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Pure Effect of Temperature on Rectangular and Trapezoidal Box-Girder Bridges – A Finite Element Investigation

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ABSTRACT

Since the temperature distributions on concrete bridges are nonlinear, they lead to the self-equilibration of the stress distributions. To have a discussion about strains, deflection, and moment brought on by temperature changes. Three-dimensional finite element, Computers and Structures, Inc (CSI) Bridge finite element software is used to analyze 2 box girder bridge specimens; rectangle and trapezoidal cross section. The box girders were same in depth, span length, cross section details and material properties. These specimens were subjected to different temperatures values. They were tested under AASHTO thermal loading and temperature gradient specification. The finding showed that changing the temperatures at a constant rate during the days of the year, by increasing and decreasing, affects by a fixed amount all of the values of deflection, stresses, and moments, for each of the rectangular and trapezoidal sections by the same amount. Through the values of deflection, stresses and moments for both the trapezoidal section and the rectangular section, it can be seen that the trapezoidal section is affected by the temperature change in a lesser way than the rectangular section. That happened because the rectangular section is affected by the temperature gradient along the section in a greater proportion than the trapezoidal section by 16% in stresses and 56% in terms of deflection.

1. Introduction

Although bridges are intended to last hundred years, they are actually used for far longer periods of time. Depending on the environmental circumstances, they are subjected to thermal effects daily, seasonally, and annually [1]. One of the most important parameters affecting bridges is the rise and fall of temperatures. Structure orientation, material, deck surface finishing layer, structure dimensions, and cross-section geometry have a secondary impact on temperature changes. The performance of bridges may be affected by nonlinear thermal load brought on by these phenomena [2-3]. These thermal loads can result in complex thermal impacts on the structures' temperature field. Thermal impacts caused by the climate on bridges are acknowledged as major design elements. The safety of concrete may be affected by stresses from constrained thermal movements, which have been estimated to be of a similar size to those brought on by traffic loads [4-6]. Because they are a limiting load, thermal actions are distinct from other load types. If these deformations are constrained, temperature changes produce thermal stresses, which may cause the stress field of the structure's length and cross-section to change as a result [7,8]. Additional bending moments in the vertical and horizontal planes are caused by the vertical and

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horizontal temperature gradients, respectively. This makes additional research into thermal activities in bridge design exciting [9,10].

In (2014), Rojas [11] investigated the impact of temperature variations in the California and Utah bridges over a period of more than two years by analyzing the data from the temperature sensors. The highest and lowest average bridge temperatures over time are identified and contrasted with the requirements of the present codes. Estimates of long-term bridge temperatures that are based on ambient historical data have been found to go over code requirements. The most important conclusions are as follows:

1- The highest recorded average bridge temperature for the California Bridge was 45°C in June 2013, which was 0.28°C higher than the AASHTO LRFD Bridge Design Specifications (2010) [12].
2- The maximum and minimum average bridge temperatures on the California bridge were predicted by the Edyson Rojas Lopez (ERL) Method to be 49 °C and -3.42 °C over the long term, as opposed to be 44.7 °C and -1.11 °C set in the AASHTO LRFD Bridge Design Specifications (2010).
3- The AASHTO LRFD Specifications (2010) values were surpassed by the greatest observed negative temperature gradient on both bridges. The Priestley Method (1978) with the 76.2 mm. asphalt overlay best described the maximum recorded positive temperature gradient for the Utah Bridge, indicating that the asphalt overlay plays a significant role as an insulator on the temperature gradient.

In 2016, Abid, et al. [13] assessed the heat transmission in deep concrete box-girder bridges while taking into account variations in air temperature, solar thermal radiation, and wind speed using a three-dimensional finite element thermal analysis. Then, taking into account the weather in Gaziantep, Turkey, the temperature distribution in deep concrete box girders was evaluated using the suggested finite element model. The concrete temperatures were correctly anticipated by the current finite element study, with temperature uncertainties ranging from 0.1°C to 1.7°C. The results showed that the expected temperature gradients along the clear depth of the webs, at the bottom and top surfaces, were almost identical to those predicted by the AASHTO LRFD Specifications (2017) gradient model [14]. Along the upper 1 m, however, the behavior was different. The distribution of the greatest temperature gradient along the 14 depths of the deep box-girder in Gaziantep during the summer can be divided into three distinct sections. A sharp nonlinear temperature fall in the top constitutes the first region. The third region, which extends along the lower 0.2 of the bottom slab, is followed by a region of semi-constant temperature along the clear depth of the web in addition to the top depth of the bottom slab, and it concludes with the temperature gradient showing a small, semi-linear increase down to the bottom surface.

In 2019, Yang, et al. [15] investigated by examining the tracked data of a small concrete box-girder bridge, it is possible to determine the existence of a structural response that lags behind a reference temperature. The disconnect between temperature load and structural reaction brought on by this time-lag effect makes it challenging for the structural health monitoring (SHM) system to issue real-time warnings. Yang, et al. suggested a phase difference subtraction technique based on the Fourier series fitting algorithm to solve this issue. The effectiveness of the strategy was subsequently confirmed through a case study. The following are the primary conclusions:

1. Under non uniform temperature load, the temperature-induced effect of a small concrete box-girder determines a time-lag phenomenon. In particular, the summer time-lag phenomena are more noticeable since the summer time-lag curve is fuller than the winter one.
2. A steel construction has a shorter lag time than a concrete structure.

In 2021, Lu, et al. [16] examined how sun irradiation and extremely hot temperatures affected concrete box girder bridges. Through field observations and calculations, the box girder's temperature distribution and solar radiation intensity were determined. The effects of variables on temperature distribution, including solar intensity, wind speed, air temperature, and shadow occlusion, were taken into account. The key findings of Lu, et al. are listed below:

1. The effects of solar radiation on the various surfaces of the box girder clearly changes over time. From 10:00 to 16:00, it reaches its highest value and remains steady on the upper deck.
2. The effective depth of solar radiation is approximately 30 cm, and the overall temperature of the sun-facing web is higher than that of the shielded web. Direct sun radiation has the greatest impact on the temperature difference, according to the analysis of the temperature difference components.

In reality, temperature fluctuations have a big impact on bridges. Large total length changes, expansion, or contraction result from variations in uniform temperature. These length fluctuations affect internal forces, structural dynamics, and the constant expansion and contraction could harm important bridge members [16]. In the event that these deformations are constrained, temperature changes lead to thermal stresses, which may cause unanticipated tensile cracks and, as a result, reinforcement corrosion. Additional bending moments are produced in the vertical and horizontal planes, respectively, due to differences in temperature [17] as shown in Figure 1.

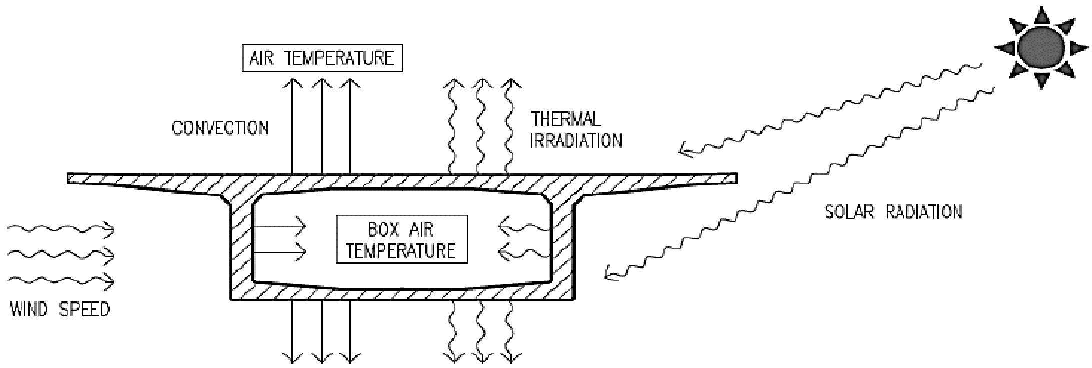


Figure 1. Environmental effects on bridge temperature change [17]

In the current paper, the CSI-Bridge finite element software [18,19] has been used to conduct a thorough analysis of tow box cross-sections; Rectangular and Trapezoidal. The change in temperature values on rectangular and trapezoidal box girders was studied to predict the behavior of these models. The behavior of these box girders has been analyzed using a linear analysis according to AASHTO thermal load and temperature gradient rules [12,14].

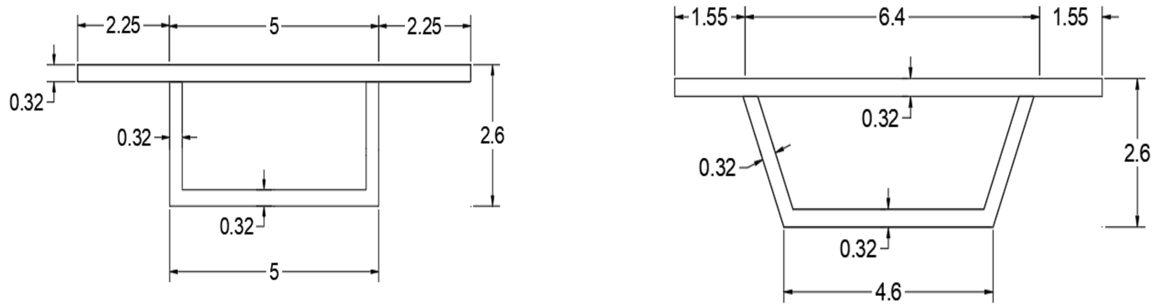
In Iraq, the temperature contrast increases between the seasons and also increases during the day itself. Therefore, it became very necessary to study the thermal changes along the longitudinal direction of the bridges and to validate them by comparing these results with other previous studies results. The deformations, the deflection, and the stresses for the bridges must be predicted by using the finite element method that used by CSI bridge software.

1.1 Modeling methodology

The current study builds 3D models and using the CSI-Bridge software. Reinforced concrete bridges can be constructed and retrofitted rapidly and easily using finite element software. The creation of simple or complex bridge models is made possible using parametric modeling, which offers the user complete control over the design process. Superstructures and substructures may be created quickly, and width of lane effects are taken into account. An easy-to-use wizard is included in the CSI-Bridge finite element software to walk users through the procedure for creating a bridge model. A four-node, three-dimensional shell element with six degrees of freedom at each node is used to represent the pinned supported box-girder bridges. To determine the ideal number of elements that produces the most accurate results with the least amount of processing time and effort, the number of elements has been investigated.

2. Box girder details

This essay analyzes the two concrete boxes, rectangular and trapezoidal section of a single-cell with single span length about 40 m and depth about 2.6 m. The Box-Girder sections' details are seen in Figures 2a and 2b.



a) b)

Figure 2. Single-cell cross-sections of Box girders used, all dimension in meter. a) Single-cell Rectangular cross-section of Box girder. b) Single-cell Rectangular cross-section of Box girder

The bridge analysis used a span of 40 m for two cross sections; rectangular and trapezoidal, the same bridge deck width, and the same cross-sectional area. It was assumed that the bridge cross section has a constant slab thickness of 0.32 m for constant depth parameters. According to ASHTOO [12], [14], linear analyses for transversal thermal loading and temperature gradient were performed on both of the bridge's cross sections. The results and graphs are obtained using the CSI-Bridge finite element software [18,19].

3. Thermal loads

A vital parameter that needs to be taken into account for the duration of the bridge's life is thermal load. As shown in Figure 3, the four following vital constituent elements can be used to break down the temperature distribution inside a single structural member [20]:

1. Component of uniform temperature (ΔT_u).
2. Temperature differential component around the y-axis that changes linearly (ΔT_{My}).
3. Temperature differential component around the z-axis that changes linearly (ΔT_{Mz}).
4. Temperature difference component that is nonlinear, (ΔT_{E}). As a result, the element is subjected to a system of self-equilibrated stresses that has no load effect on it.

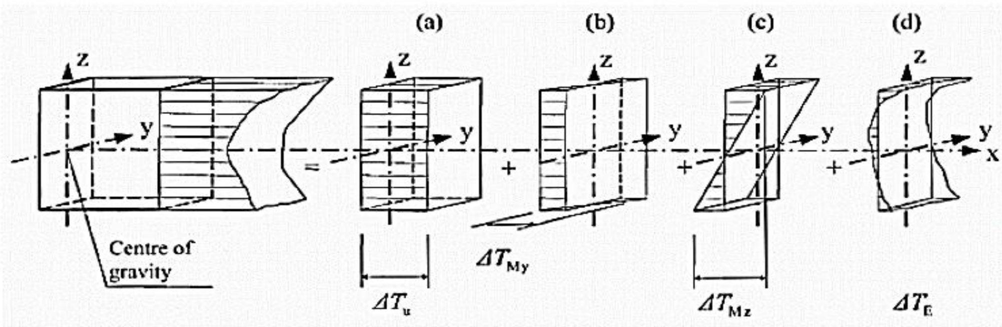


Figure 3. Diagrammatic representation of a temperature profile's constituent parts a) Component of uniform temperature. b) differential component (y-axis). c) differential component (z-axis) d) component that is nonlinear [20]

The expansion or contraction of bridge components in the longitudinal direction is dependent on the highest and minimum temperatures that the bridge reaches over the given timeframe. For statically determined structures, the linear elastic approach can be used to determine the movement of the structures related to effective bridge temperature. Because these deformations are constrained, temperature changes cause thermal stresses in statically indeterminate structures [16]. The bending moments in the vertical plane are caused by the vertical temperature differential (also known as the temperature gradient), which is the difference in temperature between the top surface and lower levels throughout the depth of the superstructure. When conditions are favorable, heat is gained through the top surface of the superstructure as a result of solar radiation and other parameters [15]. In contrast, a reverse temperature gradient happens when the upper surface of the bridge deck loses heat due to radiation and other parameters. Practically, all bridge specifications include information on the effective bridge temperature and the vertical temperature difference. For thermal load, the AASHTO standard thermal load and temperature gradient [12], [14] is used in the current study, which takes in account all specification above.

4. Procedure for the analysis

The rectangular and trapezoidal cross sections of 2 distinct reinforced concrete box girder bridges are examined in the current study using the CSI-Bridge finite element software. The cross-sectional details of the box girder bridges are shown in Figures. 2a and 2b. The 2 box girders were subjected to variable temperature values which different from positive 30, 40, 50 and 60 °C to negative 0, -5, -10 and -15 °C with same temperature gradient criteria all over the section depth according to AASHTO [12,14]. Box girder bridges consideration for analysis were same depth, width of the bridge deck and the area of the cross section. For all variations of box girder bridge sections, the bridge's span is assumed to be 40 m. All bridge cross-sections are taken into consideration with a constant thickness of 0.32 m. M30 concrete is utilized as a constructional material. Using CSI-Bridge finite element software, assessments of box girder bridges are performed thermal load and temperature gradient for the tow cross-sections of the bridges. The rectangular and trapezoidal box girder bridge deck models in CSI-Bridge finite element software are shown in Figures 4a and 4b.

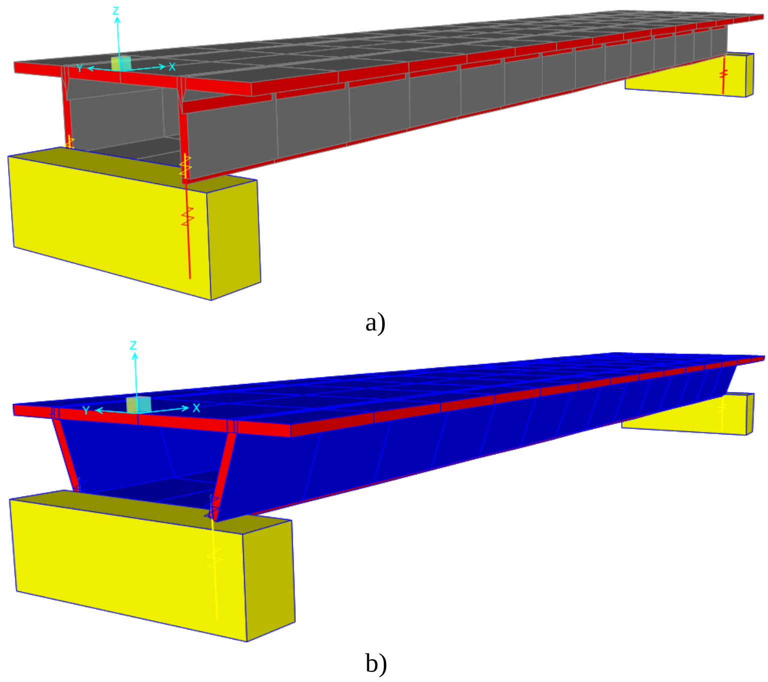


Figure 4. 3D view of bridge model for rectangular and trapezoidal box girders

5. Verification

In order to verify the results of the current research work, a comparison was conducted with the results of another research work [21], in which the authors extracted their results in a similar way and with the same finite element software, Table 1.

Table 1: Verification of results

reference no.21	current work	reference no.20 / current work	current work	reference no.20	reference no.21 / current work
Deflection (mm)			moment (kN)		
50	35	1.4	965	1076	0.9
100	77	1.3	1874	2087	0.9
150	160	0.94	2345	2989	0.8
200	208	0.96	3983	4032	0.99

6. Results for analysis

6.1 Rectangular box girder

6.1.1 Positive temperature for rectangular box section

Rectangular box section under positive temperatures (maximum temperature at summer days), which are represented the components of uniform temperature (effective bridge temperature), were analyzed and results are summarized in Table 2.

Table 2: Analysis of rectangle box girders for positive temperature

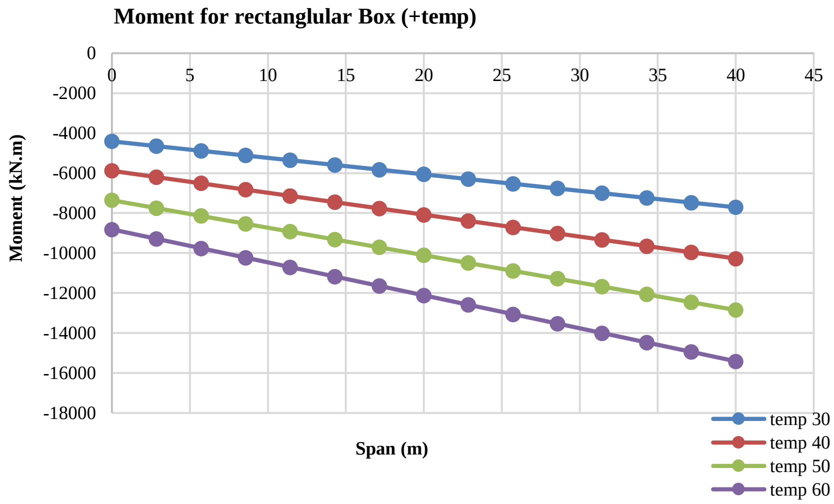
Positive temperature (C°)	Max bending moment along span (kN.m)	% Increase in moment	Max-deflection (mm)	% Increase in deflection	Max-Longitudinal Stresses in Top Flange (kN/m^2)	% increase in Top Flange Stress	Max-Longitudinal Stress in Bottom Flange (kN/m^2)	% increase in Bottom Flange Stress
30	7709	-	0.0087	-	384.22	-	-3101	-
40	10278	33.33	0.0117	33.1	512.29	33.33	-4134	33.33
50	12849	66.66	0.0146	66.66	640.37	66.66	-5168	66.66
60	15417	100	0.0175	100	768.44	100	-6201	100

When increasing the temperature from 30 to 60 °C, by 10° each time, the deflection and moment increase by 33%. This is due to the fact that the high temperatures cause the expansion of the concrete forming the bridge, which causes an increase in its size. Thus, the formation of additional compressive stresses on the structural parts causing an increase in deflection by 33%, 66% and 99% when the temperatures increase by 40, 50 and 60 °C.

The highest deflection is in the middle of the span, and the highest transverse bending moment is at the end of it. The reason is that the box girder is pinned on both sides, so the load caused by temperature stresses will be as high as possible at the hinge and lower at the roller support., Table 2 and Figures 5a and 5b. Since the temperature change along the span is within a regular linear gradual change according to AASHTO code for the temperature gradient of the concrete members, the stresses that are generated as a result of the high temperatures increase regularly with each time the temperature changes. Notting that, with fixing the section shape, cross-sectional area, height and span length for each change in temperature, each of the deflection and transverse bending moment increase uniformly by 33% as well.

It is also seen that when the temperature is increased from 30 to 60 °C, by 10 degrees each time, the stress in the upper flange and the lower flange increased by 33% due to the size expansion generated inside the concrete forming the bridge. In more detail, the stresses in the upper flange increased by 33%, 66%, and 99% when the temperature values increased by 40, 50, and 60 °C.

into tensile stresses at the second end of the span. This is because the upper flange is wider than the lower flange, i.e., it contains a hangover arm, which affects the stress distribution from the beginning of the girder. That is, the roller, where a slight compression occurs in it despite the high temperatures, the tensile stresses begin to increase as load moves on the span towards the support (hinge).



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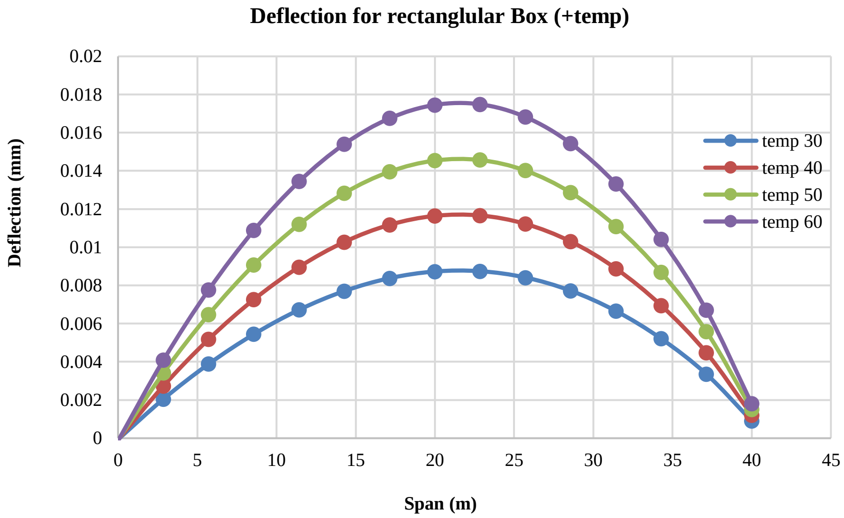
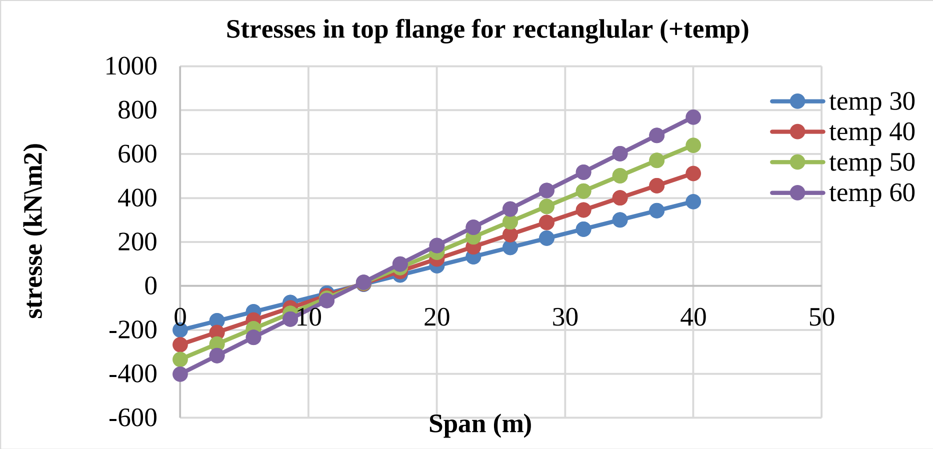


b)

Figure 5. Variation in bending moments and deflection for single cell rectangular box girders a) Top flange. b) Bottom flange

That change in stress distribution will cause a camber phenomenon in the bridge. The reason for the camber is that the upper surface of the box is more affected by heat than the lower surface of it. As for the lower flange, it gets compressive stresses only as a result of the occurrence of the camber as well, Table 2 and Figures 6a and 6b



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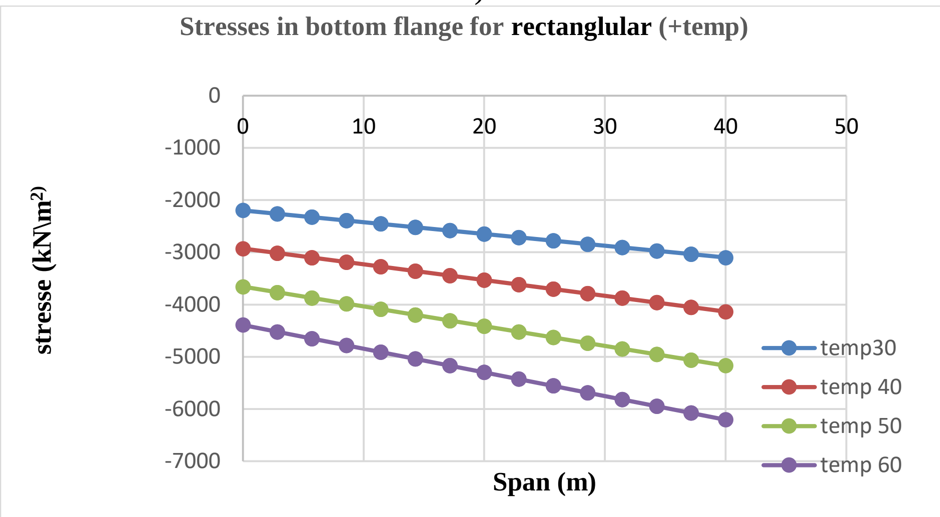


b)

Figure 6. Longitudinal bending stresses in top and bottom flanges along the span for single-cell rectangular box-girder bridge a) Top flange. b) Bottom flange

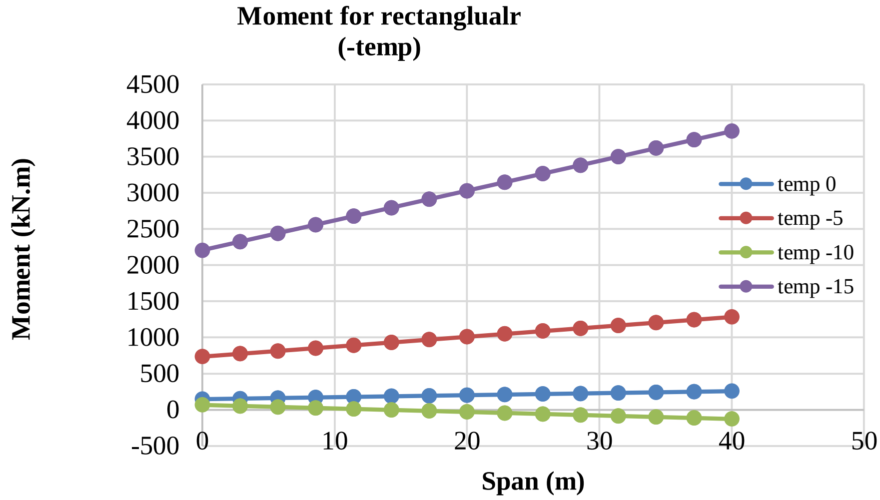
6.1.2 Negative temperature for rectangular box section

Rectangular box section under negative temperatures (minimum temperature at winter days), which are represented the components of uniform temperature (effective bridge temperature), were analysed, Table 3.

Table 3: Analysis of rectangle box girders for negative temperature

Negative temperature (C°)	Max bending moment along span (kN.m)	% increase in max moment along span	Max-deflection (mm)	% Increase in deflection	Max-Longitudinal Stresses in Top Flange (kN/m^2)	% Decrease Percentage in Stress	Max-Longitudinal Stresses in Bottom Flange (kN/m^2)	% increase in Bottom Flange Stresses
0	257	-	0.00029	-	-12.81	------	103	-
-5	1281	400	0.0015	400	-64.04	400	517	400
-10	2570	900	0.0029	900	-128.07	900	1034	900
-15	3854	1400	0.0044	1400	-192.11	1400	1550	1400

When the temperature is increased from 0 to -15 °C, by 5° each time, the deflection and moment increase by 500%. This is due to the fact that the temperature drop to this extent reduces the size of concrete mass forming the bridge. Thus, internal compressive forces are formed, causing an increase in both the moment and deflection by 400%, 900% and 1500% at a decrease in temperatures -5, -10 and -15 °C. The highest deflection appears in the middle of the bridge, and the highest bending moments at its end, Table 3 and Figures 7a and 7b. The temperature gradient along the span is a temperature gradient according to the winter accompanied by a small difference between the temperature of the concrete in the support zone and in the mid span, what caused the change of the moment along the span.



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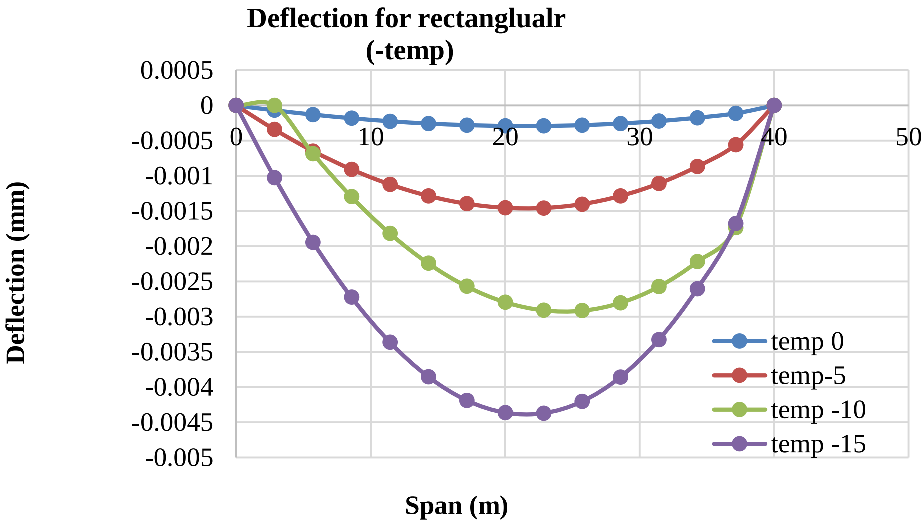
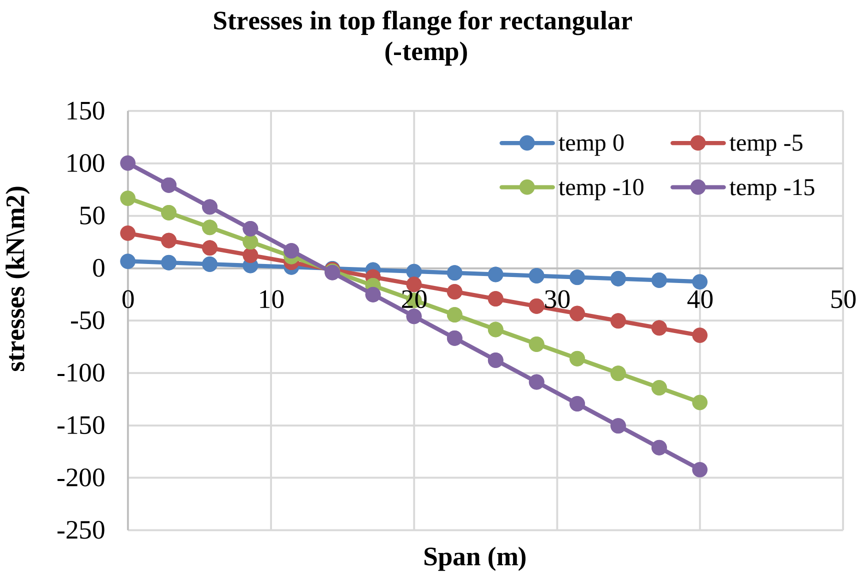


b)

Figure 7. Variation in bending moments and deflection for single cell rectanglualr box girders a) Bending moment. b) Midspan deflection

It is also seen that when the temperature decreases from 0 to -15 °C, by 5 degrees each time, the stresses in the upper flange and the lower flange increase by 500% each time due to the increase in the stresses that are generated within the concrete forming the bridge as a result of size reduction. The stresses in the upper and lower flange increase by 400%, 900% and 1400% when temperatures drop from 0 to -5, -10 and -15 °C. Since the span is pinned at the two ends, that is, there is no possibility for the movement of the concrete mass forming the bridge from both sides (as a result of its size reduction), stresses are generated in the upper and lower flanges. The stresses in the upper flange are compressive stresses and in the lower flange are tensile ones because the upper parts of the section are affected by temperature more than the lower parts as a result of the distribution of heat along the cross section according to winter. Consequently, the upper parts of the box shrink more than the lower parts, causing tensile stresses in the upper flange and compressive stresses in the lower flange, Table 3 and Figures 8a and 8b.



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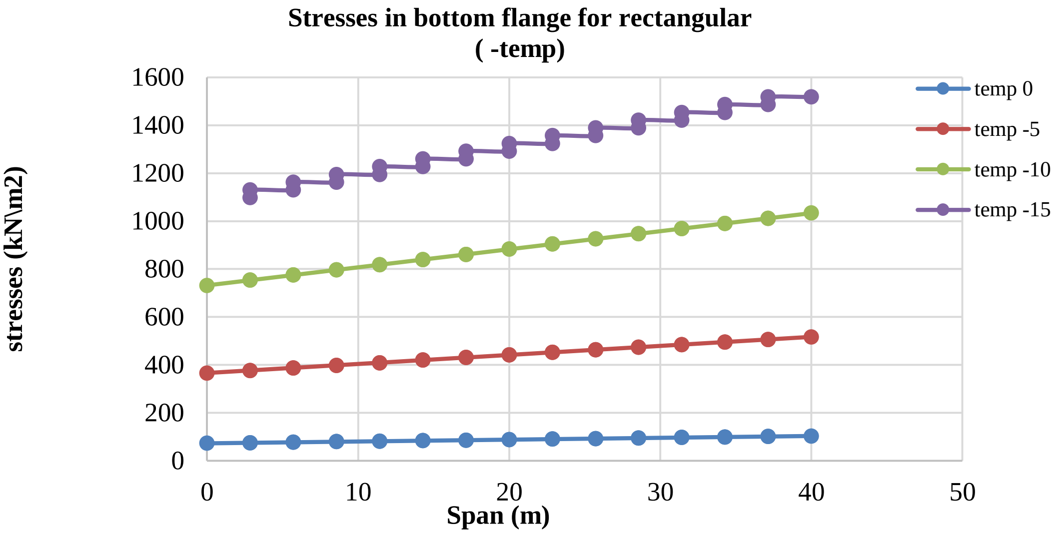


b)

Figure 8. Variation of longitudinal stresses in top & bottom flange along the span for single-cell rectangular box-girder bridge. a) Top flange. b) Bottom flange

6.2 Trapezoidal box section

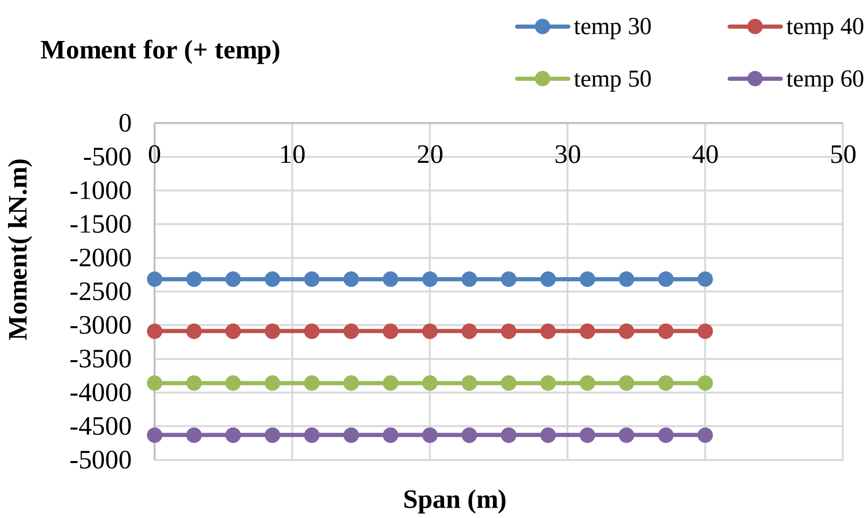
6.2.1 Positive temperature for trapezoidal box section

Trapezoidal box section under positive temperatures (maximum temperature at summer days) which are represented the components of uniform temperature (effective bridge temperature), were analyzed, Table 4.

Table 4: Analysis of trapezoidal box girders for positive temperature

Positive temperature (C°)	Max bending moment along span (kN.m)	% increase in moment	Max-deflection (mm)	% Increase in midspan deflection	Max-Longitudinal Stresses in top flange (kN/m^2)	% increase in top flange Stresses	Max-Longitudinal Stresses in bottom flange (kN/m^2)	% increase in bottom flange Stresses
30	-2315		0.0036		101		-1159.62	
40	-3086	33%	0.0048	33%	135	33%	-1546.16	33%
50	-3858	67%	0.006	67%	169	67%	-1932.7	67%
60	-4629	100%	0.007	100%	203	100%	-2319.25	100%

When the temperature is increased from 30 to 60 °C, by 10 degrees each time, the deflection and moment increase by 33%. This is due to the fact that the high temperatures cause the size expansion of the concrete mass forming the bridge. Therefore, additional compressive forces form in the structure parts, causing an increase in deflection by 33%, 66%, and 99% at an increase in temperatures of 40, 50, and 60 °C, respectively. The highest deflection occurs in the midspan of the bridge and the highest moment at the end of the bridge, Table 4 and Figures 9a and 9b. Since the temperature gradient along the span is a temperature gradient according to AASHTO, the forces that are generated as a result of high temperatures increase regularly with each time the temperature is changed. Accordingly, both the deflection and the moment increase regularly as well every time the temperature changes.



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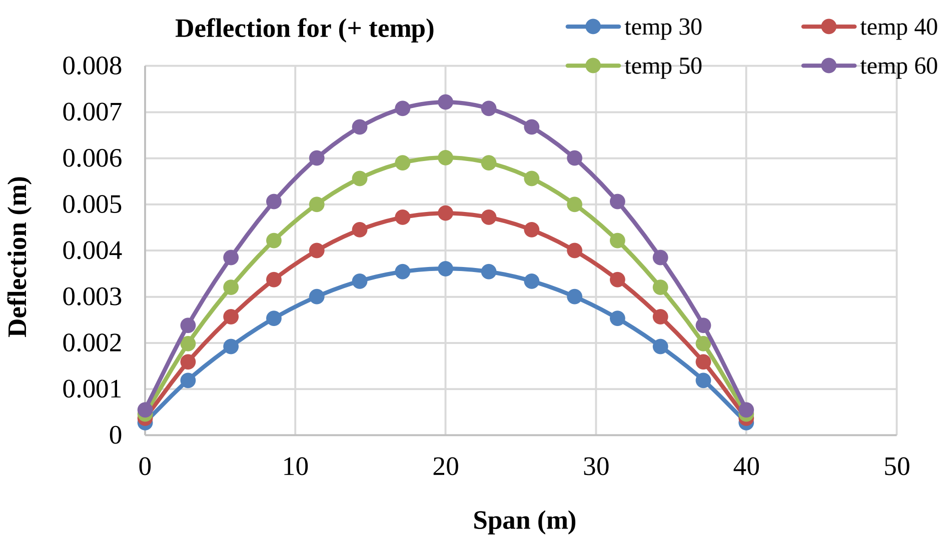
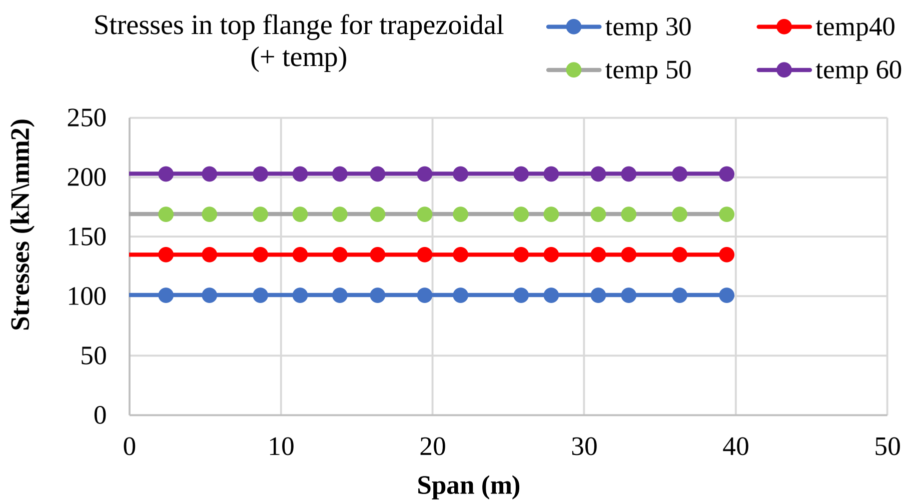


b)

Figure 9. Variation in bending moment and deflection for single cell rectangle box girder

It is also observed that when the temperature is increased from 30 to 60 °C, by 10 degrees each time, the stresses on the upper and lower flanges increase by 33%. This increase is also due to the internal forces that are generated inside the concrete mass forming the bridge as a result of its size expansion by the effect of heat. Accordingly, the stresses in the upper flange increase by 33%, 66%, and 99% when the temperature increases by 40, 50 and 60 °C, respectively.

The stresses in the upper flange are tensile stresses and they are equal along the length of span. The reason of that is because the effect of thermal stresses, whether increasing or decreasing, is equal along the span with respect to the trapezoidal section, because the web of the trapezoidal section is inclined, the thermal change of the section along the span is very slight, not taken into consideration. The change in stress distribution will cause a camber phenomenon in the bridge because the upper flange of the box is more affected by heat than the lower one. Consequently, the upper flange expands by a greater amount than the lower flange. As for the lower flange, only compressive stresses take place due to the occurrence of the camber as well, Table 4 and Figures 10a and 10b.



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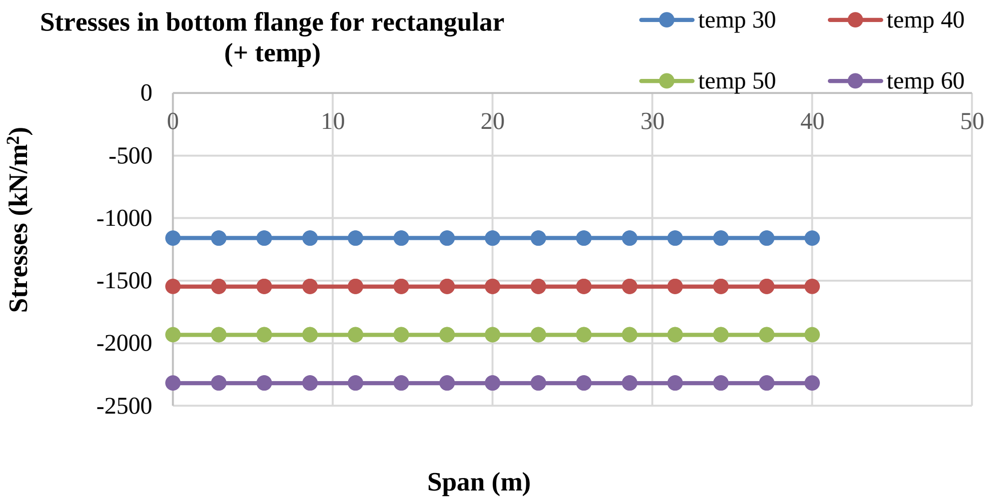


b)

Figure 10. Variation of longitudinal stresses in top & bottom flange along the span for single-cell trapezoidal box-girder bridge. a) Top flange. b) Bottom flange

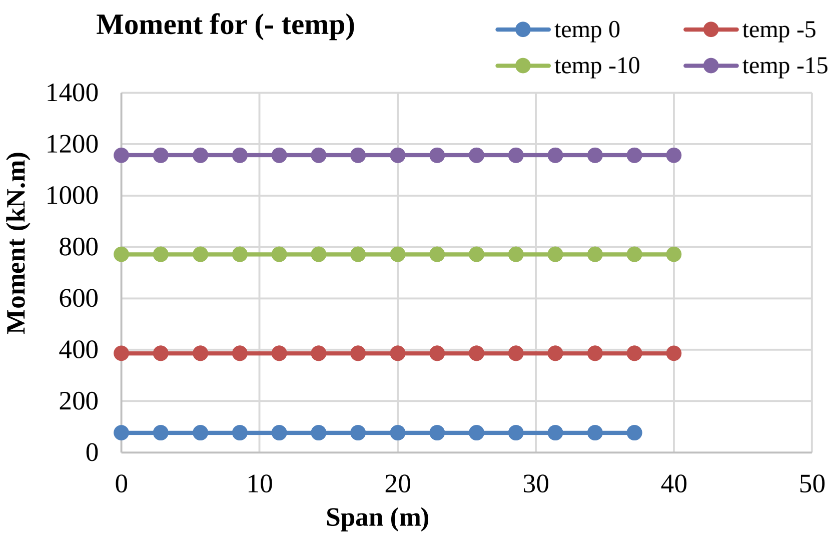
6.2.2 Negative temperature for trapezoidal box section

Trapezoidal box section under negative temperatures (minimum temperature at winter days) which are represented the components of uniform temperature (effective bridge temperature), were analyzed as shown in Table 5.

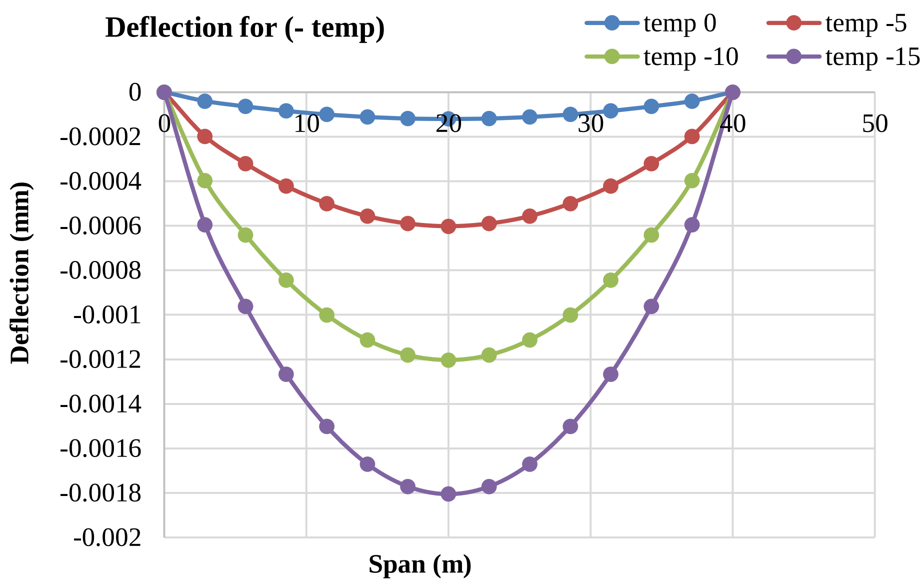
Table 5: Analysis of trapezoidal box girders for negative temperature

Negative temperature (C°)	Max Bending moment along span (kN.m)	% increase in moment	Max-deflection (mm)	% Increase in max-deflection	Max-Longitudinal Stress in Top Flange (kN/m^2)	% increase in top Flange Stresses	Max-Longitudinal Stress in bottom Flange (kN/m^2)	% increase in Bottom Flange Stresses
0	77		0.00012		-3.38		39	
-5	386	400	0.0006	400	-16.92	400	193	400
-10	772	900	0.0028	900	-33.84	900	387	900
-15	1157	1400	0.0018	1400	-50.76	1400	579	1400

When the temperature is decreased from 0 to -15 °C, by 5 degrees each time, both deflection and moment increase by 500%. This is due to the fact that the temperature drops to this extent caused the size reduction of the concrete mass forming the bridge. Therefore, compressive forces are formed, causing an increase in both the moment and deflection by 400%, 900%, and 1500% at an increase in temperatures -5, -10 and -15, respectively. The highest deflection occurs in the midspan of the bridge and the highest moments occur at the ends, Table 5 and Figures 11a and 11b. The amount of temperature change of the box section along the span is a regular and slightly linear change according to AASHTO with a small difference between the temperature of the support and the midspan, causing the change of the moment along the span. That is, the forces that are generated as a result of high temperatures increase regularly every time the temperatures change, each of the deflection and moment increase regularly by 33% in every change of temperature.



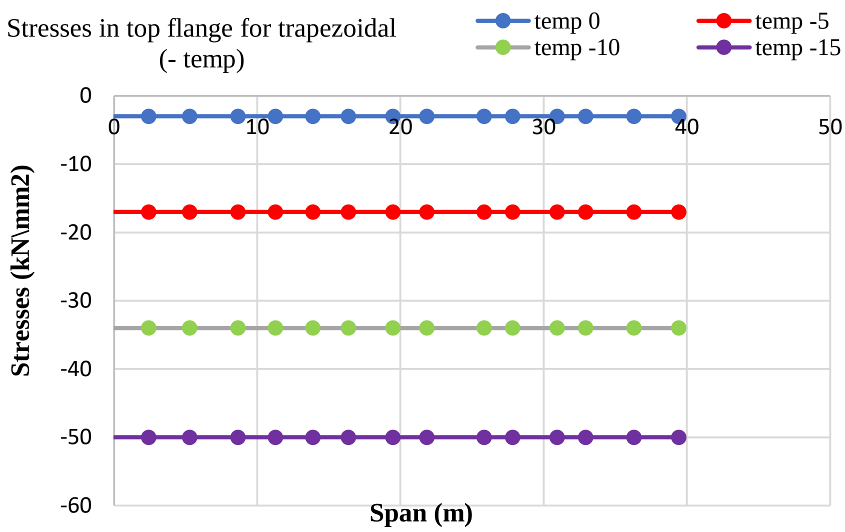
a)



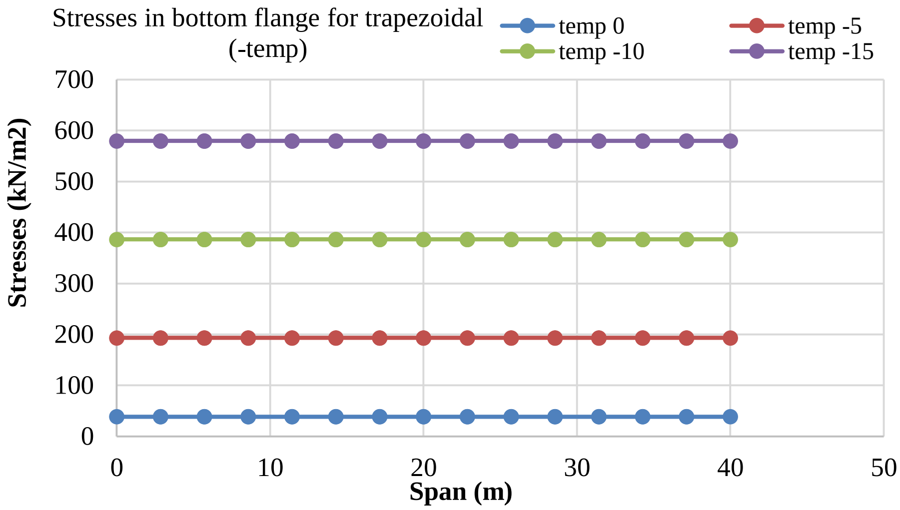
b)

Figure 11. Variation in bending moments and deflection for single cell trapezoidal box girders a) Bending moment. b) Midspan deflection

It is also seen that when the temperature decreases from 0 to -15 °C, by 5 degrees each time, the stresses in the upper and lower flanges increase by 500% each time as a result of the decrease in bridge size. This causes stresses to be generated in the upper and lower flanges, where the rate of increase in these stresses is 400%, 900%, and 1400% at lower temperatures of -5, -10, and -15 °C, respectively. The stresses in the upper flange are compressive and tensile stresses in the lower flange. Because the upper parts of the section are affected by the change in temperature more than the lower parts according to the AASHTO (pertaining to the distribution and temperature gradient along the cross-section of the box), the upper parts of the box lose size more than the lower ones. This causes tensile stresses on the upper flange and compressive stresses in the lower flange, Table 5 and Figures 12a and 12b.



a)



b)

Figure 12. Variation of longitudinal stresses in top & bottom flange along the span for single-cell trapezoidal box-girder bridge. a) Top flange. b) Bottom flange

7. Conclusion

In Iraq, thermal impact on concrete box girder bridges is a significant aspect that needs to be taken into account while designing a bridge. In the current study a concrete box girder bridge's temperature gradient and uniform temperature (over the length of the bridges) for two different cross sections; rectangular and trapezoidal have both been studied. A comparison was made between the behavior of the rectangular and trapezoidal box-girder bridges under different temperature change during hot and cold days. The terms that were studied in this comparison are deflection in the middle of span, transverse bending moment and the longitudinal bending stresses. This comparison was conducted using the well-known finite element method, specifically the CSI-Bridge software. From the current research work, the following conclusions were made:

1- When changing the temperature during the hot summer days from 30 to 40, 50 and 60 °C, the transverse bending moments, midspan deflection, and longitudinal bending stresses in the upper and lower flanges change by 33% each time, i.e. the increase is 33%, 66%, and 99%. This increase is approximately the same for both the rectangular and trapezoidal sections. The values of stresses and deflection are different for the two sections, but the percentages of increase are linear because the surface areas of both sections are equal.

2- When changing the temperature during the cold winter days from 0 to -15 °C, by -5 degrees in each change, the transverse bending moments, midspan deflection, and longitudinal bending stresses in the upper and lower flanges change by 500% each time, i.e. the increase is 400%, 900%, and 1400%. This increase is approximately the same for both the rectangular and trapezoidal sections.
3- When temperature rises, tensile stresses occur in the upper flange and compressive stresses in the lower flange. The reason for this is as a result of the expansion of the upper parts of the box girder at a greater rate than the lower parts, according to the AASHTO code for temperature gradient and heat distribution along the cross-section of the box. Therefore, the camber occurs for both rectangular and trapezoidal sections.
4- Through the values of deflection, stresses and moments for each of the trapezoidal and rectangular sections, it can be seen that the trapezoidal section is affected by the temperature change less than the rectangular section. This is due to the fact that the rectangular section is affected by the temperature gradient through the section depth in a greater proportion than the trapezoidal section.
5- For the cross-section of the bridge, when the top surface is hotter than the bottom of the cross-section, the deflection is upwards and vice versa, i.e. when the top surface is less hot than the bottom, the deflection is downward.
6- the effect of thermal stresses, whether increasing or decreasing, is equal along the span with respect to the trapezoidal section, because the web of the trapezoidal section is inclined, the thermal change of the section along the span is very slight, not taken into consideration.

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