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A Comparative Study of Precast Pre-stressed Integral & Continuous Bridge Deck

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ABSTRACT

Presently there is a trend to switch to Continuous or Integral precast girder bridges made of pre-stressed, if suitable foundation is available. Bridges made Integral with the support through proper connections are gaining popularity because of economy, stiffness, durability etc. These bridges may utilize either pre-tensioned or post-tensioned girders, the former being superior because of advantages associated with factory production; very high quality control is achieved. These bridges, however, are subjected to large secondary effects which are quite complicated. Since secondary effects may affect the design stresses their inclusion in the design has been investigated. General profiles used for these bridges by the designers are with U, Y and W-girders. A designer initially finds it difficult to select a suitable and economic girder profile. This paper presents a comparative study of U, Y and W-girder continuous and integral bridges to ascertain the feasibility and economy of the selected girder profile with respect to span and economy considering the primary and secondary effects.

Keywords: Precast girder bridges,Secondary effects, pre-stressed, Integral bridges, Continuous bridges.

INTRODUCTION

Continuous bridge decks are provided with expansion joints at abutment and intermediate pier location depending on length of continuity are therefore prone to ingress of water/de-icing salts (cold climates) into the bridge deck and substructure. This leads to severe durability problems. To overcome the problem, bridge decks up to 60 meters in length and skews not exceeding 30^0 are generally made integral with their supports[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 super structure, substructure and foundation. But, due to the movement restraints, the additional stresses developed (referred as secondary effects) may sometimes be comparable to the primary effects.

Since bridge engineers are divided over the importance of secondary effects and their inclusion in the design, a proper study of secondary effects is required in the analysis and the design of Integral and Continuous bridges because they may affect the design stresses. The behaviour of integral and continuous bridge as a whole is very complex due to involvement of several parameters. Some of which that play an important role in the modeling and design of these bridges are as follows.

(I) Appropriate structural modeling of continuity connections among the structural members for estimating rigidity.

(II) Estimation of soil properties and appropriate modeling of soil structure interaction.

(III) Estimation of effect of seasonal temperature variation on the structure.

(IV) Redistribution determination of time dependent deformation of creep and shrinkage and

(V) Construction sequence effect on the primary and secondary forces.

The two dimensional modeling of the integral bridge does not reflect the three dimensional effects of lateral loads on the pier, abutments and wing walls. Therefore a three dimensional model is needed to analyze the structure for the effect of lateral loads. For the design of deck-abutments and deck-pier joints, weight of slab, girder, diaphragm, superimposed loads, live loads, earth pressure and temperature variation effects need to be considered. Further for the soil- substructure interaction co-relation between the temperature variation and effects of earth pressure needs to be modeled. The earth pressure coefficient will depend on the type of movement in earth retaining structure. Active earth pressure is created due to displacement away from the backfill soil. The earth pressure coefficient will vary among $\boldsymbol{K_a}$(active) $\boldsymbol{K_0}$(rest) and $\boldsymbol{K_p}$(passive). Its value depends upon the direction and displacement suffered.

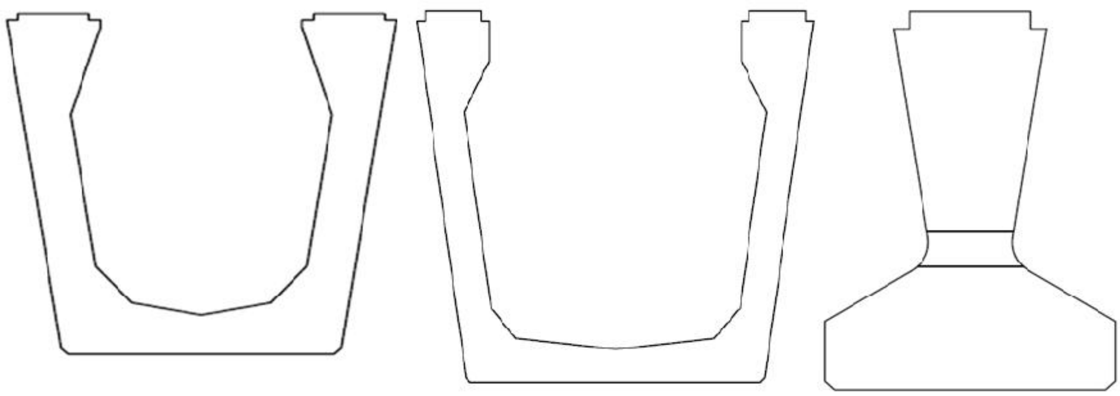
Integral bridges are generally designed with stiffness and flexibility spread throughout the structure-soil system. This results in all the supports to accommodate the effects of thermal and braking loads. The abutments and their foundations are so designed that they are flexible and less resistant to 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 must be fully taken into account during the design.

The profile of the girder is generally predefined without a consideration of economy and span length. This however needs to be investigated as besides aesthetics ultimately the cost factor and saving of natural source materials, leads to national economy.

MODELLING AND DESIGN

For comparison design forces, a two span six lane bridge of width 24.4 m is considered. Both Continuous and integral bridges are modelled using U, W and Y-girders Fig.1. The sections used in the modelling are obtained after three cycle analysis and design iterations.



(a) U-Girder (b) W-Girder (c) Y-Girder

Fig 1: Sectional profile of girders

Table 1. Span and Depth of Girder

Span (m)	Depth of girder					
	Integral Bridge			Continuous Bridge		
	U-Girder (mm)	W-Girder (mm)	Y-Girder (mm)	U-Girder (mm)	W-Girder (mm)	Y-Girder (mm)
20	1600	1200	1200	1200	1000	1000
30	2100	1800	1700	1800	1600	1500
40	2900	2400	2200	2600	2200	2100
50	3600	3100	2800	3300	2900	2700

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All the different types of the bridges are modelled as 3-D structure. The girders and deck is modelled using beam element. The foundation and abutments are modelled using 4-noded plate element. Span and depth details of the different models considered for analysis are listed in Table 1. The 3-D models of integral and continuous bridges are shown in Figs. 2 to 5, respectively.

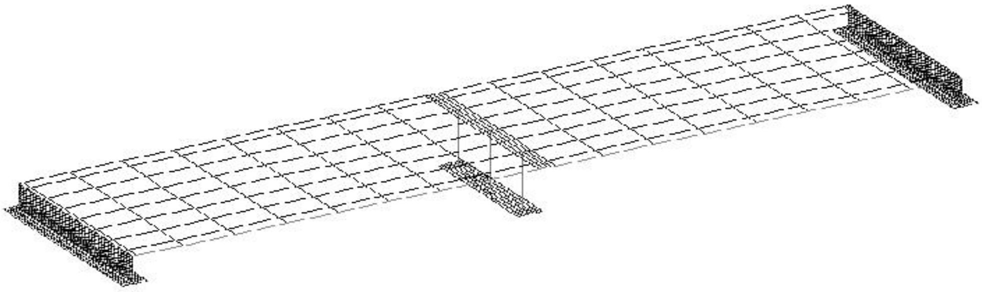

Fig 2: 3-D Model of Integral bridge (U & W Girder)

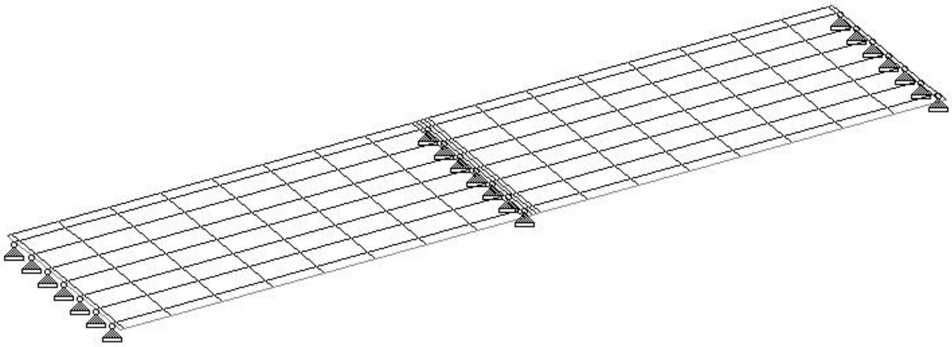

Fig 3: 3-D Model of Continuous bridge (U & W Girder)

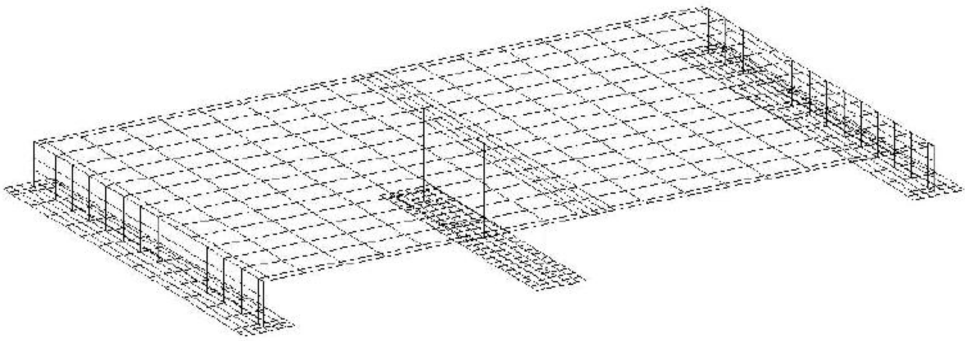

Fig 4: 3-D Model of Integral bridge (Y Girder)

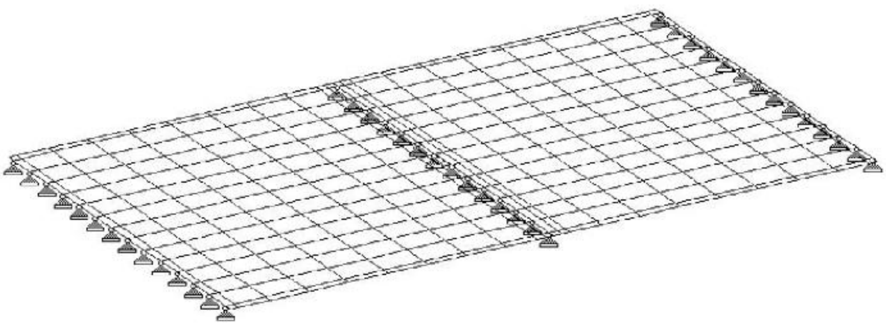

Fig 5: 3-D Model of Continuous bridge (Y Girder)

Number of girders and spacing for U and W- girder are 7 and 3.4 m.

Number of girders and spacing for Y-girder are 14 and 1.7 m.

Properties of the materials used in the study are listed in Table 2.

Table 2. 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

Figs. 6 to 12 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 for Y, U & W 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.

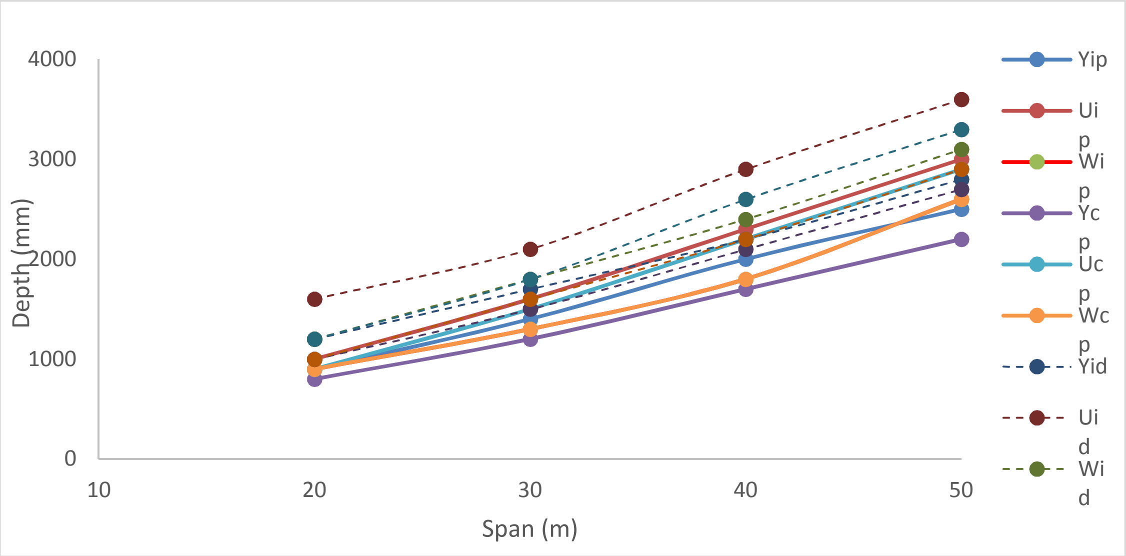

Fig 6: Variation of Girder Depth for Primary and Design BM with Span

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 19, 34, 31 and 24, 21, 17% more

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than those required from primary BM consideration for Integral (Y, U & W) and Continuous (Y, U & W) bridges, respectively.

The variations of deck weight, required for primary and design BMs with span for Integral and Continuous bridges are shown in Fig. 7. When the primary BMs are considered, the difference in weight of concrete is insignificant for Integral and Continuous bridges. But with regards to design BMs, 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 11, 18, 17 and 14, 11, 9% more than those required from primary BM consideration for Integral (Y, U & W) and Continuous (Y, U & W) bridges, respectively.

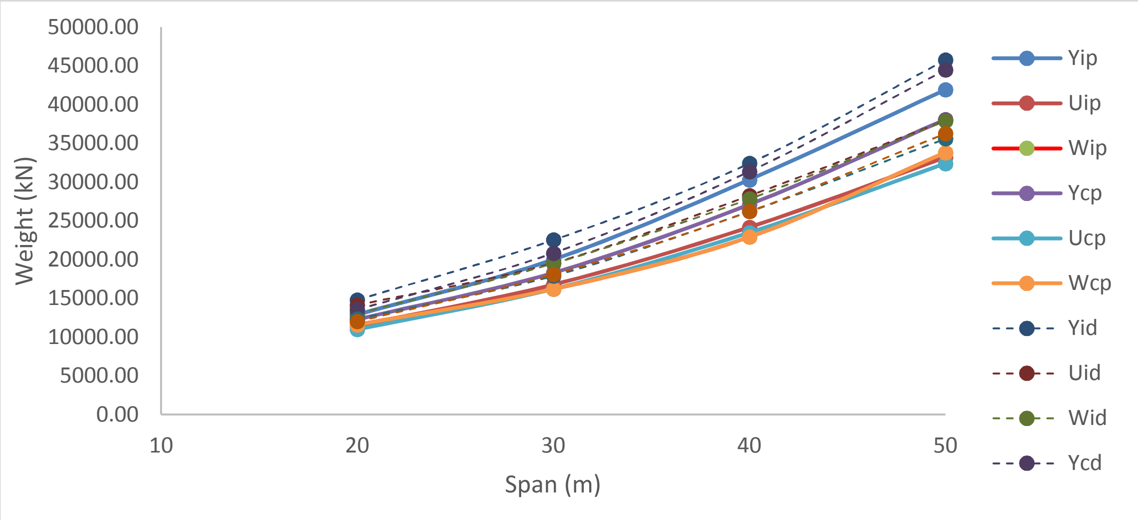

Fig 7: Variation of Deck Weight for Primary and Design BM with Span

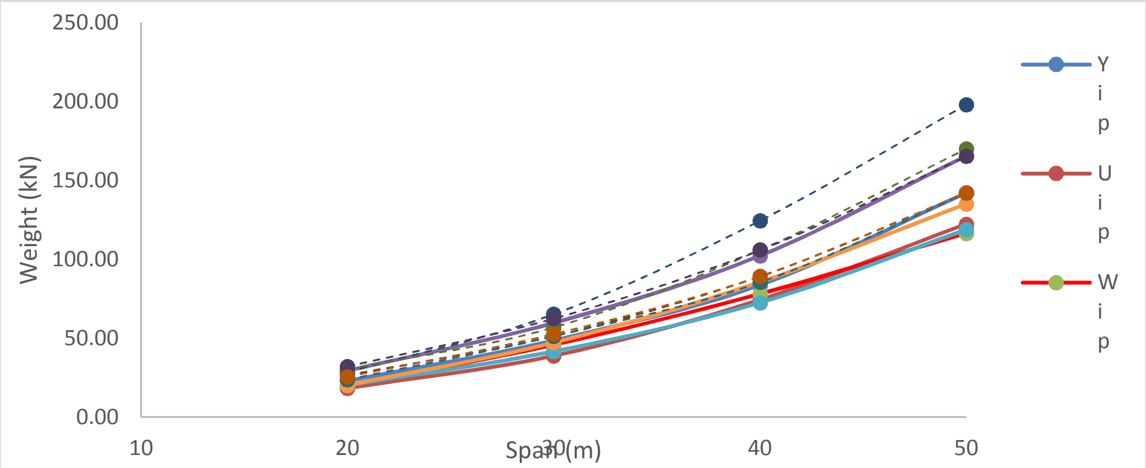

Fig 8: Variation of Girder Strand Weight for Primary and Design BM with Span

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 37, 28, 39 and 4, 20, 12% more than those required from primary BM consideration for Integral (Y, U & W) and Continuous (Y, U & W) bridges, respectively.

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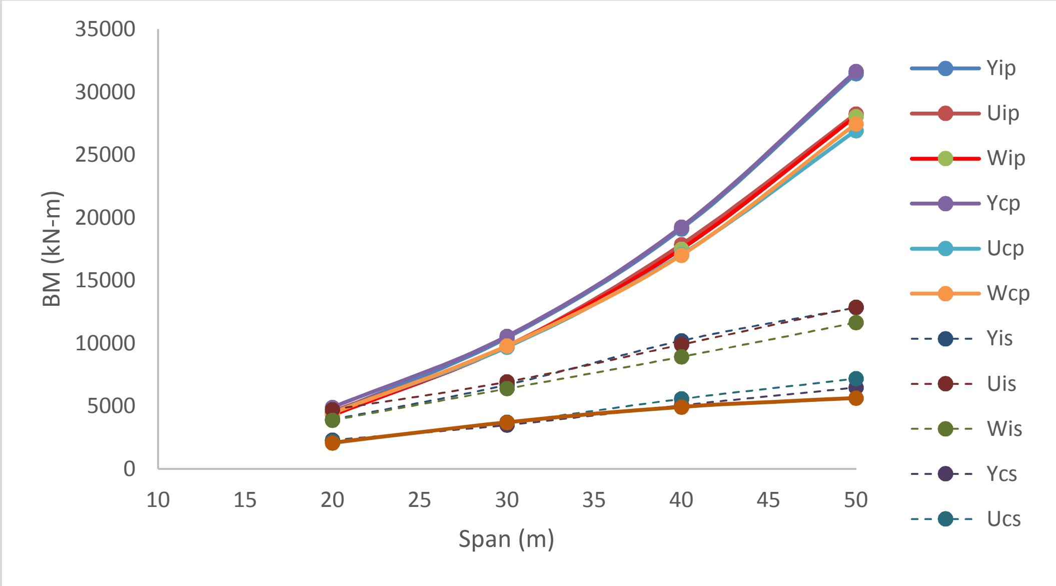

Fig 9: Variation of Primary and Secondary BM with Span at Mid-Span

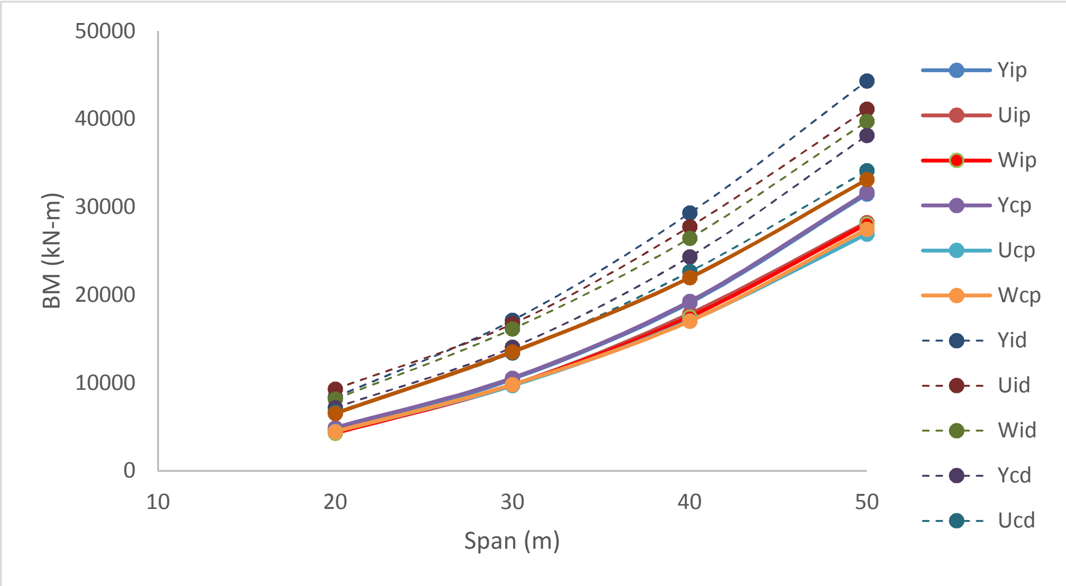

Fig 10: Variation of Primary and Design BM with Span at Mid-Span

The variations of primary and secondary 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 Y, U & W girder Integral and Continuous bridges is insignificant for span upto40m. The secondary BMs are on an average 64 and 34% of primary BMs for Integral and Continuous bridges, respectively. The variations of primary and design BMs (at mid-span) with span for Integral and Continuous bridges are shown in Fig. 10. The design BMs are on an average 64 and 34% higher than that of primary BMs for Integral and Continuous bridges, respectively.

Fig. 11 & 12 shows the variations of primary, secondary BMs (at pier support) with span for Integral and Continuous bridges respectively. The difference between primary BMs for Integral and Continuous bridges is not appreciable. The secondary negative BMs are on an average 93, 81, 74 and 20, 22, 19% of primary BMs for Integral and Continuous (Y, U & W girder) bridges, respectively. There is a stress reversal at this location and the secondary negative BMs are on an average 2.63, 2.69, 2.25 and 1.32, 1.36, 1.26 times of primary BMs

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for Integral and Continuous (Y, U & W girder) bridges, respectively. The difference between the secondary positive BMs of integral and continuous bridges is not appreciable.

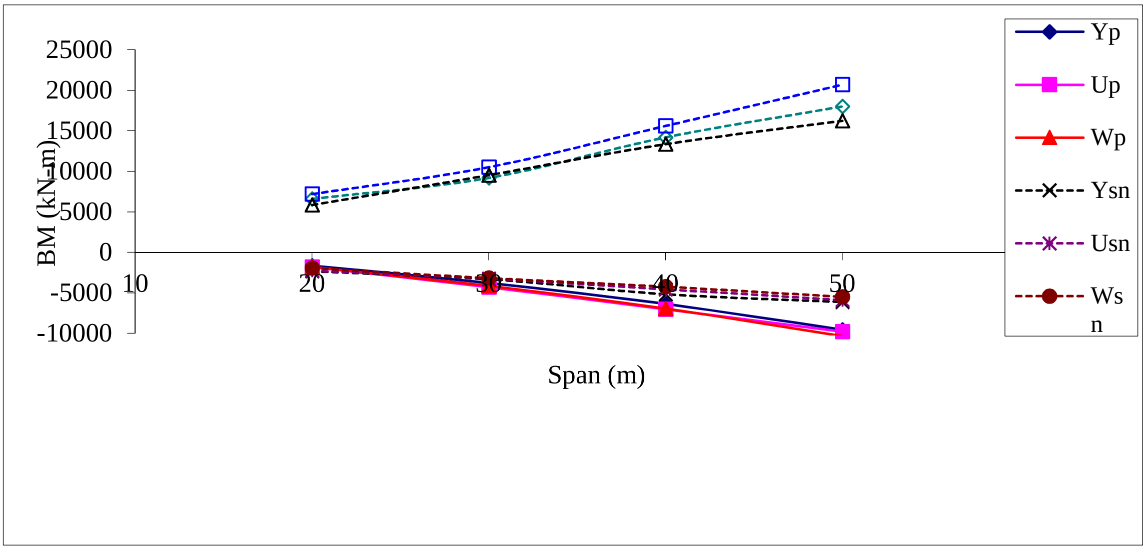

Fig 11: Variation of Primary and Secondary BM with Span at Pier (Integral Bridge)

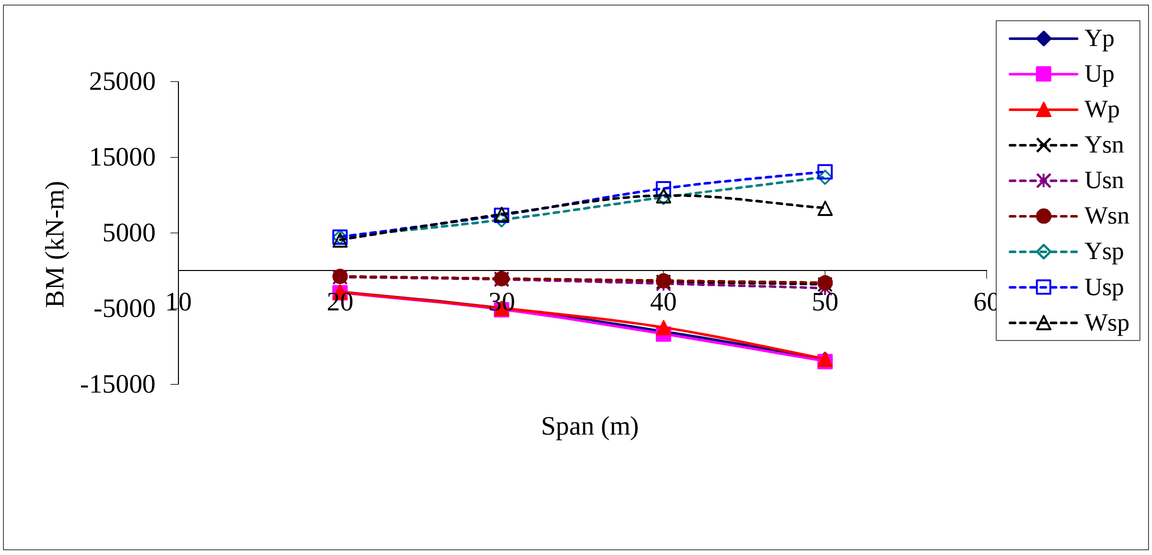

Fig 12: Variation of Primary and Secondary BM with Span at Pier (Continuous Bridge)

CONCLUSION

From the present study it can be concluded that integral bridges with Y-type girders are not economical for large spans. 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 for large spans and small girder spacing in general, are larger for Integral bridges than those in Continuous bridges, it is recommended that U-type girders may be provided for spans up to 30 m with a girder spacing up to 3.6 m. W-type girders may be provided for span between 20 to 50m with a girder spacing up to 3.6m for Integral & Continuous bridges.

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