Finite Element Analysis of Bridge Deck Girders under Load Model 1 (EN 1991-2) Using Staad Pro

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Abstract

In this paper, a system of slab on precast beam (T-beam) bridge with five girders was loaded with Load Model 1 according to Eurocode (EN 1991-2). The width of carriageway is 7.2m, and with Eurocode specifications, two notional lanes (3m wide each) and a remaining area that is 1.2m wide was produced. The bridge was modelled on Staad Pro V8i software and Load Model 1 was applied and analysed as static loads. The results show that the arrangement adopted produced maximum internal stresses on the exterior and penultimate girder.

Keywords*:* T-beam Bridge, Eurocode, Load Model 1, Staad Pro, Finite Element Analysis

1.1 Introduction

EN 1990 Annex A2 and EN 1991 Part 2 covers the design of road, rail, and foot bridges. It is pertinent to note that while traditional bridge codes used real vehicles for static loads, modern codes such as the Eurocode replaced real traffic loads with artificial load models for static verification which will reproduce the real values of the effects induced in the bridge by real traffic. The static load model for bridges according to EN 1991-2 is calibrated for bridges with width less than 42m and length less than 200m.

Calibration of traffic models for road bridges was based on real traffic data recorded in two experimental campaign performed in Europe between 1980 and 1994 and mainly on the traffic recorded in May 1986 in Auxerre on the motorway Paris - Lyon [1].

In EN 1991-2, four load models are considered for vertical loads and they are;

- Load Model 1 (LM1): This generally reproduces traffic loads which are to be taken into account for global and local verifications. It is made up of concentrated loads and uniformly distributed load.
- Load Model 2 (LM2): This load model reproduces effects on short structural members. It is comprised of a single axle load on a specific rectangular tire contact areas.
- Load Model 3 (LM3): Special vehicles to be considered on request; in transient design situations. It represents abnormal vehicles not complying with national regulations on weight and dimensions of vehicles.
- Load Model 4(LM4): Crowd loading

1.2 Load Model 1

The Load Model 1 which represents the effects of normal traffic comprises of tandem axles (TS) superimposed over a uniformly distributed load (UDL) which its intensity remains constant with the loaded length. The model is very different from Type HA loading given in BD37. Type HA loading consists of a uniformly distributed load, the intensity which varies with the loaded length, and a constant Knife Edge Load (KEL) of 120 KN. There are also lane factors for different lengths which account for simultaneity of loading in adjacent lanes as a function of loaded length. Eurocode (EN 1991-2) load model also differs with BD37 in the way that the carriageway is divided into notional lanes [2]. In EN 1991-2, the notional lane width is constant at 3.0m except for a small range of carriageway width between 5.4m and 6.0m when the lane width varies from 2.7m to 3.0m. (See Table 1.0)

Table 1.0: Subdivision of carriageway into notional lanes

Carriageway width (w)	Number of notional lanes (n)	Width of notional lane	Width of the remaining area
$w < 5.4$m	1	3m	$w - 3$m
$5.4 \leq w < 6$m	2	$0.5w$	0
$6\text{m} \leq w$	Int(w/3)	3m	$w - (3 \times n)$

The characteristics of the Load Model 1 according to EN 1991-2 are as shown below in Table 2.0;

Table 2.0: Load Model 1 Characteristic Values

Position	Tandem Axle Load Q_{ik}	UDL q_{ik} (KN/m^2)
Notional lane 1	300	9.0
Notional lane 2	200	2.5
Notional lane 3	100	2.5
Other notional lanes	0	2.5
Remaining Area	0	2.5

The distribution and application of Load Model 1 on a typical 3 lane carriageway is as shown in Figure 1.1 below.

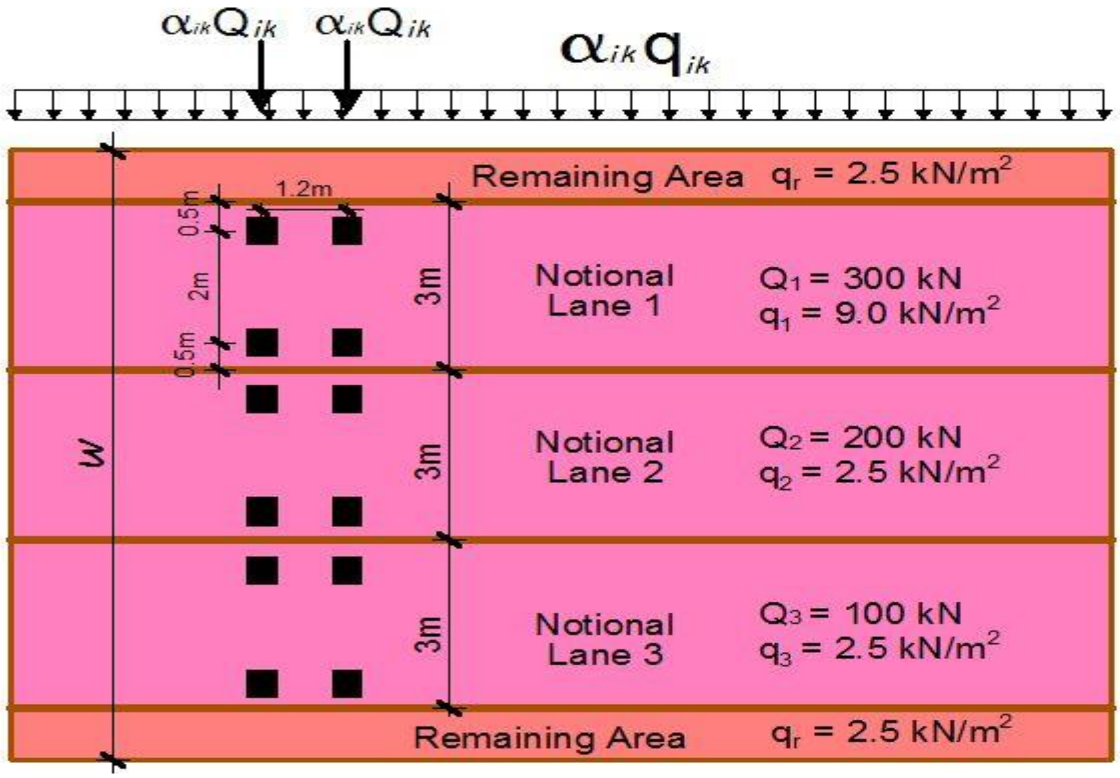

Figure 1.1: Application of Load Model 1 on a deck with 3 notional lanes

Typical rules for Applying Load Model 1

1. In each notional lane, only one tandem system should be considered, situated in the most unfavourable position

2. The tandem system should be considered travelling in the longitudinal axis of the bridge.
3. When present, the tandem system should be considered in full i.e with all its four wheels
4. The UDL's are applied longitudinally and transversally on the unfavourable parts of the influence surface.
5. The two load systems can insist on the same area.
6. The dynamic impact factor is included in the two load systems
7. When static verification is governed by combination of local and global effects, the same load arrangement should be considered for calculation of local and global effects.

1.3 Finite Element Method

The finite element method seeks to replace a continuous type of structural problem, which is alternatively represented by a set of partial differential equations, by a set of discrete, simultaneous linear equations which may be readily solved by computer [4]. The discretization is achieved by sub-dividing the surface to be considered into a number of regions and so creating a set of elements and nodes. It is important to realize that the sub-division process is not a physical separation of the surface so that it becomes joined only at the nodes. The intention is purely to create regions in which the deformation will be assumed to be represented by a particular algebraic function of position. The deformation within different regions (elements) will be represented by different functions, although these will all be of the same general form and will normally be chosen such that displacement continuity is preserved along the element boundaries so that the possibility of element separation will not arise.

On the basis of the assumed displacement function, it is possible to derive an element stiffness matrix linking element nodal 'forces' to element nodal 'displacements'. The analysis then closely follows the normal stiffness method as applied to skeletal structures, in that the element stiffness matrices are used to assemble a set of *structure* (system, overall) stiffness equations which represent, in terms of the nodal displacements, the conditions of equilibrium of the total forces acting at the nodes with the applied nodal loads [4]. The solution of this set of linear equations yields the nodal displacements from which the internal element forces may be determined.

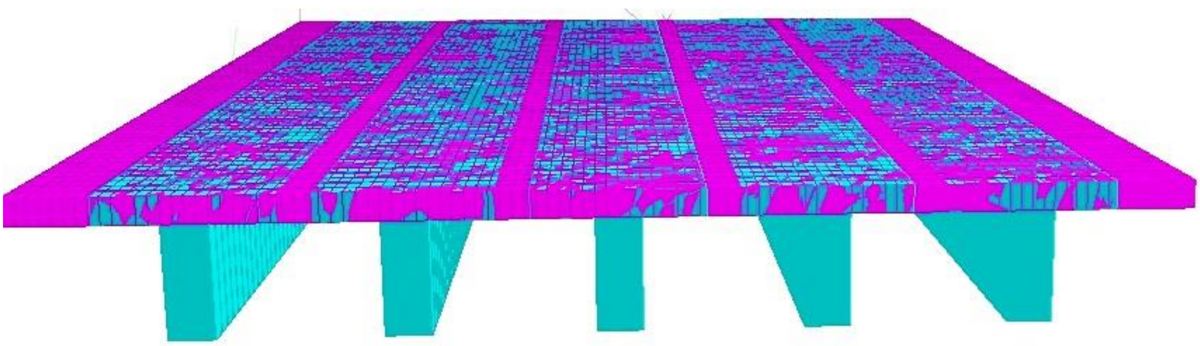

Figure 1.2: Finite Element Model of the Bridge Deck on Staad Pro V8i

The accuracy of the results of a finite element model increases as the element size decreases [3]. The required size of elements is smaller at areas where high loads exist such as location of applied concentrated loads and reactions. For a deck slab, the dividing the width between the girders to five or more girders typically yields accurate results. The aspect ratio of the element (length-to-width ratio for plate and shell elements and longest-to-shortest side length ratio for solid elements) and the corner angles should be kept within the values recommended by the developer of the computer program. Typically aspect ratio less than 2 and corner angles between 60 and 120 degrees are considered acceptable [3]. In case the developer recommendations are not followed, the inaccurate results are usually limited to the non conformant elements and the surrounding areas. When many of the elements do not conform to the developer recommendation, it is recommended that a finer model be developed and the results of the two models compared. If the difference is within the acceptable limits for design, the coarser model may be used. If the difference is not acceptable, a third, finer model should be developed and the results are then compared to the previous model. This process should be repeated until the difference between the results of the last two models is within the acceptable limits. For deck slabs with constant thickness, the results are not very sensitive to element size and aspect ratio. In this study the finite element model was carried out by using StaadPro V8i.

1.4 Analysis Example

In the example considered in this paper, let us look at a simply supported bridge beam and deck slab spanning between two abutments with a distance of 15m centre to centre. The total width of the bridge deck is 10.1m, while the width of the carriageway (w) is 7.2m.

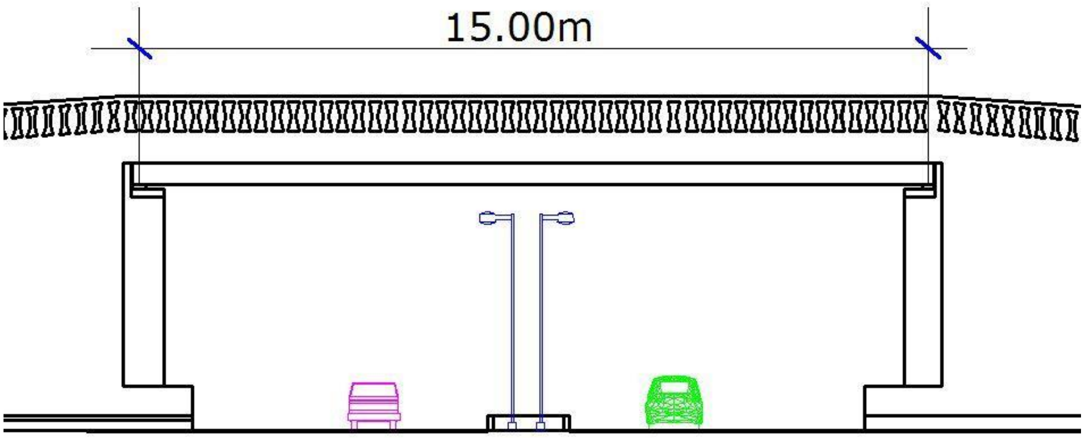

Figure 1.3: Elevation of the bridge

Figure 1.4: 3D View of the bridge

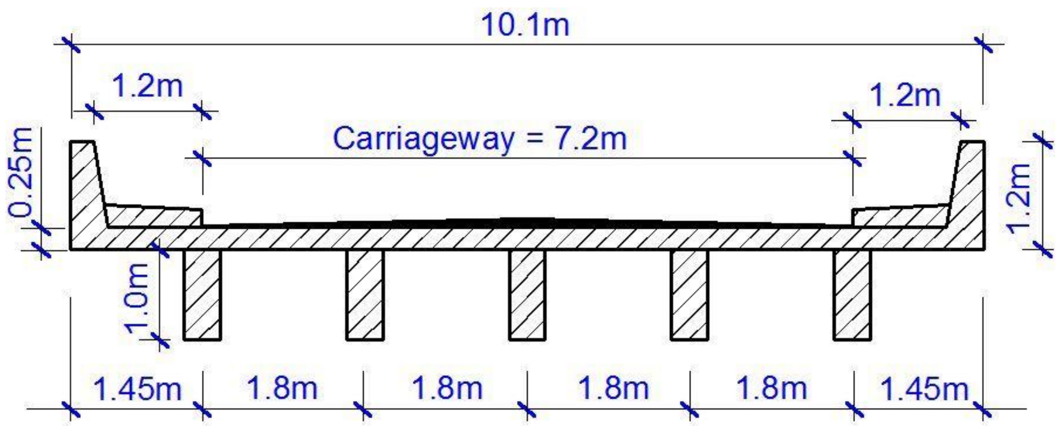

Figure 1.5: Section through the bridge deck

The main details of the bridge are given in the data below;

Width of the carriageway = 7.2m

Spacing of girders = 1.8m centre to centre

Dimensions of precast beam = 1000mm x 400mm

Thickness of slab = 250mm (concrete slab is not pre-stressed).

Length of span = 15.00m (centre to centre of bearings)

Surfacing = 60mm thick asphalt surfacing

While this paper is mainly concerned with the traffic load, let us briefly review the analysis of the permanent loads.

1.4.1 Analysis of loads

Density of concrete = 25 KN/m^3

Self weight of the precast beam = 25 KN/m^3 × 1.0m × 0.4m = 10 KN/m

Self weight of the cast in-situ R.C. slab pertaining to each longitudinal beam = 25 KN/m^3 × 0.25m × 1.8m = 11.25 KN/m

Self weight of concrete parapet

Cross-sectional area of parapet = 0.5(0.4 + 0.25) × 1.2 = 0.39m^2

Self weight of parapet = 25 KN/m^3 × 0.39 m^2 = 9.75 KN/m

Self weight of bridge side walk (per metre length) = 25 KN/m^3 × 1.2m × 0.15 = 4.5 KN/m

Self weight of non-structural elements

Considering the density of asphalt = 22 KN/m^3

Weight of 60mm thick asphalt pertaining to each longitudinal beam = 22 KN/m^3 × 0.060m × 1.8m = 2.376 KN/m

Traffic Loads

According to EN 1991-2, traffic loads should be applied on the carriageway longitudinally and transversally in the most adverse position, according to the shape of the influence surface in order to maximise the considered load effect. In this design example, we are trying to maximise the load on the first and second longitudinal girder (girder 1 and 2).

Notional lane;

Width of carriageway (w) = 7.2m

Since w > 6.0m; Number of notional lanes (n) = int$\left[\frac{w}{3}\right]$ = int$\left[\frac{7.2}{3}\right]$ = 2.0

Width of remaining area = w – (3 × n) = 7.2 – (3 × 2) = 1.2m

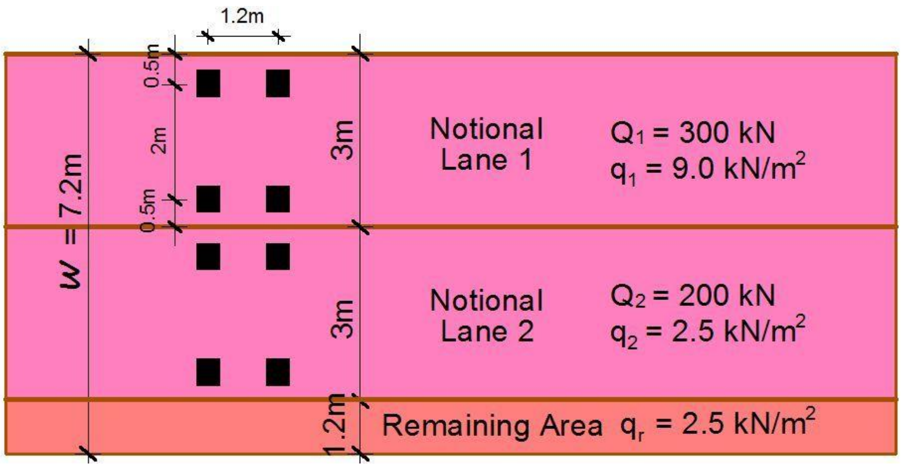

Figure 1.6: Application of Load Model 1 to maximise the effects on longitudinal beams 1 and 2

For global verifications, only Load Model 1 has been considered as shown in Figure 1.6. All adjustment factors were taken as $\alpha Q_i = \alpha q_i = 1.0$. We will also consider crowd load on the pedestrian sidewalks on the bridge. The nominal value is 5.0 KN/m^2 while the combination value is 3 KN/m^2.

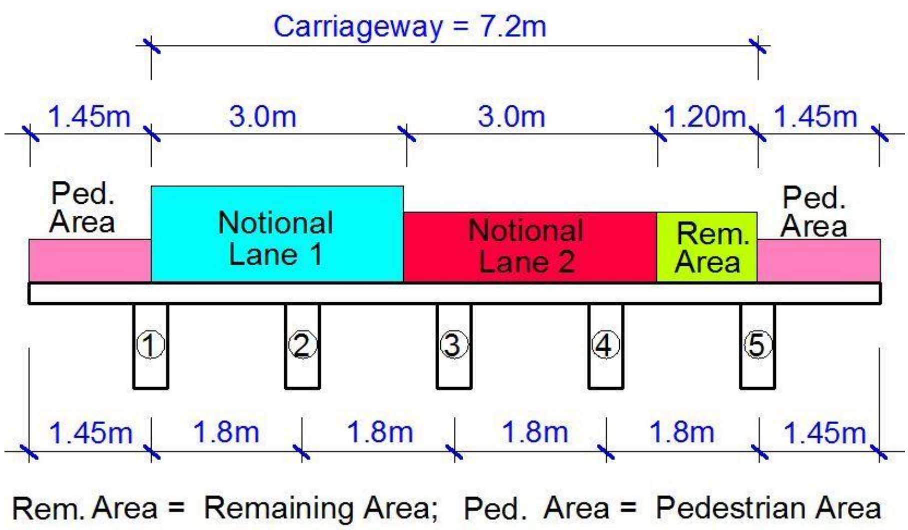

Figure 1.7: Sectional View of the Application of Load Model 1 on the deck

The full loading of the bridge deck under Load Model 1 (including crowd live load of 3.0 KN/m^2 on the sidewalks) is as shown in the figure 1.8 below. However, I must point out that for this bridge being designed, this crowd load is a very unlikely situation.

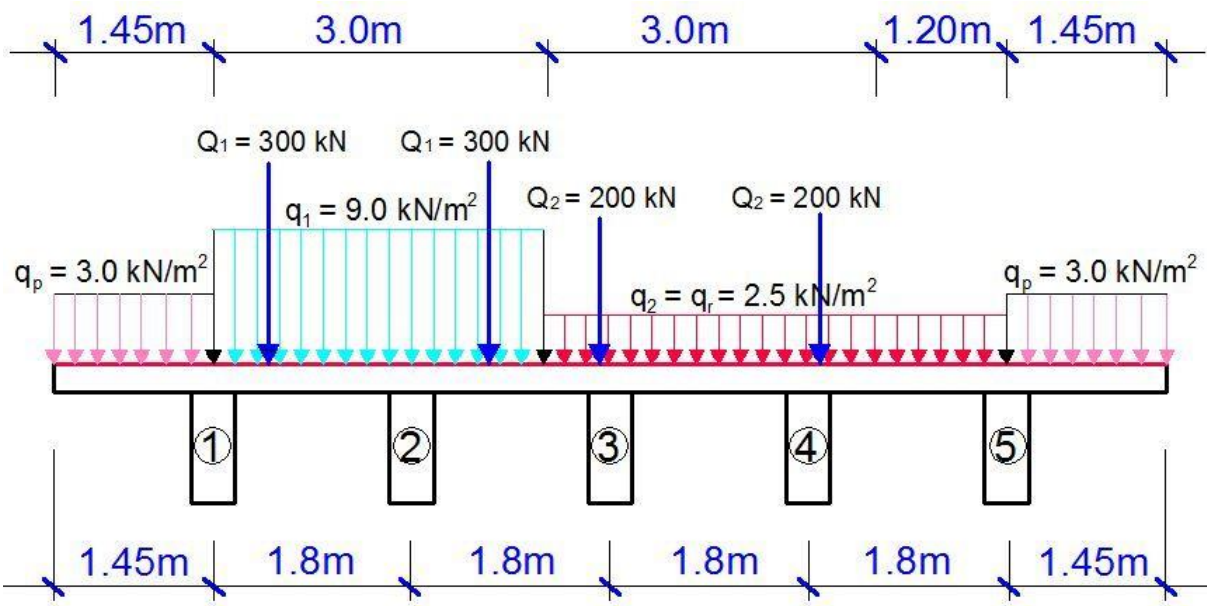

Figure 1.8: Full loading of the bridge

1.4.2 Structural Analysis

The full 3D elastic Finite Element Analysis has been carried out on Staad Pro v8i with the four wheels on each notional lane fully represented as shown in Figure 1.9.

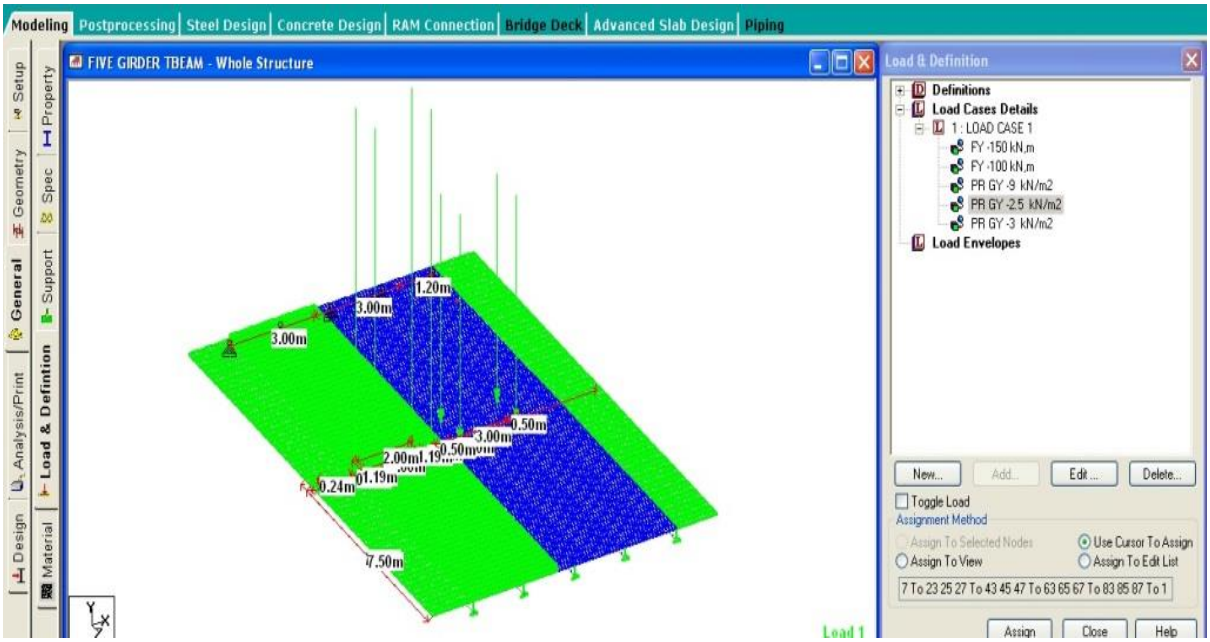

Figure 1.9: Modelling and Application of Load Model 1 on the bridge deck using Staad Pro

1.4. 3 Analysis Results

The result from the static analysis is as shown below.

Bending moment on the beams due to traffic load is shown on Figure 2.0.

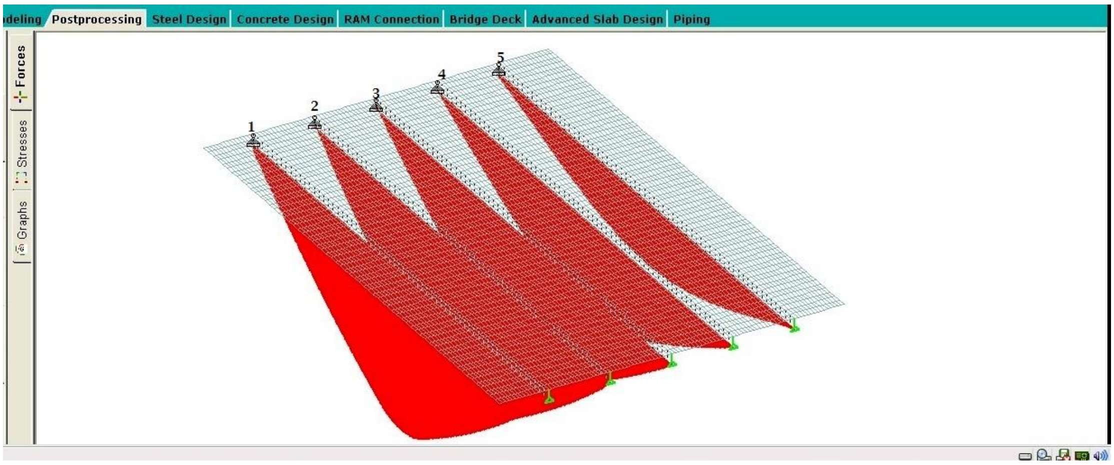

Figure 2.0: Bending moment in the beams due to traffic load (Load Model 1)

Shear force on the beams due to traffic load is shown in Figure 2.1

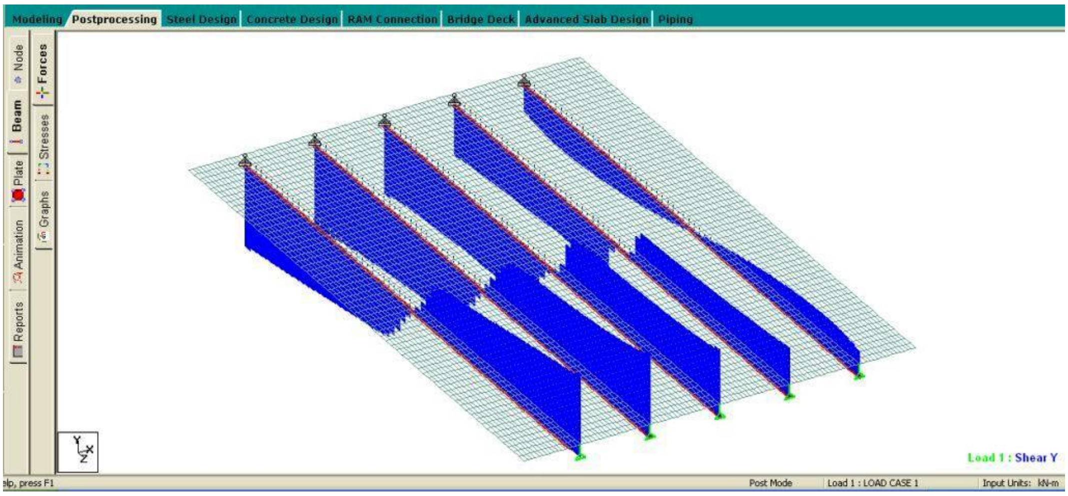

Figure 2.1: Shear force in the beams due to traffic load (Load Model 1)

In summary, the analysis results are as shown in the Table 3.0 below;

Table 2.0: Summary of analysis results from Staad Pro V8i

Beam No	Maximum Bending Moment (KN.m)	Maximum Shear Force (KN)
1	922.48	207.88
2	945.19	217.77
3	840.71	173.34
4	605.19	125.10
5	360.71	79.36

Conclusion

It can be seen from the analysis results that the load arrangement maximised the internal stresses in beams no 1 and 2. The load arrangement produced more severe effect in beam number 2. In order to check the arrangement that will maximise the internal stresses in beam No 5, we will have to rearrange the loads again. But by symmetry, it is possible to see that the effects will largely be the same (just like mirroring the loads to the right hand side). In order to verify the results obtained, we can apply other methods of analysis such as;

- Grillage Analysis
- Distribution Coefficient Methods
- Finite Strip Method
- Modified Courbon's Method etc

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