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Effects of construction sequences on a continuous bridge

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ABSTRACT: The construction of bridge is the most complex and challenging operation to engineers. Different methods and techniques exist for the construction of bridge superstructures. To achieve a safe and economical process in planning and implementation of the construction operations, the effect of the chosen erection method need to be considered. Failure of bridges during construction phase is very essential of this issue. In balanced cantilever method of construction of a continuous bridge, bending moment in the bridge increases at each stage of addition of a new segment during construction. As the segments is added as cantilever form in balanced condition of both side of pier, the bending moment arise in the pier is negative and increases with the addition of each new segment. When the key blocks are added the bridge converted from cantilever form to a continuous form and the negative bending moments on the pier decreases and arise a positive moment. So, if the bridge is design using the final bending moment only, it would collapse during the construction stage. For this reason, the increment of moment during construction should be investigated in the design and construction phase. In this paper, a study was conducted to investigate the effect of construction sequences on a continuous bridge erected by balanced cantilever method. For this operation a bridge model was generated using a finite element software and to perform the analysis. Bridge model was investigated to observe the rate of change of moment and deflection at different stages of construction. Different length, width and height of segment were used to understand the variation of moment and deflection with them. It has been observed that before joining the key block negative moment is about 30%-50% higher than continuous bridge negative moment and also the deflection at cantilever end was about 80%-100% higher than that of continuous bridge after full construction at pier top.

1 INTRODUCTION

The construction of bridge superstructure is a highly complex process due to the interrelationship between the erection method used and the manifold internal and external effects related to loads and behavior and to environmental influence. Analyzing those concepts on a particular example helps to develop better understanding of the construction engineering practice and contributes to the safety and economy of future bridge structures (Lucko 1999).

There are several methods used in the construction of segmental bridge. One of them is balanced cantilever method. In this method the stages of construction is very important, as the moment and the deflection in the bridge changes at each stage of addition of new segment. For this reason, the investigation of the rate of change of moment and deflection is very important (Podolny and Muller 1982).

The main objective of this study was therefore to investigate the rate of change of moment and deflection at each stage of construction of a continuous bridge in the balanced cantilever method. Here, it is also investigated the rate of change of moment and deflection with the variation of span length, superstructure width and height.

2 STUDY APPROACH

The balanced cantilever method was developed to minimize the falsework required for in situ construction. Temporary shoring is expensive especially in the case of high level bridges. Erection of falsework crossing a river may be hazardous or even impossible. Over navigable waterways, trafficked roads or railways, falsework is either not allowed or severely restricted. Cantilever construction eliminates such difficulties (Victor 1991).

Using this method of construction the supporting pillars are constructed first. Then the sections which are to carry the deck of the bridge are built outwards. Balance cantilevering needs to be safe against overturning moments from construction loads until closure of span. In order to balance the weight of both arms of the cantilever superstructure the segments will be about equally placed at both ends. To finish the process, the cantilevered sections are joined by link spans, which are dropped into place by crane.

The figure 1 illustrates the construction of a bridge by the balanced cantilever method. To facilitate the cantilever construction, a short section of the deck with a counter balance to one side (a hammer head) is cast on falsework supported from ground at each pier. Temporary strutting is provided on the counter balancing side to ensure stability. The sequence of construction of the cantilevers must ensure that the counter balance is always maintained (Tele Kenyalang 2005).

Figure 1(a). Construction of pier.

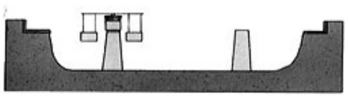

Figure 1(b). Set up and adjust gantry.

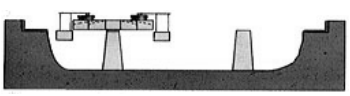

Figure 1(c). Addition of concrete blocks to both sides of pier.

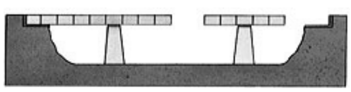

Figure 1(d). Continuation of addition of concrete blocks.

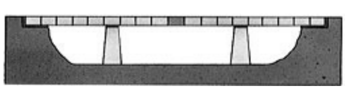

Figure 1(e). Addition of key block.

Figure 1.The construction sequence of a continuous bridge by balance cantilever method (Tele Kenyalang 2005).

There are variations to the method described above. In the case of a low level bridge it may be more economical to cast the end spans on falsework. Where the bridge deck is monolithic with the piers, the temporary struts at the hammerheads could be eliminated.

The formwork to cast the cantilevers is supported on a traveling gantry. The gantry moves forward on rails attached to the deck of the completed structure. With the gantry in place, a new segment is formed, cast and stressed to the previously constructed segment.

3 METHODOLOGY

In the study of the balanced cantilever method of segmental bridge construction finite element software, ANSYS was used. Two models were built using ANSYS for this purpose. The first was a test model named beam model, and the second was the bridge model. In the beam model, the stage of construction was used to see the scope of this study using the software ANSYS. This operation was done using ANSYS Birth and Death feature. And it was observed that the objective of the study would be fulfilled with this software. Finally, the bridge model was used for the analysis. In this model the span length, superstructure width and height were varied to observe the effect of those parameters in the rate of change of moment and deflection.

4 NUMERICAL MODEL

4.1 *Model l:*

The test model of a beam was created using the finite element software ANSYS. In the finite element model, BEAM3 element was used. BEAM3 was used for the two-dimensional modeling of structures. This element is normally defined by two nodes having three degree of freedom at each node: translation in the node x, y, and rotation in z directions.

4.2 *Model 2:*

The model of the proposed bridge was created using the finite element software ANSYS. In the finite element model, SOLID45 was used to represent the concrete. SOLID45 was used for the three - dimensional modeling of structures. This element is normally defined by eight nodes having three degree of freedom at each node: translation in the node x, y, and z directions. The model with the stages of construction i.e. the addition of each individual segment to each pier is shown in figure 2(a), figure 2(b), figure 2(c) and figure 2(d), respectively. In figure 2(a), 2(b) and 2(c), segment of concrete block was added to both side of each pier and finally, in figure 2(d) key block of concrete segment was added to complete the construction.

The construction of Dapdapia bridge is near completion. The experience gained by Project Builders Limited (PBL) through the construction of Dapdapia Bridge could be successfully utilized in the construction of bridges over major rivers anywhere in Bangladesh or elsewhere, using solely local expertise. The concrete properties used for Model 2 are given in Table 1 as below.

Table 1. Concrete properties (Model 2)

Young modules Pa	Density kg/m^3	Poison ratio
2.482e10	2400	0.2

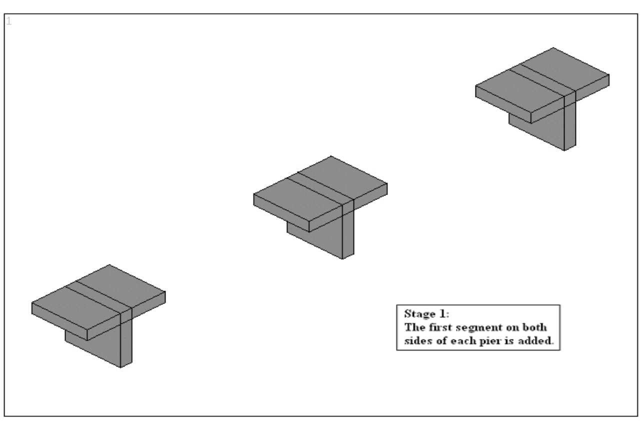

Figure 2(a). The first segment on both sides of each pier was added.

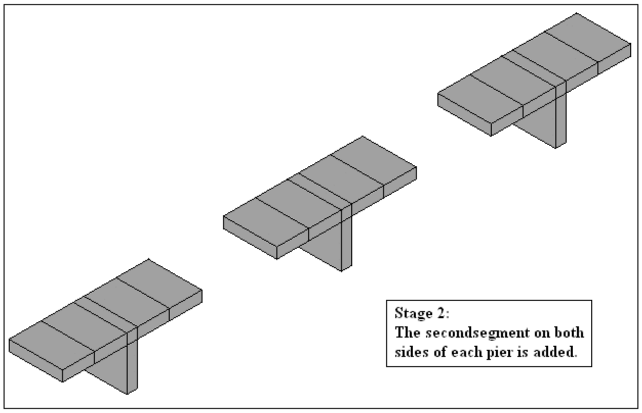

Figure 2(b). The second segment on both sides of each pier was added.

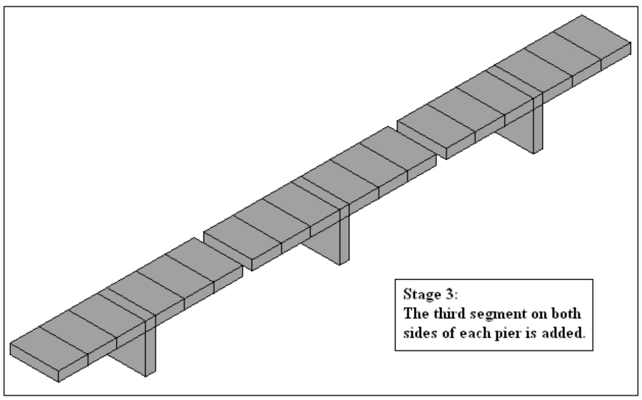

Figure 2(c). The third segment on both sides of each pier was added.

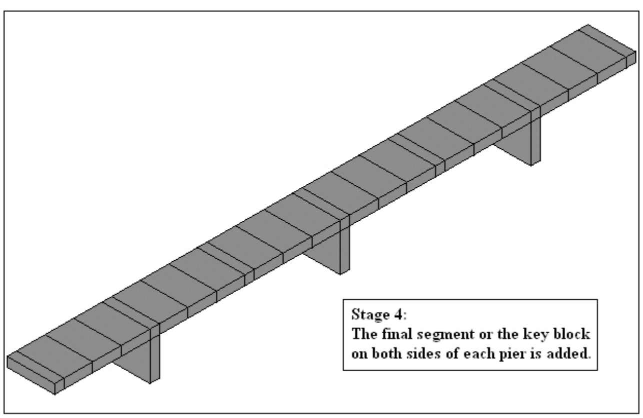

Figure 2(d). The forth and the final segment (key block) on both sides of each pier was added.

4.3 *The Parameters*

The moment variation in the balanced cantilever method of a continuous bridge due to addition of each new segment was studied in several cases with variables span length, width and height which is shown in Table 2 and 3.

Table 2. Parameter studied with certain width, height and different span

Height	Width	Span
m	m	m
2	10	40 45 50

Table 3. Parameter studied with certain Span, Width and different Height

Span	Width	Height
m	m	m
40	8	2
		3
		4
	10	2
		3
		4
	12	2
		3
		4
45	8	2
		3
		4
	10	2
		3
		4
	12	2
		3
		4
50	10	2

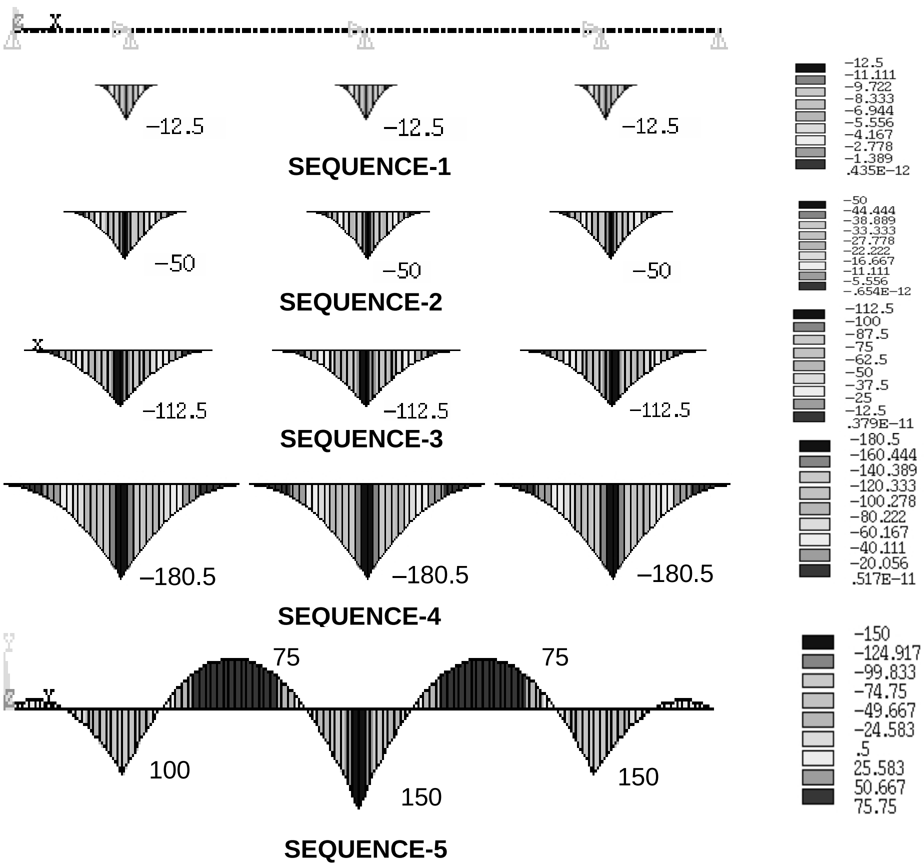

Figure 3. Sequential bending moment diagram of the continuous beam bridge model.

5 ANALYSIS AND RESULTS

5.1 *Model with Beam3 Element (Model 1)*

For checking ANSYS death and feature it was firstly analyzed with a simple beam of BEAM3 element of span length 120ft. Here, the elements are BIRTHED at five stages of construction sequentially. Figure 3 shows moment diagram at different sequences. It was observed that at fourth stage, before the addition of key block, the moment is about 80% higher at first pier and 20% higher at second pier compared to the fifth and final sequence where it is important to notice that in sequence-5, after the addition of key block, negative moment at support was reduced and positive moment was developed at support.

5.2 *Bridge Model with Solid45 Element (Model 2)*

In figure 4 moment variation are shown in different stages (four stages of construction) of construction of model having span length = 40m, width = 8m and height = 2m. Figure represents comparison of moment diagram between before jointing key blocks and after full construction.

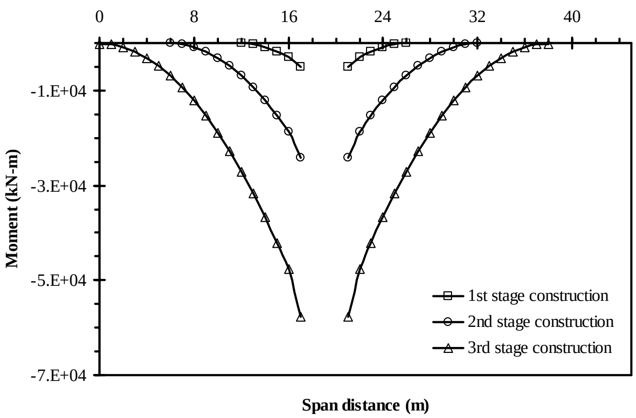

Figure 4. Moment diagram at different stages of construction with span=40m, width=8m and height=2m.

From figure 5 it is clear that before jointing key block elements (in 3rd stage) moment is about 40% higher than the moment after completing construction. Discontinuity of graph is due to presence of support. Moment of this section is omitted due to stress concentration.

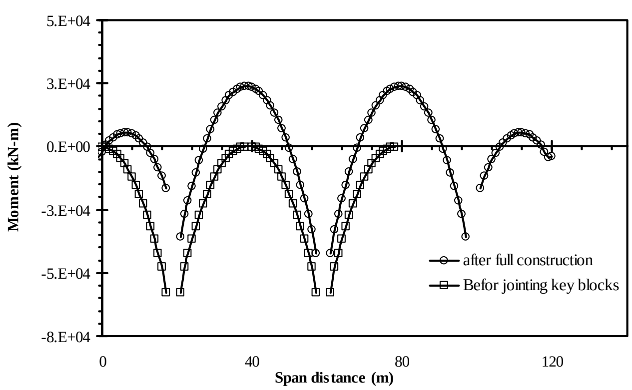

Figure 5. Comparison of moment diagram before jointing key blocks and after full construction with span=40m, width=8m and height=2m.

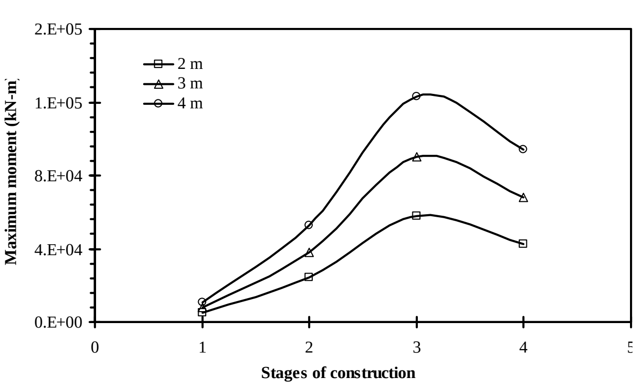

Figure 6. Maximum moment variation at different stages of construction of different super structure height with span=40 m and width=8m.

In figure 6 some curves are drawn for maximum moment of different stages of construction with different superstructure height for span length = 40m and superstructure width = 8m. This curve shape is nonlinear in nature as the solution is nonlinear solution.

Another curve is plotted in figure 7 presenting the maximum deflection at various stages of construction with different superstructure height for span length = 40m and superstructure width = 8m. Here the curve of 2 m height shows the maximum deflection at 3rd stage construction. Deflection is about 100% higher in 3rd stage construction than after full construction.

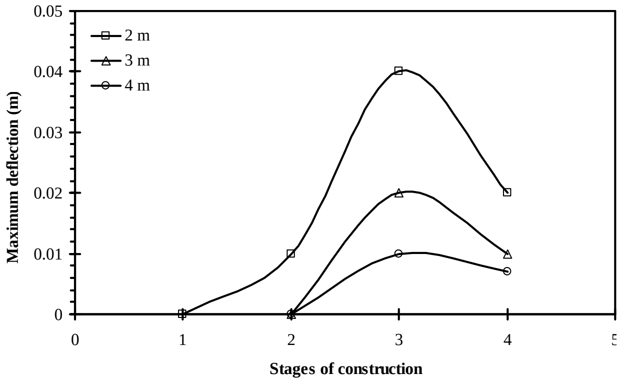

Figure 7. Maximum deflection variation at different stages of construction of different super structure height with span=40 m and width=8 m.

In figure 8 maximum moment variation at are plotted different stages of construction of different super structure width with span = 40m, height = 2m. In figure 9 maximum deflection variation at different stages of construction of different super structure width with span = 40m and height = 2m is shown. It describes that there is no variation of deflection with the change of width.

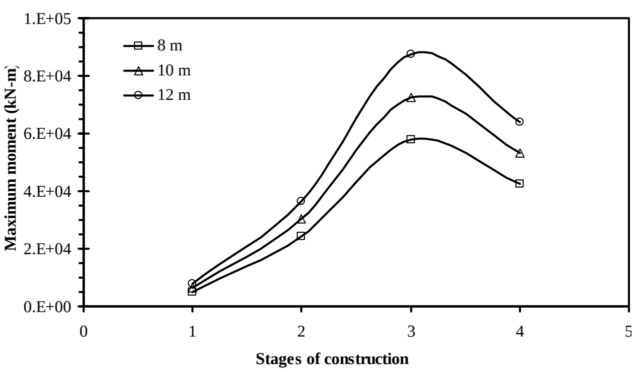

Figure 8. Maximum moment variation at different stages of construction of different super structure width with Span = 40m, height=2m.

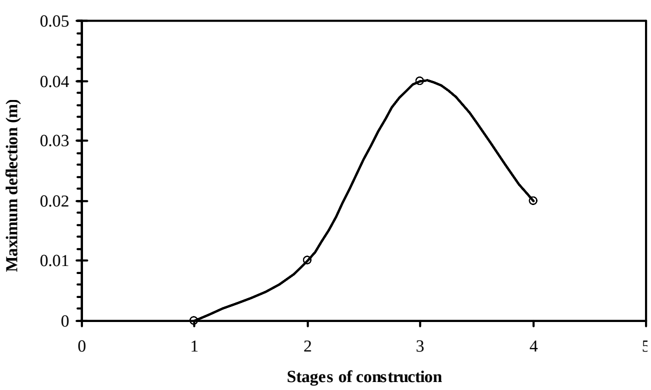

Figure 9. Maximum deflection variation at different stages of construction of different super structure width with span = 40m and height = 2m.

In figure 10 maximum moment variation are plotted at different stages of construction of different Span length with width = 10m and height = 2m. It shows that curve of 50m span has the maximum moment at different stages of construction.

In figure 11 maximum deflection variation are plotted at different stages of construction of different Span length with width = 10m and height = 2m. For model of span length = 50m and height = 2m shows the excessive deflection which is 13cm at 3rd stage construction.

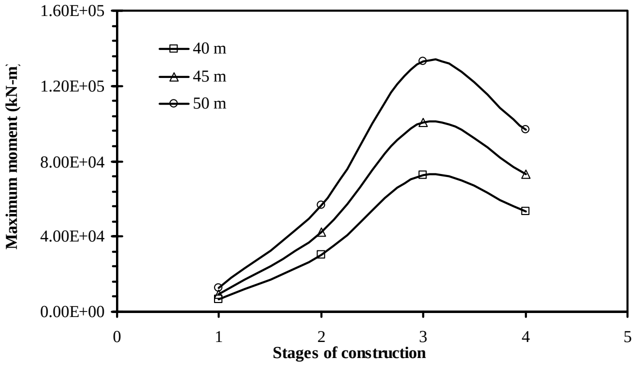

Figure 10. Maximum moment variation at different stages of construction of different Span length with width = 10m and height=2m.

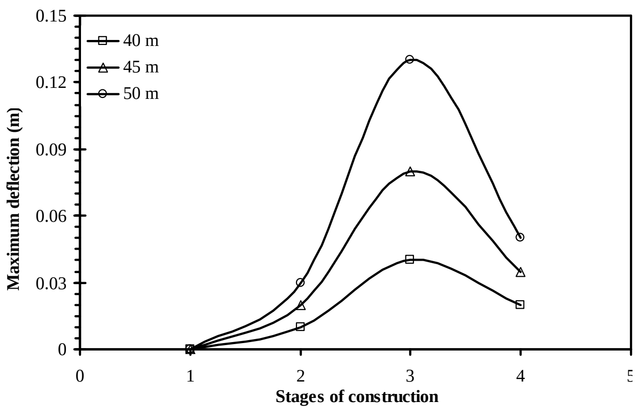

Figure 11 Maximum deflection variation at different stages of construction of different Span length with width = 10m and height=2m.

The summary of the analysis for different span length, width and height are shown in tabular form. Table 4 shows the percentage of increment of moment for different width height and a certain span and Table 5 shows the percentage of increment of moment for a certain span and different width height.

Table 4. Percentage of increment of moment for a certain span and different width height.

Width	Height	Span	Moment Before jointing key blocks	Moment After full construction	% of decrease of moment after jointing key block
m	m	m	kN-m	kN-m	–
		40	72600	53200	37%
10	2	45	100500	73300	37%
		50	133000	96600	38%

Table 5: Percentage of increment of moment for different width height and a certain span.

Span	Width	Height	Moment Before jointing key blocks	Moment After full construction	% of decrease of moment after jointing key block
m	m	m	kN-m	kN-m	–
40	8	2	58000	42500	37%
		3	90000	68000	33%
		4	123000	94100	31%
	10	2	72600	53200	37%
		3	112700	84800	33%
		4	153000	117600	30%
	12	2	87500	64000	37%
		3	135700	102000	33%
		4	184000	141000	30%

6 DISCUSSION

After examining the results of the parametric study, it may be concluded that, negative moment that developed before the addition of key block which was 30%-40% higher than the moment after full construction. If a bridge is constructed using the balanced cantilever method and if it is not considered the construction stage moments then the bridge must be collapsed during construction stage.

In this study, it was also considered the deflection at construction stages. It was found that the maximum deflection vary between 4-13 cm. Before jointing key blocks, the deflection was about 80%-100% higher than after full construction. This deflection may get much higher problems created during jointing key blocks.

Finally, it may be concluded that continuous bridge construction using the balanced cantilever methodology, much more considerations are required during construction stage for overall economy and safety.

7 CONCLUSION

This study was undertaken to investigate the effects of sequences of continuous bridge construction using Balanced Cantilever method. And for this purpose a bridge model of solid45 element of ANSIS is used which is described earlier of this paper. The emphasis of the parametric study was placed on the effect of moment and deflection in various stages of segmental construction with different span length, superstructure width and height. For simplicity it was used solid rectangular superstructure (no hollow as used in segmental construction), which is erected segmentally. A pier consisting of transverse twin walls is advantageous as it provides stability for cantilevering but allows horizontal movement of the superstructure from thermal elongation through flexing of the wall panels.

The following conclusion may be drawn with respect to the cases studied in the parametric study. i) Due to self-weight stress pattern is linear throughout the cross section of the superstructure. ii) Moment increases as the addition of new segment on each pier sequentially until jointing key blocks. iii) Before joining the key block moment is about 30%-50% higher than after the full construction. iv) Moment increases with the increment of model height, width and span length. v) Deflection decreases with the increment of superstructure height. vi) Deflection increases with increasing span length.

Therefore, it could be concluded from this study that the change of moment during construction should be investigated. Otherwise, if the bridge is design using the final moment it will be collapsed during construction stage.

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