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Structural Analysis of Arch Bridge with a Span of 350m Using STAAD.Pro: A Case Study

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Abstract — *This paper presents the design of a steel arch bridge considered to be located at Jaipur using STAAD.Pro. The arch bridge is proposed with 350 meter span and 13.3 meter width with an average height of 29.977 meter in this study. The design is carried out by considering wind load, seismic load, live load & dead load for the arch bridge. The design is carried out as per the Indian Standards and by the help of the structural analysis and design software STAAD.Pro.*

Keywords- *Steel arch bridge, STAAD.Pro., AutoCAD, Wind Load, Design*

I. INTRODUCTION

An arch is defined as a curved structural member which gives a high resistance to bending forces. The weight of an arch bridge is carried outward along the curve of the arch to the supports at each end. These supports are known as the abutments. They carry the loaded keep the ends of the bridge from spreading outward.
When load is placed on the bridge i.e., supporting its own weight and the weight of crossing traffic, every part of the arch is under compression. Due to advancement of technology, it possible to build longer and more elegant arches by using materials like steel and pre- stressed concrete viz., New River Gorge, West Virginia.
Arch bridge can be constructed, where the ground or foundation is solid and stable. Bending stresses are developed due to multiple loadings (dead load, live load, wind load, seismic load etc.) in the arch rib which are generally small compared with the axial compressive stress.
In this paper, Structural Analysis of Arch Bridge with a Span of 350m and 13.3 meter width with an average height of 29.977 meter is presented using STAAD.Pro

II. METHODOLOGY

To analyze and design a Steel Arch Bridge (3 dimensional frames)] using STAAD. Pro, following procedure is followed:

III. CALCULATIONS OF LOAD

For analysis and design of any structure we have to consider all loads acted on structure. Following loads are considered in this study.

(i) Normal Loads (a) Dead Load (b) Live Load
(ii) Occasional Loads ---Wind load
(iii) Extraordinary Loads --- Seismic forces

III.A Dead Loads

All permanent constructions of the structure form the dead loads. The dead loads may be calculated from the dimensions of various members and their unit weights using steel table (IS: 4923:1997) and IS: 800:2007.

III.B Live Loads

Live loads produced by the planned use or occupancy of a bridge including the weight of movable partitions, distributed and concentrated loads, load due to impact and vibration and dust loads. Loads due to wind, seismic activity, snow, and loads imposed due to temperature changes are not included while calculating live loads(IS:875 Part-2).

III.C Wind Load

Wind loads play important role in the analysis of structures. Wind means the motion of air relative to the surface of the earth. The response of structures to wind depends on the characteristics of the wind. The wind causes due to rotation of earth and differences in terrestrial radiation. Due to radiation effects, convection of air either upwards or downwards will occur. The wind generally blows horizontal to the ground at high wind speeds.
Vertical components of atmospheric motion are relatively small; the term 'wind' denotes almost wholly the horizontal wind. The wind speeds are calculated with the help of anemometers or anemographs, which are installed at

meteorological observatories at heights generally varying from 10 to 30 meters above ground. The intensity of wind forces as specified in IS: 875 Part-3 can be used for determining the basic wind pressure for the analysis of bridge (Ponnuswamy, S., 2017)

Design Wind Speed (V_z)

The basic wind speed (V_b) for any site of interest is obtained from the basic wind speed map given in IS 875(part -3). The design wind speed can be obtained by using formula (1) as per IS875(part3).

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$$Vz = k_1 * k_2 * k_3 * V_b \quad (1)$$

Where,

k_1= Risk level

k_2= Terrain roughness, height and size of structure

k_3= Local topography

V_b= Basic wind speed (m/s)

Wind Pressures

The wind pressure is calculated by using the formula (2) as per IS875(part3).

$$Pz = 0.6V_z^2 \quad (2)$$

Where,

P_z = Design wind pressure

V_z = Design wind speed

The wind load acting normal to a surface is obtained by multiplying the area of that surface or its appropriate portion by the pressure coefficient (C) and the design wind pressure at the height of the surface from the ground. The wind load is calculated by formula (3) as per IS875(part3).

$$F = (Cpe - Cpi) * A * P_d \quad (3)$$

Where,

Cpe = external pressure coefficient

Cpi = internal pressure- coefficient

A = surface area of structural or cladding unit

P_d = design wind pressure

The pressure coefficients are always given for a particular surface or part of the surface of a bridge. The average values of these pressure coefficients for some bridge shapes. Average values of pressure coefficients are given for critical wind directions in one or more quadrants. In order to determine the maximum wind load on the bridge, the total load should be calculated for each of the critical directions shown from all quadrants.

III.D Seismic Load

If the bridge is located in earthquake prone zone, seismic forces should be taken into consideration and earthquake resistance features should be embodied in the design. The bridges are designed for earthquake resistance, as per recommendation of IS: 1893. (Dr.B.C.Punmia1995)

Design Lateral Force

The design lateral force shall first be computed for the bridge as a whole. The total design lateral force or design seismic base shear (V_B) along any principal direction shall be determined by the following expression

$$V_B = Ah * W \quad (4)$$

Where,

Ah = horizontal acceleration spectrum

W = seismic weight of structure

Fundamental Natural Period

The approximate fundamental natural period of vibration (Ta), in seconds, of a moment-resisting frame may be calculated by the following formulas (IS1893:2002).

$Ta = 0.075\ h^{0.75}$ for RC frame

$Ta = 0.085\ h^{0.75}$ for steel frame

Where,

h = Height of structure, in m. The approximate fundamental natural period of vibration (T_a), in seconds, of all other structure, including moment-resisting frame may be estimated by the empirical Expression:

$$T = .09H/\sqrt{D} \quad (5)$$

Where,
H= Height of structure
D= Base dimension of the structure in m, along the considered direction of the lateral force.

Distribution Of Design Force

Vertical Distribution of Base Shear

The design base shear (V_B) shall be distributed along the height of the structure as per the following expression:

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2} \qquad (6)$$

Q_i=Design lateral force
W_i=Seismic weight structure
h_i=Height of structure

IV. NUMERICAL STUDY

The analysis and design of the proposed Steel arch bridge is performed using STAAD. Pro 2007 and IS codes. Structural components of the study considered for the analysis and design are:

- ✓ Main arch rib
- ✓ Truss Arch
- ✓ Spandrel column
- ✓ Bracings
- ✓ Portal Frame
  - Main frame connections
  - End frame connections

V. DIMENSIONS OF ARCH BRIDGE

Following dimensions of arch bride are taken for this case study:
Length of the arch bridge : 350 m
Width of the arch bridge : 13.3 m
No. of bays along length: 33 Nos. of each 5.455 m
20 nos of each 5.100m & 14 Nos. of each 4.857m
No. of bays along width: 1 Nos. of each length 13.3m
Height of the arch bridge: 29.977 m
All components of arch bridge are shown in Fig.1.

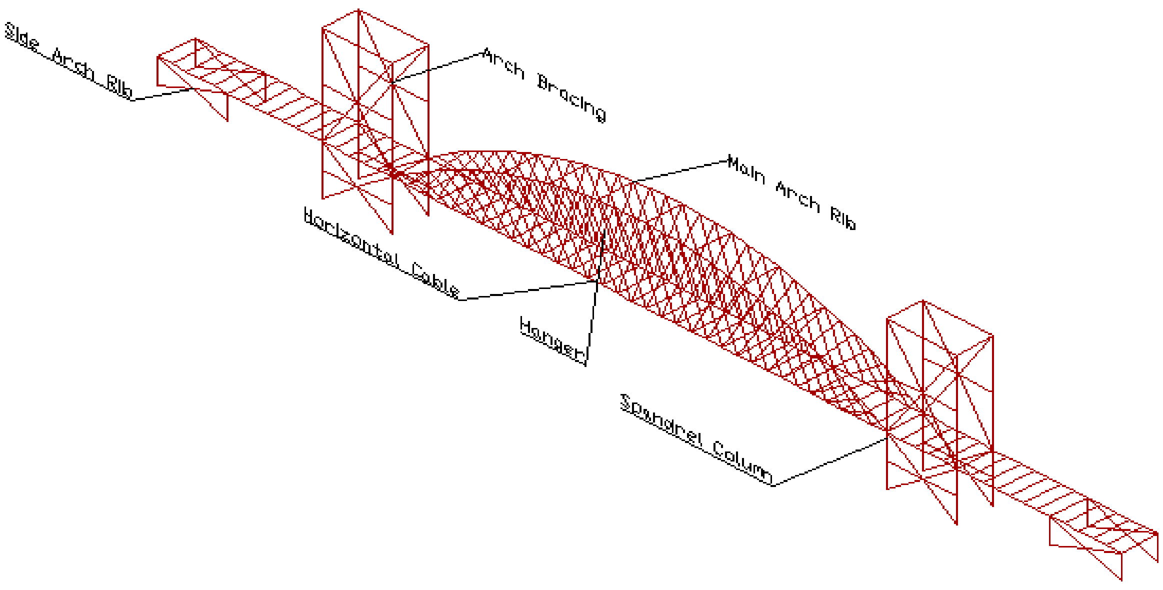

Fig.1: View of Arch Bridge

Section details of different components of arch bridge are calculated using STAAD.Pro. Dimensions of different components are taken after considering loads acting on the bridge. Based on Limit state design method, Dimensions for different components are taken after analysis in STAAD.Pro. In figure 2, circular section 1.0 m diameter is taken for the portion shown in red colour. Square section (SQU) 1.7m X 1.7mX 0.02m is taken for the red portion in Fig.3. Square section (SQU) 3.0m X 3.0m X 0.4m is taken for the red portion in figures4-5.

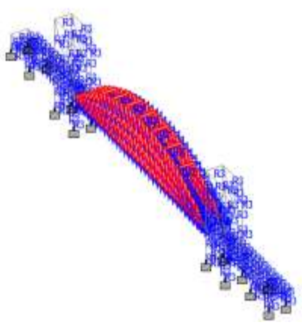

Fig 3. SQU 1.7m X 1.7m X 0.02m

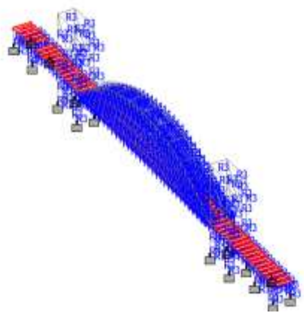

Fig 2. CIRCULAR 1.0 m

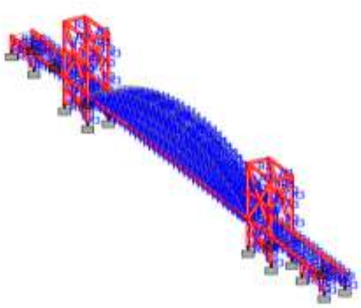

Fig 4. SQU 3.0mX3.0mX0.4m

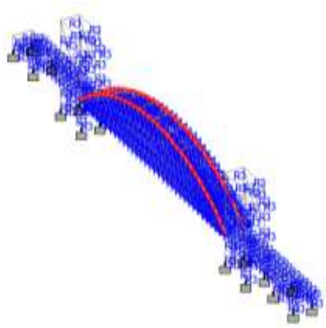

Fig 5. SQU 3.0mX3.0mX0.4m

In figure 6. Wind load action on arch bridge is shown.

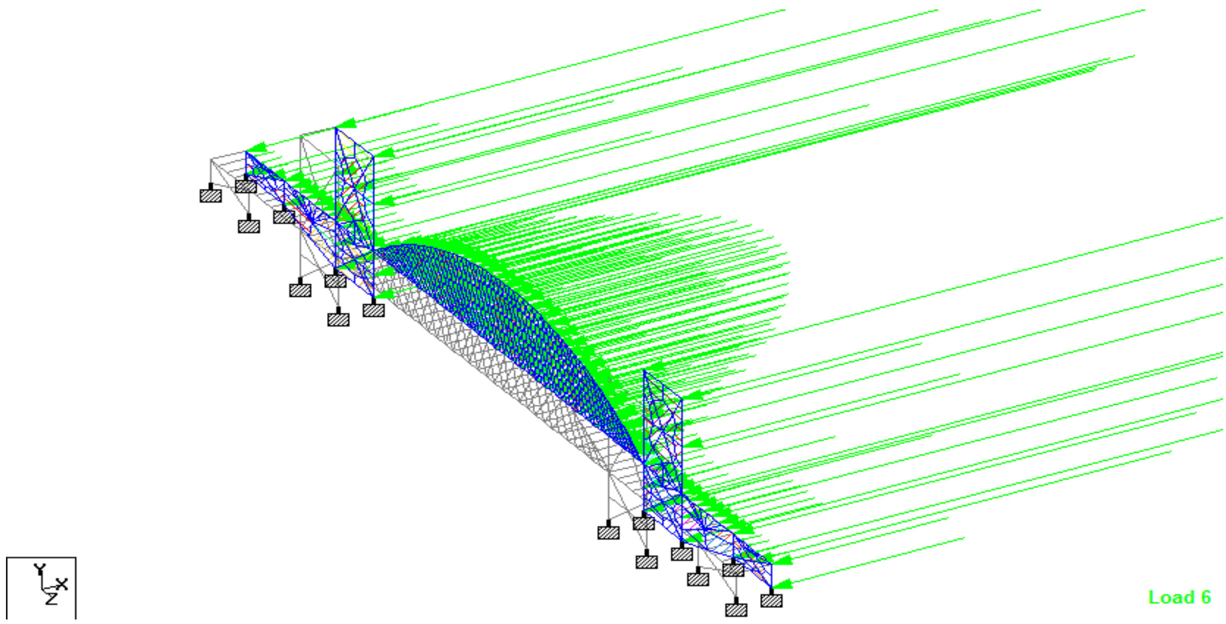

Fig6. Wind load Action

After deciding the section details of different components of arch bridge, bending moment diagrams, deflected shapes and beam Stress of steel arch bridge obtained by STAAD.Pro. Bending moment diagram for different components of arch bridge is shown in Fig.7.

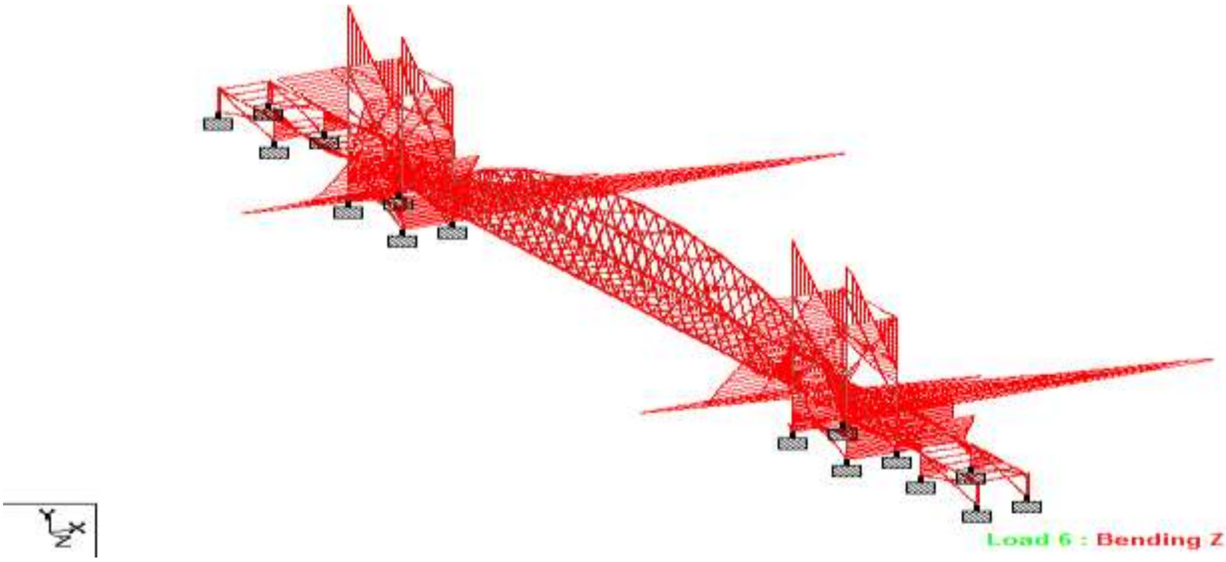

Fig.7: Bending Moment Diagram of Steel Arch Bridge

Deflected shape of different components of arch bridge is shown in Fig. 8.

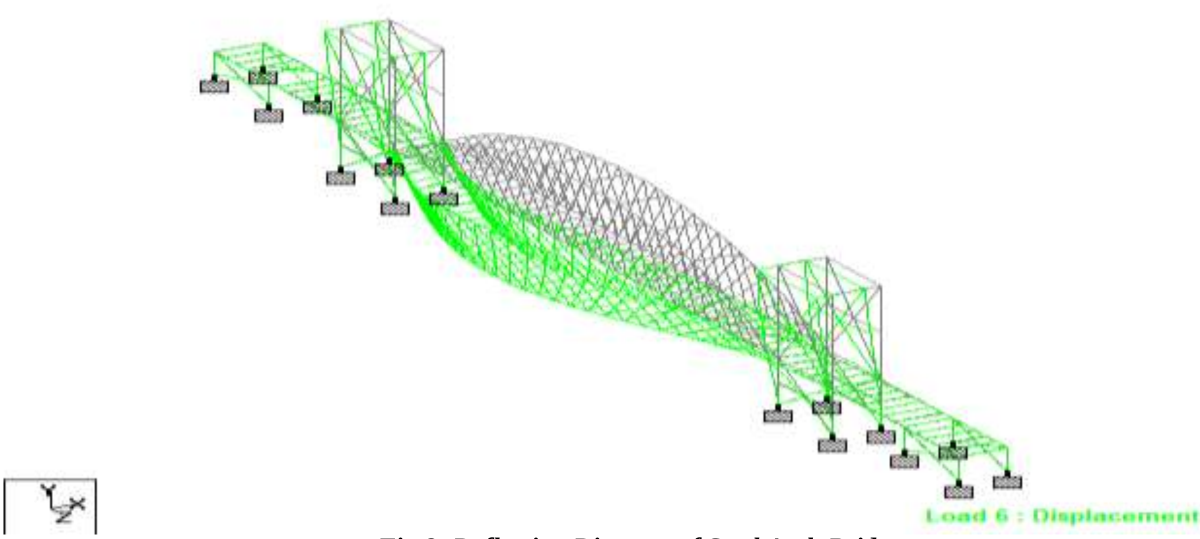

Fig.8: Deflection Diagram of Steel Arch Bridge

Combined Axial and Bending Stresses of single section in Steel Arch Bridge shown in Fig. 9.

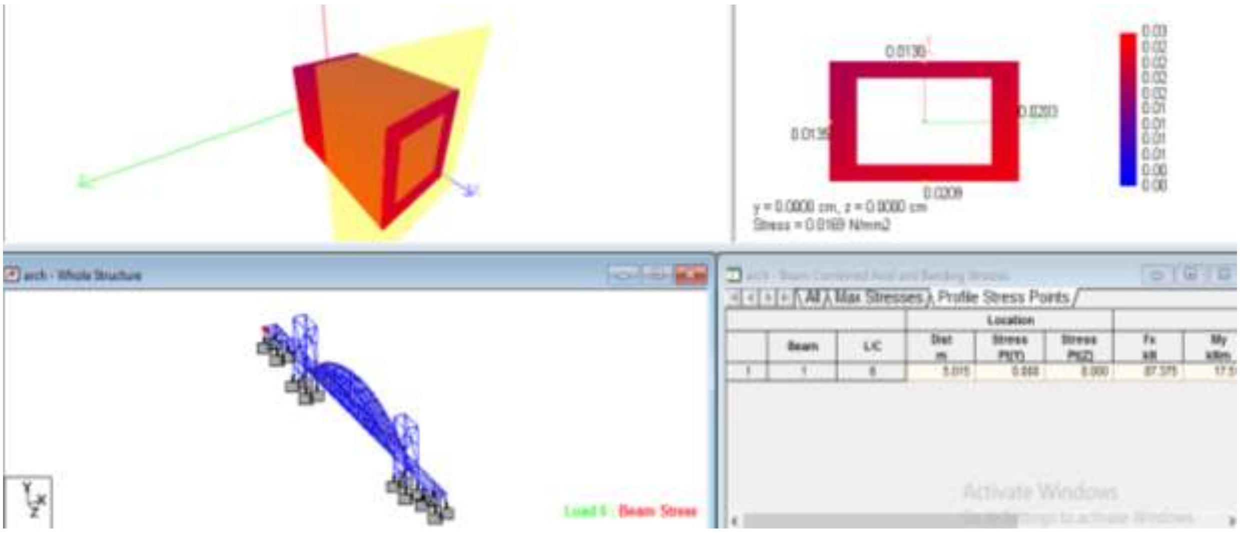

Fig.9: Stress Diagram of Single Section

After post processing, results are obtained in form of table. A sample table for 29 components is shown in Fig.10

Beam	Analysis Property	Design Property	Actual Ratio	Allowable Ratio	Normalized Ratio (Actual/Allowable)	Clause	L/C	Ax cm2	Iz cm4	Iy cm4	Ix cm4
1	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.080	1.000	0.080	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
2	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.253	1.000	0.253	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
3	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.102	1.000	0.102	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
4	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.989	1.000	0.989	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
5	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.326	1.000	0.326	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
6	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.174	1.000	0.174	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
7	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.096	1.000	0.096	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
8	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.040	1.000	0.040	IS-7.1.1(A)	161	44204.001	486.11846E6	486.11846E6	729.90761E6
9	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.126	1.000	0.126	IS-7.1.1(A)	161	44204.001	486.11846E6	486.11846E6	729.90761E6
10	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.051	1.000	0.051	IS-7.1.1(A)	161	44204.001	486.11846E6	486.11846E6	729.90761E6
11	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.495	1.000	0.495	IS-7.1.1(A)	161	44204.001	486.11846E6	486.11846E6	729.90761E6
12	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.163	1.000	0.163	IS-7.1.1(A)	161	44204.001	486.11846E6	486.11846E6	729.90761E6
13	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.087	1.000	0.087	IS-7.1.1(A)	161	44204.001	486.11846E6	486.11846E6	729.90761E6
14	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.048	1.000	0.048	IS-7.1.1(A)	161	44204.001	486.11846E6	486.11846E6	729.90761E6
15	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.064	1.000	0.064	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
16	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.068	1.000	0.068	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
17	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.065	1.000	0.065	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
18	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.097	1.000	0.097	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
19	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.065	1.000	0.065	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
20	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.068	1.000	0.068	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
21	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.064	1.000	0.064	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
22	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.080	1.000	0.080	IS-7.1.1(A)	163	44204.001	486.11846E6	486.11846E6	729.90761E6
23	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.032	1.000	0.032	IS-7.1.1(A)	161	44204.001	486.11846E6	486.11846E6	729.90761E6
24	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.034	1.000	0.034	IS-7.1.1(A)	161	44204.001	486.11846E6	486.11846E6	729.90761E6
25	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.033	1.000	0.033	IS-7.1.1(A)	161	44204.001	486.11846E6	486.11846E6	729.90761E6
26	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.097	1.000	0.097	IS-7.1.1(A)	161	44204.001	486.11846E6	486.11846E6	729.90761E6
27	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.033	1.000	0.033	IS-7.1.1(A)	161	44204.001	486.11846E6	486.11846E6	729.90761E6
28	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.034	1.000	0.034	IS-7.1.1(A)	161	44204.001	486.11846E6	486.11846E6	729.90761E6
29	SQU 3.0X3.0X0.4	SQU 3.0X3.0X0.4	0.032	1.000	0.032	IS-7.1.1(A)	161	44204.001	486.11846E6	486.11846E6	729.90761E6

Fig.10: Post Processing Result Table Diagram

VI. SUMMARY AND CONCLUDING REMARKS

Using the software STAAD.Pro, the structure considered was analyzed & designed.
The paper contains the analysis and design concepts of Steel Arch Bridge. The various inferences made from the study are as follows.

S. No.	Parameter	Result
1	Steel take off (kN)	1157379.943
2	Maximum moment (kNm)	151.08845E3
3	Maximum shear force (kN)	9804.490
4	Support reaction (kN)	240.62656E3
5	Total volume of steel sections(Cum)	15066.22

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