PLANNING AND DESIGNING OF TOLL PLAZA

[1]Dipti S. Kshirsagar, [2]Vaibhav G. Mohol , [3]Prachi R. More,[4] Pushpanjali R. Punekar,
[5] S. S. Kudale
[1,2,3,4] Undergraduarte Student & [5] Assistant Professor
Department of Civil Engineering
KJEI's Trinity Academy of Engineering, Pune, India

Abstract : In the present situation, highways and expressways are built on the principle of BOT (Build- Operate - Transfer) for which toll fee is levied from the users for a period of 20-30 years from the time of allotment of the work. For the collection of toll fees, a toll plaza structure containing more than one toll booth is built on highways. To avoid traffic congestion in cities, toll plazas are built away from the cities i.e. at the suburbs of the city. This makes the toll structure, economical in construction. The planning and design of toll plaza includes design of steel space frame for toll canopy. A space frame or space structure (3D truss) is a lightweight, truss like structure constructed from interlocking struts in a geometric pattern. They can be used to span large areas with few interior supports. Like the truss, a space frame is strong, due to its inherent triangle capacity. Bending moments are transmitted as tension and compression loads along the length of each strut. Steel space frames provide great freedom of expression and composition, as well as evenly distribute loads along each rod and external constraints.Staad.pro software is used for the steel space frame analysis and the load applications and combinations are as per IS 800-2007. For the space frame, main hindrance in design, is the wind action which requires special attention throughout the design. Hence, the wind load is designed as per IS 875- Part III. In proper planning, resource management plays an important part for the project to be economical. Hence, costing and estimation of the quantity of 3Ms required in construction is estimated. The primary focus of the project is to design a toll canopy with the idea in future of solar PV system on its roof, to make the toll plaza a self-reliant structure, in case of electricity.

***Index Terms* : Toll plaza, Staadpro, steel space frame.**

I. INTRODUCTION

Space frame structures are structural systems with three dimensional assembling of linear elements in which the forces are transferred in three dimensional manner[5]. Space frames can be used to span large areas with few interior supports. This structure is lightweight but is capable of carrying heavy loads with huge scale spans.(Kate et al. 2018) These structures are widely used to construct airports, shopping malls, stadiums, sugar storages, etc. It can also form some architectural manners in long skywalks, pedestrian bridges and can add aesthetic, rigidity and long life to smaller span structures like metro stations, petrol pums, gates, toll gates etc.

1.1 COMPONENTS OF SPACE FRAME

Space frame is a network of linear axial members interconnectors. These Axial members can be of any material but steel hollow sections are used for economy and lightweight. The most critical points are the nodes. Usually the node connectors occupy 20-50% of the total amount of steel required for the space structures. The node connectors are the most expensive and important component in the space structures [6]. Different types of node connectors are available in market but only few of them are used like the MERO connector.

II. STUDY AREA OF TOLL PLAZA

Design of toll plaza includes the toll canopy, it is rectangular 19.08m in width and 55.12m in length. The toll plaza consists of 10 toll booths for 6 lane expressway on highway depending on the traffic density. The same size of toll plaza can be used for all places become the design of toll plaza is as per IRC: SP-99-2013.

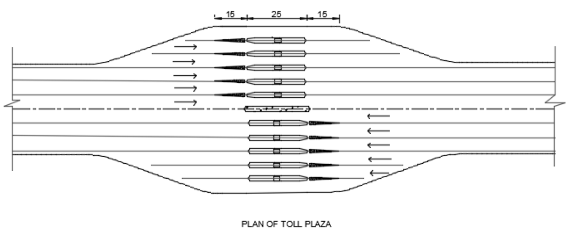

Fig.1 Plan of toll plaza

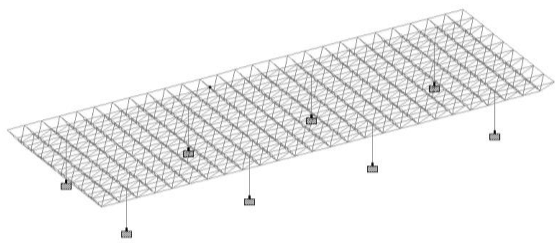

Fig. 2 Geometry of toll plaza

2.1 STEEL SPACE FRAME

The space frame takes stress form of flat or curved surface [5]. There are 2 types of space frame according to geometric properties, latticed sheds and double grid layer. Double layer grid is a space frame consisting of 2 planar networks of member forming top and bottom layer parallel to each other and interconnected by inclined and vertical members. All members can resist tension or compression.

Grid spacing is an important factor while designing the truss. Grid spacing is the distance between the two nodes. The height of truss depends on grid spacing [5]

Table 1- Grid spacing and depth of grid

Grid spacing	Depth of frame
2.0-3.0 m	Up to 1.5 m
2.4-3.0 m	1.5-2.1 m
2.4-3.6 m	2.1-2.5 m
3.6-4.8 m	2.5-4.0 m
4.8-6.0 m	3.6-4.8 m

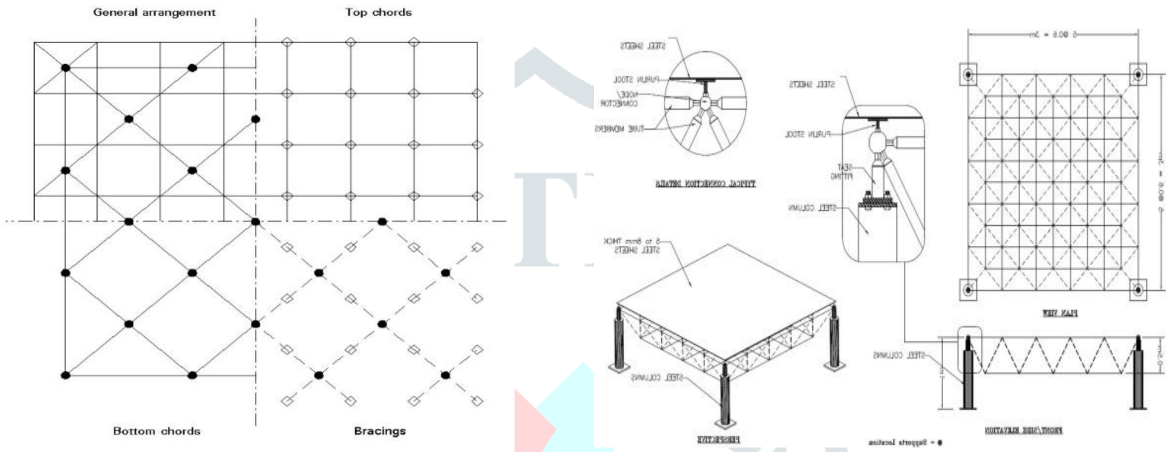

Fig. 3 Geometry of toll plaza

III. MODELING AND ANALYSIS

3.1 GENERAL

For a structural design to be satisfactory, four main objectives are considered- utility, safety, economical and elegance [3]. Structural analysis is process of forecasting performance of given structure under given loading condition. The performance includes stress resultant, deflection and support reaction.

In order to analyze in staadpro, we have to generate model geometry, assign members property and its constant, specify supports and lastly assign loads [1].

Staadpro based on load cases generate load combinations. In staad, loads are applied to nodes or joints only.

3.2 LOADINGS

3.2.1 DEAD LOAD (IS : 875 (PART I)-1987)-

Staad is able to calculate the self weight which is uniform by distributed over the structure. Different joint or nodal loads may be applied to any free joint of the structure [2].

Grid Spacing = 2.12 m
Vertical Height = 1.5 m
Service Load = 20 Kg/m^2 (Galvanized Sheet)
Purlin Load = 5 Kg/m^2 (Assume)
Total Load = 20+5 = 25 Kg/m^2
[25 /100] x 2.12 x 2.12 = 1.12kN at Intermediate Node
[25 /100] x 2.12 x 2.12 / 2 = 0.56 kN at External Node
[25 /100] x 2.12 x 2.12 / 4 = 0.28 kN at Corner Node
Facia Load= 20 Kg/m^2(Load of Sign Board assume 2.0 mm Aluminium Sheet including)
[20/100] x 2.12 x [1.5+0.75] / 2 =0.477 kN at External Node
[20/100] x 2.12 x [1.5+0.75] / 4 =0.238 kN at Corner Node
Node load 10.0 kg at junctions

3.2.2 LIVE LOAD (IS:875(PART2)-1987)-

It is also known as imposed load, other than dead load. The values depend on the functional requirement of the structure.

0.75x 2.12 x 2.12 = 3.37 kN at Intermediate Node
0.75 x 2.12 x 2.12 / 2 = 1.69kN at External Node
0.75 x 2.12 x 2.12 / 4 =0.845 kN at Corner Node

3.2.3 WIND LOAD (IS:875 (PART3)-1987)-

These loads depend on the velocity of the wind at the location of the structure, permeability of the structure, height of the structure, etc. They may be horizontal or inclined forces depending on the angle of inclination of the roof for pitched roof structures.
Basic Wind Speed V_b = 39 m/s (Consider max. V_b at Pune as Per IS 875-part-lll)
Terrain Category =2
Class = B
K1 = 1,K2= 0.98,K3 =1
Design Wind Speed $V_z = V_b$ x K1 x K2 x K3 = 39 x 1 x 0.98 x 1= 38.2 m/s
Design Wind Pressure $P_z = 0.6 \times V^2{}_z$ = 0.6 x 38.^{2} =0.88 kN/m^2

DOWN WARD WIND PRESSURE

External Pressure Coefficient = 0.2 (For Zero degree roof angle) (IS 875- Part-III, Page 19)
0.2 x 0.88 x 2.12 x 2.12 =0.79 kN at Intermediate Node
0.2 x 0.88 x 2.12 x 2.12 / 2 =0.395 kN at External Node
0.2 x 0.88 x 2.12 x 2.12 / 4 =0.2 kN at Corner Node

UP WARD WIND PRESSURE

External Pressure Coefficient = 0.5 (For Zero degree roof angle and Zero solidity ratio) (IS 875- Part-III, Page 19)
0.5 x 0.88 x 2.12 x 2.12 = 1.97 kN at Intermediate Node
0.5 x 0.88 x 2.12 x 2.12 / 2 = 0.94 kN at External Node
0.5 x 0.88 x 2.12 x 2.12 / 4 =0.47 kN at Corner Node

LATERAL WIND LOAD +VEZ

b =55.12 m , h = 1.5m
b/h= 36.77
Force Coefficient = 1.71
1.71 x 0.88 x 2.12 x 1.5 / 2 = 2.38 kN at Intermediate Node
1.71 x 0.88 x 2.12 x 1.5 / 4 = 1.19 kN at External Node

LATERAL WIND LOAD -VEZ

1.71 x 0.88 x 2.12 x 1.5 / 2 =2.38 kN at Intermediate Node
1.71 x 0.88 x 2.12 x 1.5 / 4 = 1.19kN at External Node

LATERAL WIND LOAD +VEX

b=19.08 m , h= 1.5m
b/h=12.73
Force Coefficient =1.35
1.35 x 0.88 x 2.12 x 1.5 / 2 =1.87 kN at Intermediate Node
1.35 x 0.88 x 2.12 x 1.5 / 4 = 0.94 kN at External Node

LATERAL WIND LOAD -VEX

1.35 x 0.88 x 2.12 x 1.5 / 2 = 1.87 kN at Intermediate Node
1.35 x 0.88 x 2.12 x 1.5 / 4 = 0.94 kN at External Node

3.3 MEMBER SPECIFICATION

As discussed before steel hollow section are best suited for its lightweight and economical parameters. Tubular sections have higher strength to weight ratio that results into 30-40% steel saving [4]. But, the shape of section also plays an important role in resisting the structure against wind action.

Table 2- Drag coefficient for various sections

Section	Drag Coefficient
Circular Hollow Section	0.5-1.2
Rectangular Hollow Section	0.6-2.0
Open Rolled Section	2.0

3.4 estimation and costing

Estimating and costing in construction management is the calculation of quantities of materials, tools, equipments, labours, etc. and cost associated with them.

As per market survey, Cost of Aluminium is Rs.147 per Kg.
Aluminium is more costly than steel.

Table 3- Steel Takeoff

STEEL TAKE-OFF

PROFILE	LENGTH(METE)	WEIGHT(KN)
ST PIP483H	2622.95	112.230
ST PIP889H	1210.65	118.111
ST PIP1016H	33.92	3.804
ST PIP3556H	141.78	95.192
	TOTAL =	329.338

Total Steel weight = 329.338 KN
= 33583.13 Kg
Cost of steel as per market rate
= total weight x price per kg
=33583.13 x 58
=Rs.19,47,821.54
Cost of GI Sheet 4mm thik.= Rs.284/-
Total Cost of GI Sheet
=AreaxCost of per sheet
= (55.12 x 19.08) x 284
= Rs.2,98,677.12
Total Cost of Structure
=19,47,821.54+2,98,677.12
= **Rs.22,46,498.66**

IV. RESULTS AND ANALYSIS

After the structure is designed and analyzed, there is check for utility under the post processing mode. It should be always less than 1.
Deflection and displacement are too short

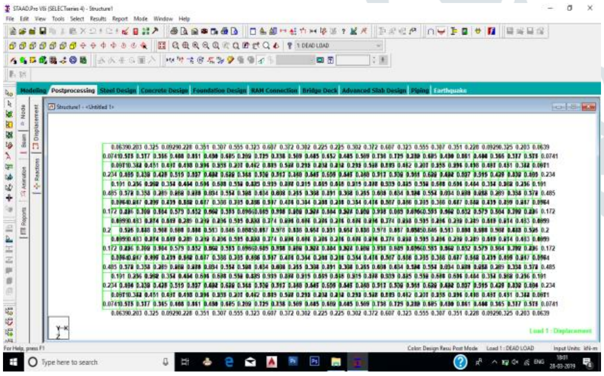

Fig. 4 Utility Ratio of each member

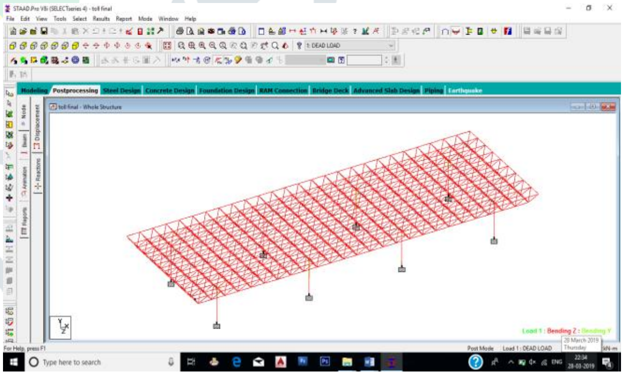

Fig. 5 Bending Moment Diagram

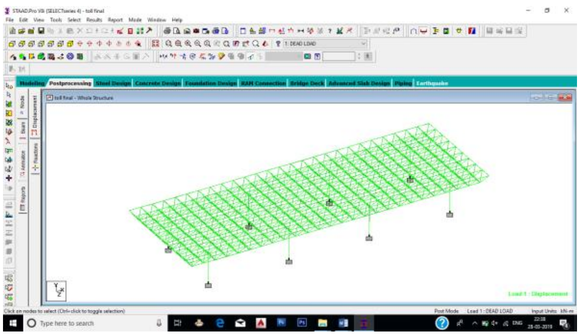

Fig. 6 Displacement Diagram

V. CONCLUSION

- The analysis was done using the software package Staad.Pro V8i, which proved to be premium software of great potential in analysis and design sections of construction industry. All the structural components were design by using ActoCAD-2013 software.
- Due to space frame the structures become light weight and easy to construct which saves the time and cost.
- The composite action reduces the maximum deflection of the truss, and improves the stiffness significantly for the imposed load.

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