International Journal of Scientific Research in Civil Engineering
© 2021 | IJSRCE | Volume 5 | Issue 6 | ISSN : 2456-6667

Analysis of a Segmental Bridge Considering Lateral Forces Using Analysis Tool

Singh Rathore*, Rahul Satbhaiya

Department of Civil Engineering, Infinity Management & Engineering College Sagar, Madhya Pradesh, India

Article Info
Volume 5, Issue 6
Page Number : 167-180

Publication Issue :
November-December-2021

Article History
Accepted : 02 Dec 2021
Published : 25 Dec 2021

ABSTRACT

This study aimed at examining the feasibility of using carbon fiber-reinforced polymer (FRP) rebars instead of steel ones in prestressed segmental concrete beams (PCBs) with external FRP tendons. By applying an experimentally validated program, numerical tests were performed on simply supported PCBs, with investigated variables including rebars' type and area. Two types of tendons were considered, i.e., FRPs and reinforcing steel. The ratio of tensile rebars ranged from 0.22% to 2.16%. The results indicated that the beams with CFRP rebars exhibited better crack mode and higher ultimate load than the beams with GFRP or steel rebars. GFRP rebars led to considerably higher ultimate deflection and tendon stress increment than steel rebars. In addition, several models for calculating the ultimate stress in unbonded tendons were assessed. An analytical model was also proposed to predict the tendon stress at ultimate and flexural strength in externally PCBs with steel and FRP rebars. The model predictions agreed well with the numerical results.

A finite element model is proposed for numerical analysis of mechanical properties of precast segmental concrete test beam with external tendons. The 3D finite element model of test beam is established by SAP 2000 software, while the dry joint between segments is simulated by contact element, and the attachment between concrete beam and external prestressed tendons is achieved by node coupling method. Numerical simulation analysis reveals structural behavior, stress variations and crack opening cases of joints of the test beam by considering the concrete material and geometric nonlinearity. Influencing factors of the bending mechanical properties of the test beam are researched with different tendon types, secondary effect of external tendons and external tendon slip at deviation. Results of the numerical analysis reveal that the segmental joints are in the compressive state below the 300kN.Crack opening is the key factor of the mechanical properties of the test beam above the 300kN.The results can be used for structural design of precast segmental bridge.

Keywords: fiber-reinforced polymer; beams; rebars; flexural strength; structural analysis.

I. INTRODUCTION

Over the past four decades, segmental bridges have been built widely all over the world, especially in the United States, France, Spain, Italy, and China, but most of these bridges are restricted to the use of external or internal prestressing. For these bridges, the internal tendons were fully bonded, and the external prestressing tendons were unbonded. Many problems with segmentally constructed bridges were found as a result of poor construction practices and design errors. In recent year, growing attention has been given to the investigation, development and application of the hybrid tendons systems for the segmental bridge. Many test investigations on segmental structures have been carried out in several countries over the last few decades.

Segmental concrete bridges are bridges which involves assemblage of smaller pieces of concrete members called segments using post tensioning tendons to form a bridge structural system, either superstructure or substructure. the posttensioning system can be bonded, unbonded tendons, or a combination of both.it can be external or internal. Segments can be produced by cast-in-place or precast/prefabricated methods. There are mainly three construction method for the precast segmental bridge which are balanced cantilever construction method, span by span construction method and incremental launching method. From above three I have selected balanced cantilever construction method.

Steel corrosion would lead to the deterioration of reinforced or prestressed concrete beams (RCBs or PCBs). An effective solution to this problem is to replace steel reinforcement with fiber-reinforced polymer (FRP). In addition to their non-corrosive property, FRP composites are high-strength, light-weight, and nonmagnetic. These composite materials are increasingly used for strengthening structural elements. Different types of FRP composites are available, such as aramid, basalt, carbon, and glass FRPs (AFRP, BFRP, CFRP, and GFRP). Unlike steel reinforcement with ductile characteristics, FRP composites are linear-elastic materials without yielding. In addition, the FRP modulus of elasticity is usually lower than that of steel reinforcement. Hence, some concerns on the use of FRP reinforcement instead of steel reinforcement may arise, e.g., ductility and deflection issues due to the lack of yielding and low modulus of elasticity for FRP composites. The bond performance of FRP reinforcement in concrete under environmental exposure is also a concern. It was generally demonstrated that harsh environments have adverse effects on FRP reinforcement’s bond durability.

1.2 Precast Segmental Structures

Precast structures are completely constructed before positioning them. A precast structure is constructed from pre-stressed concrete and the final form of the structure is then positioned where it has to be used. Precast concrete is made up of fine stone gravels, cement, water, and admixtures. The mixture is prepared in the factory's batch plant according to the concrete mix design specified by the civil. The approved batch of concrete is transported to the molds by means of a dispensing machine using an overhead crane. Discussing the construction of the bridges, all the bridges that are constructed with CFST or concrete materials are constructed in two ways. One is the “Single Span Construction Method”, while the other is the “Segmental Construction Method”. In a single span bridge, the whole span of the bridge is constructed at once. The whole span of the bridge is in consolidated form, and no part of the bridge span is separated from the other part. The span of the bridge does not include piers and abutments. The span of the bridge consists of three parts i.e. beams, deck, and parapets. Abutments, piers, foundations, and arch are not included in the span of the bridge. As we mentioned, a CFST or concrete bridge can be built either in the form of a single span as well as in a segmented form. In a segmented span bridge, there are many spans of the bridge which are placed on the piers. The pier to pier connection is built by means of segmented spans. In other words, the span of the bridge has been divided into many segments or parts. It is done because of the convenience of lifting the beams and slabs in parts. It is very difficult to even for the heavy machines to lift a consolidated beam. Therefore, the beam is pre-casted in segments on the ground, then these segments are lifted above the top of the piers.

The construction of such novel prestressed segmental concrete beams offers some advantages, such as the following:

- Reduction of the duration of construction at the site and shortening of construction periods. The construction of the segmental concrete bridges with both external tendons and internal tendons can speed up when it is associated with a span-by-span construction process. For the construction of each of the spans, the concrete segments are placed next to each other, suspended from a beam or arranged in a mobile falsework, and assembled by means of external prestressing and internal prestressing.
- Improvement of the durability and quality of the structure by factory production of segmental beams and the ability to replace the external tendons over time and apply epoxy resin between the joint faces of the segments.
- Improvement of the ductility by use of internal tendons. The more significant characteristic of this beam construction is the nonexistence of bond reinforcement crossing the joint faces. Therefore, the addition of internal tendons will inevitably improve the beam ductility because of the bonding force..

Fig 1 Precast Segment Structure

Objectives of the Study

Considering the previous study about joint behavior did not cover the possible failure modes: when subjected to loads in the immediate vicinity of joints, beams may lose bearing capacity due to the concrete breaking on the upper part of the joint plane under compressive combined with shear stresses with the joint opening to a certain height, this paper presents the experimental study about this possible failure of joints in PCSB with external tendons. Two types of joints (dry and epoxied) were applied in the tests and the models were subjected to bending moments, combined shear and bending, and direct shear respectively to achieve the following objectives:

1. Analyzing the differences in failure processes and modes of the specimen under direct shear, combined shear and bending, and pure bending;
2. Qualitatively studying the resistance mechanism of the specimen under combined shear and bending, analyzing the differences in resistance mechanism comparing with traditional bending or shear failure;
3. Investigating the contribution of stirrups to the strength of joints under combined shear and bending;
4. Proposing simplified failure modes of two types of joints under combined shear and bending;

II. Literature Review

H. M. Hekmet and A. F. Izzet (2019) the research paper illustrated observations, record accurate description and discussion about the behavior of twelve tested, simply supported, precast, prestressed, segmental, concrete beams with different segment numbers exposed to high fire temperatures of 300°C, 500°C, and 700°C. The test program included thermal tests by using a furnace manufactured for this purpose to expose to high burning temperature (fire flame) nine beams which were loaded with sustaining dead load throughout the burning process. The beams were divided into three groups depending on the precast segment number. All had an identical total length of 3150mm but each had different segment numbers (9, 7, and 5 segments), in other words, different segment lengths. To simulate genuine fire disasters, the nine beams were exposed to high-temperature flames for one hour along with the control specimens. The selected temperatures were 300°C (572°F), 500°C (932°F), and 700°C (1292°F) as recommended by the standard fire curve (ASTM–E119). The specimens were cooled gradually at ambient laboratory conditions. The performance of the prestressed segmental concrete beams through the burning process was described with regard to the beams camber, spalling, and occurred deterioration.

Results stated that Increasing burning temperature had a bad effect on the residual final camber at the end of burning and cooling cycle, denoting more deterioration occurred. The increase in the residual camber for SPC beams of 9 segments was 153%, 169%, and 236% for burned beams at 300˚C, 500˚C, and 700˚C respectively compared to the initial camber before burning. Whilst, for SPC beams of 7 and 5 segments it was 152%, 175% and 266%, and 150%, 182% and 253% for the same temperatures. Comparing the effect of segment number on the residual camber of post fire SPC beams, the results show that, camber decreases with decreasing number of segments. Exposing SPC beams composed of 7 and 5 segments to 300˚C decreased the final camber by 78% and 56% respectively compared to that of 9 segments. It decreased by 80% and 63%, and 82% and 69% for SPC beams composed of 7 and 5 segments compared to 9 segments at 500 C, and 700˚C respectively.

Shun Chai et al (2020) in the research paper, six large-scale PCS box-girders with dry joints were tested to failure under two-point loading and Strain increments, tendon forces, deflections at mid-span, and cracks were recorded during the tests. Multiple factors were investigated with regards to their influence on flexural performance of girders. It was found that most specimens failed due to the excessive force in tendons, while the specimen with external tendons failed due to concrete compressive crushing. Larger shear span ratio resulted in greater increase in tendon force and concrete strain during loading and, accordingly, the lowest ultimate flexural capacity. Lower concrete strength resulted in larger increase in concrete strain and tendon force during loading and relatively smaller deflection at failure. For the specimen with four segments, a significant increase in tendon force and smaller deflections at failure was observed as compared with specimen 1, though the failure load was similar. Numerical simulation was further conducted, where it was found that the area of prestressed tendon and the number of joints have a significant influence on ultimate flexural bearing capacity and deflection; besides, deflection control standard of PCS girders should be stricter than that of the integral cast girder. The corbel joints, in general, show better ultimate performance than the castle-shaped joints.

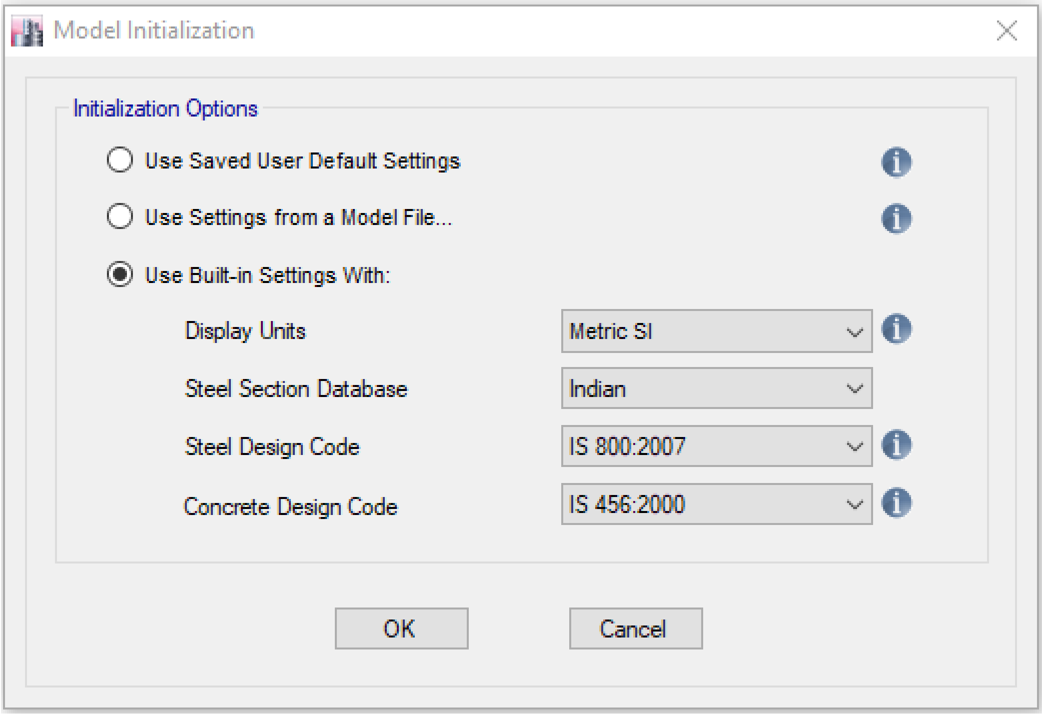
Tan D. Le et al (2019) the research paper investigated the use of carbon fibre reinforced polymer (CFRP) tendons on precast segmental beams (PSBs) to tackle the corrosion problems which are likely to occur at joint 8 locations of PSBs prestressed with steel tendons. Up to date, the use of CFRP tendons was extensively documented for monolithic beams while their application on PSBs has not been reported yet. Three precast segmental T-section beams including two beams with unbonded CFRP and one with steel tendons were built and tested under four-point loads in this study. The test results showed that CFRP tendons can be well used to replace the steel tendons on PSBs. The beams with CFRP tendons demonstrated both high strength and high ductility as compared to the beam with steel tendons. However, the stresses in the unbonded CFRP tendons at ultimate loading conditions of the tested beams were low, ranging from only about 66% to 72% of the nominal breaking tensile strength. The type of joints i.e. dry and epoxied, greatly affects the initial stiffness of the beams but has no effect on the opening of joints at ultimate loading stage. Moreover, a comprehensive examination on four existing code equations to predict the stress in the unbonded tendons showed that the four examined codes predicted well the stress at the ultimate loading condition of the unbonded steel tendons, however, they significantly under predicted those in the CFRP tendons. A modification in the strain reduction 22 coefficient used by ACI 440.4R for predicting the stress increment in unbonded CFRP tendons 23 of monolithic beams is therefore proposed for PSBs based on the experimental results.

III. Methodology

For this research work following steps should be followed:

Step 1 First step is to study different research papers from authors all across the globe to understand the research done in the same field and this gave our study base and scpe for further research.

Step 2 this step includes defining the unit to design the model initialization where the units is measured as Metric SI. Steel code and concrete design code is locked as IS 800:2007 and IS 456:2000.



Model Initialization

Initialization Options

○ Use Saved User Default Settings

○ Use Settings from a Model File...

● Use Built-in Settings With:

Display Units: Metric SI

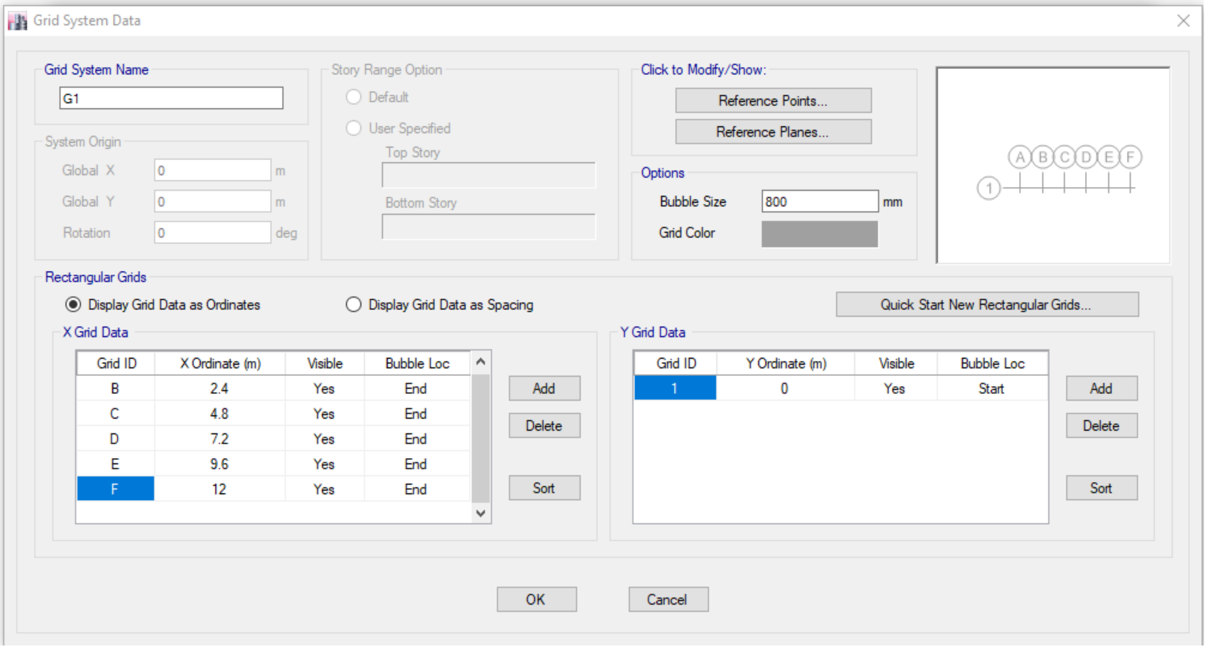
Steel Section Database: Indian

Steel Design Code: IS 800:2007

Concrete Design Code: IS 456:2000

Fig 2 Model Initialization

Step 3: Etabs provides an interface to design 3d modelling on the 3 axis on grid system. Here the grid system is pointed in X direction as 1,2,3,4,5…….. and Y direction as A,B,C,D…..



Grid System Name: G1

System Origin

Global X: 0 m

Global Y: 0 m

Rotation: 0 deg

Options

Bubble Size: 800 mm

Rectangular Grids

● Display Grid Data as Ordinates ○ Display Grid Data as Spacing

X Grid Data

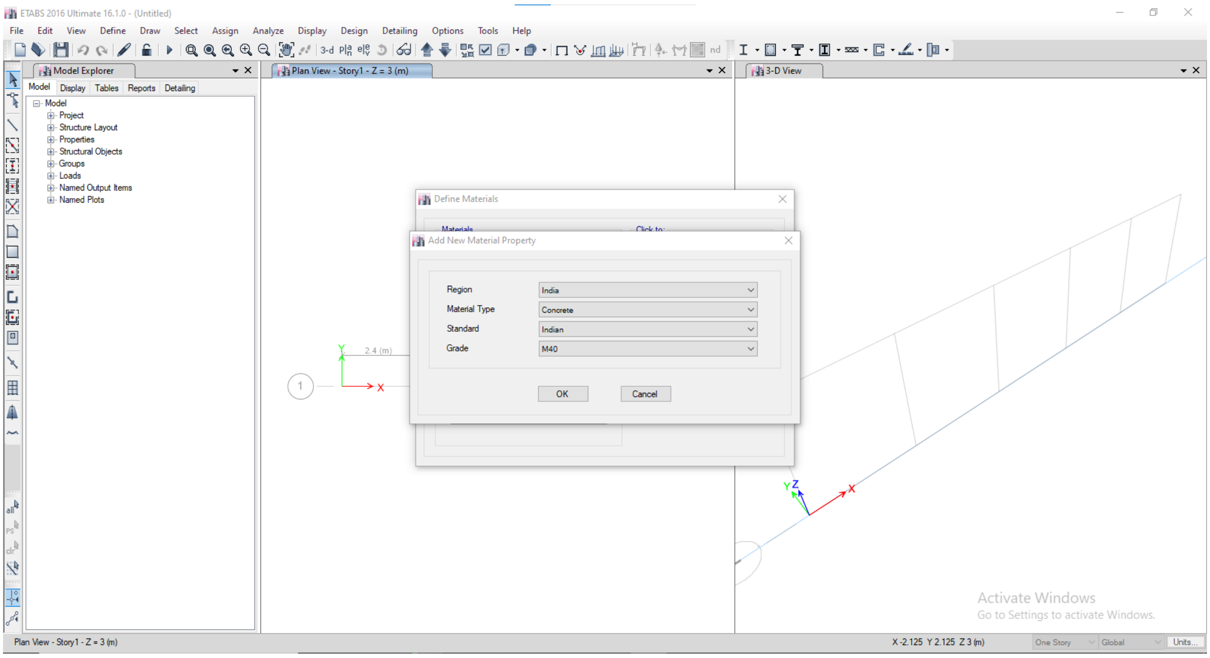
Grid ID	X Ordinate (m)	Visible	Bubble Loc
B	2.4	Yes	End
C	4.8	Yes	End
D	7.2	Yes	End
E	9.6	Yes	End
F	12	Yes	End

Y Grid Data

Grid ID	Y Ordinate (m)	Visible	Bubble Loc
1	0	Yes	Start

Fig 3 Grid Sytem Data

Step 3: Defining material for the segmental beams comparing two cases with different tensons.



Region: India

Material Type: Concrete

Standard: Indian

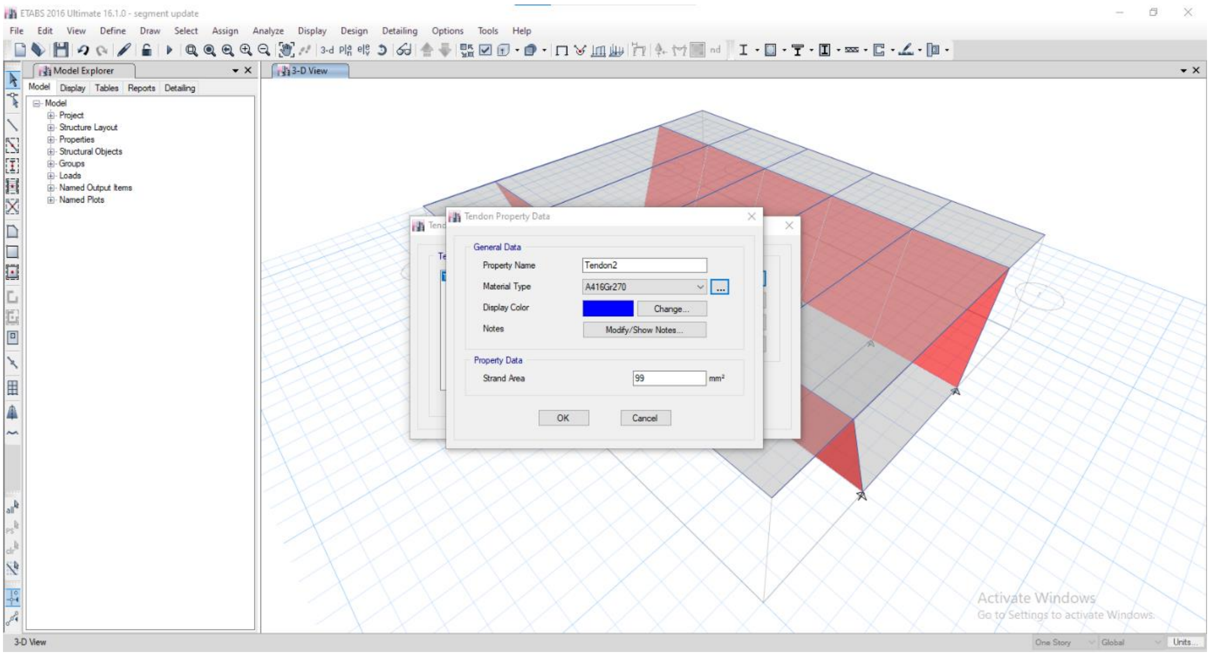
Grade: M40

Fig 4 Defining Material Properties

Step 4: Assigning tendons to precast segmental beam.

Start the modeling of bridge by specifying the lane width. Utilizing bridge wizard change the material properties and also entering the vehicle classes i.e. IRC class AA loading, IRC class A loading ,IRC class 70 R loading using Indian codes. Mention the deck section properties. Using the bridge object data enter the diaphragms along the span of the bridge at equal interval. Mention the abutments, bents, bent cap with its dimensions in the frame properties, Specify where the bent assignment is being applied, it is basically applied at the end of the span. The diaphragm assignment includes a diaphragm location, property, and orientation, in span diaphragms are assigned as a part of bridge object definition. Diaphragms that occur at abutments, bents and hinged are assigned as a part of the bridge object abutment, bent and hinge assignments respectively.

Load the bridge model available in ETABS. A moving load analysis can be utilized to decide the reaction of a bridge structures as a result of weight of vehicular live loads. Lanes are required if vehicular loads are to be added to a bridge model. Vehicles move in both directions along each lane of the bridge. Vehicles are consequently situated at such positions along the length and width of the lanes to produce the maximum and minimum response quantities throughout the structure.



Tendon Property Data

General Data

Property Name: Tendon2

Material Type: A416Gr270

Display Color

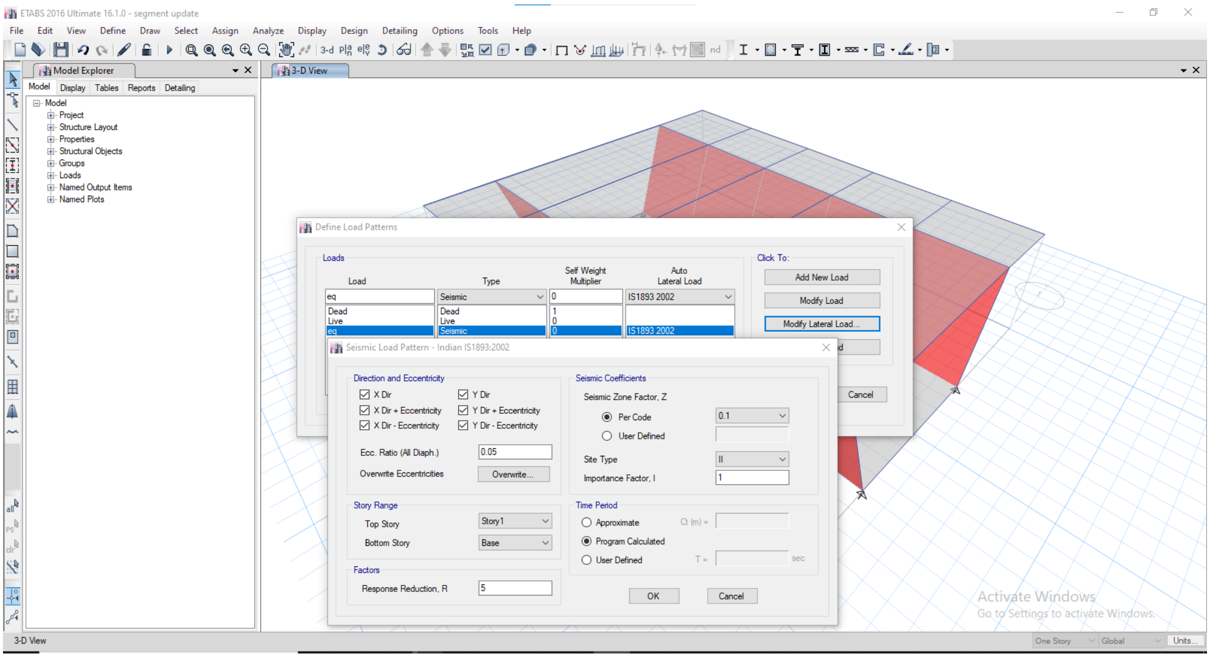
Notes

Property Data

Strand Area: 99 mm²

Fig 5 Assigning Tendons.

Step 5: Assigning Loading conditions to the model Precast Segmental beam with tendons.



Define Load Patterns

Loads

Load	Type	Self Weight Multiplier	Auto Lateral Load
eq	Seismic	0	IS1893 2002
Dead	Dead	1	
Live	Live	0	
eq	Seismic	0	IS1893 2002

Seismic Load Pattern - Indian IS1893:2002

Direction and Eccentricity

☑ X Dir ☑ Y Dir

☑ X Dir + Eccentricity ☑ Y Dir + Eccentricity

☑ X Dir - Eccentricity ☑ Y Dir - Eccentricity

Ecc. Ratio (All Diaph.): 0.05

Overwrite Eccentricities

Seismic Coefficients

Seismic Zone Factor, Z

● Per Code: 0.1

○ User Defined

Site Type: II

Importance Factor, I: 1

Story Range

Top Story: Story1

Bottom Story: Base

Time Period

○ Approximate Ct (m) =

● Program Calculated

○ User Defined T = sec

Factors

Response Reduction, R: 5

Fig 6 Assigning Loading Condition

Step 6: Analyzing the model and rendering the structure

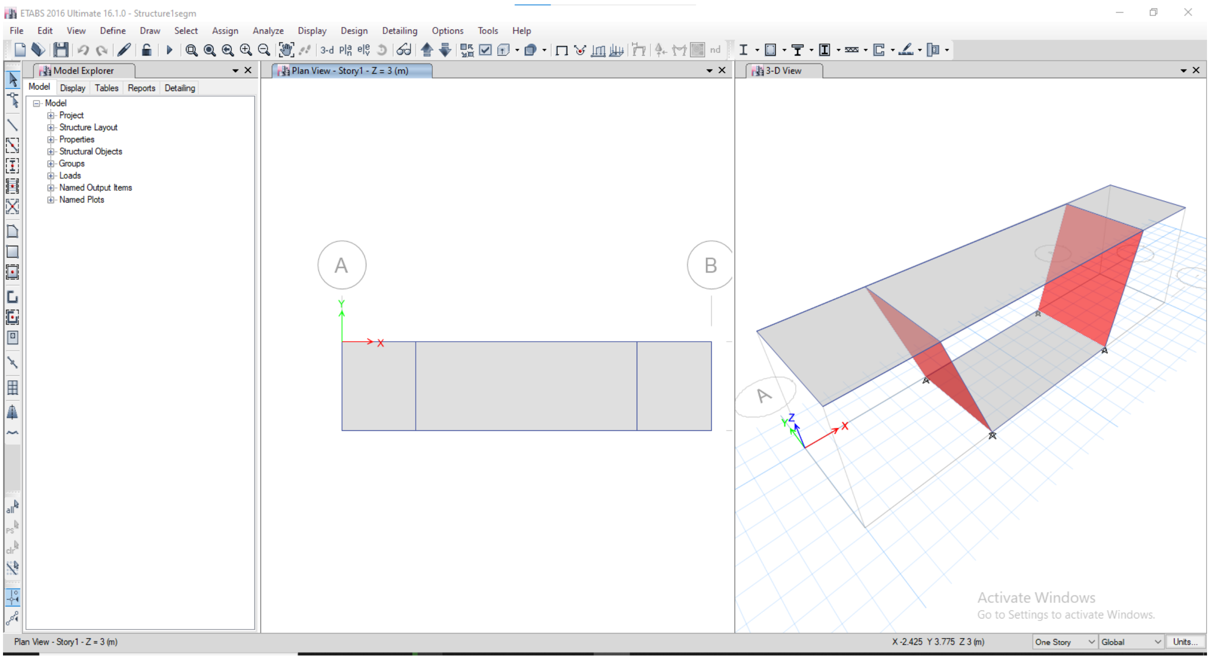


Fig 7 cross-section of beam with tendons

Step 7: Analyzing the stress analysis on the model

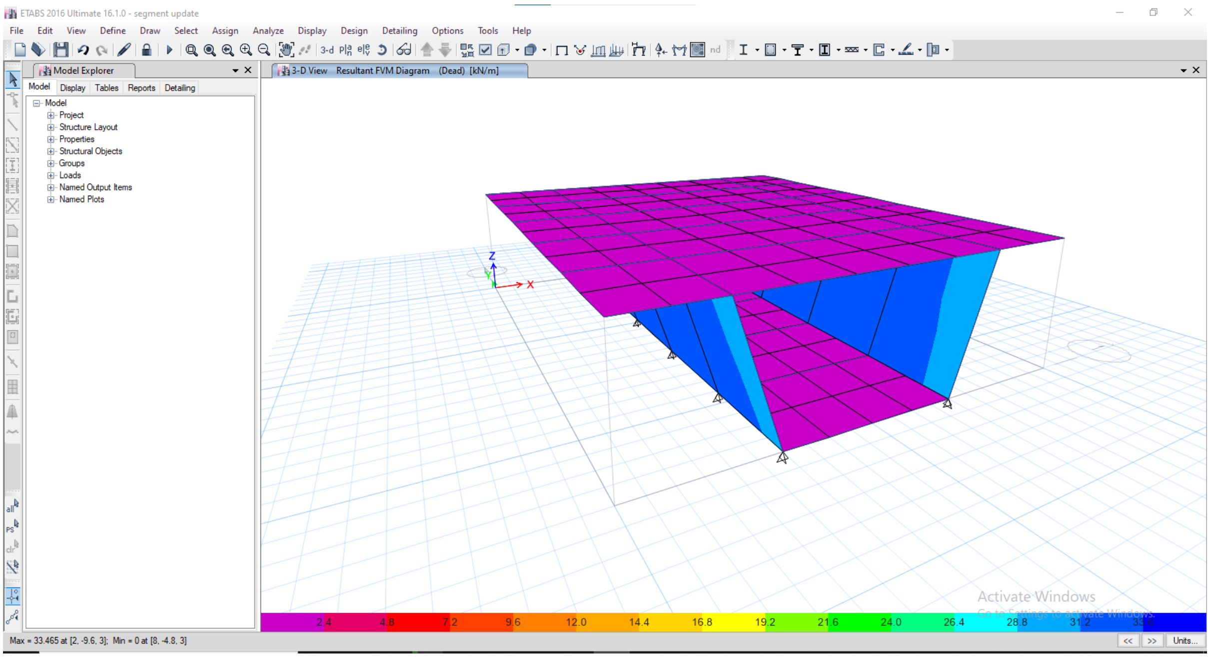
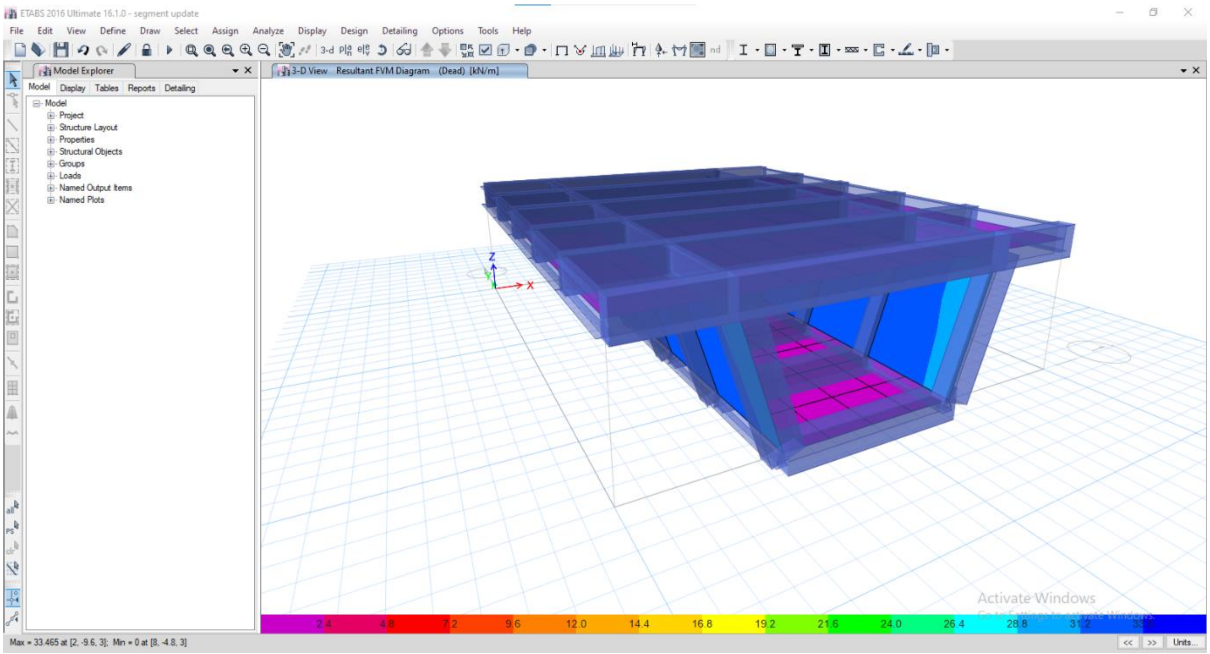


Fig 8 Deflection



Max = 33.465 at [2, -9.6, 3]; Min = 0 at [8, -4.8, 3]

Fig 9 Stress Analysis

Table 1 Technical Properties of Carbon Fibres.

Technical Properties of Carbon Fibers	
Property	**Results**
Fibre type	High strength carbon fibers
Fiber orientation	The fabric equipped with special weft fibers which prevent Loosening of the roving (heat set process)
Areal weight	0.13 mm (based on total area of Carbon fibers).
Tensile strength of fibers	3500 MPa
Tensile E – modulus of fibers	230 GPa
Elongation at break	1.5 %
Fabric length/roll	≥ 45.7 m
Fabric width	305/610 mm

Table 2: Dimension of the Model

Dimension of the model	
Length	2440 mm

Height	200 mm
Shear key Joint Type	Concave
Web thickness	35 cm
Area	4.89 m2
Moment of inertia	3.582 m4
Distance from top to centroid axis	0.781m
Tendon eccentricity	1.57 m
Span to depth ratio L/H	18.8
No. of tendons	12

Case Study

Two cases were considered in the research considering two dfferent tendons:

Case I Model considering Steel Tendons

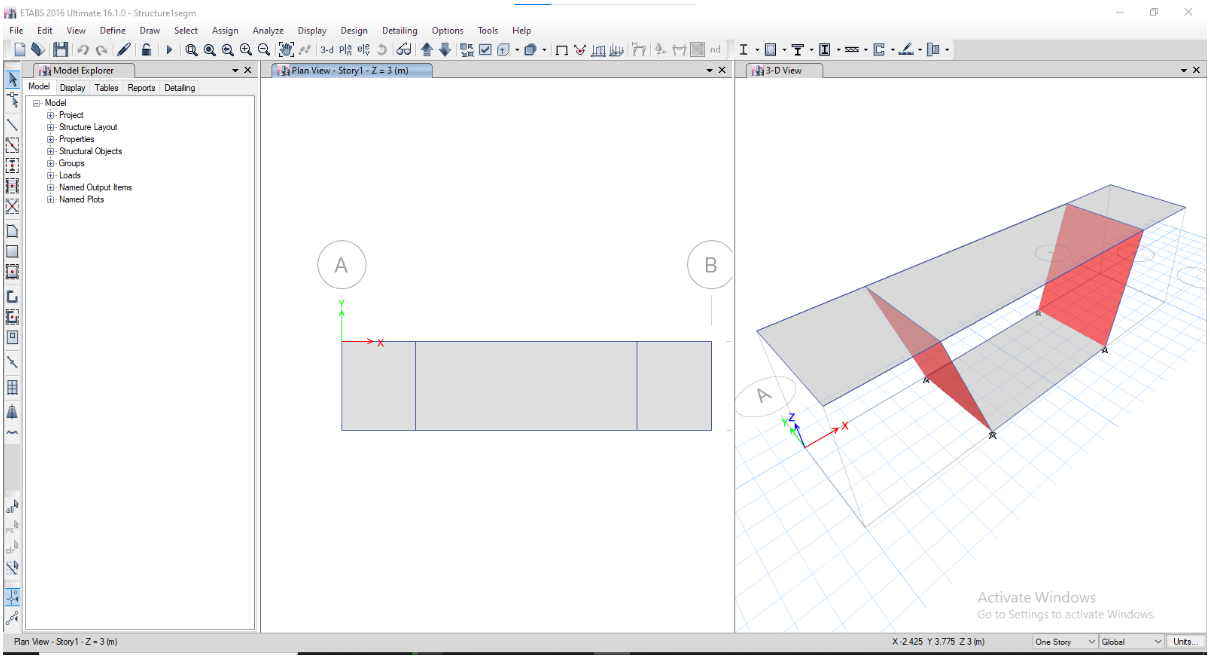


Fig 10 Model with steel tendons

Case II Model considering Carbon fibre tendons.

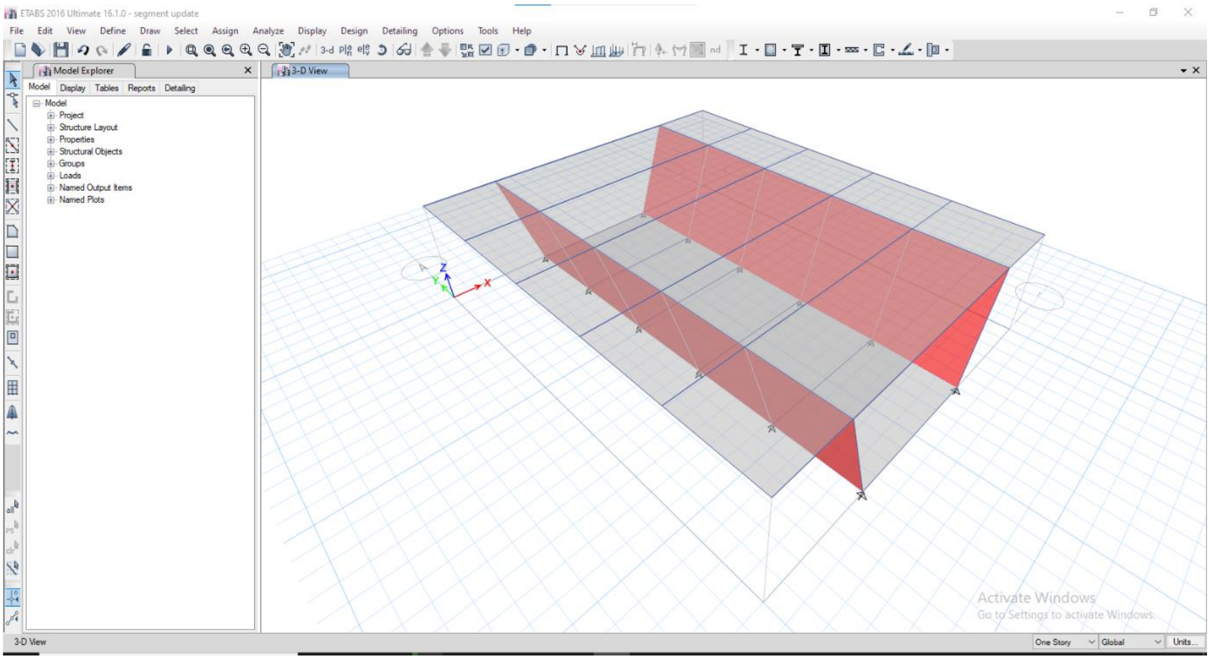
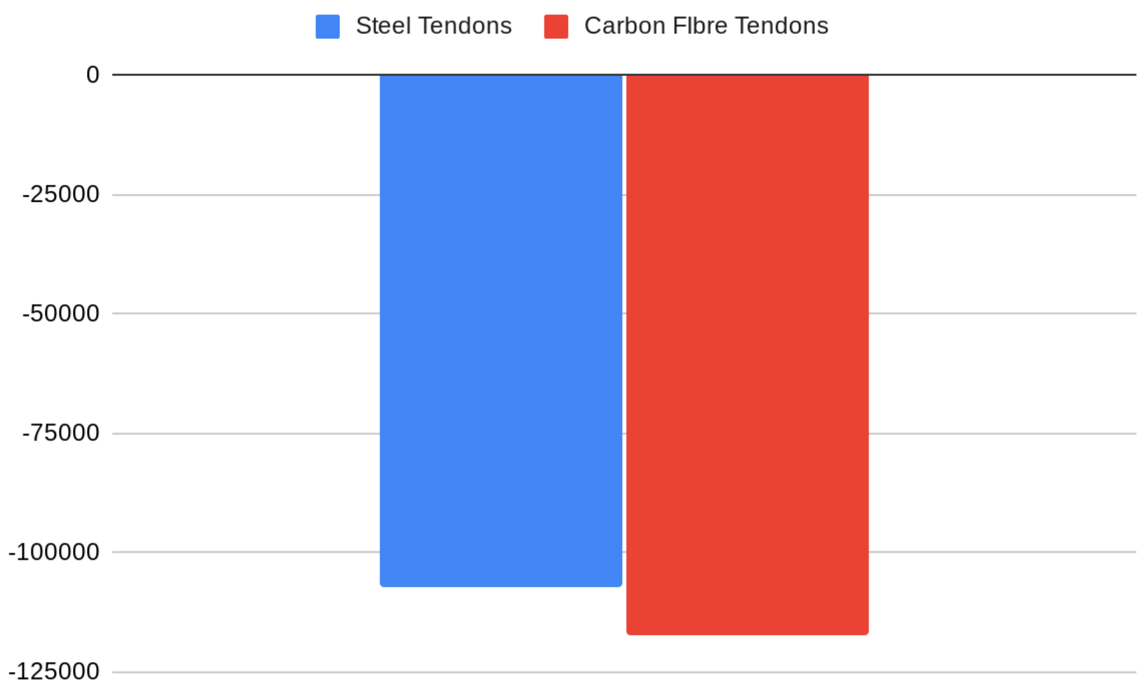


Fig 11 model with Carbon Fibre Frp Tendons

IV. ANALYSIS RESULT



Deflection in mm	
Steel Tendons	Carbon Fibre Tendons
63.754	59.505

V. CONCLUSION

Bending moment was found maximum in case with steel reinforced tendons due to extreme effect of hogging when stress was applied in comparison to model with carbon fibre reinforced polymer (CFRP) tendons. For equilibrium, the moment created by external forces (and external moments) must be balanced by the couple induced by the internal loads. If clockwise bending moments is negative, then a negative bending moment within an element will cause "hogging", and a positive moment will cause "sagging.

Shear stress occurs when two fastened structures (or two parts of a single structure) are forced in opposite directions. If left unchecked, the shear force can literally rip bridge materials in half. A simple example of shear force would be to drive a long stake halfway into the ground and then apply lateral force against the side of the upper portion of the stake. Shear force was found to be high as 46170.2 KN in case of reinforced steel tendons and 13754.6 KN in case of carbon fibre reinforced polymer (CFRP) tendons

The word “axial” is used because the force is straight down the middle of the member, so there is no bending or twisting. Imagine a bridge member in a tug of war; this is a simplistic but effective image. An example where axial tension is the only force is in bridge cables and in this case its tendons.Positive axial force is tension and negative axial force is compression. Positive moment indicates compression on the top of the section.

Here in the case axial force was found maximum in the case of the model with steel reinforced tendons in comparison to model with carbon fibre reinforced polymer tendons. Hence the second case was stable.

Deflection, in structural engineering terms, means the movement of a beam or node from its original position. It happens due to the forces and loads being applied to the body. Deflection also referred to as displacement, which can occur from externally applied loads or from the weight of the body structure itself. Here the deflection was 63.754 mm in case of model with reinforced steel tendons and 59.505 mm in case of model with carbon fibre reinforced polymer (CFRP) tendons.

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Cite this article as :

Vijay Singh Rathore, Rahul Satbhaiya, "Analysis of a Segmental Bridge Considering Lateral Forces Using Analysis Tool", International Journal of Scientific Research in Civil Engineering (IJSRCE), ISSN : 2456-6667, Volume 5 Issue 6, pp. 167-180, November-December 2021.
URL : https://ijsrce.com/IJSRCE215634