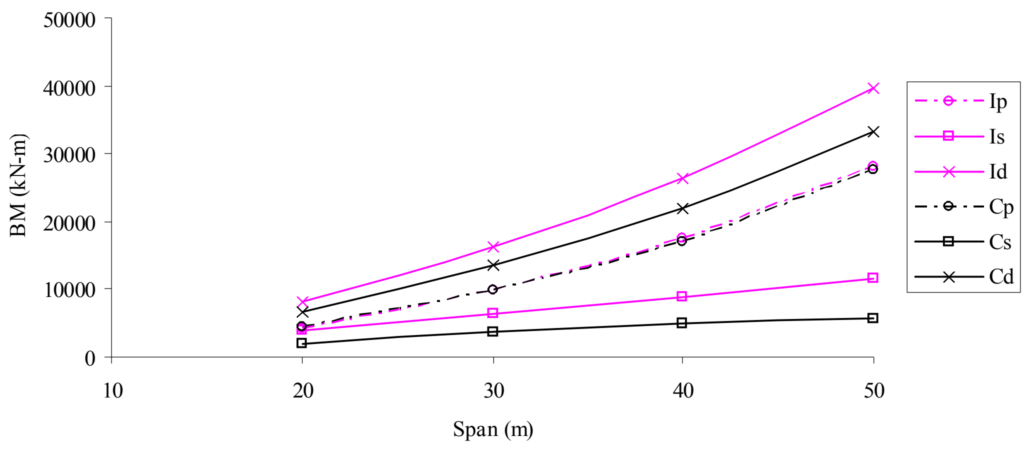
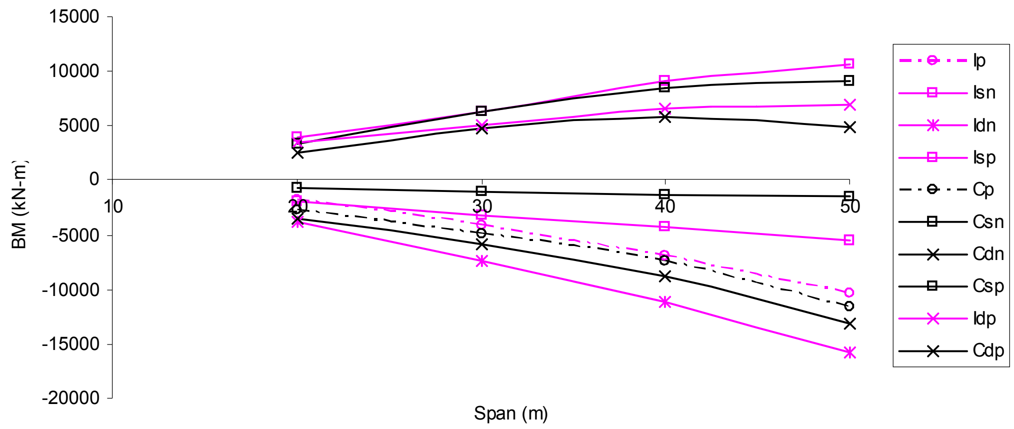


Figure 9: Variation of Primary, Secondary and Design BM with Span at Pier



consideration, for Integral and Continuous bridges respectively.

The variations of primary, secondary and design BMs (at mid-span) with span for Integral and Continuous bridges are shown in Figure 8. From the figure, it is seen that the difference between primary BMs for Integral and Continuous bridges is not appreciable. The secondary BMs are on an average 62 and 34% of primary BMs for Integral and Continuous bridges respectively. The design BMs are on an average 62 and 34% higher than that of primary BMs for Integral and Continuous bridges respectively.

The variations of primary, secondary and design BMs (at pier support) with span for Integral and Continuous bridges are shown in Figure 9. From the figure, it is seen that the difference between primary BMs for Integral and Continuous bridges is not appreciable. The secondary negative BMs are on an average 74 and 19% 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 1.18 times of primary BMs in case of Integral bridge. This positive BM varies from 1.89 to 0.67 times of primary BM when span is increased from 20 to 50 m. The BMs at pier location change sign in case of Continuous bridge also. The average positive BMs developed are 0.77 times of primary BMs. The positive BMs range from 0.95 to 0.42 times of primary BMs when span is increased from 20 to 50 m. The difference between the secondary positive BMs of integral and continuous bridge is not appreciable.

CONCLUSION

The following conclusions are drawn in the present work.

1. In general, the primary BMs are larger in case of Continuous bridges as compared to the Integral bridges.
2. The secondary BMs are larger in case of Integral bridges as compared to continuous bridges.
3. The design BMs are larger in case of Integral bridges as compared to continuous bridges.
4. The girder depths required for Integral and continuous bridges on primary BM consideration are almost same.
5. When design BMs are considered, the Integral bridge requires more depth than the continuous bridge.
6. The weight of concrete required for Integral bridge is higher than that of continuous bridge.
7. The strand weight calculated on primary BM consideration is more for continuous bridge, whereas it is more for Integral bridges when design BMs are considered.

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