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Use of PBridge for analysis and design of single span prestressed concrete bridge subjected to wind and thermal loads

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Abstract

The research introduced "PBridge," a computer program designed for the analysis and design of single span prestressed concrete bridges. These analyses and design were modeled based on the design procedures of Eurocode 1 2003 Part 2, EN 1991 Part 1-4 and Part 1-5. The bridge model is single span design with a main span of 25m length and two side spans of 7.2m carriageway of the proposed bridge consist in each direction of two notional traffic lanes of 3m each. It is expected to span a fresh water river such as River Niger in Onitsha located at Anambra State of Nigeria. The Total initial prestress force of 15330kN, Total prestress force of 21000kN that required 72 Number of strands for the single span prestressed bridge was obtained for both manual and PBridge results. The satisfied prestressed strand of Y1820S7G - 15.2mm diameter, 7 wire drawn strands was adequate for the single span. To further validate the authenticity of the obtained results, the Bending Moment and Share Force results for both the STAAD Pro and PBridge were compared in Table 4.17 for Single span. The percentage difference at 2.5 metre from the end support was 0.0048 for the moment of the single span and that of continuous span was 0.0044 at a distance of 5m from the end support. For Share Force, it was 0.075 for Single span at 2.5m. These imply that the developed programme can reliably be used for analysis and design of prestressed concrete bridge.

Keywords: Pbridge; Computer Program; Prestressed Concrete; Single Span; Bridge

1. Introduction

A bridge is a structure used in civil engineering that crosses a river, a road, or other obstacles to support a path, a road, railings, etc [1] Since ancient times, it has been utilized as a civil engineering construction to overcome a subsurface obstacle. Who would have thought that what began as a straightforward log of wood support used to bridge obstacles would be used in so many different ways and include so many different materials to become such a vast area of research in Civil Engineering at this point? Bridges are currently among the most significant and well-known components of civil engineering structures [2]. The emergence of sophisticated and improved structural analysis, design, and manufacture of equipment and materials in engineering and science has led to the construction of several types of bridges nowadays [3]. The main Engineers involved in the planning and building of bridges are structural [4].

Historically, stepping stones were among the first and most basic forms of bridges. Neolithic people also constructed a type of boardwalk to cross marshes; two examples of these bridges, dating back about 6000 years, are the Sweet Track and the Post Track in England [5]. Probably some of the earliest large-span bridges constructed by humans were made from purposefully chopped trees [6]. One of the oldest arch bridges still in use today, dates back to the Greek Bronze Age (c. 13th century BC). The Peloponnese is home to many intact Hellenistic arched stone bridges [7]. Gascoigne [8] hinted that Romans were the greatest bridge builders in history.

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Before the advent of computer programming, most of the engineering structures are analysed and designed manually. Engineering computer programming is now a fundamental aspect of the modern world. Because it allows engineers to design, simulate, and test their creations before they are physically built. This lowers the possibility of mistakes and failures in the finished product in addition to saving time and resources. They serve as the foundation for all software, including the most complex and easy-to-use programs [9].

This study created a Java-based software application that facilitates the precise analysis and design of single span composite prestressed concrete bridges in accordance with Eurocodes. It also distinctively considered the effect of temperature variations and wind blow on bridges associated the recent climate changes.

1.1. Prestressed Concrete Design to Eurocode

Prestress is the process of applying pre-compression to control the stresses caused by external compressive forces or overcome tensile stresses brought on by inevitable loads from the wind, gravity, temperature rise etc. The major reason is to overcome the compressive stress below the neutral axis of the beam that is developed when the external load exceeds the plain concrete's allowable limits [10]. If concrete can be compressed externally to counteract the tensile stresses brought on by applied loads, then the aforementioned issues can be resolved.

The concrete is precompressed, indicating that pre-compression is applied even before the structure starts to function, introducing compressive stresses into potential tensile stress areas. Among the benefits of prestressing are, firstly, the structural components' high quality at the time of production because the product's quality is guaranteed [11]. Furthermore, the use of prestressed concrete will reduce project costs because less labour is needed. After all, the material is manufactured in a factory. Thirdly, prestressed concrete can be used to build bridges with a longer span [12].

Prestressed concrete design is an intricate, iterative process. The structure must concurrently meet several distinct design specifications as outlined in the Eurocodes. It is necessary to design for each of these requirements independently, and meeting one does not imply meeting all of them [13]. The serviceability limit states and the ultimate limit states are the two categories into which the Eurocodes divide these requirements. While bending moment resistance, shear resistance, and fatigue verifications are covered by the ultimate limit states, stress limitations, crack control, and deflections are covered by the serviceability limit states [14].

Many of the Eurocodes need to be used during the design phase. The two that are most frequently used for designing prestressed concrete bridges are [15], which deals with concrete bridge design, and which covers general building regulations. Owing to the complex stress distributions found in prestressed concrete, three stages of consideration must go into the design of a composite prestressed concrete beam to account for the entire range of loading that the member will experience in its lifetime [16].

2. Materials and method

2.1. Bridge Design Specifications

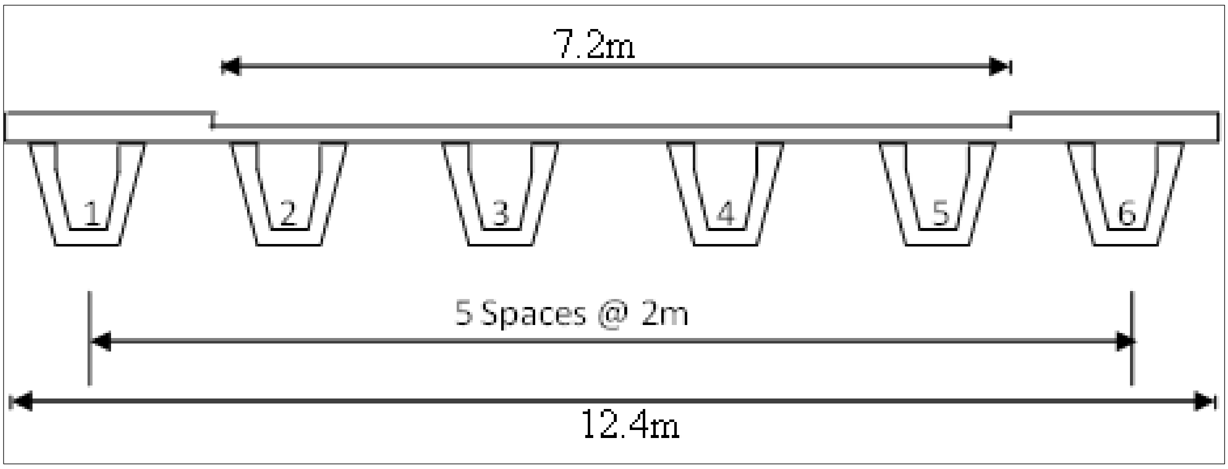

Figure 1 Single Span Bridge cross section

The composite prestressed concrete bridge designed to Eurocodes is expected to span a fresh water river such as River Niger in Onitsha located at Anambra State of Nigeria. The bridge is a single span design with a main span of 25m length and two side spans of 7.2m carriageway of the proposed bridge consist in each direction of two notional traffic lanes of 3m each. The diagrams and dimensions of the specific elements of the bridges are shown in Figure 1 and Table 1 respectively.

Table 1 Design Assumptions of single design bridge

Span length	**25.0m**
Beam type	Pre-tensioned U12 Beams
Beam Spacing	2.0m
Deck width	12.4m
Carriageway width	7.2m
Concrete grade for the beam	C50/60
Concrete grade for the slab	C40/50
Cement grade	42.5
Average wind speed of the site	18km/h
Basic wind speed of the site Vb	5m/s
Density of air	1.25kg/m3
Bottom of the bridge deck above the ground	7m

2.2. Applied Load Analysis

2.2.1. Traffic Loading on a Bridge

A bridge's application of traffic loading is one of its most difficult design elements. The leading variable action in the combinations of actions will typically be traffic. As a result, it's critical to analyze this loading thoroughly and in detail. Guidelines for traffic actions on road, pedestrian, and railway bridges are provided by the Eurocode [17]. Four vertical load models are defined by [17] and are required to be taken into account for serviceability and ultimate limit state verifications on road bridges. The traffic loadings considered in this work are all determined using the procedure outlined in Figure 2.

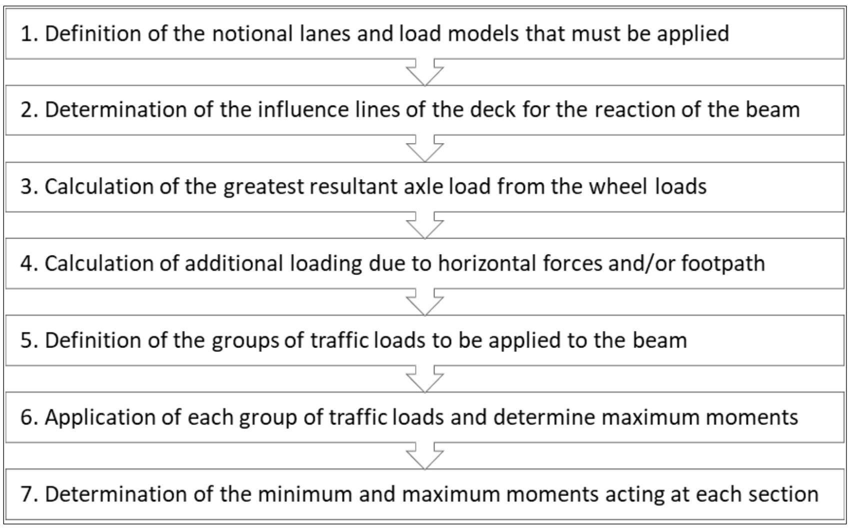

Figure 2 Procedure for application of traffic loads to the beam

2.2.2. Wind action on the bridge

As per the Eurocode [18] standard, bridges with a single deck and one or more spans that are of constant depth and have a span of less than 40 meters do not typically require a dynamic response procedure rather requires only static procedure, where the example in this work belongs. The wind force in the x-direction can be found using Equation (1) in cases where it has been determined that a dynamic response approach is not required.

$$F_w = \frac{1}{2} . \rho . v_b^2 . C . A_{ref,x} \qquad \dots \dots \dots. \quad (1)$$

Where
ρ is the density of air,
$v_b$is the basic wind velocity,
C is the wind load factor for bridges,
$A_{re*f,x}$is the reference area.

The reference area $A_{ref,x}$ for decks with plain beams or webs without traffic should be defined as given in Equation (2) as:

$$A_{ref,x} = d_{tot} \, .L \qquad \dots \dots \dots \dots. \ (2)$$

Where$d_{tot} = d + d_1$ is defined according to Figure 3.52 and Table 3.20; L is length of a span of the bridge deck.

2.2.3. Thermal actions on the bridge

In accordance with Eurocode [19], taking into account thermal effects on the bridges. The temperature difference and uniform temperature components should be used to evaluate the representative values of thermal actions. The vertical temperature difference should typically contain the non-linear component, according to the Eurocode. Note that a country's National Annex contains the choice of strategy to be applied there.

It is necessary to take into account both the temperature difference $\Delta T_{M,heat}$ (or $\Delta T_{M,cool}$) and the maximum range of uniform bridge temperature component $\Delta T_{N,exp}$ (or $\Delta T_{N,con}$) assuming simultaneity, the following Equations (3) and (4) are used (which should be interpreted as load combinations).

$$\Delta T_{M,heat}(or\ \Delta T_{M,cool}) + \omega_N \Delta T_{N,exp}(\text{or } \Delta T_{N,con}) \qquad \dots \dots \dots. \qquad (3)$$

or

$$\omega_M\ \Delta T_{M,heat}(or\ \Delta T_{M,cool}) + \ \Delta T_{N,exp}(\text{or } \Delta T_{N,con}) \qquad \dots \dots \dots \dots.. \qquad (4)$$

Where, the one that will have the worst impact should be selected.

When dealing with both linear and non-linear vertical temperature changes, it is recommended to substitute ΔT_M with ΔT, which encompasses both ΔT_M and ΔT_E.

2.2.4. Development of Computer Programme for Prestressed Concrete Bridge

The computer programme PBridge is a standard Desktop programme developed for analysis and design of a prestressed concrete bridge. The application requires Java Run Time Environment (JRE) 1.5 and above, to function effectively in computer windows. Java is an object-oriented, class-based, high-level programming language with minimal implementation dependencies. The modeling of the PBridge computer program was illustrated using Unified Modeling language (UML) shown in Figure 3. The programme input interface where the required parameters are inserted for execution is shown in Figure 3.

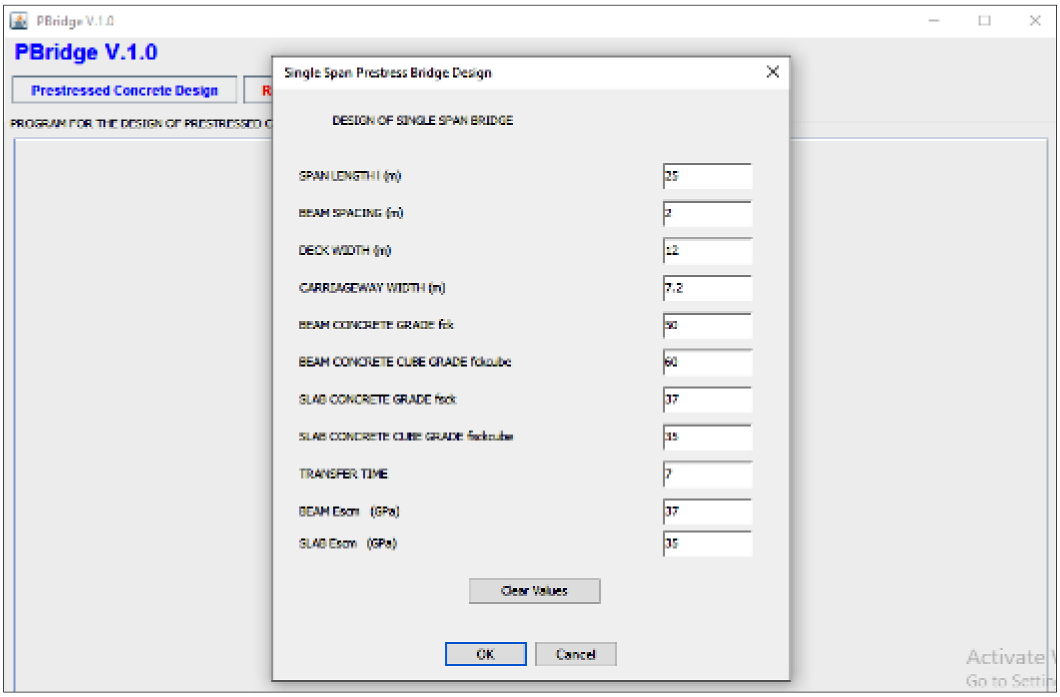

Figure 3 The programme input window

3. Results and Discussion

3.1. The computer programme for the design of the Prestressed Bridge

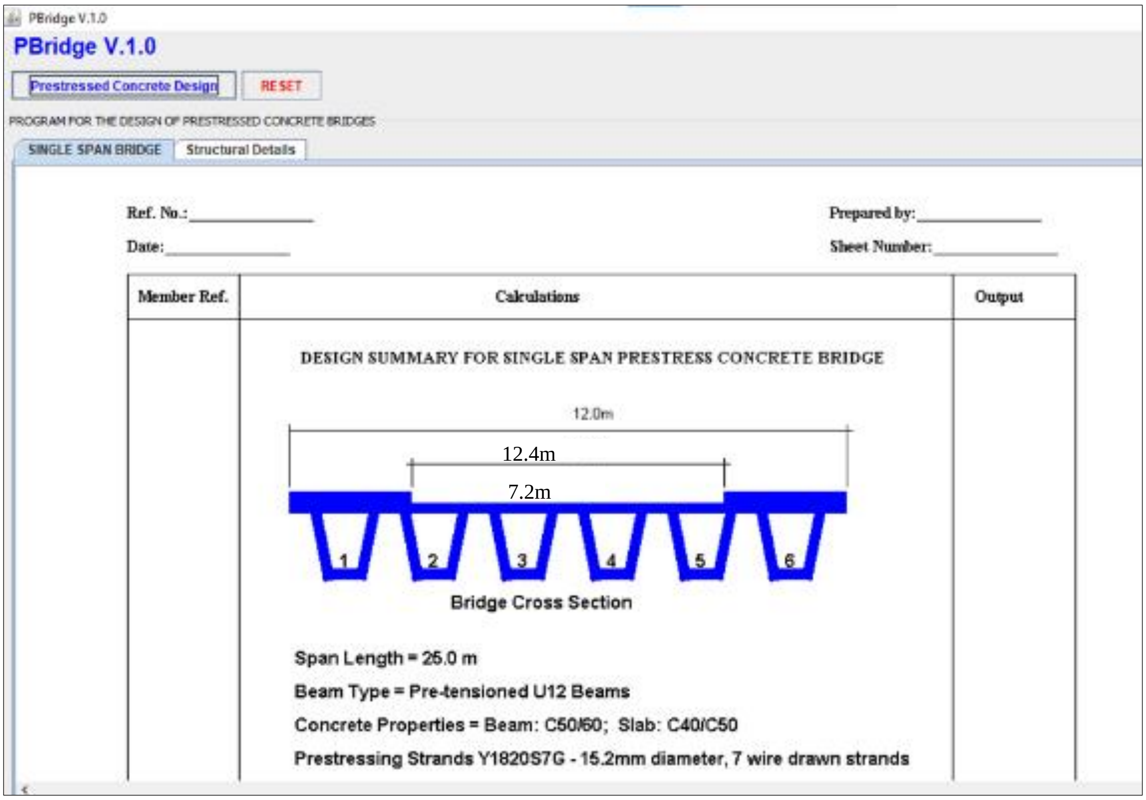

Figure 4 Interface of the PBridge developed programme

The computer programme for the design of the prestressed concrete bridge was developed using Java programming language and it's named PBridge. The interface of the programme window was presented in figure 4. The parameters used in the manual calculations were used to build up the required data of the PBridge programme and the results of the design were in line with that of manual calculations.

3.2. Limits of eccentricity for the prestressed beam

Figure 5 defines limits of eccentricity for the prestressed beam with regards to their basic Mb and Mbs at multiple locations along the beam at intervals of 2.5m. And displayed the symmetric nature of the eccentricity.

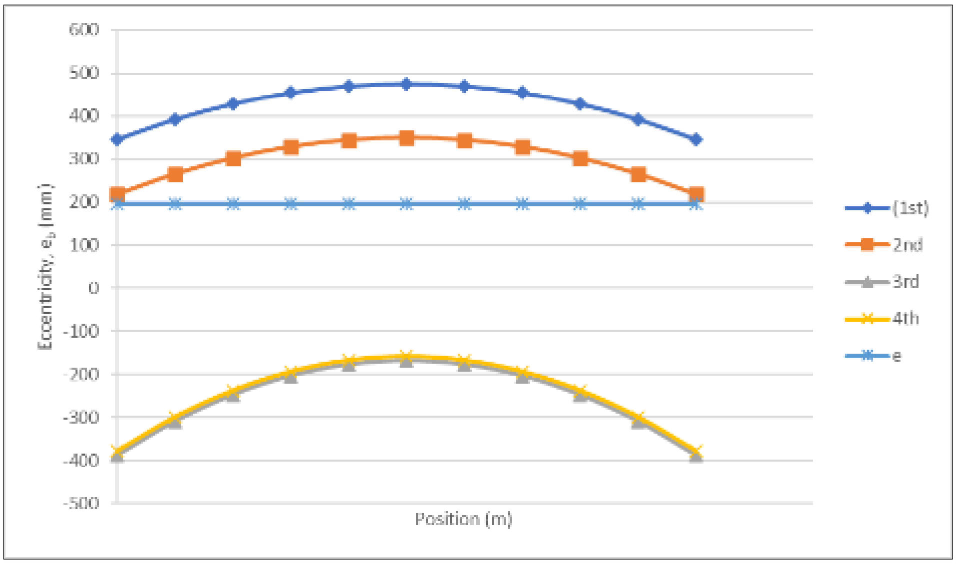

Figure 5 Profile of eccentricity limits for the prestressed beam

It can be seen from Figure 4.2 that second and fourth equations of eccentricity will serve as a control and balance for the eccentricity of straight tendon profile given as 196.148 mm. The symmetrical balance of the eccentricity provides the needed stability required for the bridge to resist all the traffic and weathering forces.

3.3. Verification of the beam at all locations for composite section

The outcome of determination of effect of the Stresses in the beam is verified every 2.5m along the beam. The values of the M_{sf}, M_{gr5} and M_{imp} shown in table 2 are obtained from the calculation results. All results are symmetric about the centre support.

Table 2 Effect of Imposed loading at every 2.5m

Position (m)	M_{sf} (kNm)	M_{gr5} (kNm)	M_{imp} (kNm)
0	0.000	0.000	0
2.5	120.319	1535.272	3705
5	213.900	2709.682	4924
7.5	280.744	3511.724	5842
10	320.850	4007.999	6329
12.5	334.219	4159.000	6543

The result of the Verification of the concrete stresses are presented in table 3 and it was observed that the obtained values for the individual stresses are within the acceptable limits and also met the requirements at all locations. The highest values of f_{tbm} was 17.117 MPa and that of f_{ctbm} was 22.291MPa which are below the stipulated maximum limit of 30MPa. Also, the lowest limits of f_{bbm} and f_{cbbm} which are 0 and -4.1 respectively were not reached for the two stresses. This indicates that the obtained values of the stresses are dully acceptable and the structure will not fail even at increased temperature and wind loads.

Table 3 Verification of concrete stresses in the beam

Position (m)	e_b **(mm)**	M_{imp} **(kNm)**	f_{tbm} **(MPa)**	f_{bbm} **(MPa)**	f_{ctbm} **(MPa)**	f_{cbbm} **(MPa)**
0	196.148	0	7.843	23.179	7.766	19.934
2.5	196.148	3705	11.182	20.322	13.040	13.128
5	196.148	4924	13.779	18.101	17.118	7.883
7.5	196.148	5842	15.634	16.514	19.988	4.224
10	196.148	6329	16.746	15.562	21.728	1.994
12.5	196.148	6543	17.117	15.244	22.291	-2.831
Limits			30	0	30	-4.1

3.4. Analysis of Wind and Temperature effect

The effect of wind was analysed to obtain the Peak velocity pressure. The average wind speed of River Niger in Anambra State was 18km/h (5 m/s). The wind force was obtained using equation (1) as presented in Figure 6.

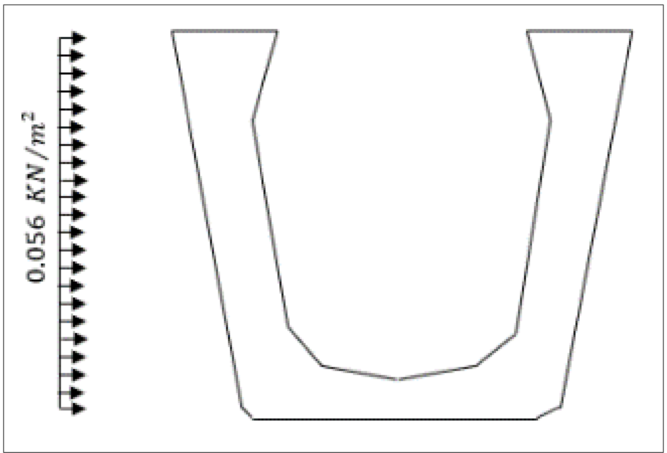

Figure 6 Application of wind load on the bridge

Also, the effect of temperature variation was analysed and the final stress distribution for heating is presented in Table 4.The least temperature during heating occurs at the soffit point whereas the peak temperatures occur at distance of 530mm from top as diagrammatical representation in Figure 7.

Table 4 Final stress distribution on the bridge

Position from top	**σ (MPa)**	**-ΣF/A (MPa)**	**y (mm)**	**-(ΣM/I)y**	**Final stress (MPa)**
130 (key)	-1.59	1.14	596	1.26	0.80
150 (key)	-1.11	1.14	576	1.21	1.24
250 (key)	-0.67	1.14	476	1.00	1.47
400 (web)	0	1.14	326	0.69	1.83
726 (N. Axis)	0	1.14	0	0	1.14

1600	0	1.14	-874	-1.84	-0.70
2800 (soffit)	-0.93	1.14	-1074	-2.26	-2.05

Recall that yb = 1074mm ; yc = 726mm and Ic = 4.503x1011mm4.

$$Note: Finalstress = \sigma + \left(-\sum F/_{A}\right) + \left(-\sum M/_{I}\right) y \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

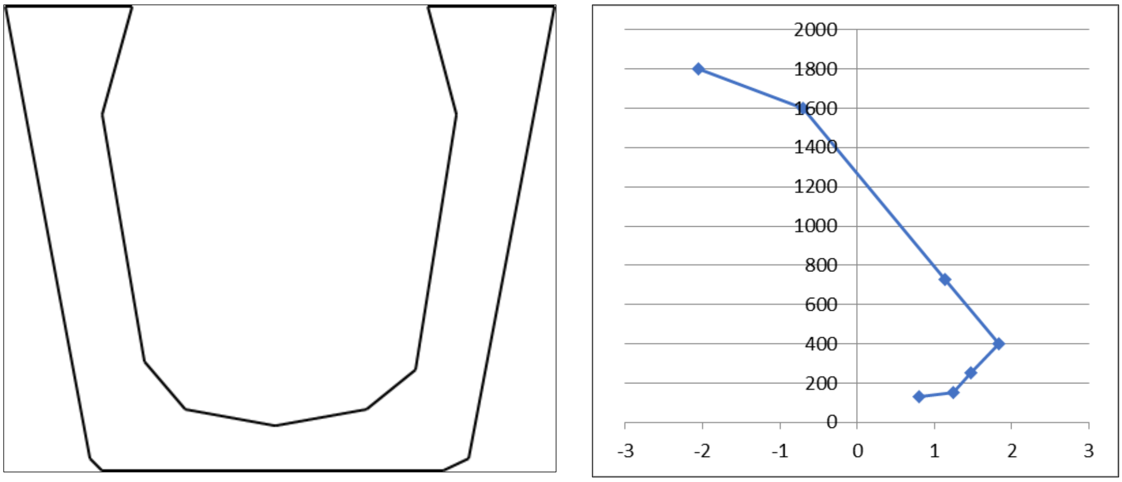

Figure 7 Final stresses: heating

Also, Table 5 presented the Final thermal stress distribution of cooling on the bridge and indicated that only the top and bottom surface has a positive values where as other sections of the bridge has negative stress values. Figure 8 demonstrated the variations from top to bottom of the bridge.

Table 5 Final Stress Thermal stress calculation (cooling)

Position from top	**σ (MPa)**	$-\Sigma F/_{A}$ **(MPa)**	**y (mm)**	$-(\Sigma M/_{I})$**y**	**Final stress (MPa)**
0	3.11	-0.81	726	0.16	2.46
250	0.19	-0.81	476	0.10	-0.52
700	0	-0.81	26	0.01	-0.80
950	0	-0.81	-224	-0.05	-0.86
1200	0.29	-0.81	-474	-0.10	-0.62
1550	0.37	-0.81	-824	-0.18	-0.62
1800	2.41	-0.81	-1074	-0.23	1.37

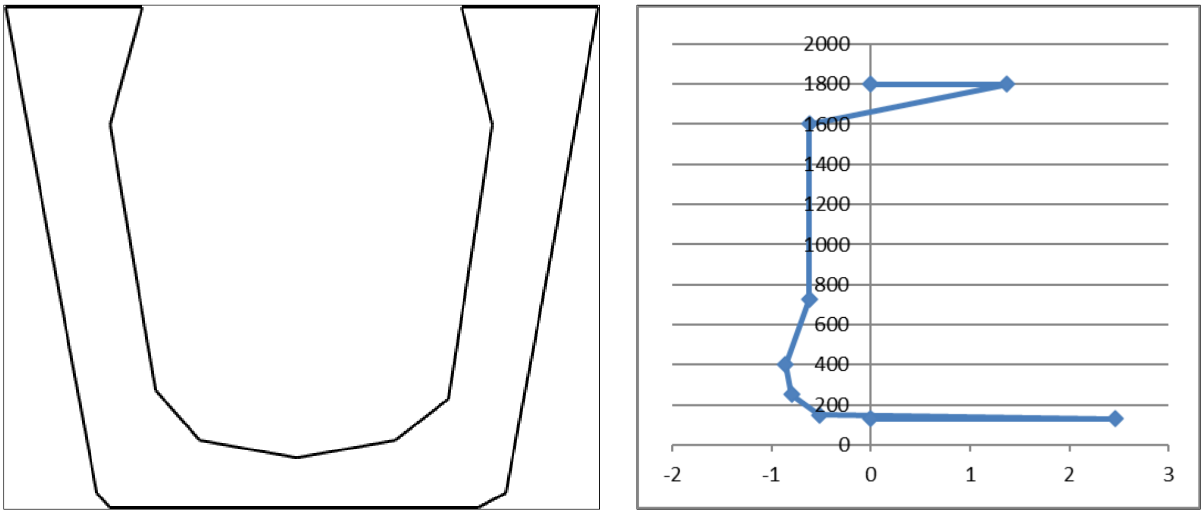

Figure 8 Final stresses: Cooling

3.5. Shear Forces Acting on the Beam

The Shear Force values on the beam were calculated from the summation of all the forces acting on the beam including the thermal and wind forces. It was highest at the outer support (zero distance) with the value of 1438kN and lowest at midpoint 12.5m with the value of 144kN as shown in table 6. It is worthy of note that the shear force values are symmetrical about the midspan.

Table 6 Summary of shear forces acting on the beam

Position (m)	V_{bs} (kN)	V_{sf} (kN)	V_{gr5} (kN)	V_{Ed} (kN)
0	360.331	55.946	655.380	1438
1.25	324.545	50.599	638.634	1360
2.5	288.759	45.251	547.295	1180
3.75	252.973	39.904	519.641	1090
5	217.187	34.556	444.258	934
6.25	181.401	29.209	410.281	8833
7.5	145.615	23.861	326.000	665
8.75	109.829	18.514	302.196	578
10	74.043	13.166	216.206	407
11.25	38.257	7.819	205.894	338
12.5	0.000	0.000	102.172	144

In order to simplify the design, the shear links are designed based on the maximum shear force at zero meters. True design demands that a distance d from the support should be main considerable factor.

3.6. Detailing of the design

The details of the beam design is summarized in this section, the values are obtained from the calculations using the PBridge and in accordance with the stipulations in [15]. Figure 9 represents the cross section of the beam.

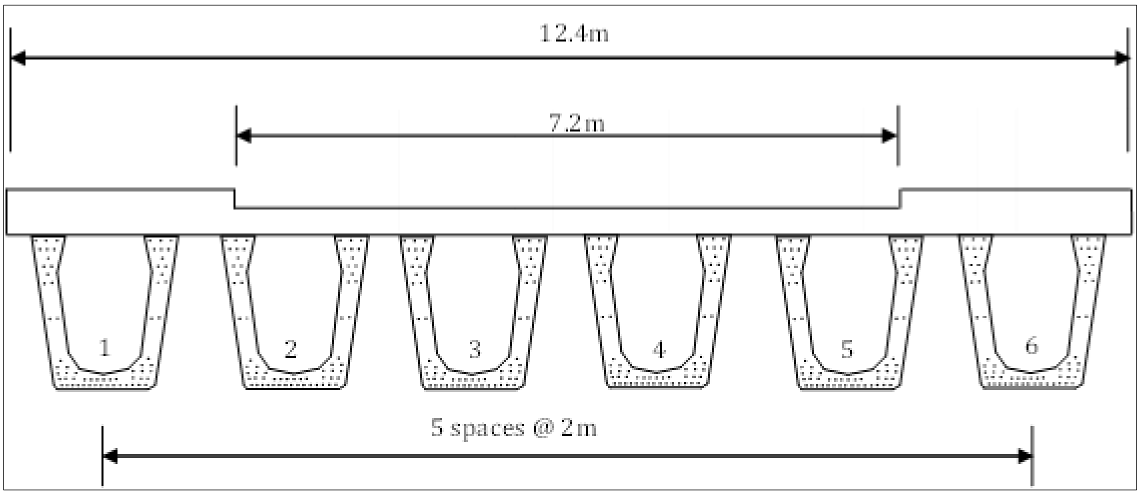

Figure 9 Single span Bridge cross section

3.7. Comparison of the results

To further validate the authenticity of the obtained results, the Bending Moment and Share Force results for both the STAAD Pro and PBridge were compared in Table 7 for the single span. The percentage difference at 2.5 metre from the end support was 0.0048 for the moment of the single span. For Share Force, it was 0.075 for Single span at 2.5 distance. These imply that the developed programme can reliably be used for analysis and design of prestressed concrete bridge.

Table 7 Percentage Difference of Moment and Shear force for the Single Span

	StaadPro		PBridge		Percentage difference	
Dis (m)	M_{imp} (kNm)	V_{Ed} (kN)	M_{imp} (kNm)	V_{Ed} (kN)	M_{imp} (kNm)	V_{Ed} (kN)
0	0	1438	0	1437.453	0.0000	0.038
2.5	3705	1180	3704.824	1179.111	0.0048	0.075
5	4924	934	4923.911	935.023	0.0018	-0.110
7.5	5842	665	5841.926	666.214	0.0013	-0.183
10	6329	407	6329.011	406.781	-0.0002	0.054
12.5	6543	144	6543.008	143.982	-0.0001	0.013

4. Conclusion

The development of Computer Programme “PBridge” in order to alleviate the complicated nature and challenge of designing a prestressed concrete bridge are amply demonstrated by the study. Development of PBridge which can assist in providing the designer with a set of load models that are calibrated to reflect the effects of traffic, wind and temperature loads as stipulated in Eurocodes which cover a variety of potential actions on structures is a wonderful development in Engineering [20].

Not minding the fact that there are a lot of defined models used in Manual analysis and design, it is frequently difficult to determine what combination of loads will have the most detrimental effect on the structure even with the defined load models. Therefore, it is concluded that the developed programme can now assist in accurate and timely results of structural analysis.

The developed programme assists the engineer/designer to create a more cost-effective and durable designs because they have a better understanding of the material's properties and how it responds to stress. Even with all of the information available today, prestressed concrete is still a relatively new form of construction, and more is discovered regarding its properties and strengths every day. The study of prestressed concrete illustrates why engineers must commit themselves to a lifelong learning process. Although the design does become somewhat complicated, the results of this study clearly demonstrate the benefits of prestressed concrete design.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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