Bridge Grillage Analysis using Finite Element Methods

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ABSTRACT: This paper introduces a two dimensional bridge deck for a cantilever bridge with a 15 m long span that has been modelled and analysed using computational modelling software (LUSAS) to obtain maximum moments and shear forces. The significance of the problem is to determine the worst scenario case within the deck in terms of highest bending moment and shear force, for example, the most affected parts of deck under load. The problem was tackled with the aid of LUSAS Bridge Plus which is part of LUSAS software package. Generally, LUSAS Bridge Plus works by analysing equations and allowing combinations of load case results.

KEYWORDS: Bridge Engineering, Structural design, Structural analysis, FEA, LUSAS Bridge Plus.

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I. Introduction

A. Scope of work

This report is about bridge grillage analysis of a problem using LUSAS Bridge Plus. The grillage analysis is considered to be one of the famous methods used for analysing bridge decks. One of the most reliable ways of grillage analysis is the usage of computer-aided method. This is due to many reasons such as its accuracy in conducting analysis for different types of bridges, easy to use and cost effective (Hambly et al., 1991).

In the first section of this report, the analysis specification is presented with a description of the structure and analyses carried out such as, explanation of the analysis stages and work done by the author from modelling the structure, creating grillage, applying loads and carrying out load combinations. The results obtained for the structure will be presented, along with a brief discussion on what they indicate and mean. Furthermore, the results will be discussed in terms of maximum shear forces and bending moments. Finally, the conclusions will be stated clearly with an answer to the client question and reliability of results obtained.

B. Aims of the paper

The main objectives of the manuscript are:

- To analyse the structure using LUSAS Bridge Plus in an effective manner.
- To calculate the maximum bending moments and shear forces within deck.
- To find the associated forces and moments experienced by deck.
- To design appropriate cantilever bridge deck, applying Eurocode loadings to it and determining the bridge behaviour under these loadings.
- To present and discuss the results obtained for the analysed bridge deck.

II. Literature Review

Wang and Huang et al. (1996) did a study on the dynamical behaviour of highway girder bridges under different loads. They applied different dimensional simulations on nine girder bridges with span lengths ranging from 40 to 120ft. The design of the girder bridge was referenced to the AASHTO standard highway bridges. Their findings showed that there is a direct correlation between the roughness of the road surface and the maximum impact factors. However, their study was majorly based on numerical calculations and lack of software FEA modelling.

Linzell and Shura et al. (2009) investigated the rates of accuracy and reactional response of girders by modelling grillage models and analysing the bending stress elevations. They recommended further study on the selection of modelling techniques to find a response prediction of the already existing curved bridges.

Adamakos and Vayas et al. (2010) has focused on numerical modelling of curved bridges with steel I-girders. They concluded that using FEA modelling for analysing the structural behaviour of curved and straight bridges cannot provide an efficient prediction of bridges in real life situations. Moreover, more 3D bridge modelling with a refined meshes are needed to be analysed on different types of bridges and more research on using alternative methods.

Kwasniewski et al. (2006) has numerically modelled a case study of a highway bridge in Florida – US 90 using FEA method. However, the study was based only on a multi-girder bridge. The study carried out by Barth et al. (2006) illustrated plastic ultimate load behaviour for a bridge of a slab on top of

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a steel stringer using FEA. He used ABAQUS software to model, mesh refining and structural analysis of a 3D FE model.

Alaylioglu et al. (1997) presented a numerical analysis and calculations to assist the plastic response of a highway bridge using FE hybrid model. He validated his assessment method to effectively predict the stiffness properties of the highway bridge. Similarly, Kirsch et al. (1998) has suggested a developed a method for grillage structures in general to approximate the rigidity using stiffness analysis formulations.

Brien and Keogh et al. (1998) did a 3D bridge deck model with 2 spans using FEA method. They used a new upstand technique to indorse their model and to proof the accuracy of the method in forecasting the longitudinal bending stresses.

Lu, Xie and Shao et al. (2012) has conducted both numerical and experimental studies on a composite bridge. They designed a 3D FEA composite curve interface bridge and validated the results with the experimental part to demonstrate the efficiency of their model in predicting the structural stability and serviceability when compared with a real life situations.

III. STATEMENT OF THE PROBLEM

A. Description of the problem

The distribution of loads applied on deck is variable and obviously would be different in some zones than others. It is known that the bridge deck will have various forces and moments at different parts by which some zones will have low magnitudes and other parts would have high magnitudes. Thus, the problem is associated with the most affected parts of the structure with respect to maximum forces and moments.

B. Characteristics of the problem

The deck is made from Concrete BS5400, Short Term C50 with a footway density of 2400 kg/m^3 and a surface density of 2000 kg/m^3. The deck is 15 m long (span), 11m in width and with a diaphragm height of 0.5 m as revealed in

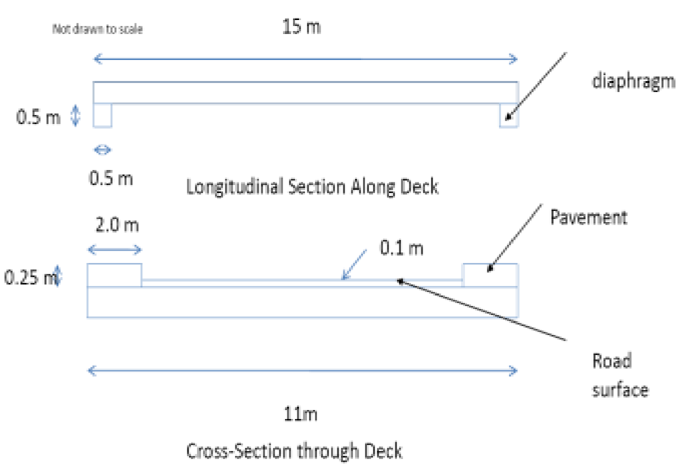


Figure 1: Shows longitudinal section along deck and cross-section through deck.

Figure 1. Also the pavement of the deck has a height of 0.25 m, 2 m in width and a road surface thickness of 0.1 m. Figure 2 demonstrates the cantilever cross section through the deck with relative dimensions of sections.Initially the LUSAS Bridge Plus was selected and the units set for the model was (kN, m, t, s, c) and a vertical axis to Z. After that the cantilever section was divided into several sections to make it simpler to apply them on the deck. The section properties created consisted of six sections.

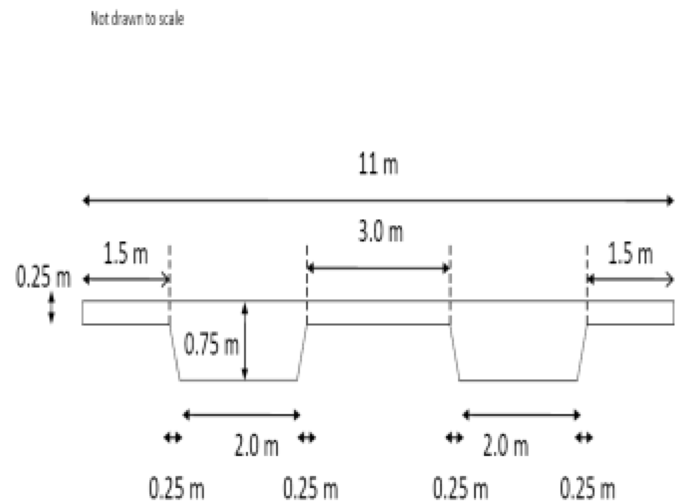


Figure 2: Cantilever section properties.

IV. ANALYSIS SPECIFICATION

A. Purpose of carrying out the analysis

The main purpose of the analysis is to calculate the maximum forces and moments which are most likely to be experienced by the bridge deck under various loads which will be discussed further in more details in the next section of the report. The worst case situation from the load combinations used will have the most attention and discussion. Another important aspect of the analysis is to produce a reasonable modelling of the deck.

B. Section properties

The first section (longitudinal section 1) was a simple rectangular solid (standard section) and it was created using section property calculator, with a height of 0.25m and a width of 1.5m as revealed in figure 3 After that the section was added to local library to be used later in the deck. Mackie et al. (2011) has stated that "the section property calculator tools in LUSAS software automatically calculate the section properties of a certain section once the dimensions are identified". Table 1 shows the list of section properties that were created.

Table 1: List of section properties.

Description	Area (m^2)	Iyy (m^4)	Izz (m^4)	Jxx
Longitudinal (Sec.1)	0.375	1.953E-3	0.070	3.496E-3
Longitudinal (Sec.2)	1.75	0.074	0.801	0.121
Longitudinal (Sec.3)	0.75	3.906E-3	0.562	7.402E-3
Transverse Section	0.375	1.953E-3	0.070	3.496E-3
Right diaphragm	0.437	0.021	0.015	0.020
Left diaphragm	0.437	0.021	0.015	0.020

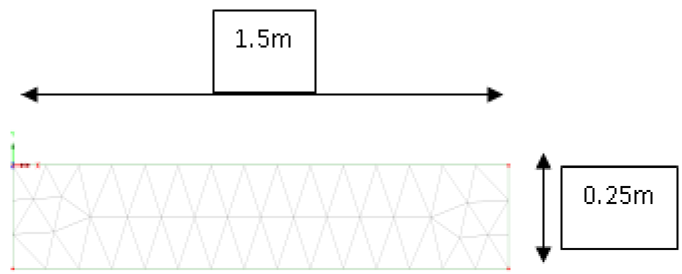


Figure 3: Longitudinal section 1.

The second section (longitudinal section 2) was irregular section and it was not possible to form the section using section property calculator. Thus, the section was drawn by identifying coordinates of a new surface as demonstrated in Figure 4. The coordinates of this section was identified according to

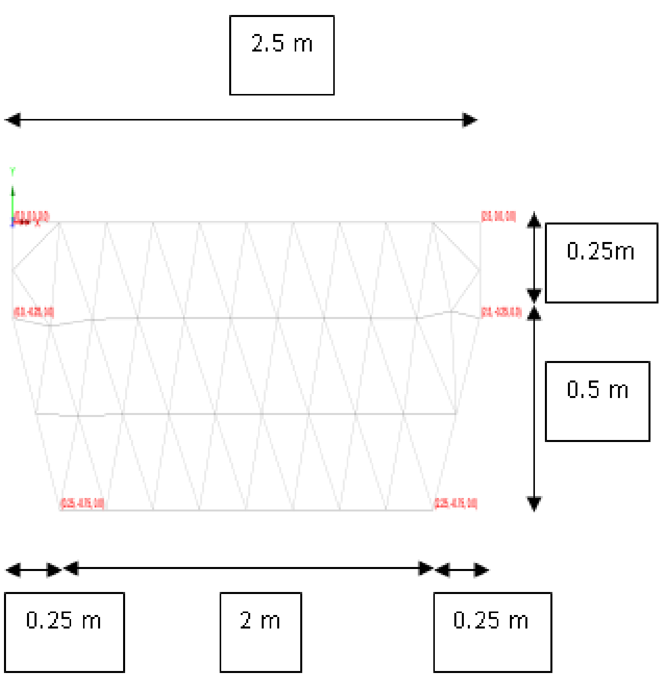


Figure 4: Longitudinal section 2.

dimensions and divided for assembling. The surface was then selected and the section type chosen was arbitrary section from the section property calculator, by which the Max. elts/line was 10. After that the section was added to local library. The procedure of creating the third section (longitudinal section 3) was same as that carried out in section 1 since it is also simple rectangular solid (standard section). The dimensions of section 3 are presented in figure 5.

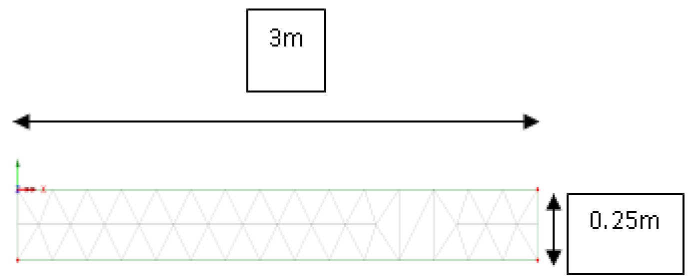


Figure 5: Longitudinal section 3.

Moreover, the fourth section (transverse section) is exactly the same as first section in terms of dimensions and properties as shown in Figure 6.

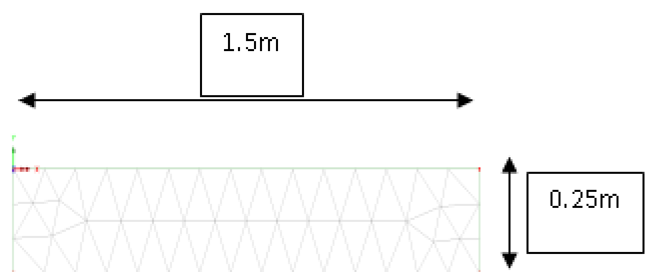


Figure 6: Transverse section.

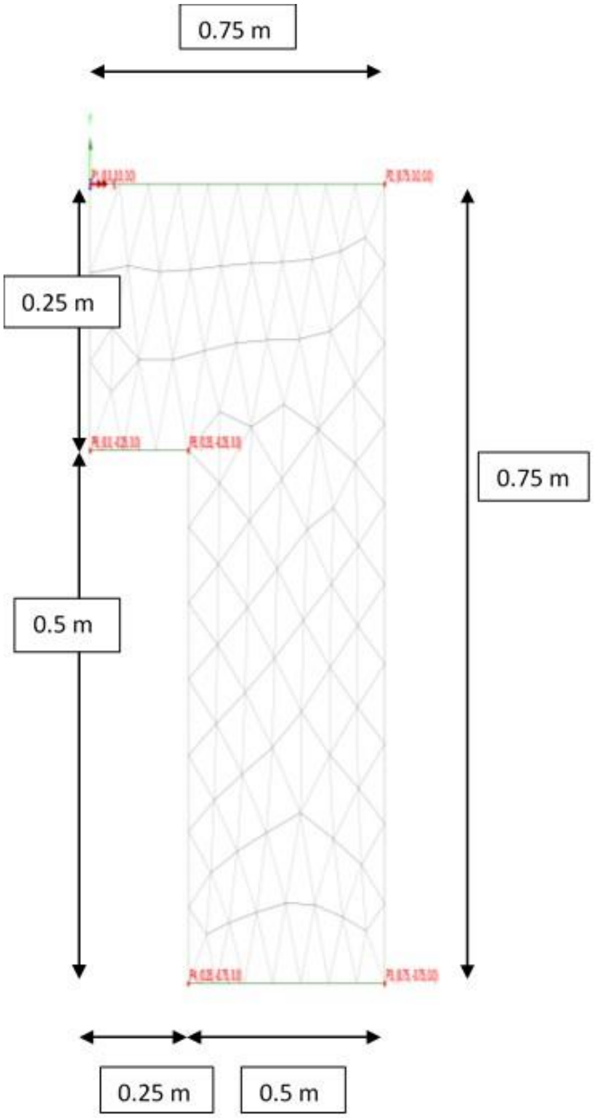


Figure 7: Right diaphragm section.

The fifth section (right diaphragm section) was performed in the same manner as section 2. Since this section is irregular in shape its coordinates was initially identified and it was then drawn as a surface. Figure 7 shows the coordinates and dimensions of the section. Additionally, section 6 (left diaphragm section) is the same as section 5 with respect to its dimensions and properties but facing left side (Fig. 8). After creating the sections they were all added to local library to be applied later on the grillage.

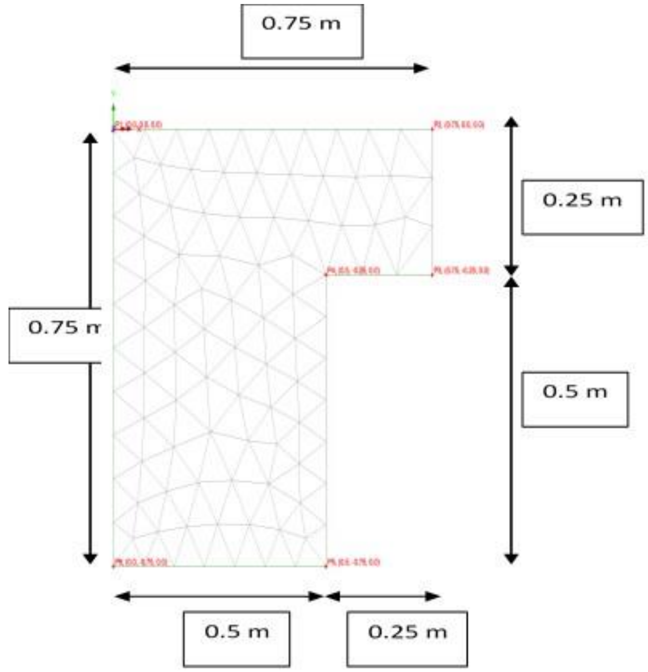


Figure 8: Left diaphragm section.

C. Grillage

The grillage wizard had some problems due to the student version software, thus, the grillage was carried out manually. Figure 9 shows the grillage used with the arrangement used and relevant dimensions. The horizontal arrangement is 15m which is the span of deck; it was decided to divide it into 10 equal parts where each part is 1.5m. The vertical distance is 9.5m and the arrangement is 2m, 2.75m, 2.75m and 2m. This arrangement was carried by taking the distance of centre of section 1 to centre of section 2 which is 2m. The 2.75m is the distance from centre of section 2 to centre of section 3, by which it is also the same distance as that from centre of section 3 to centre of section 4. Finally, the distance from centre of section 4 to centre of section 5 is 2m. Figure 10 demonstrates the distance of the vertical arrangement of grillage.

Initially the grillage was done by creating a line with a coordinates of (0, 0) and (1.5, 0). The line was then selected and copied 9 times by 1.5m in x-direction. The next step was selecting everything and sweeping it by 2m in y-direction. The upper line was then selected and sweep twice by 2.75m in y-direction. The last part of conducting the grillage was selecting the upper line and sweeps it again by 2m. The above procedure has resulted in the formation of the grillage. Since the deck is made of concrete, a material has been recognized as Concrete BS5400 with a Short Term C50. After that the material was applied along with Grillage element div=1 on all the grillage. The diaphragms of grillage were fixed in Z support.

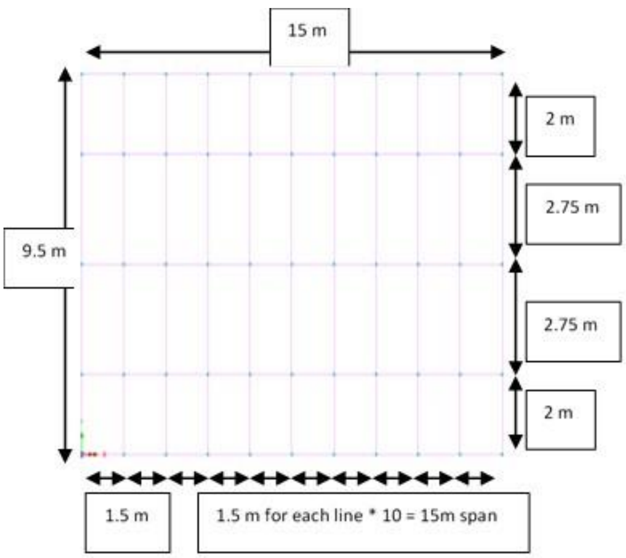
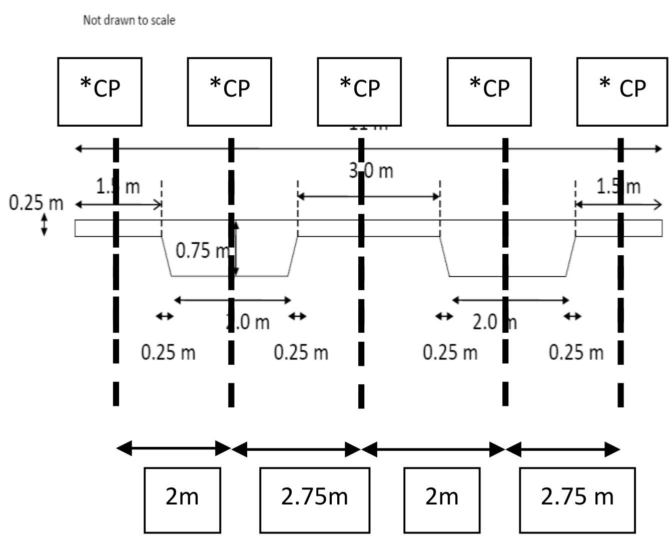


Figure 9: Refined mesh with the geometry of structure to be analysed.



* Centre Point

Figure 10: Shows the distances of the vertical arrangement.

D. User sections

The grillage was divided into six groups in order to assign the appropriate user sections to them. But before creating the groups, the user sections were modified from geometric section library. The modification of all the user sections included setting usage of section to grillage and half the torsion value. According to Mackie (2011) "Half of the torsion (J) value should be included in section property, otherwise, the torsion value may be calculated twice" Therefore, the J value was edited and half of it was included in properties of user sections. The user sections were then assigned to relevant parts of the grillage by copying the section from attributes and pasting it in the appropriate group under groups tab.

The first group created was Left Diaphragm and the user section applied on this group was section 6 (left diaphragm section). Additionally, the second group was right diaphragm and the user section applied on this group was section 5 (right diaphragm section). The third group was transverse lines and the user section assigned to this group was section 4 (transverse section). The fourth group was top and bottom longitudinal lines and the user section allocated to this group was section 1 (longitudinal section 1). The fifth group was section 2 longitudinal lines and the user section applied on this group was section 2 (longitudinal section 2). The sixth group was middle longitudinal lines and the user section assigned to this group was section 3 (longitudinal section 3).

E. Loading points

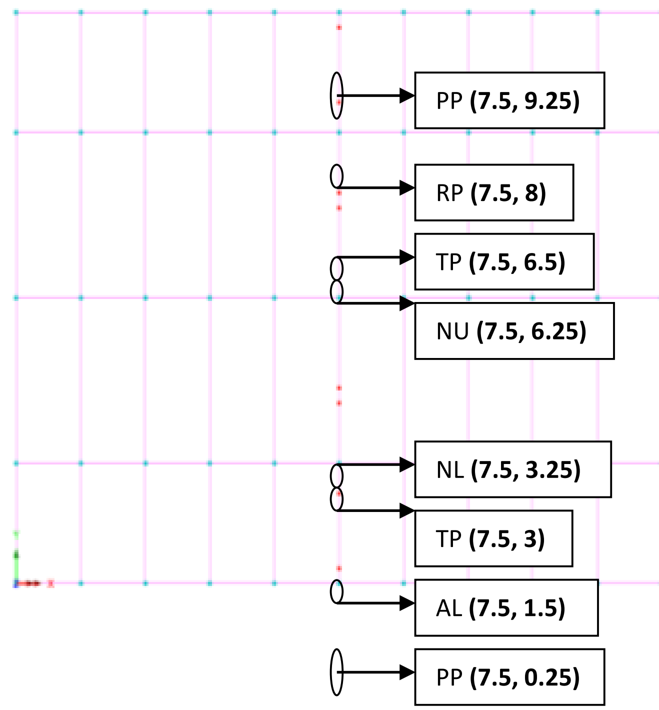


Figure 11: Shows the position and coordinates of loading nodes on the refined mesh.

The loading points were identified and plotted on the grillage to apply the appropriate loads to them. Those points are not part of the grillage; they are just used for assigning loads. In this case there are eight different points which are two pavement points, one remaining point, two tarmac points, and normal upper, normal lower and abnormal lower. Figure 11 presents these points on the grillage with their coordinates. Additionally, the grillage was sketch on AutoCAD Civil in order to find the position of loading points. The x-coordinates of loading point are all the same 7.5m which is half the span.

F. Loading

Two types of loadings were applied on the deck which is dead load and traffic loads. Initially this was done by creating gravity loading from bridge loading and applying it just on the longitudinal members. The load case 1 was then renamed as Dead load. The tarmac (deals with loading due to the road surface) was then recognized from bridge loading surfacing with properties set as 2t/m2 for density, 15m for length (span), 3.5m for width and 0.1 for thickness. This surface load was assigned to the two tarmac points with coordinates (7.5, 6.5) and (7.5, 3) as illustrated in figure 11. Moreover, the load was applied to Dead Load. Another load was created for pavement surface which has been also identified from bridge loading surfacing with properties set as 2.4t/m2 for density, 15m for length (span), 2.0m for width and 0.25 for thickness. This surface load was assigned to the two pavement points with coordinates (7.5, 9.25) and (7.5, 0.25) in Fig. 11. Furthermore, the load was applied to Include Full Load.

The vehicle loading that has been chosen was Eurocode Bridge Loading. This was carried out by identifying the Tandam System for Load Model 1 – Tandem as Lane number 1 – 300kN and the loading data for Load Model 1 – lane Load was set as 15m for length and 9.0 for surface load. Additionally, the abnormal loads were recognized from Load Model 3, where the vehicle type selected was 1800/200. After this the remaining load was adjusted as a patch type from Attributes/Loading tool with a 4 node patch and -7.5, 7.5, 7.5, -7.5 in the X column, -0.25, -0.25, 0.25, 0.25 in the Y column, zeroes in the Z column and intensity of the load -2.5 kN/m2 in the Load column. The loads were applied to suitable construction points (loading points) as demonstrated in table 2 below:

Table 2: List of loads applied to the structure.

Load node	Load applied	Set to
PP (7.5, 9.25)	Surfacing 15m x 2m Density = 2.4t/m3	Full load
RP (7.5, 8)	Remaining load	Dead load
TP (7.5, 6.5)	Surfacing 15m x 3.5m Density = 2t/m3	Dead load
NU (7.5, 6.25)	5: Eurocode Lane 9kN/m2 Load	Normal upper
	4: Eurocode Load Model 1 300kN	Normal upper
NL (7.5, 3.25)	5: Eurocode Lane 9kN/m2 Load	Normal lower
	4: Eurocode Load Model 1 300kN	Normal lower
	6: Eurocode Load Model 3 1800/200	Abnormal lower
TP (7.5, 3)	Surfacing 15m x 3.5m Density = 2t/m3	Dead load
AL (7.5, 1.5)	Remaining load	Dead load
PP (7.5, 0.25)	Surfacing 15m x 2m Density = 2.4t/m3	Full load

The model was run successfully after assigning the appropriate Loadings to loading and construction points as shown in Table 2.

G. Load combinations

Although several load combinations has been carried out, the main aim was to take the worst case scenarios into consideration. The first combination was the Normal load combination which was named as Normal – both lanes basic. It is a basic combination which includes Normal Upper and Normal lower and the load factor that has been used for each load is 1.35. This load factor was chosen with respect to Eurocode 1: Actions on structures / Part 2: Traffic loads on bridges. Another basic combination was recognized with same procedures carried out as that in normal load combination. This combination includes Normal upper and abnormal lower and was named as Abnormal Lower, Normal Upper. The load factor used in this combination was also 1.35. Then the live load combinations (Normal both lanes and Abnormal Lower, normal upper) were enveloped. Basically this was carried out by using the Envelope tool in Utilities, changing the file extension from *.mys to Model and adding combination (Normal both lanes and Abnormal Lower, normal upper). The envelope was then named as Live load envelope. According to Mackie (2011) "the envelope utility creates a minimum and a maximum load cases for a specified entity". After that a new combination was identified and performed. This combination was a smart one and it was named as Design Combination. The combination included the Dead Load, Live Load Envelope (Max) and Live Load Envelope (Min). During the commencement of this combination the factors included in the grid were set as presented in table 3 below:

Table 3: Factors set in grid for loads used in design combination.

Type of factor	Dead load	Live load Envelope (Max.)	Live load Envelope (Min.)
Permeant	1	0	0
Variable	0.275	1	1

V. RESULTS

A. Results presentation

Table 4: Maximum shear force for Max and Min combinations and envelopes.

Combination	Maximum Shear force (kN)	Node
Design (Max.) Combination	1.605E3	Gauss point 11 of element 30
Design (Min.) Combination	-1.605E3	Gauss point 11 of elementLive
load Envelope (Max.)	965.658	Gauss point 1 of element 30
Live load Envelope (Min.)	-965.658	Gauss point 1 of element

Table 5: Maximum bending moment for Max and Min combinations and envelopes.

Combination	Maximum Bending moment (kNm)	Node
Design Combination (Max.)	-2.072E3	Gauss point 1 of element 94
Design Combination (Min.)	-6.921E3	Gauss point 1 of element 86
Live load Envelope (Max.)	-3.562E3	Gauss point 1 of element 94
Live load Envelope (Min.)	-4.279E3	Gauss point 11 of element 63

B. Discussion of the results

The results were obtained from LUSAS Bridge Plus as a contour map which shows haw the shear forces and bending moments are distributed in all regions of the deck. Moreover, the contour map provides maximum shear forces and bending moments which is the case of interest in this problem. The analysis of the deck was carried out with two design combinations (Max and Min) and two live load envelopes (Max and Min). Each combination and envelope had different maximum bending moment magnitudes. It was discovered that the maximum bending moment for design combination (Max) was in the middle of the deck (Figure 12) with a value of -2.07241E3 kNm. Furthermore, the maximum bending moment for design combination (Min) was -6.92183E3 kNm (Figure 14). Additionally, the maximum bending moment for live load envelope (Max) was -3.56281E3 kNm (Figure 16) and for live load envelope (Min) it was -4.27951E3 kNm (Figure 18). Therefore, the worst case scenario was the design combination (Min) with highest bending moment magnitude of -6.92183E3 kNm at gauss point 1 of element 86. Table 5 shows the results of maximum bending moments for all combinations and envelopes.

Conversely, the results obtained for maximum shear forces were in a totally different situation than that for bending moments in terms of magnitude when comparing combinations and envelopes. For instance, the design combination (Max) had a magnitude of 1.60548E3 kN (Figure 13) and design combination (Min) had a magnitude of - 1.60548E3 kN (Figure 15). Also live load envelope (Max) had a magnitude of 965.658 kN (Figure 17) and live load envelope (Min) had a magnitude of -965.658 kN (Figure 19). This demonstrates that there is a modulus or absolute value relationship in the magnitudes (lxl) between combinations and envelopes, which indicates that the value is the same regardless of the sign. Therefore, the worst case scenario was the design combination (Min and Max) with highest shear forces value of l1.60548E3l kN at gauss point 11 of element 30 and gauss point 11 of element 72 with respect to Max and Min design combinations. Table 4 shows the results of maximum shear forces for all combinations and envelopes.

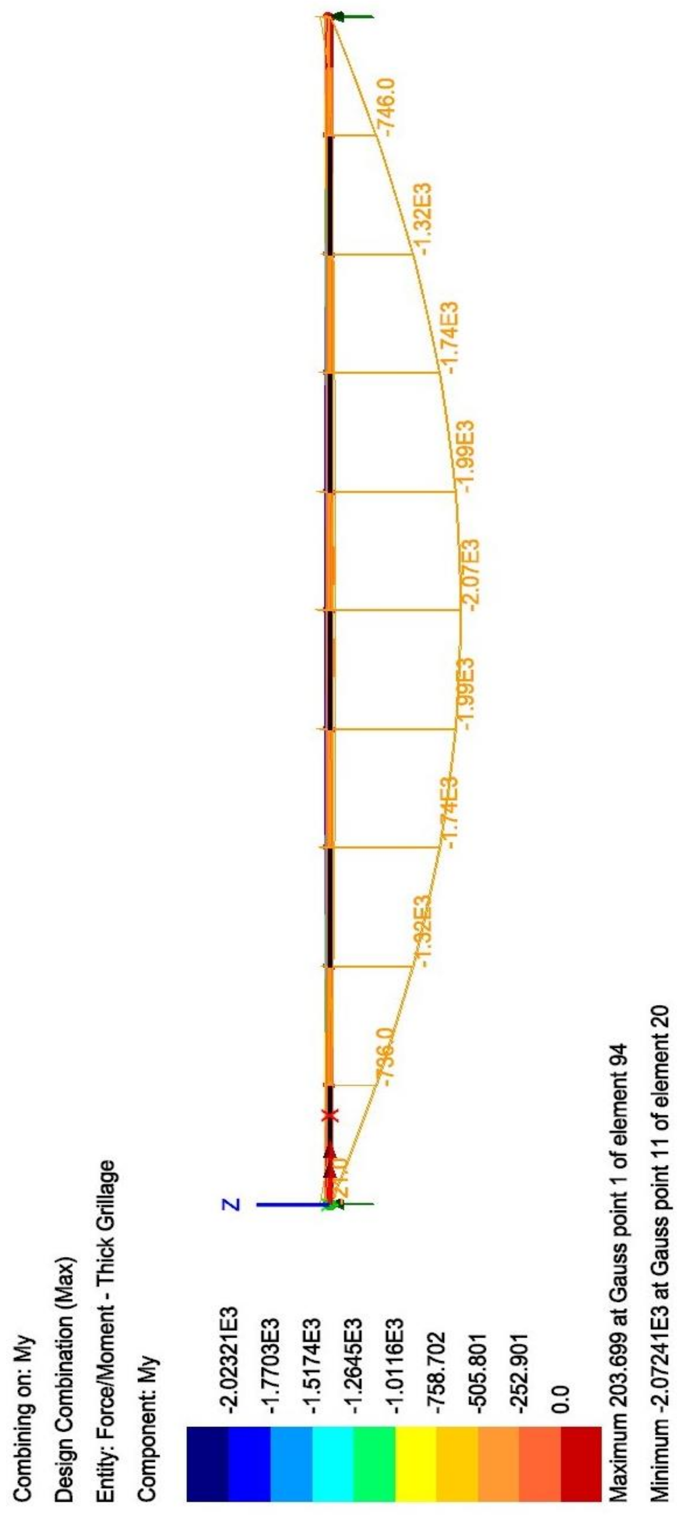


Figure 12: Maximum bending moment diagram (Design Combination Max).

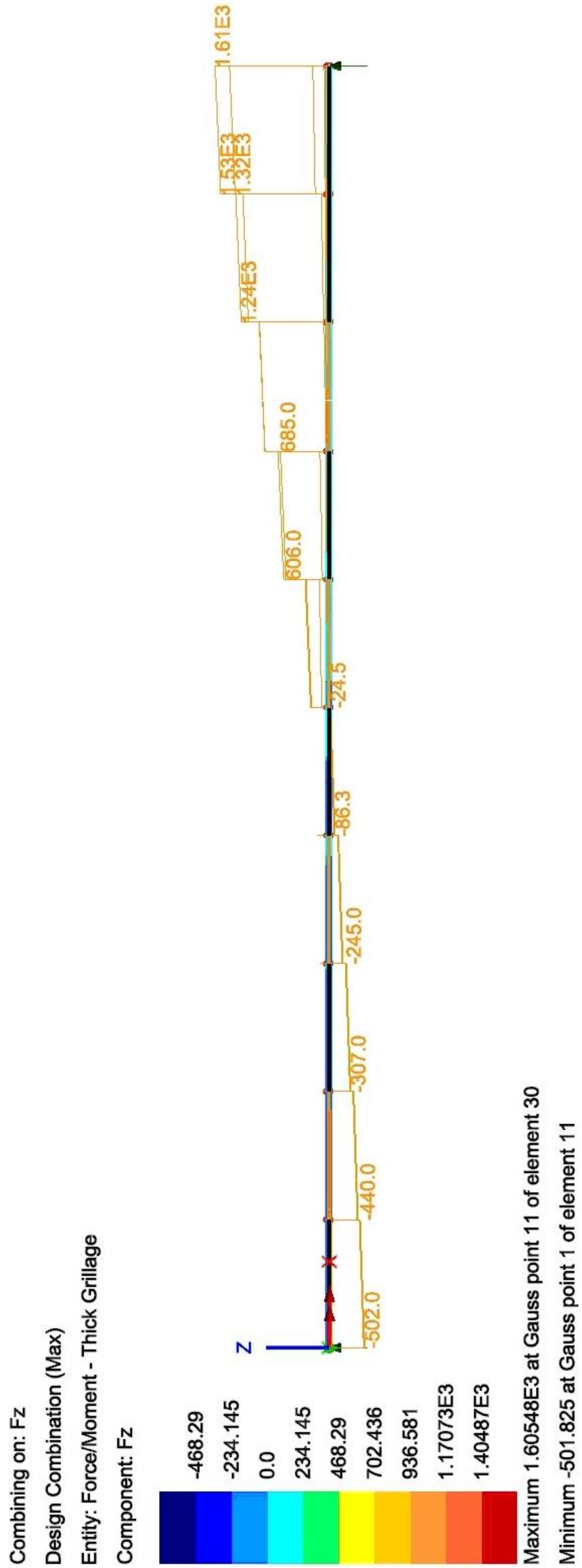


Figure 13: Maximum shear force diagram (Design Combination Max).

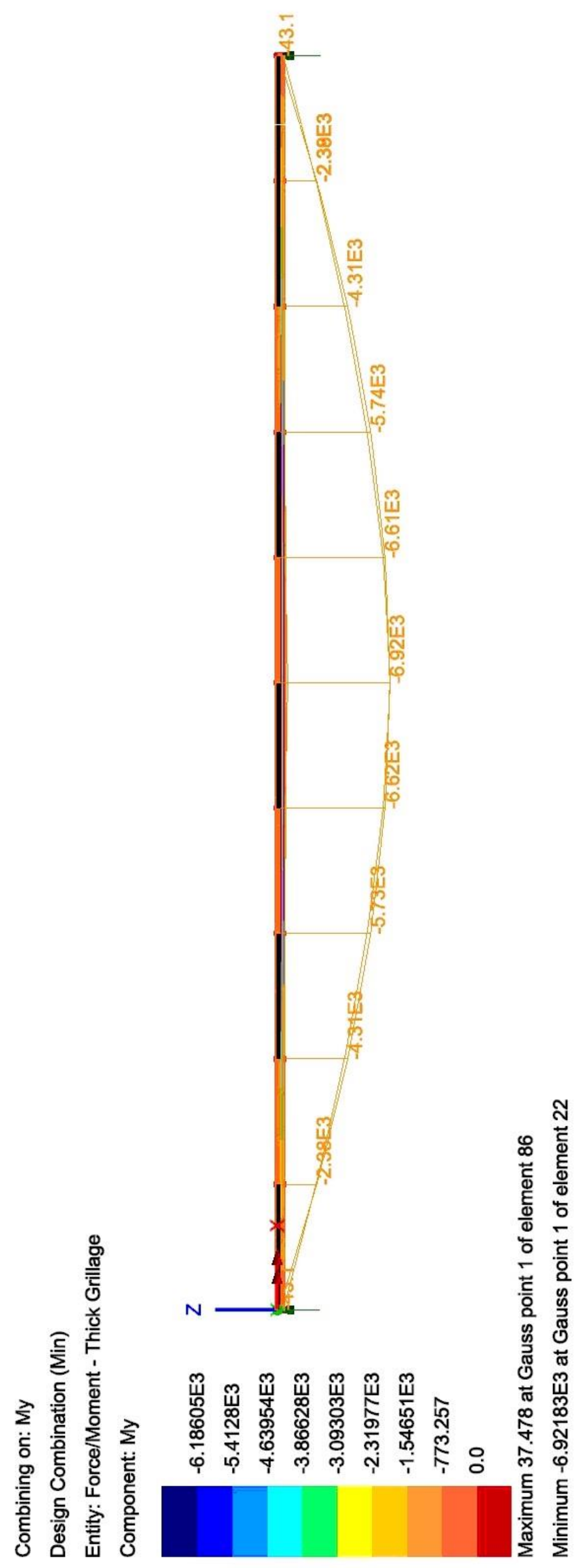


Figure 14: Maximum bending moment diagram (Design Combination Min).

Figure 15: Maximum shear force diagram (Design Combination Min).

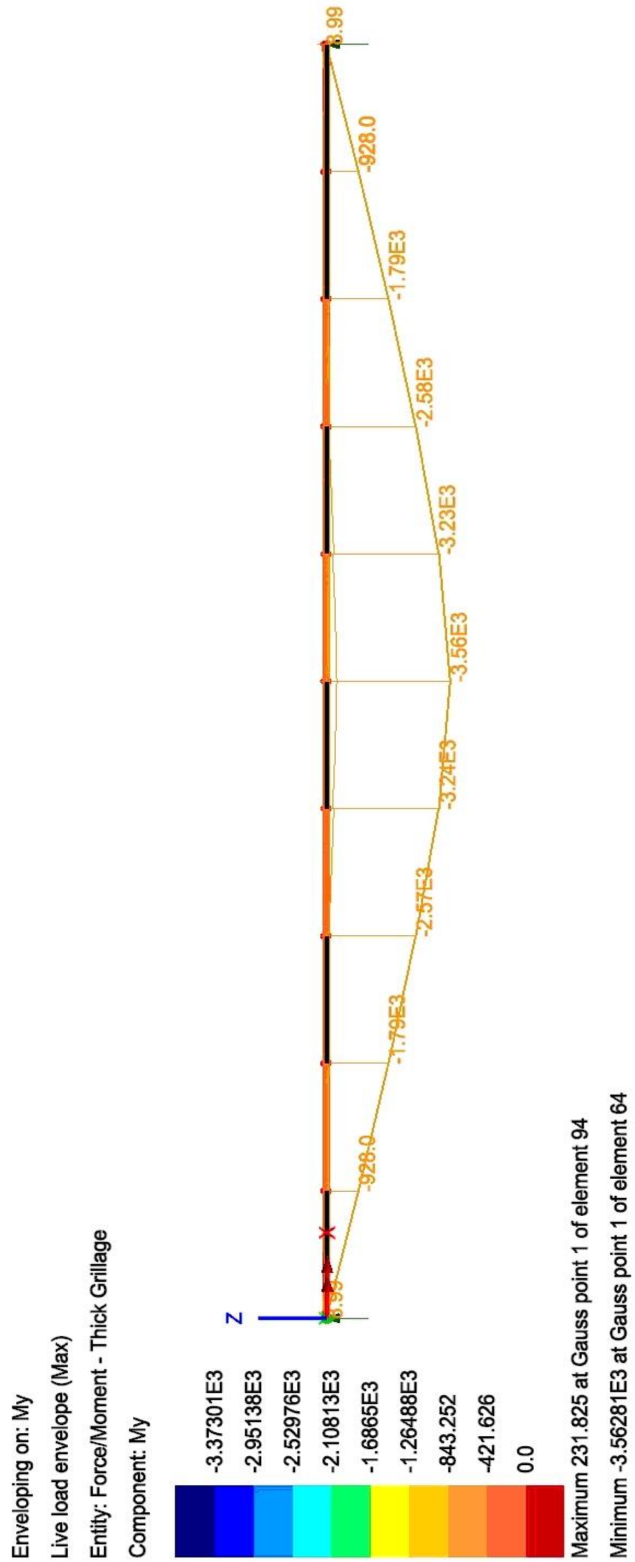


Figure 16: Maximum bending moment diagram (Live load envelope Max).

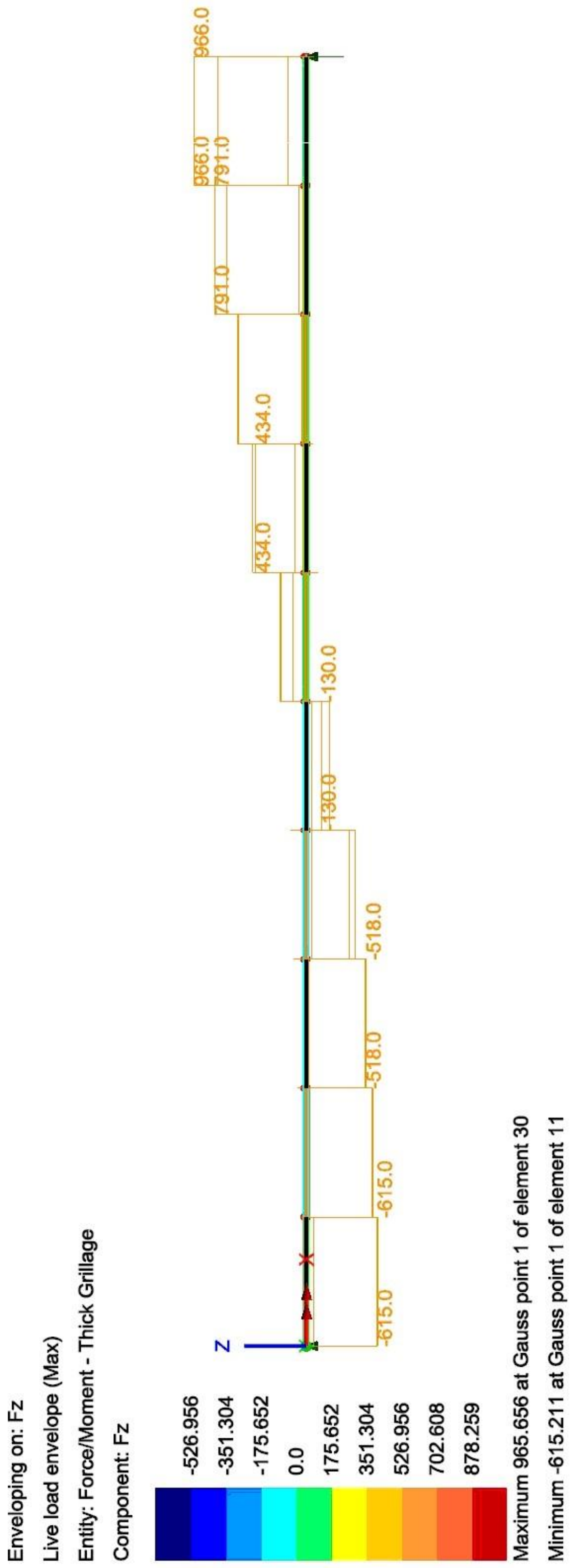


Figure 17: Maximum shear force diagram (Live load envelope Max).

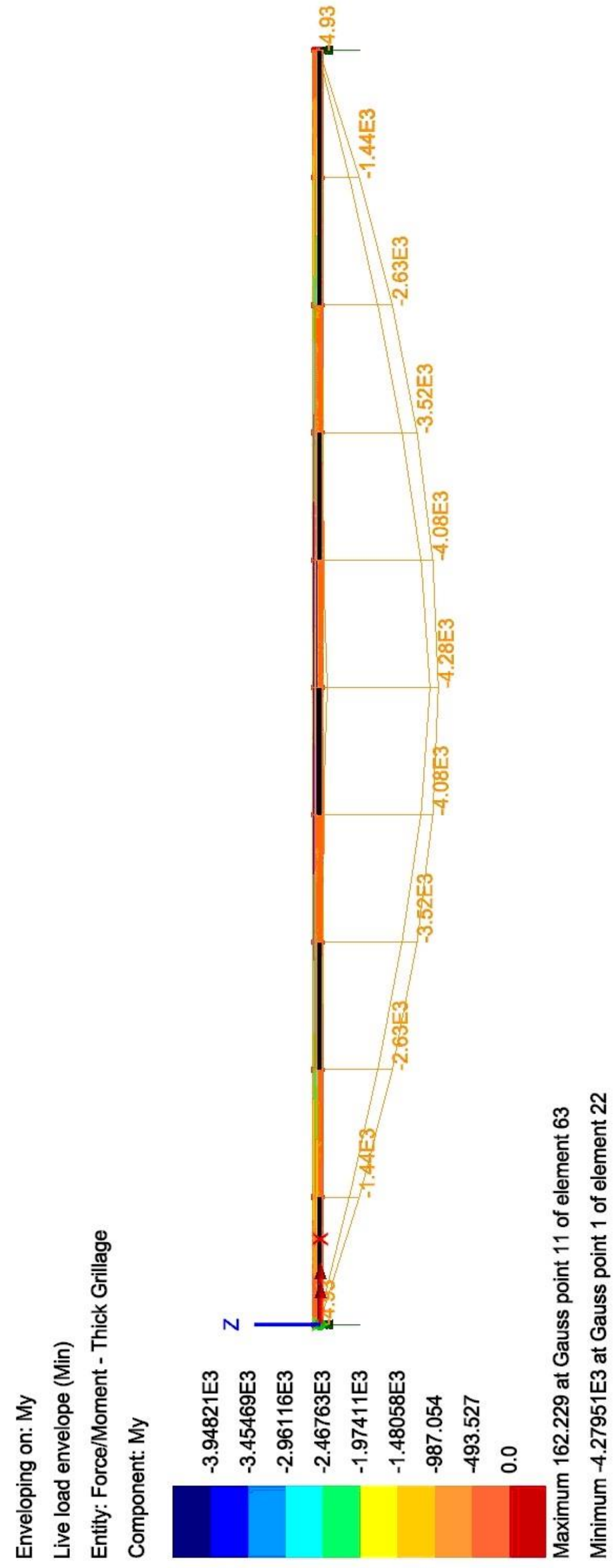


Figure 18: Maximum bending moment diagram (Live load envelope Min).

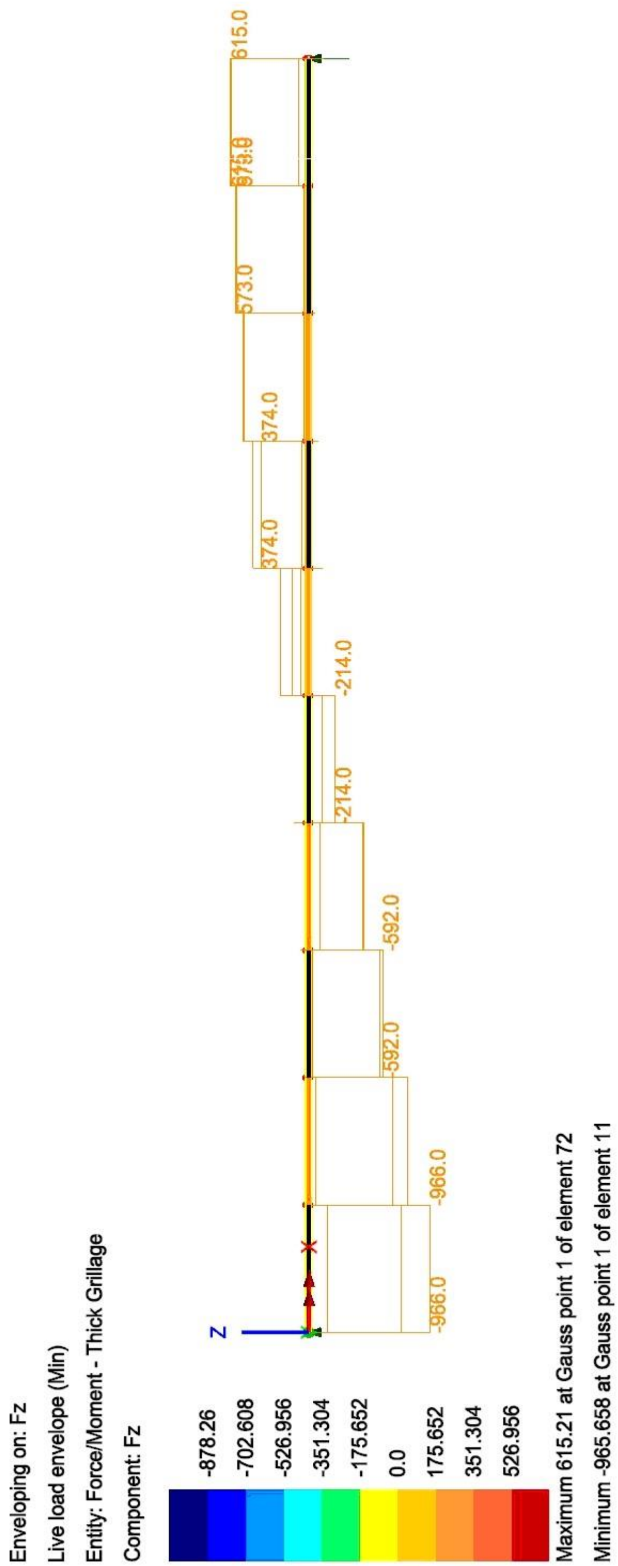


Figure 19: Maximum shear force diagram (Live load envelope Min).

VI. CONCLUSION

The bridge engineering analysis of a problem using LUSAS Bridge Plus (Figure 20) was set to find the worst load combination/envelope case of the deck in terms of maximum shear force and bending moment for a cantilever bridge type. The grillage analysis using computer-aided software was carried out because it is considered to be one of the most reliable and efficient methods used for analysing bridge decks. Accordingly, the grillage analysis was conducted in an effective manner for the sake of accurate results. Two types of loadings were applied on the deck which is dead load and traffic loads.

Moreover, the analysis included two design combinations (Max and Min) and two live load envelopes (Max and Min). It was found that there is a variance in the maximum bending moments experienced by the deck from one combination and envelope to another. Additionally, the maximum shear forces were modulus which means that there is an absolute value relationship in terms of the magnitudes. Thus, there values at different combinations and envelopes were the same regardless of the sign.

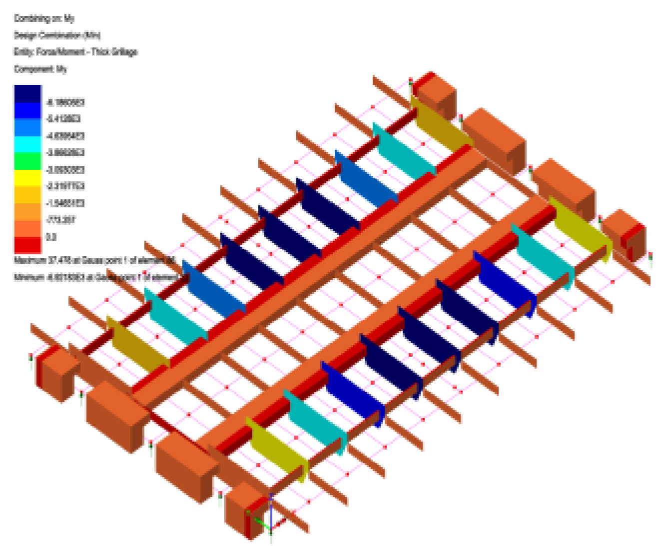


Figure 20: The analysed bridge grillage overall contour map view.

The results obtained revealed that design combination (Min) was the worst case scenario in the structure with a maximum bending moment magnitude of -6.92183E3 kNm at gauss point 1 of element 86. Moreover, the worst situation for maximum shear forces was at design combinations (Max and Min) with a magnitude of l1.60548E3l kN. According to results the following has been concluded:

- The shear forces and bending moments given by the grillage only acts for a certain grid line by which it is part of bridge deck.
- The maximum bending moment is variable at different load combinations/envelopes.
- The maximum bending moment experienced by the part of bridge deck (grid line) was -6.92183E3 kNm.
- The maximum shear forces for different combinations and envelopes were similar.
- The maximum shear force experienced by the part of bridge deck (grid line) was 1.60548E3 kN.
- The bridge deck using grillage analysis showed that deck is behaving in a logical manner under loading.

It is believed that the results are accurate to some extend and could have been improved if more load cases is to be applied, by using the full version of LUSAS Bridge Plus software since it allows more than 10 load cases which is the case when using student version (evaluation limit of 10). Also due to variety of loading that can be applied on the bridge, the author believes that extending the analysis by applying further loadings on the bridge such as wind, hydraulic, impact and seismic loading can improve the results and give more information and details about the behaviour of the structure in real life.

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