The Long Term Performance Of Skew Integral Bridges

Popoola, Oladele.O.
Civil Engineering Department
Afe Babalola University
Ado-Ekiti, Nigeria
oladelepope@yahoo.com

Wasiu, John
Civil Engineering Department
afe Babalola University
Ado-Ekiti, Nigeria
johnwasiu@yahoo.co.uk

***Abstract*—Four types of integral bridges were modelled using the Midas Civil software; analysis of the results in terms of displacement, deflection, moments and torsion were considered. Creep and shrinkage, traffic and temperature loadings are taken into account. Skew angles were increased and sizes of abutments varied. The skew bridge had the majority of displacement on the short term of 40 days; a considerable percentage of displacement takes place on the long term up to 25%. The abutment angle affects the displacement of the skew bridges; the abutment with the acute angle had horizontal displacement of 27.2 mm while the abutment with the obtuse angle had less horizontal displacement of 13.2 mm on the long term when the abutment size is 0.5 m. For deflection, skew bridges has more deflection than the square bridges. Increasing the skew angle, the deflection increases. On the long term, it was discovered that about 5% of the deflection takes place. Comparing the result of the skew to the square bridge, the 8.6^0 bridge had 73% displacement more than the prestress bridge and 44.5% more than the non prestress bridge. The 13^0 skew bridge has higher deflection comparing with the non-prestress and prestress respectively. There were hogging moments because of the traffic loading that was considered during the modelling of the bridges. Normally, without a skew angle, the deck will act like it was simply supported with positive moments (sagging). The greatest sagging moment occurred in the non prestress 13^o skew bridge deck with a magnitude of 6499.77 k Nm on the long term while the hogging moment has -1157.1 k Nm on the obtuse angle side of abutment. When the skew angle was increased, hogging moments increased as well. According to (Eugene, 1999), large skew angle correspondingly bring about great end hogging moments nearing wl^2/12.**

Keywords— Integral, Bridge, Skew, Deflection, Moment, Abutment, Prestress.

1.Introduction

An integral bridge is defined as a bridge constructed as a framed structure which may be single span or continuous multiple -span extending from the beginning of an abutment (on intermediary supports) to the end of the other abutment exclusive of moving joints.

A skew integral bridge comes into play when the major axis of the substructure is not at a 90^0 degree angle to the longitudinal axis of the superstructure. The angle of skew (usually given in degrees) is the angle between the major axis of the substructure which is perpendicular to the longitudinal axis of the superstructure.

The sought-after characteristics of bridges that contain joints is for it to accommodate thermal movements, water tightness, smooth ride ability, low noise level, wear resistance and resistance caused by snowplough blades. However, the performance of many of the joints are unsatisfactory and the fundamental function of bridging the gap or discontinuity in two elements of a structure moving whilst allowing the movement of the structure under the influence of temperature, shrinkage and creep is inadequate.

Assessing the bulk of bridges built in the present day, we have some form of skew or curve. The various reasons for this are the limited availability of space which every sector is competing for, restrictions, such as terrains; settlements and archaeological sites. These rationales therefore, have brought about the increase in the bridges that are skew to a feature that they cross. Also, due to the increasing speed of traffic, skew bridges will be necessary to function as speed control.

Benefits of the integral bridges include its simple design, construction without joints, pressure resistance, rapid construction and extra redundancy.

The aim of the research was to check the behaviour of skew integral bridges and how it performs in a long term under the influence of temperature, creep & shrinkage, applied load, varying skew angles, and behaviour of the fill material behind the abutment wall. This is compared with other standard bridges so that safe and performing skew integral bridges can be designed.

2. Materials and method

1) CONCRETE – DECK

BS (RC) C35, Modulus of elasticity: 26,567 N/mm^2, Poisson ratio: 0.2 Density: 23.6 kN/m^3 Deck total thickness: 200 mm Deck structural thickness: 185 mm, Cross beam depth: 185 mm (same as thickness of deck) Interior cross beam width: 3 m (c/c distance between adjacent cross beams) End cross Beam width: 1.5 m.

2) CONCRETE PRECAST BEAMS: BS (RC) C55, Modulus of elasticity: 33,304 N/mm^2 Poisson ratio: 0.2, Density: 23.6 kN/m^3 Concrete strength (28-day) 55 N/mm^2

TENDON:Steel Prestress tendons: 12.7 mm diameter, low relaxation, Modulus of elasticity: 196,000 N/mm^2 Poisson ratio:0.3 Ultimate strength: 1,862 N/mm^2, Yield strength: 1,675 N/mm^2

3) CONCRETE –ABUTMENT: BS (RC) C35 Modulus of elasticity: 26,567 N/mm^2, Poisson ratio: 0.2, Density: 23.6 k N/m^3

4) LOADS: dead load (Concrete deck) Exterior PC Beam :(0.2m) (2.25m)(23.6 k N/m^3) = 10.62 k N/m. Interior PC Beam :(0.2m) (2.75m)(23.6 k N/m^3) = 12.98 k N/m

5) TEMPERATURE LOADS Temperature: 21^{o}c

2.2 Methods

The time dependent material properties is selected and used for analysis. They include the time dependent material (creep and shrinkage), time dependent material function and the time dependent material (compressive strength).

To analyse the creep and shrinkage, the CEP –FIB model is utilised by the Midas software to obtain the coefficients. At this stage, the considerations to determine the rate of creep and shrinkage coefficient are provided by the software. The considerations are characteristic strength of the concrete at age of 28days, relative humidity in the surrounding area (which is between 40 and 99), the Notational size of the member, the type of cement and the concrete age at the beginning of shrinkage. The rate in which the building creeps and shrinks (change with time) is based on the coefficients.

The section properties are added and are stated as follows: (UK PSC SY6) Inner composite beams, Outer composite beams, Left End Cross beams, Right End Cross Beams, Inner Cross Beams, Abutment Cross beams. The numerical values of the sections above are stated in the appendix.

B. STRUCTURAL MODELLING

The modelling of the various bridges is done using nodes and elements. Firstly, the nodes are created specified to the dimensions, and then the elements are created joining the nodes. The precast beam are first created in the elements followed by the cross beams which include the inner cross beams, left end cross beams and right end cross beams. Lastly the abutment walls were created joining the bridge span at both ends.

C. THE STRUCTURE SUPPORT CONDITIONS.

In this stage the boundary conditions are set for the structure which includes the fixing of the abutment to the foundation which is 1 m in depth and 3 m width. It is fixed in the x, y and z plane. The abutment is framed with the deck and it is fixed in the Y and Z directions but not fixed in the X direction. This is to allow the deck of the structure to move due to expansion when the effect of temperature, braking force, creep and shrinkage. Furthermore, the material behind the abutment (soil), is to act like a spring which is also used in the frame of the bridge structure.

D. LOADING DATA

The skew and straight bridges have the same load intensity applied on them; Load groups, Static loads, Prestress loads, Moving loads.

1) LOAD GROUPS

They are to facilitate the assignment of loads to their respective groups. Under the load group we have the Deck, Wearing surface, Barrier, PSC beams, Prestress and temperature. The same applies to the static load group

2) PRESTRESS DATA AND LOADS

Since concrete is weak in tension, prestressing it increases the capacity in tension. Prestress is applied as an external force by the use of wires strands or bars which brings about the increase in strength of the concrete. This becomes an advantage as it gives room for longer spans and can be aesthetically better. Each prestressed beam has two tendons and a jacking stress of 1400 N/mm^2 is applied. The steel tendon is located at the centre of each beam and it consists of 12 wire strands 12.7mm diameter each produce an effective tendon area of 1118 mm^2. Each tendon is threaded through ducts of 50 mm.

3) MOVING LOADS

Primarily for the moving load analysis, the moving load code used is the BS. The bridge deck is divided into four different lanes of 3metres each. For the load analysis, the moving load code utilized is the BS. The vehicular load type is HA&HB (Auto).

3. Results and Discussion

3.1 HORIZONTAL DISPLACEMENT

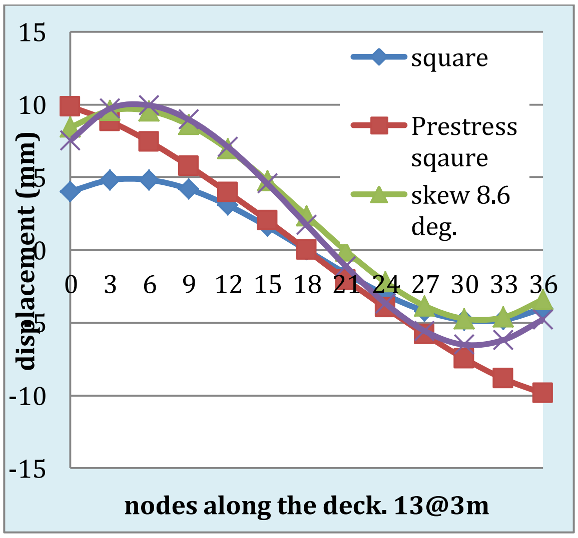

Figure1: Δx 40days (short term).

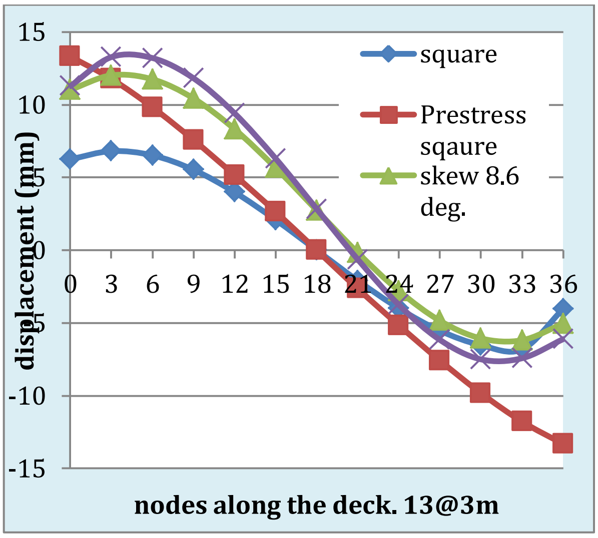

Figure 2: Δx 10,040days (long term).

Movement is caused majorly by creep and shrinkage of the deck over a period of time which affects the entire four models. For the pre-stress model, it has the highest movement on the 40th day and this is due to the effect of pre-stress which acts on the slab to create a compressive force which adds to the effect of creep thereby making the bridge to move more inwards.

Table 1: Δx for the models after 40 and 10,040 days

Bridge type	Short term 40days (mm)	Long term 10,040days (mm)	%DX (long term)
Non prestress	4.82	6.26	23
Prestress	9.86	13.32	26
Skew 8.6^{O}	9.60	12.02	20
Skew 13.0^{O}	9.94	13.30	25

3.2. DEFLECTION (VERTICAL DISPLACEMENT)

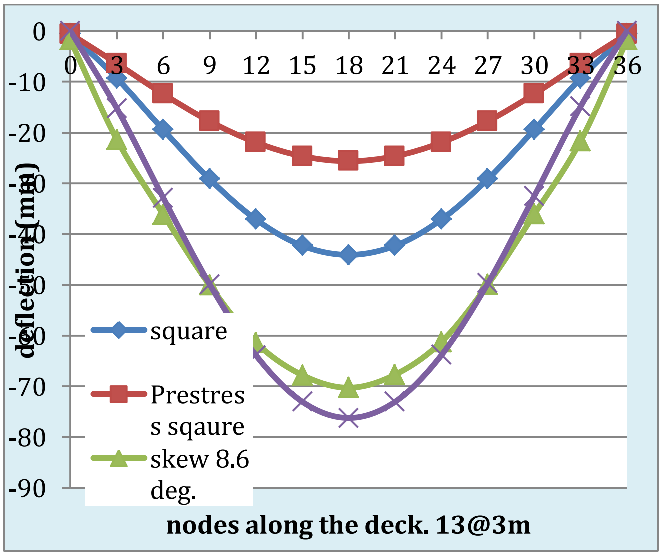

Figure 3: vertical deflection at 40days (short term).

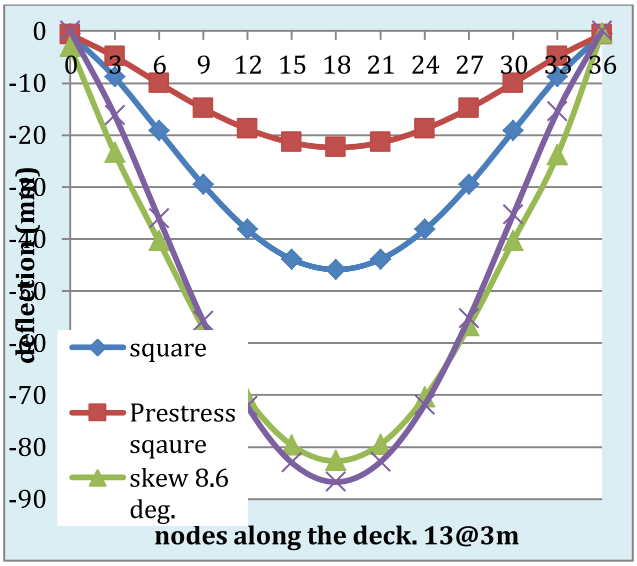

Figure 4: vertical deflection at 10,040days (long term).

It was observed that most of the deflections occurred between the first 40 days for the short term with the prestress model having the lowest deflection of 25.63mm while the skew 8.6 and 13 degrees show the highest deflections of 82.70mm and 86.74mm respectively.

Table 2: vertical deflection

Bridge type	Short term(mm)	Long term(mm)	% DZ (long term)
Non prestress	44.09	45.87	3.9
Prestress	25.63	22.41	-14.4
Skew 8.6^{O}	79.10	82.70	9
Skew 13.0^{O}	80.25	86.74	7.5

It is observed that the prestress bridge has the lowest deflection. This is due to the fact that the tendons present are used to provide a clamping load which produces a compressive force that counteracts the tensile force that the concrete compression member would otherwise experience due to a bending load. The prestress model has a 25.63mm deflection in the short term and it has a 22.41 deflection on the long term. It should be noted that the rate at which creep and shrinkage affects the slab reduces with time, that is why the values between observed between the short and long term is not so much yet the days in between is 1000.

Also, it was observed that the more the skew the more the vertical displacement. The 13 degrees skew bridge shows more deflection than the 8.6 degrees bridge on the short term and on the long term. The non-prestress bridge has 44.09mm deflection at the short term and 45.87mm at the long term. This implies that the non-prestress had almost all the deflection exhibited just as the bridge is constructed and does not deflect highly after a long period of time as compared to the skewed bridges. But it should be noted that the deflection poised by the non-prestress is still higher than that of the prestress. The research is to show the long term effects that the bridges are subjected to over a long period because most people take into cognizance the effect over a short period, but creep and shrinkage takes place continuously over a long period of time, with the rate of creep of a concrete reducing as the concrete age.

3.3. MOMENTS

Another comparison being made is the bending moment of the bridges. The assessment is based on the bending moment on the short term and the long term. According to (Eugene, 1999) ascertained that skew supports have the trend of initiating hogging moments at the edges of the abutment bridge.

The graph below shows the summary of the moments amongst the four different models in the short term.

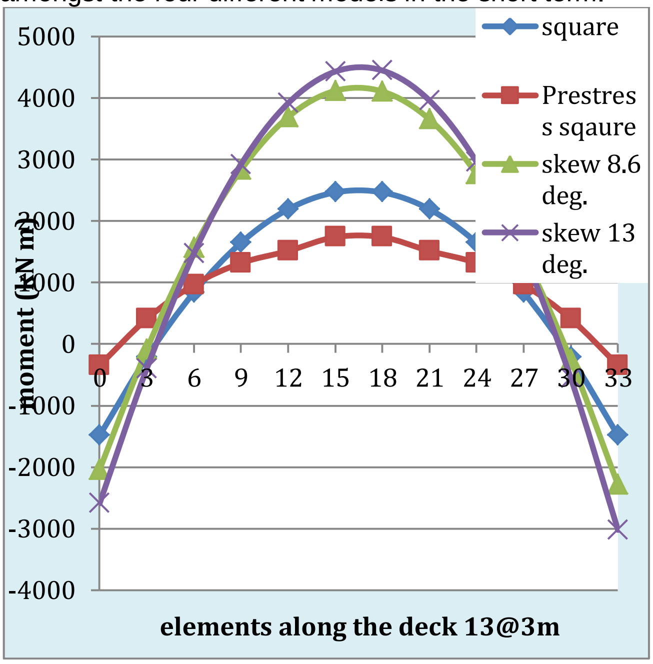

Figure 5: BMD after 40days (short term)

4) ANALYSIS OF RESULTS FOR SHORT TERM:

Normally, a short term moment would not exist but because the deck was designed to carry traffic loading, it gave rise to the moments being seen on the short term. From the bending moment graph on the short term it shows how the bridge deck behaves and also, it shows the effect of the abutment on it. On the short term, it shows that there is hogging moment on the four bridge models with the prestress deck having the least hogging moment of 344 k Nm. The x-axis represents the length of the deck while the y-axis is the magnitude of the moments formed. It is observed that the two ends of the abutment have got negative values which depicts hogging moments and the mid-span of the have the positive values which is the sagging moments.

From the graphs it was observed that the 13degrees skew bridge has the highest hogging moment at the abutments which substantiate the previous researches and correlates with the findings in the literature review of this research. The 8.6 degrees skew shows a high hogging moment more than the non-prestress and the prestress but not as high as the 13 degrees skew deck.

The moments of the decks are tabulated below to show in details to allow any observer to see the differences between the decks in another form.

Table 3: maximum hogging and sagging moments over 40 days.

Bridge type	Max. Hogging moments (k Nm)	Max. Sagging moments (k Nm)
Non prestress	- 1486.54	2466.03
Prestress	- 344.58	1738.77
8.6^{o} skew	- 2288.56	4106.93
13^{o} skew	- 3021.82	4448.24

It should be noted that the negative sign implies hogging moment. One other important observation is that the prestress and the non prestress bridges have equal magnitude of hogging moment at the abutments of -344 k Nm and -1486.54 k Nm respectively but the skew bridges do not have equal hogging moments at the abutment.

It was discovered that there is less hogging moments in the skew bridges on one side of the abutment. The side with a lower angle (acute angle) has lower magnitude of hogging moment while the side with the obtuse angle has a higher hogging moment. The table below shows the differences in the moments.

Table 4: hogging moments at abutment ends over 40 days.

Bridge type	Max. Hogging moment (acute angle)	Max. Hogging moment (obtuse angle)
8^{o} skew	-2042.23	- 2590.27
13^{o} skew	-2288.56	-3021.82

5) ANALYSIS OF RESULT FOR LONG TERM

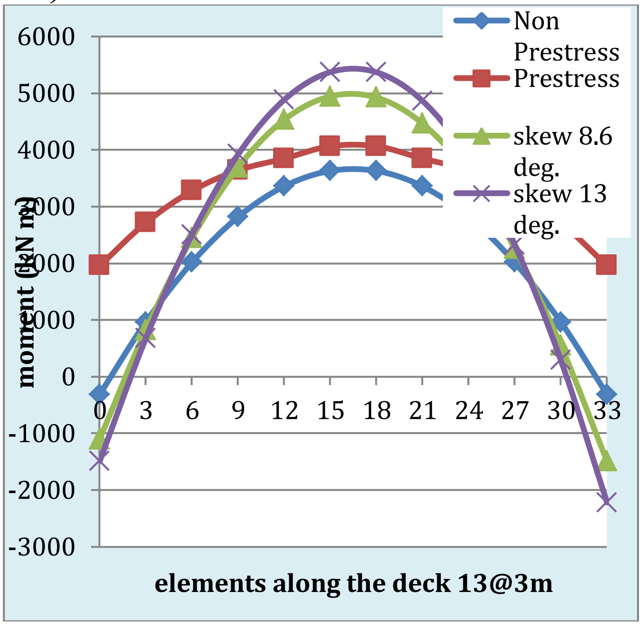

Figure 6: BMD after 10,040days (long term).

The graph above shows the behaviour of the four different models over a long period of time which is 10,040 days. The curves are similar to the short term graph but there exists the difference as well which is the most important.

Considering the graph, it is observed that after a long period of time, the hogging moments at the abutments reduces with a corresponding increase in the sagging moments. What is of interest is that the changes exhibited by the bridges will not be obvious when considering over short days like 20 days interval except it is analysed this way which is over a long period of time when the effect of creep and shrinkage would make it obvious.

From the graph it shows that the prestress does not exhibit a hogging moment while the other three still does.

Table 5: maximum hogging and sagging moments over 10,040 days.

Bridge type	Max. Hogging moments(k Nm)	Max. Sagging moments(k Nm)
Non prestress	-313.72	3629.21
Prestress	1958.36	4065.30
8.6° skew	-1491.31	4945.25
13° skew	-2219.37	5372.60

In the maximum hogging moment column, it is seen that moment exhibited by the prestress concrete does not show the negative sign. This shows that there is no hogging moment there but a sagging moment.

It is also observed that the skew bridges still have the maximum hogging and sagging moments on the long term with the 13 degree skew having -2219.37 and 5372.6 k Nm followed by the 8.6 degree skew having -1491.31 k Nm and 4945.25 k Nm respectively.

Also there is a similarity in the moments portrayed at the ends of the abutments for the skew bridges with the abutment with the acute angle exhibiting the lower hogging moment and while the abutment with the obtuse angle exhibiting a higher magnitude of hogging moment. The results are shown in the table below.

Table 6: hogging moments at abutment @ 10,040 days.

Bridge type	Max. Hogging moment (acute angle)	Max. Hogging moment (obtuse angle)
8° skew	-1103.13	-1489.52
13° skew	-1491.31	-2219.37

Table 7: comparison between the hogging moments in the short term and long term (40 and 10,040 days)

Bridge type	Max. Hogging moments (k Nm) short term	Max. Hogging moments (k Nm) long term	% difference
Non prestress	- 1486.54	-313.72	79
Prestress	- 344.58	nil	
8.6° skew	- 2288.56	-1491.31	34.8
13° skew	- 3021.82	-2219.37	26.6

Table 8: shows the comparison between the sagging moments in the short term and long term (40 and 10,040 days).

Bridge type	Max. sagging moments (k Nm) short term	Max. sagging moments (k Nm) long term	% difference
Non prestress	2466.03	3629.21	32
Prestress	1738.77	4065.30	57
8.6° skew	4106.93	4945.25	17
13° skew	4448.24	5372.60	17.2

From the tables above its shows that the non - prestress exhibited a much more percentage decrease in hogging moment over a long period than the skew bridges.

Also for the sagging moments, it shows that over a long period of time that the prestress will have more sagging moments formed having a percentage of 57 relative to the other bridge models. The non prestress comes next in this regard having a moment increase of 32%. The skew bridges show that the increase in moment over a long period of time is relatively small compared to the other straight bridges having about

17% for both. In all, the moment in the skew bridges are still higher.

4. Conclusion

The effects creep and shrinkage begins in the early stage of a bridge construction and after but does not end immediately or as soon as the bridge is fit for use; it continues over the some years. The short and long term effects of the creep and shrinkage is what accounts for the pavement movement which shortening. Therefore, the inappropriate design of the bridge deck and / or inapt prediction of creep and shrinkage would have adverse effects by reducing the service life of the bridge. This could lead to vibrations and cracks which reduce the robustness hence, structural failure.

From the results, it shows that the horizontal displacement of the bridge is affected over a long period of time. According to this research, the skew bridge had the majority of the displacement is on the short term of 40 days, a considerable percentage of displacement takes place on the long term which could be up to 25% in some cases as seen in the analysis result. The angle of the abutment affects the displacement of the skew bridges; it was discovered from the research that the abutment with the acute angle had the greatest horizontal displacement of 27.2 mm while the abutment with the obtuse angle has a less horizontal displacement of 13.2 mm on the long term when the abutment size is 0.5 m.

For the deflection, it was seen that the skew bridges have more deflection than the square bridges. The more the skew angle increases, the more the deflection will increase; this is seen from the result analysis. On the long term, it was discovered that about 15% of the deflection takes place on the long term. Upon comparing the result of the skew to the square bridge, it is found out that the 8.6 degrees bridge has 73% displacement more than the prestress bridge and 44.5% more than the non prestress bridge. The 13^0 skew bridge has higher deflection in comparison with the non-prestress and prestress respectively. This establishes that the deflection is more in skew bridges and that as the bridge increase in skew angle, the deflection is more.

The moments represented in the results indicates that there are more moments in the skew bridges. For the square bridges, there were hogging moments because of the traffic loading that was considered during the modelling of the bridges. Normally, without a skew angle, the deck will act like it was simply supported with positive moments (sagging). The greatest sagging moment occurred in the non prestress 13^o skew bridge deck with a magnitude of 6499.77 k Nm on the long term while the hogging moment has -1157.1 k Nm on the obtuse angle side of abutment.

When the skew angle was increased, the hogging moments increased as well. According to (Eugene, 1999), large skew angle correspondingly bring about great end hogging moments nearing $wl^2/12$. It was obvious as well that the square prestress deck has the least sagging moment. It is confirms that the magnitude of creep contraction is time dependent, creep

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