Self-Anchored Suspension Bridge with Temporary Pylon-Anchor Technology

1Drashti Vadhel, 2Sameer Malgundkar, 3Zainab Bohra, 4Javed Shaikh
1Student, 2Student, 3Student, 4Professor
Rizvi College of Engineering

Abstract - **In a country with one of the highest congestion rates in the world, constructing any kind of infrastructure proves difficult, especially bridges. The cost of constructing a bridge by providing temporary supports along with the traffic disruption caused during the construction period becomes a two-fold problem to tackle. Our project involves comparing and designing a temporary pylon-anchor (TPA) technology for construction of self-anchored suspension bridge by considering the environmental impacts, mobility issues, and cost of the project as well. With unique characteristics of the structure system and innovative construction method, this technique assures promising construction of suspension bridges.**

keywords - **TPA technology, Self-Anchored Suspension Bridge, Traffic disruption**

I. INTRODUCTION

A suspension bridge is a type of bridge in which the deck is hung by suspension cables on vertical suspenders and the main cables are anchored by the stiffening girder. The basic structural components of a suspension bridge system include stiffening girders/trusses, the main suspension cables, main towers, and the anchorages for the cables at each end of the bridge. The main cables are suspended between towers and are finally connected to the bridge itself, and vertical suspenders carry the weight of the deck and the traffic load on it. The main load carrying member is the main cables, which are tension members made of high-strength steel. The whole cross-section of the main cable is highly efficient in carrying the loads and buckling is not problem. In addition, the aesthetic appearance of suspension bridges is another advantage in comparison with other types of bridges.

The principle of self-anchoring eliminates massive anchorage structures, which have to withstand large horizontal forces, and which are necessary for classical suspension bridges. Instead, the cables are secured to each end of the bridge deck, which resists the horizontal component of the cable tension. Therefore, the end supports resist only the vertical component of the cable tension, an advantage where the site cannot easily accommodate external anchorages. Because the stiffening girders support the cable tension, these girders must be placed before the main cable can be erected. This construction sequence, which is opposite of that of a conventional suspension bridge, limits the self-anchored form to moderate spans and suitable site conditions.

When the concept of self-anchoring is applied to a steel bridge, a considerable amount of additional steel is required in the superstructure as compared to that of a true suspension bridge in order to enable the stiffening girders or trusses to resist the thrust as well as the bending moments without being endangered by instability. The large thrust produced in the suspended bridge deck is, on the contrary, highly beneficial in the case of a concrete deck. In this case it acts as a prestressing force in the stiffening beams and helps them to withstand the bending due to live load. In the concrete case, instability is normally not a problem of any consequence, owing to the cross-section being naturally more sturdy than that of a steel suspended structure. For the same reason, a prestressed concrete suspension bridge is much stiffer than its steel counterpart and aerodynamic instability is also much more unlikely.

The self-anchored suspension bridge can also be obtained from a conventionally post-tensioned concrete bridge deck where, instead of keeping the tendons inside the concrete section, the tendons leave the girders. This allows to obtain significantly larger eccentricities which leads to a more economical solution in case of significant dead weight. The hangers provide the connection between the suspension cables and the bridge deck and transmit the upward forces created by the curved cables to the bridge deck.

II. Methodology

The construction process is as follows:

1. The pylon foundation is constructed, and the concrete girder of the side span is cast on the falsework.
2. The pylon segments are assembled by welding them to the side-span girder, and the pylon is rotated into place.
3. A temporary anchorage device is installed between the pylon and the girder.
4. The main cables and hangers of the mid-span and the stay cables of the side span are built.
5. Three temporary crossbars are installed between the two main cables.
6. The steel girder segments of the mid-span are hoisted and attached to the hangers, and the temporary crossbars are removed.

7. After the last girder segment is placed, the girder is completed by welding. The temporary anchorage device is removed, and the bridge system is transformed into the final self-balanced state.
8. The false work supporting the side span girder is removed, and the pavement is constructed.

Disadvantages of Traditional Construction technology for Self-Anchored Suspension Bridges:

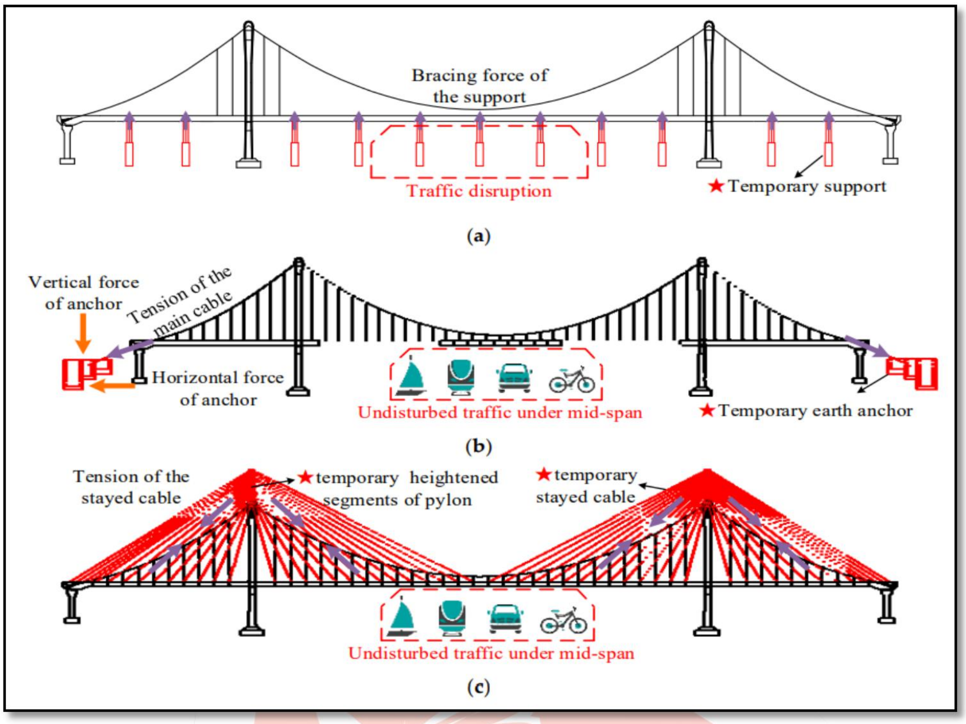


Fig. 1 - Traditional construction technologies for self-anchored suspension bridge: (a) Temporary supports technology; (b) temporary earth-anchor technology ; and (c) temporary stayed-cables technology.

1. As in fig (1.a) The traditional construction technology needs lots of temporary supports to build girders, which inevitably causes serious environmental impact and traffic disruption.
2. As in fig (1.b) For reducing traffic disruptions, the temporary earth-anchor method builds temporary earth anchor blocks to enable a construction sequence that is similar to a conventional suspension bridge. The building of earth anchor also damages the surrounding environment and produces pollution.
3. As in fig (1.c) To avoid traffic disruptions, the temporary stayed cables technology uses temporary stayed-cables to erect girder segments, just as a cable-stayed bridge, and these stayed-cables aren't removed until the main cables and hangers are erected. Although the technology reduces both environmental impact and traffic disruption, the use of expensive temporary structures (lots of stayed cables and heightened segments of the pylon) increases onsite construction cost and time.

Temporary Pylon Anchor Technology

In this study, a novel temporary pylon-anchor (TPA) technology is proposed to solve the issue in a safe and cost-effective manner for minimizing environment and traffic disruptions. The horizontal cable force is transferred to the pylon through the side span girder and is resisted by means of the bending bearing capacity of the pylon. Thus, the mid-span girder is lifted in sections and connected to the hangers. After the entire girder is erected, the horizontal cable force is transferred from the pylon to the girder, and the structure is transformed into a permanent self-balanced system. In this way, the permanent environmental impact and traffic disruption are eliminated during construction, and the onsite construction cost, time, and risk are minimized.

Analytical Approach for Antithrust System:

The GPAS is a crucial component of the proposed TPA technology. In the GPAS, the horizontal cable force is smoothly transferred from the side span girder to the pylon through the thrust shoulder. The shear capacity and stiffness of the thrust shoulder need to be designed to meet the construction performance requirements, and the girder and pylon should be non-destructive.

Girder Pylon Antithrust System:

The GPAS can be classified on the basis of the gap width between the side span girder and the pylon as follows:

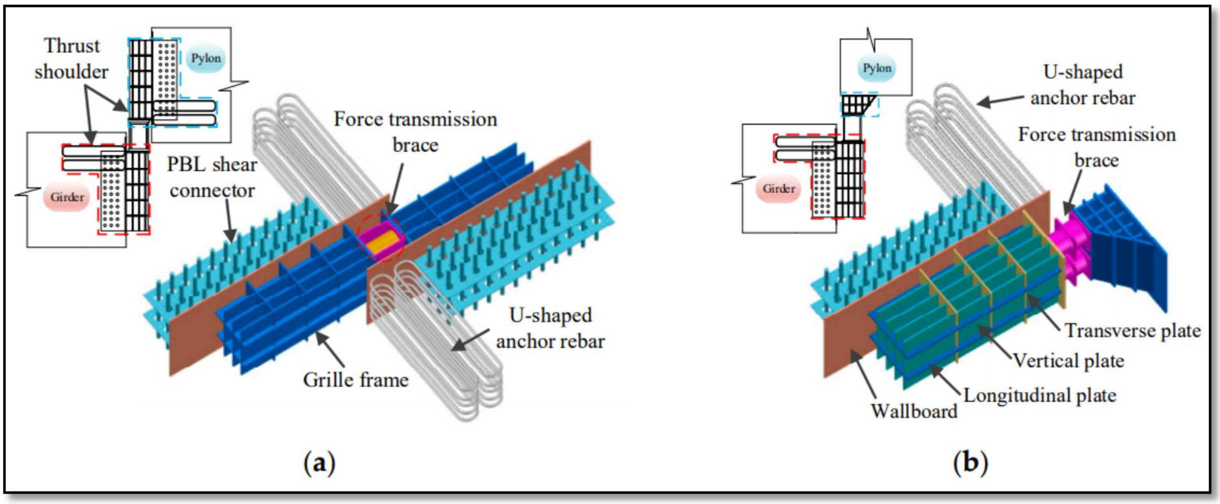


Fig. 2 – Girder Pylon Antithrust System

TYPE 1: Figure (3.a) shows the Type I antithrust system, consisting of a girder-side thrust shoulder, a pylon-side thrust shoulder, and a force transmission brace located between the set of thrust shoulders. Each thrust shoulder is composed of a grille frame, grouped PBLs, and U-shaped anchor rebars that are welded to the two sides of the wallboard. The grille frame comprises longitudinal, vertical, and transverse plates. The thrust shoulder is fastened to the lateral side of the side span girder and pylon with the aid of grouped PBLs and U-shaped anchor rebars that prevent the thrust shoulders from slip and uplift.

Type 2: The only difference between Types II (Figure 3.b) and I is that the pylon-side thrust shoulder is replaced by the foot brace to effectively transfer the thrust force and disperse the narrow gap stress.

Fig. 3 – General view of Dongtiao River Bridge

Design and Engineering Implementation:

The Dongtiao River Bridge in Huzhou, China, which is a self-anchored cable-stayed-suspension bridge with a span of 75 m + 228 m + 75 m and a semi-floating structural system, is used as the illustrative example. The bridge tower is a steel structure. The steel-concrete composite girder is used in the mid-span to reduce the self-weight, and the stay cable and prestressed concrete girder are used in the side span to balance the thrust force transmitted from the main cable to the bridge tower. Four sets of GPAS are used in the bridge to balance the thrust force of the side span generated during the construction process using the proposed TPA technology.

III. OBJECTIVES

Modelling and design analysis of a three span PSC box girder bridge using MIDAS CIVIL software.

1. To perform longitudinal analysis and transverse analysis of the PSC box girder.
2. To perform static load analysis as per IRC 6.
3. To perform moving load analysis using load combinations from IRC 6.
4. To perform ultimate limit state design as per IRC 112.
5. To perform serviceability limit design as per IRC 112.
6. To propose temporary pylon anchor (TPA) technology for the designed PSC box girder.

Material Properties of Prestressed Concrete Box Girder:

- M50 grade of concrete for girder.
- Creep and Shrinkage properties as per IRC 112:2011.
- Fe500 for reinforcing steel.

- Modulus of Elasticity = 2*10^5 MPa.
- Prestressing steel: E= 2*10^8 KN/m2.
- Poisson ratio= 0.3.
- Thermal coefficient.: 1.2*10(-5) 1/[c].
- Weight density: 76.98 KN/m3/g.

Sectional Properties of Prestressed Concrete Box Girder:
Span length – 125m (40m + 45m + 40m)

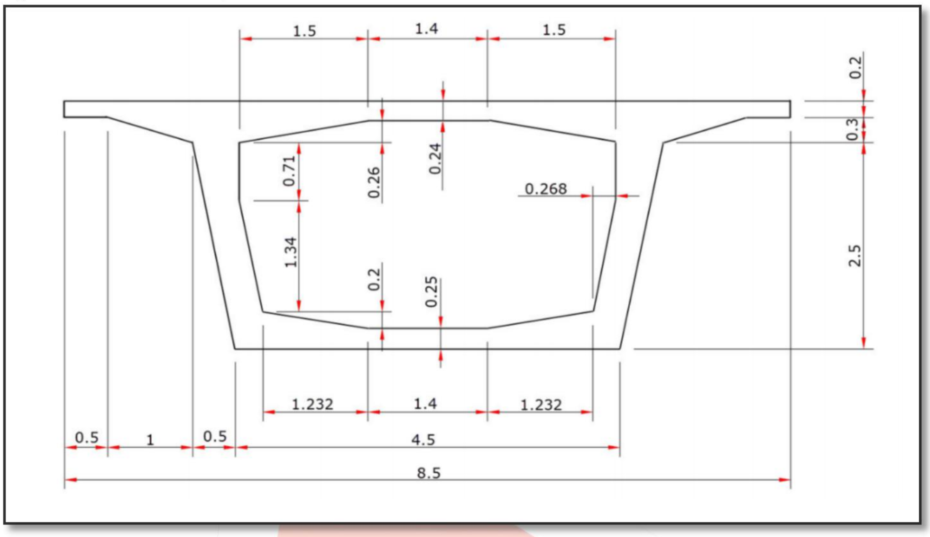


Fig. 4.a – Mid Section

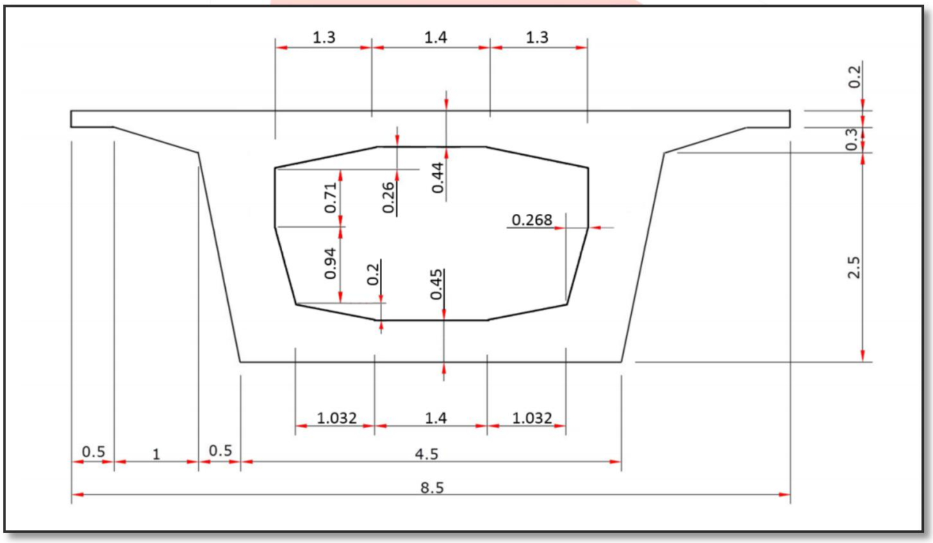


Fig. 4.b – End Section

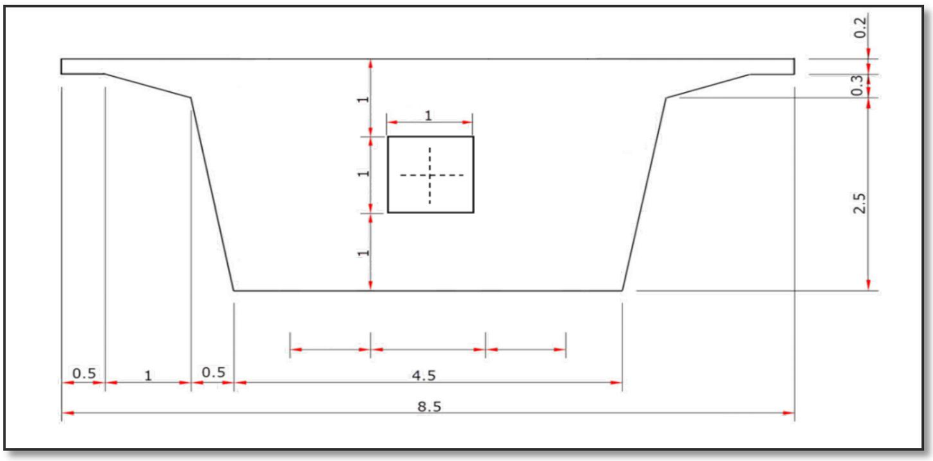


Fig. 4.c – Diaphragm Section

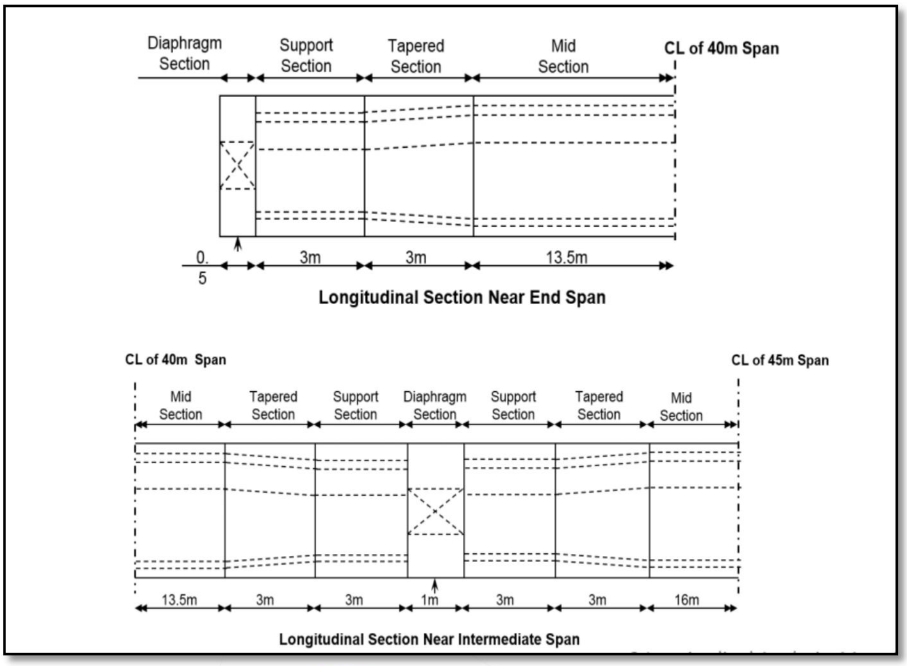


Fig. 4.e – Cross Sectional View of Tendons

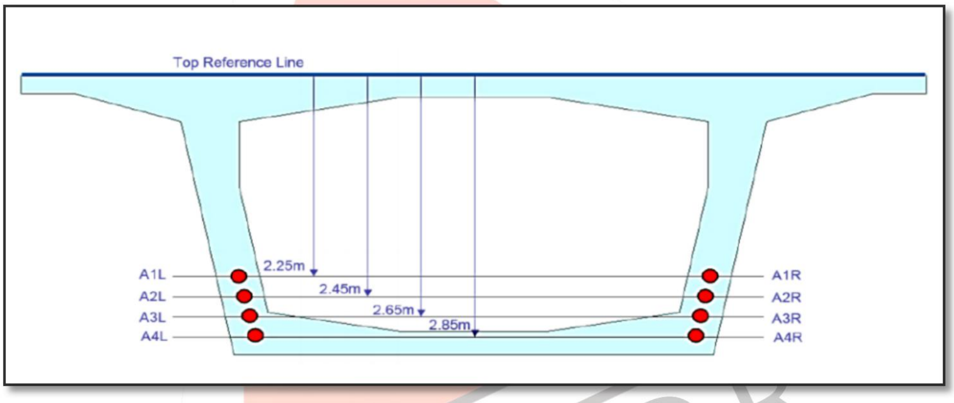
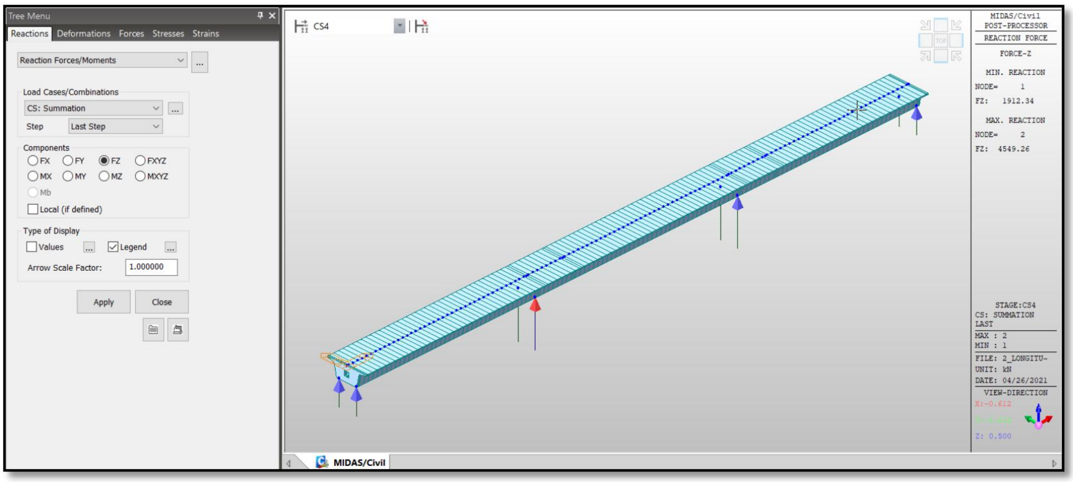


Fig. 4.d – Longitudinal View of the Span

IV. RESULTS

The SW reaction should be equal to the downward weight of the bridge.

1. Maximum Vertical reaction (Fz) = 4549.26 KN
2. Minimum Vertical reaction (Fz) = 1912.34 KN
3. Total Summation of Dead load reaction for Super structure = 21705.8 KN



Reaction Forces/Moments

Load Cases/Combinations: CS: Summation

Step: Last Step

Components: ○ FX ○ FY ● FZ ○ FXYZ ○ MX ○ MY ○ MZ ○ MXYZ ○ Mb

☐ Local (if defined)

Type of Display: ☐ Values ☑ Legend

Arrow Scale Factor: 1.000000

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MIDAS/Civil
POST-PROCESSOR
REACTION FORCE
FORCE-Z

MIN. REACTION
NODE=     1
FZ:   1912.34

MAX. REACTION
NODE=     2
FZ:  4549.26

STAGE:CS4
CS: SUMMATION
LAST
MAX : 2
MIN : 1
FILE: 2_LONGITU~
UNIT: kN
DATE: 04/26/2021
VIEW-DIRECTION
X:-0.612
Z: 0.500
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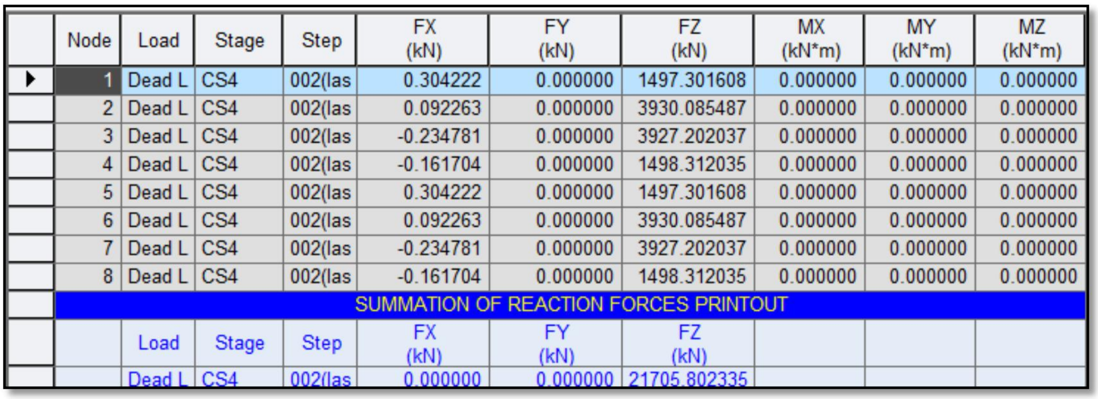
Fig. 5.a – Vertical reaction for dead load



	Node	Load	Stage	Step	FX (kN)	FY (kN)	FZ (kN)	MX (kN*m)	MY (kN*m)	MZ (kN*m)
▶	1	Dead L	CS4	002(las	0.304222	0.000000	1497.301608	0.000000	0.000000	0.000000
	2	Dead L	CS4	002(las	0.092263	0.000000	3930.085487	0.000000	0.000000	0.000000
	3	Dead L	CS4	002(las	-0.234781	0.000000	3927.202037	0.000000	0.000000	0.000000
	4	Dead L	CS4	002(las	-0.161704	0.000000	1498.312035	0.000000	0.000000	0.000000
	5	Dead L	CS4	002(las	0.304222	0.000000	1497.301608	0.000000	0.000000	0.000000
	6	Dead L	CS4	002(las	0.092263	0.000000	3930.085487	0.000000	0.000000	0.000000
	7	Dead L	CS4	002(las	-0.234781	0.000000	3927.202037	0.000000	0.000000	0.000000
	8	Dead L	CS4	002(las	-0.161704	0.000000	1498.312035	0.000000	0.000000	0.000000

SUMMATION OF REACTION FORCES PRINTOUT

Load	Stage	Step	FX (kN)	FY (kN)	FZ (kN)
Dead L	CS4	002(las	0.000000	0.000000	21705.802335

Fig. 5.b – Result Table for Summation of Vertical Reaction

Bending Moment Diagram:

Due to Dead Load, SIDL-WC, SIDL-CB, Tendon Primary, Tendon Secondary, Creep Secondary, Shrinkage Secondary:

1. Maximum Sagging moment = 11615.24 kN-m
2. Maximum Hogging moment = 11918.66 kN-m

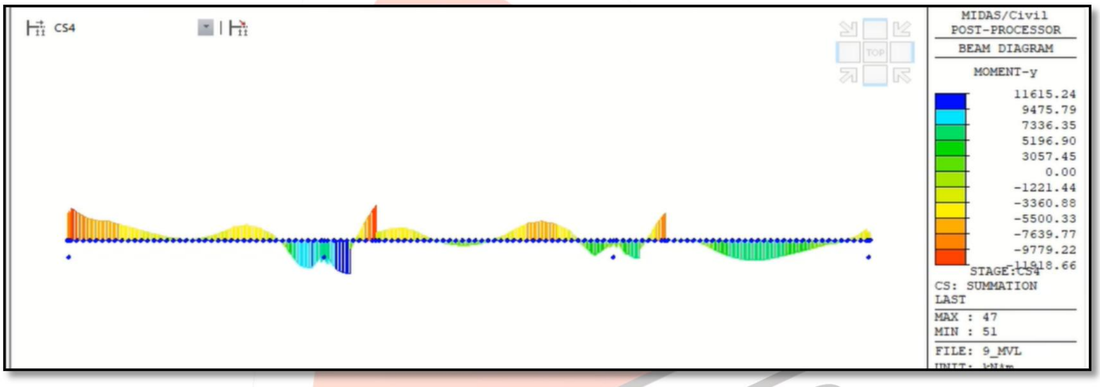


Fig. 6.a – Bending Moment Diagram

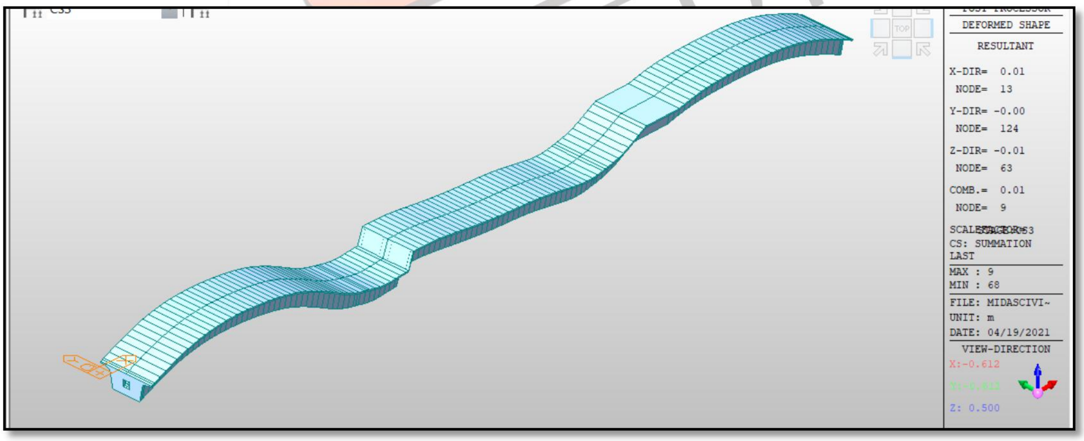


Fig. 6.b – Deformed shape of the girder due to all types of loads excluding pre-camber

Moving Load Tracer:

Moving load tracer is a striking feature of MIDAS CIVIL which can trace and graphically represent the vehicular loading condition that results in Maximum and Minimum effects. Moment can be calculated by multiplying the ILD co-ordinates with the concentrated vehicular load.

V. CONCLUSION

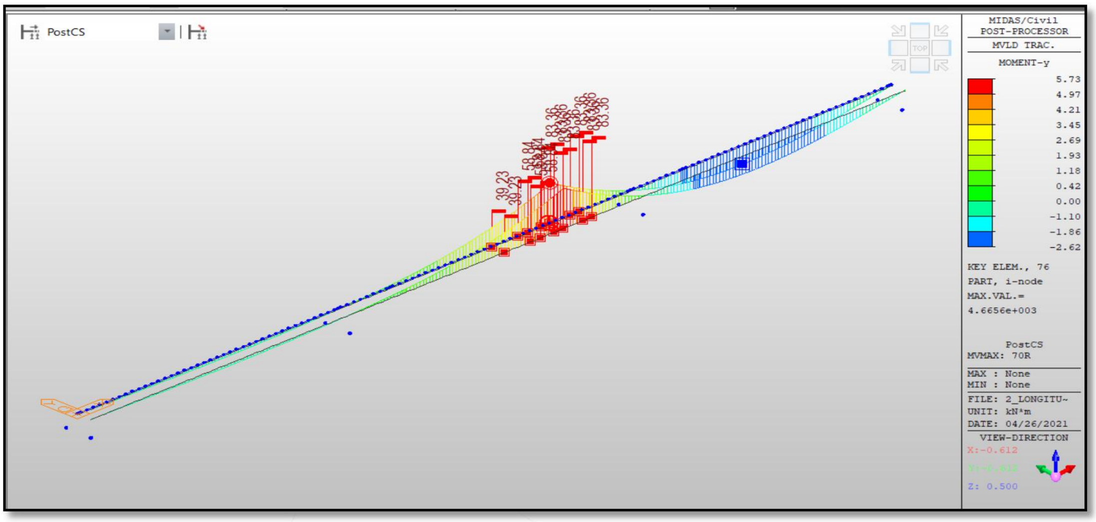


Fig. 7 – Maximum moment effect for 76th element due to 70R vehicle

- The results obtained from the MIDAS CIVIL software gave an adequate understanding of the variety of loads to be considered and their effect on the bridge structure.
- Based on the analysis, it can be reasonably stated that box section is the most appropriate choice for the self-anchored bridge due to its various advantages as well as ease of construction.
- The sustainability assessment conducted during the construction stage analysis reveal that the proposed Temporary Pylon Anchor technology (TPA) and analytical approach can facilitate the implementation of sustainable construction for self-anchored suspension bridges by considering both construction safety and sustainability.
- The TPA technology evaluated in this paper is relatively new, hence its applicability in the Indian scenario should be tested. Self-anchored suspension bridges are also very rare in the Indian subcontinent, therefore an effort has been undertaken to understand the complexity of it during the course of the project.

VI. REFERENCES

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