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Nonlinear Analysis of External Post-Tensioning anchorage of Concrete Segment

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***Abstract:** Precast concrete segmental bridges (PCSBs) have been the most common design technology used in the last decades. In these studies Non-linear structural performances of externally prestressed, precast concrete segmental bridges (PCSB). PCSBs with externally prestressed tendons have become very popular in construction because of economical and safety reasons, fast and practical construction, and outstanding serviceability. External tendons technique is widely used because it allows to inspect the cables and to replace them or to reinforce the tendons in case of damage while such kinds of actions are difficult to be taken in case of internal prestressing. It is widely recognized that segmental bridges have better durability, lower life-cycle costs and higher quality for maintenance than other types of bridges.*

However, there is lack of reliable computational model for analyzing behavior of post-tensioned PCSBs. Experimental analysis of bridge segment required more cost, time and effort for the analysis and also take cake of quality of material, cast process, curing, and testing.

This research presents the results of stress and strain state of the local bearing area caused by a Prestressed cable anchor in reinforced concrete bridge segment. Nonlinear analysis of anchorage and rebar, concrete segment can be carried out by analytical solution calculated with the reference of ACI 318/19. ANSYS software is used for model and analyze the structure. The analysis process was carried out in 3 types : linear elastic analysis, nonlinear elastic analysis, and nonlinear analysis considering the destruction of concrete, and the value is compared with ANSYS software (static structure).

I. INTRODUCTION

A. General Introduction

In reinforced concrete and prestressed concrete, steel reinforcement is used to resist the tensile forces and stresses in the concrete. In prestressed concrete, compression is introduced in concrete elements to increase load capacity and improve behavior. The beneficial effects of prestressing have lead to the development of long span structures, especially long span bridge structures. There are two methods for prestressing concrete: pre-tensioning and post-tensioning. In pre-tensioning, prestressing steel (either rods or strands) are stressed (stretched), held in place, bonded to concrete which is cast after the steel is stressed, and released after the concrete reaches a specified strength.

When the prestressing steel is released, compressive force is applied to the concrete. Typically, as long as the concrete strength is strong enough to withstand the compressive stresses that develop when the load is applied, pre-tensioning increases the tensile capacity of the structural member.

Fueled by the desire to erect bridges with longer clear spans and smaller cross-sections, engineers introduced design and construction innovations such as segmental box girder bridge construction. In segmental box girder bridge construction, post-tensioning is used to connect individual bridge segments together to create bridge spans.

In post-tensioning, concrete elements (i.e. bridge segments) are cast with embedded post-tensioning anchorage devices. When the segments are assembled, prestressing steel (most commonly steel strands) are threaded through the anchors and ducts, stressed and locked in place. As a result, large compressive forces are introduced in the bridge segments at and near the anchors.

B. Problems with Anchorage Zones in Bridges

If the post-tensioned anchorage zone is not properly detailed and designed to withstand the forces and stresses which develop, failure of the anchorage zone can occur. If there is inadequate confinement reinforcement in the local zone (the vicinity immediately surrounding the anchorage device) cracking, crushing and spalling of concrete may occur.

To prevent failure in the anchorage zone, non-prestressed (or mild steel) is used to resist the tensile stresses. Due to the large forces active in the anchorage zones much mild steel is required. Steel congestion in the area may lead to problems related to poor concrete consolidation.

II. RESEARCH OBJECTIVE

The main objective of this research was to investigate the use of steel fiber reinforced concrete (SFRC) in post-tensioning (PT) anchorage zones of bridge girders. The purpose of using SFRC is to enhance the overall performance and to reduce the amount of steel rebar required in the anchorage zone. Reducing steel congestion in post-tensioning anchorage zones can improve the constructability of post-tensioned bridge elements.

Results from an investigation by Haroon (2003) showed that the use of SFRC improved the local zone capacity and provided a reduction in secondary mild reinforcement. It was the intent of this study to consider both the behavior of the local zone and the general zone when steel fiber reinforced concrete is used. Also, It was desirable to implement a test program that considered material stress levels that are similar to those typically found in post-tensioned bridge members (such as concrete post-tensioned segmental box girders).

To achieve the objectives of this study, both experimental and analytical investigations were conducted aiming at reducing the amount of mild steel reinforcement required by the AASHTO code at the anchorage zone. The experimental part of the study involved laboratory testing of twenty-seven samples representing typical anchorage zone dimensions in post tensioned girders. The analytical study was conducted using non-linear finite element analysis in order to have a comprehensive stress analysis of the anchorage zones with and without fiber reinforcement and mild steel reinforcement. Inherent in the objective is the determination of the proper ratio of steel fibers that can be used without jeopardizing the constructability of the anchor zone. Meeting the objective of this study resulted in the development of a rational method to analyze and design the local and general zones reinforced with steel fibers.

III. PROJECT STATEMENT

A. General

As per the limitations obtained from literature review in the field of research, the problem statement and methodology that is required to fulfil the research work are discussed in the following sections.

B. Problem Statement

This research work is aimed to find the analytical value of strut & tie of bridge segment as per ACI 318/19. The dimensions of bridge segment is shown in fig 4.1. The analytical value are obtain from the hand calculations were validated with the software value by using ANSYS Static software for analysis.

C. Methodology

In this study, Analytical and Software both analysis were carried out with reference of ACI 318/19 code of practice. Analysis of the bridge Segment was calculated the following parameters with the data from the research paper of Takebayashi, Post-tentioning anchorage, strut and tie and the analysis process was carried out in 3 types : linear elastic analysis, nonlinear elastic analysis, and nonlinear analysis considering the destruction of concrete. The results were validated by compare with the software analysis results using ANSYS software.

A bridge segment is chosen, modeled and thoroughly analyzed under post tensioned loading conditions similar to what are encountered in the field. The purpose this analysis is to define the extent of the post-tensioning stresses around the anchorage zones in a full scale mode. Such a step is necessary to delineate the boundary conditions of the anchorage zone if smaller sections were to be considered.

Constitutive properties for finite element modeling including compressive strength, tensile strength. After the full scale analyses of the bridge segment, a scaled block containing two posttensioning anchors are separated from the web area of the bridge segment. This block is then analyzed using three dimensional finite element modeling to determine the boundary conditions at which stress distributions were not affected by the length of the block.

Once the geometry was input, the necessary properties of the segment had to be input in ANSYS. The necessary properties involved choosing the element that would be used to mesh the segment along with defining the material properties of the segment. The segment consists of concrete (with reinforcing steel), steel anchorages, and steel ducts. A complete list of the required material properties is provided in Table below.

IV. PROBLEM FORMULATION

Analytical solution of strut and tie is shown as per table from ACI 318/19

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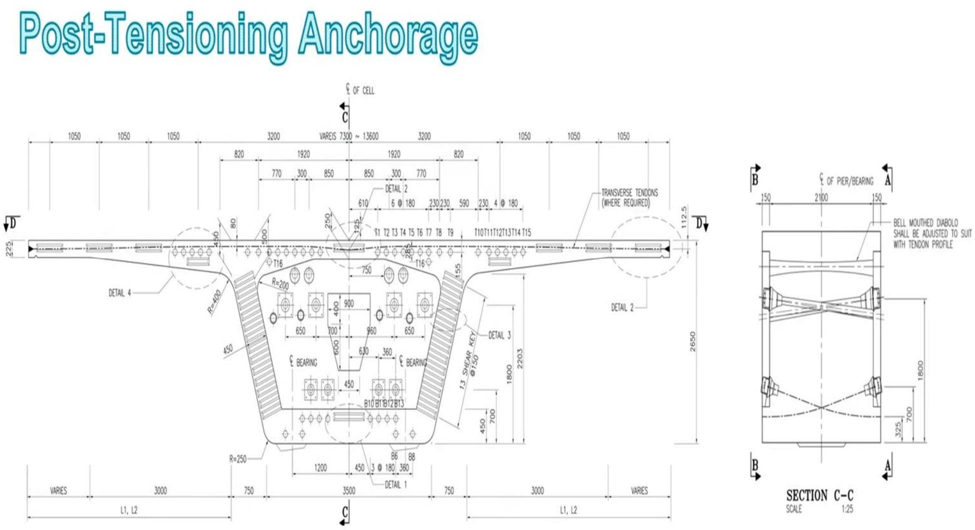


Fig 4.1 Post-Tensioning Anchorage

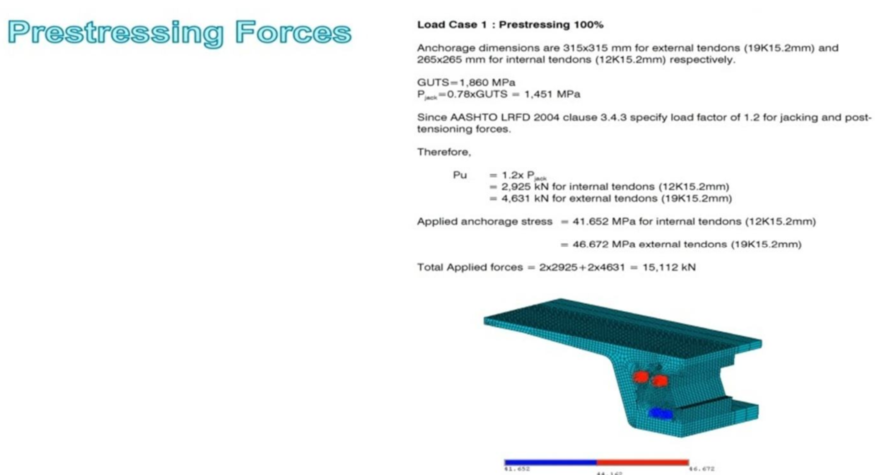
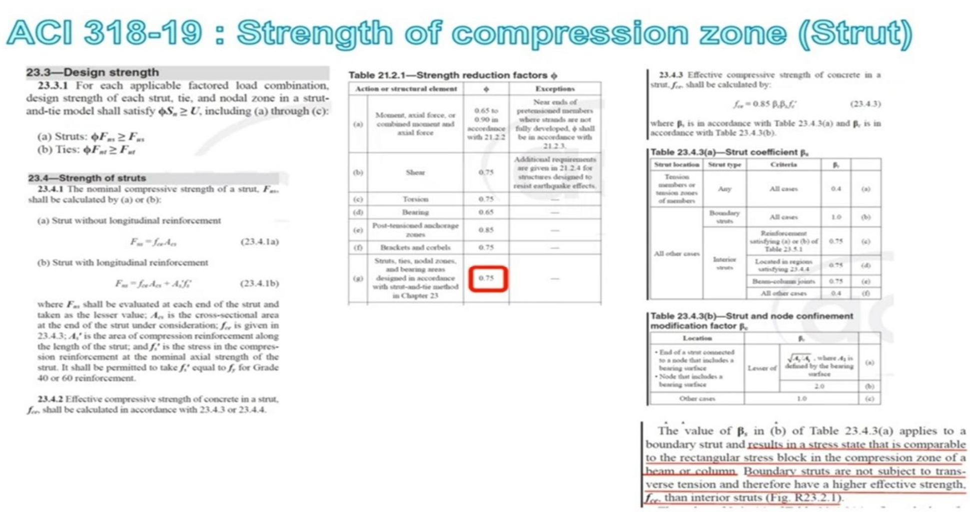


Fig 4.2 Prestressing forces



ACI 318-19 : Strength of compression zone (Strut)

23.3—Design strength

23.3.1 For each applicable factored load combination, design strength of each strut, tie, and nodal zone in a strut-and-tie model shall satisfy $\phi S_n \geq U$, including (a) through (c):

(a) Struts: $\phi F_{ns} \geq F_{us}$
(b) Ties: $\phi F_{nt} \geq F_{ut}$

23.4—Strength of struts

23.4.1 The nominal compressive strength of a strut, F_{ns}, shall be calculated by (a) or (b):

(a) Strut without longitudinal reinforcement

$$F_{ns} = f_{ce} A_{cs} \quad (23.4.1a)$$

(b) Strut with longitudinal reinforcement

$$F_{ns} = f_{ce} A_{cs} + A_s' f_s' \quad (23.4.1b)$$

where F_{ns} shall be evaluated at each end of the strut and taken as the lesser value; A_{cs} is the cross-sectional area at the end of the strut under consideration; f_{ce} is given in 23.4.3; A_s' is the area of compression reinforcement along the length of the strut; and f_s' is the stress in the compression reinforcement at the nominal axial strength of the strut. It shall be permitted to take f_s' equal to f_y for Grade 40 or 60 reinforcement.

23.4.2 Effective compressive strength of concrete in a strut, f_{ce}, shall be calculated in accordance with 23.4.3 or 23.4.4.

Table 21.2.1—Strength reduction factors ϕ

	Action or structural element	ϕ	Exceptions
(a)	Moment, axial force, or combined moment and axial force	0.65 to 0.90 in accordance with 21.2.2	Near ends of pretensioned members where strands are not fully developed, ϕ shall be in accordance with 21.2.3.
(b)	Shear	0.75	Additional requirements are given in 21.2.4 for structures designed to resist earthquake effects.
(c)	Torsion	0.75	—
(d)	Bearing	0.65	—
(e)	Post-tensioned anchorage zones	0.85	—
(f)	Brackets and corbels	0.75	—
(g)	Struts, ties, nodal zones, and bearing areas designed in accordance with strut-and-tie method in Chapter 23	0.75	—

23.4.3 Effective compressive strength of concrete in a strut, f_{ce}, shall be calculated by:

$$f_{ce} = 0.85 \beta_c \beta_s f_c' \quad (23.4.3)$$

where β_s is in accordance with Table 23.4.3(a) and β_c is in accordance with Table 23.4.3(b).

Table 23.4.3(a)—Strut coefficient β_s

Strut location	Strut type	Criteria	β_s	
Tension members or tension zones of members	Any	All cases	0.4	(a)
All other cases	Boundary struts	All cases	1.0	(b)
	Interior struts	Reinforcement satisfying (a) or (b) of Table 23.5.1	0.75	(c)
		Located in regions satisfying 23.4.4	0.75	(d)
		Beam-column joints	0.75	(e)
		All other cases	0.4	(f)

Table 23.4.3(b)—Strut and node confinement modification factor β_c

Location	β_c		
• End of a strut connected to a node that includes a bearing surface • Node that includes a bearing surface	Lesser of	$\sqrt{A_2/A_1}$, where A_1 is defined by the bearing surface	(a)
		2.0	(b)
Other cases	1.0		(c)

The value of β_s in (b) of Table 23.4.3(a) applies to a boundary strut and results in a stress state that is comparable to the rectangular stress block in the compression zone of a beam or column. Boundary struts are not subject to transverse tension and therefore have a higher effective strength, f_{ce}, than interior struts (Fig. R23.2.1).

Fig 4.2.1 Strength of strut

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ACI 318-19 : Strength of Tension member (Tie)

23.7—Strength of ties

23.7.1 Tie reinforcement shall be nonprestressed or prestressed.

23.7.2 The nominal tensile strength of a tie, F_{nt}, shall be calculated by:

$$F_{nt} = A_{ts} f_y + A_{tp} \Delta f_p \quad (23.7.2)$$

where A_{tp} is zero for nonprestressed members.

23.7.2.1 In Eq. (23.7.2), it shall be permitted to take Δf_p equal to 60,000 psi for bonded prestressed reinforcement and 10,000 psi for unbonded prestressed reinforcement. Higher values of Δf_p shall be permitted if justified by analysis, but Δf_p shall not be taken greater than $(f_{py} - f_{se})$.

Fig 4.2.2 Strength of tie

Local Zone Design

Design of Anchorage

Local Zone Design (12-15mm strand)

Anchorage device and local zone approximately 450mm from anchorage

Refer to VSL, "Detailing for Post-Tensioned".

P_S = 0.95x1860x12x140/1e6 = 2.97 MN

From $f'_{ci} = 0.70 f'_c$ = 0.70x44 = 30.8 MPa

Thus, $0.85 \cdot f'_{ci} \cdot \left(X_C^2 - \frac{\pi J^2}{4} \right) = 0.95 \cdot P_S$, J=100mm

$X_C = \sqrt{\frac{0.95 \cdot P_S}{0.85 \cdot f'_{ci}} + \frac{\pi J^2}{4}}$ = 340 mm

$A_{core} = \frac{\pi X_c^2}{4}$ = 90,792 mm2

∴ use X = 340 mm

From $(0.85 f'_{ci} + 4 f_l) \cdot A_{core} = 0.95 P_S$

where $f_l = \frac{A_{spiral} \cdot f_s}{r_i \cdot p} = \left(\frac{0.95 P_S}{A_{core}} - 0.85 f'_{ci} \right) \times \frac{1}{4}$ = 1.22 MPa

$r_i = X_c/2$ = 170 mm

p = 50 mm

f_s = 200 MPa

∴ $A_{spiral} = \frac{f_l \cdot r_i \cdot p}{f_s}$ = 51.85 mm2

Refer to Freyssinet C-Range recommend spiral R14, pitch 50 mm with r=155mm for 12C15 post-tensioned anchorage. Therefore, use R16, pitch 75 mm with r=155 mm.

Local Zone Design (19-15mm strand)

Anchorage device and local zone approximately 500mm from anchorage

Refer to VSL, "Detailing for Post-Tensioned".

P_S = 0.95x1860x19x140/1e6 = 4.7 MN

From $f'_{ci} = 0.70 f'_c$ = 0.70x44 = 30.8 MPa

Thus, $0.85 \cdot f'_{ci} \cdot \left(X_C^2 - \frac{\pi J^2}{4} \right) = 0.95 \cdot P_S$, J=100mm

$X_C = \sqrt{\frac{0.95 \cdot P_S}{0.85 \cdot f'_{ci}} + \frac{\pi J^2}{4}}$ = 422 mm

$A_{core} = \frac{\pi X_c^2}{4}$ = 139,867 mm2

∴ use X = 450 mm

From $(0.85 f'_{ci} + 4 f_l) \cdot A_{core} = 0.95 P_S$

where $f_l = \frac{A_{spiral} \cdot f_s}{r_i \cdot p} = \left(\frac{0.95 P_S}{A_{core}} - 0.85 f'_{ci} \right) \times \frac{1}{4}$ = 1.44 MPa

$r_i = X_c/2$ = 211 mm

p = 70 mm

f_s = 200 MPa

∴ $A_{spiral} = \frac{f_l \cdot r_i \cdot p}{f_s}$ = 106.3 mm2

Refer to Freyssinet C-Range recommend spiral R16, pitch 70 mm with r=200mm for 19C15 post-tensioned anchorage. Therefore, use R16mm, pitch 70 mm with r=200 mm.

Fig 4.2.3 Local Zone design

A. Load Calculations

As per guidelines given in ACI 318/19 solution are find out by given formula.

fc' = 50 MPa

fy = 420 MPa

Phi = 0.75 for both strut and tie

Beta-s = 1.0

Beta-c = 1.0

Strut strength = Phi x 0.85 x Beta-s x Beta-c x fc'

= 0.75*0.85*1.0*1.0*50 = 32 MPa

Tie Strength for rebar diameter 40 mm = Phi x fy x As

= 0.75*420*pi()*40^2/4

= 395,840 N

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V. RESULTS

A. General

In this ANSYS model after run the Analysis, we found the results of the models are shown with pictures below.

B. Software Results

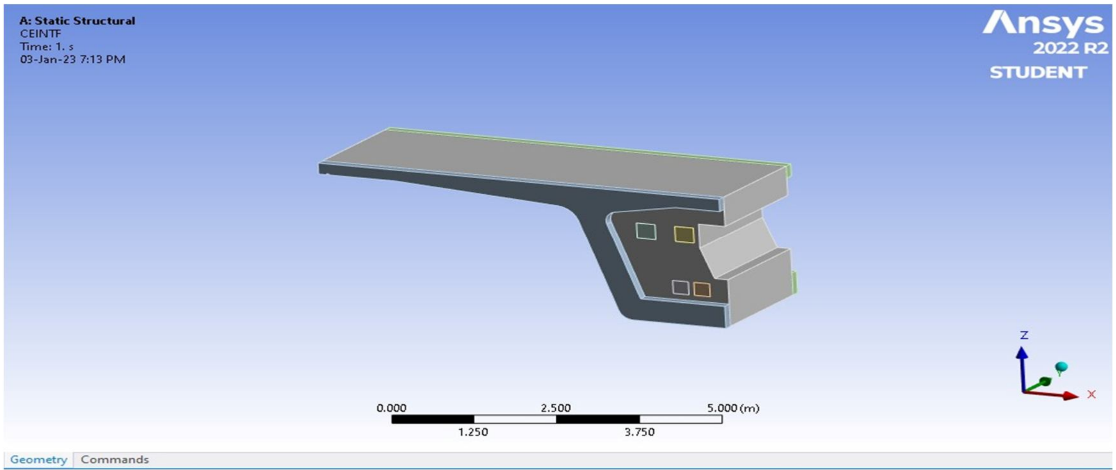

Fig 5.2.1 Static Structural CEINTF

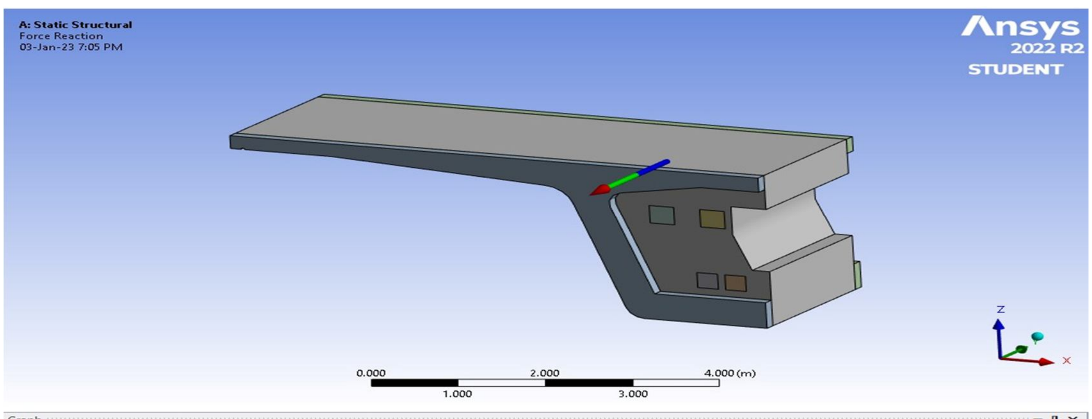

Fig 5.2.2 Force reaction

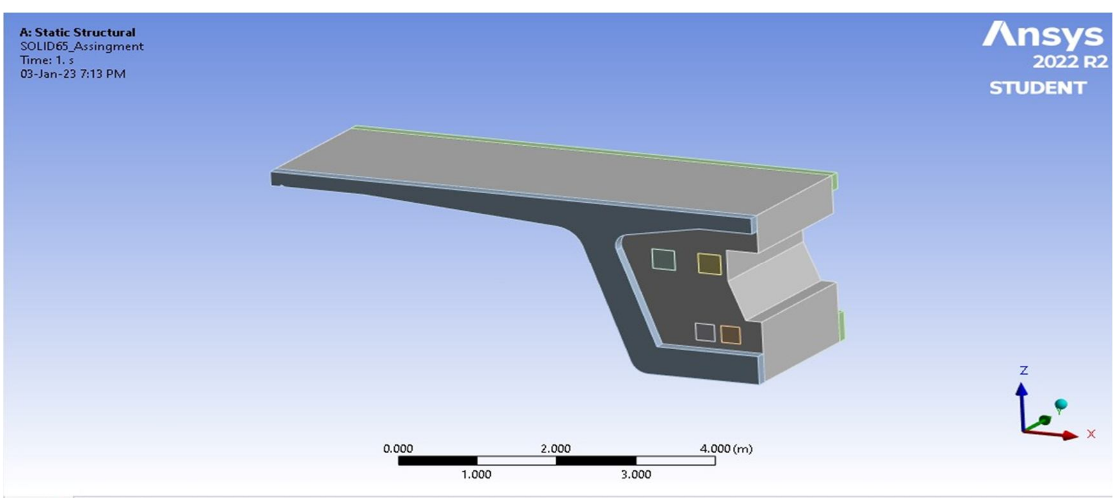

Fig 5.2.3 Solid65 Assignment

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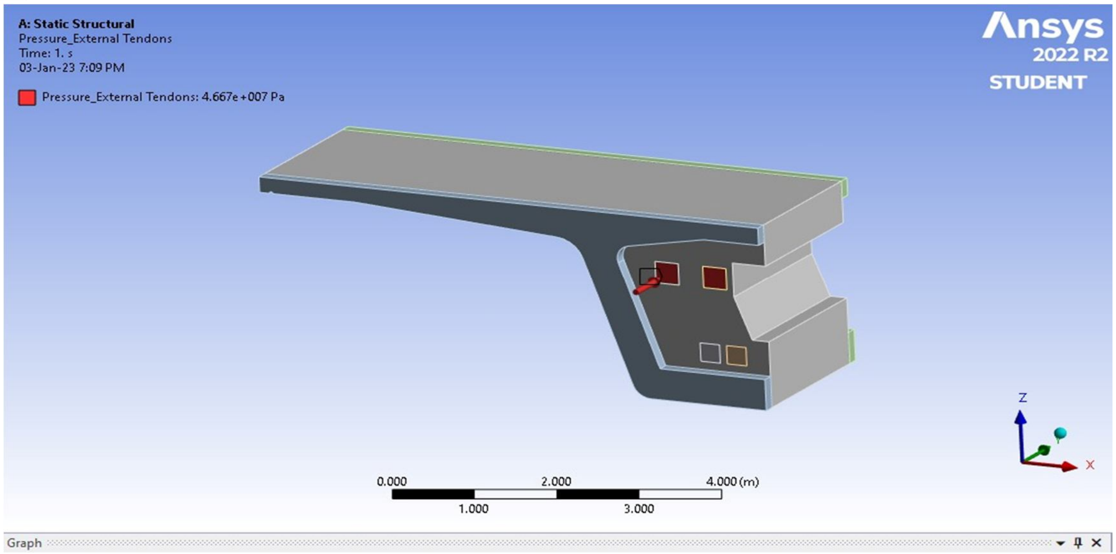

Fig 5.2.4 Pressure External Tendons

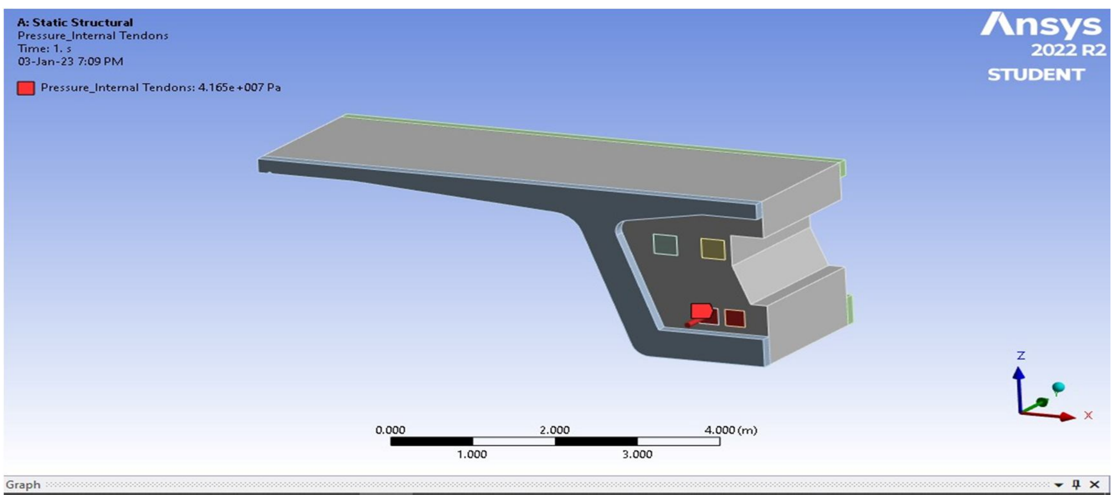

Fig 5.2.5 Pressure Internal Tendons

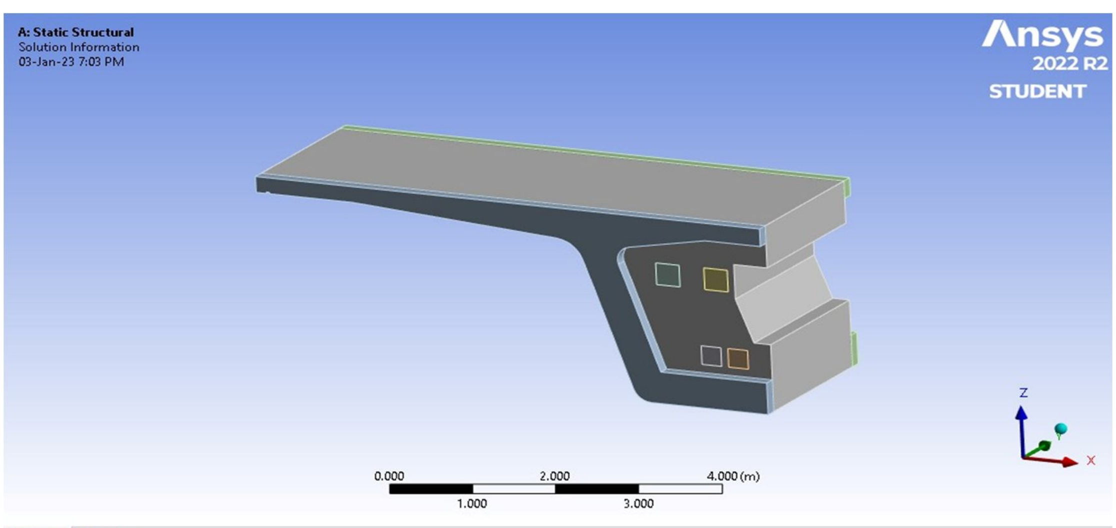

Fig 5.2.6 Solution Information

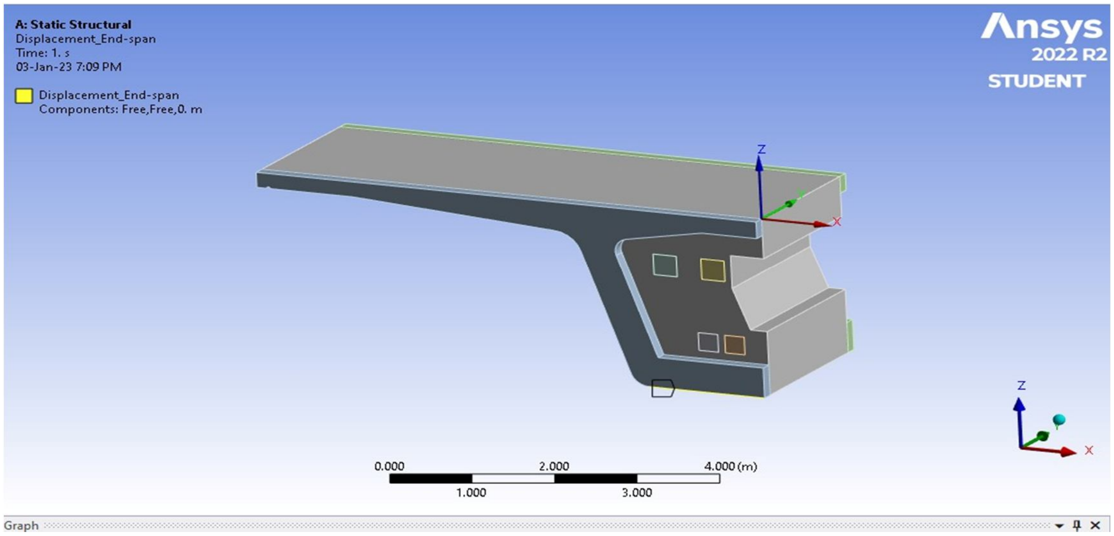

Fig 5.2.7 Displacement End Span

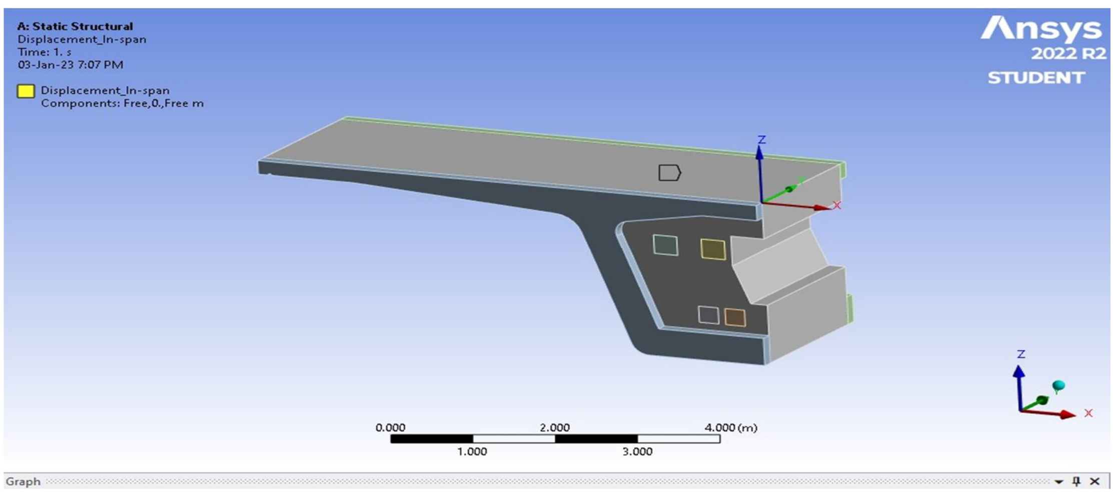

Fig 5.2.8 Displacement In Span

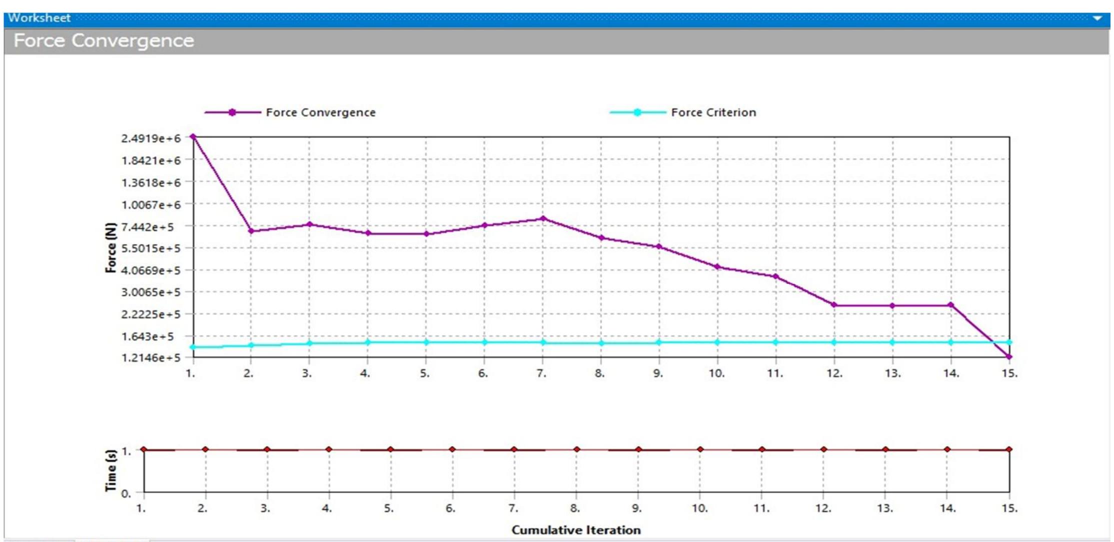

Fig 5.2.9 Force Convergence

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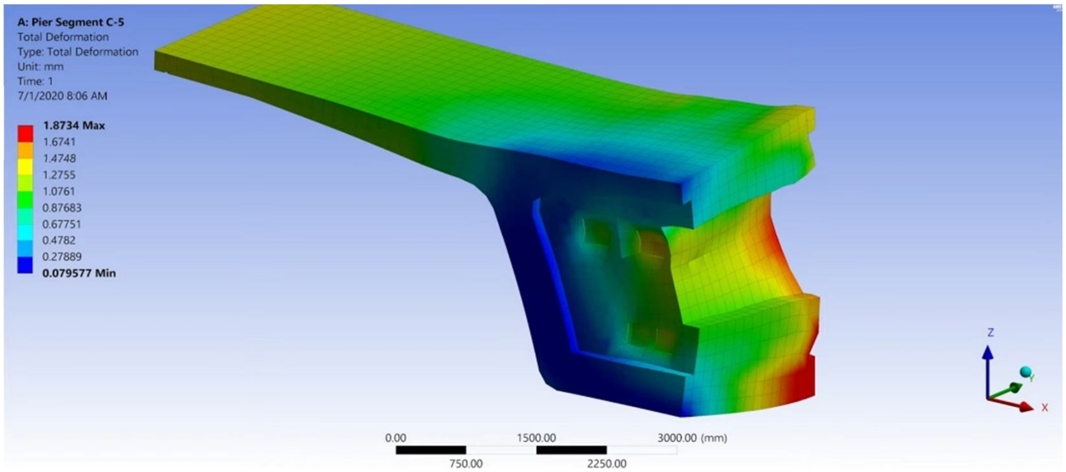

Fig 5.2.10 Total Deformation

VI. SOFTWARE VALIDATION

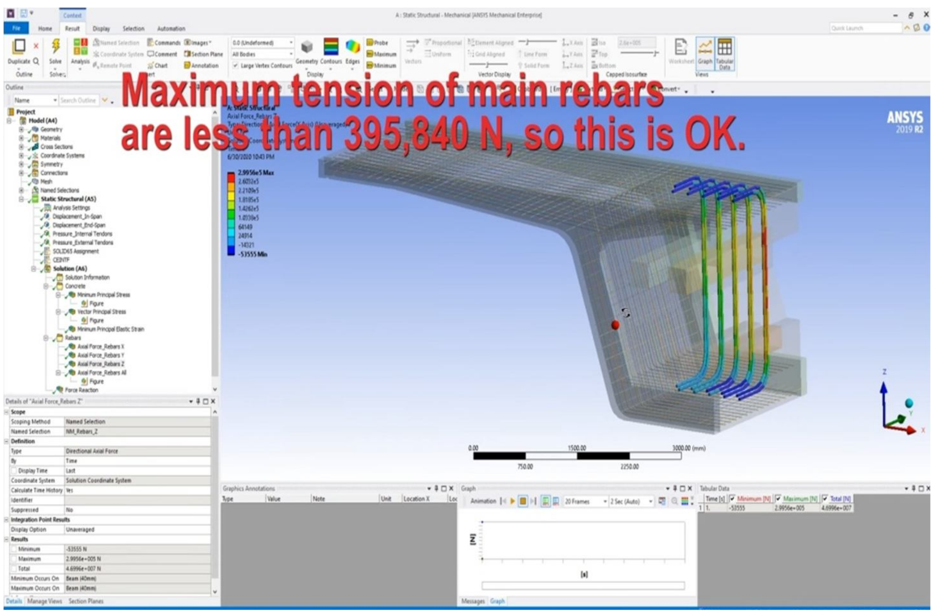

Fig. 6.1 Maximum tension in rebars

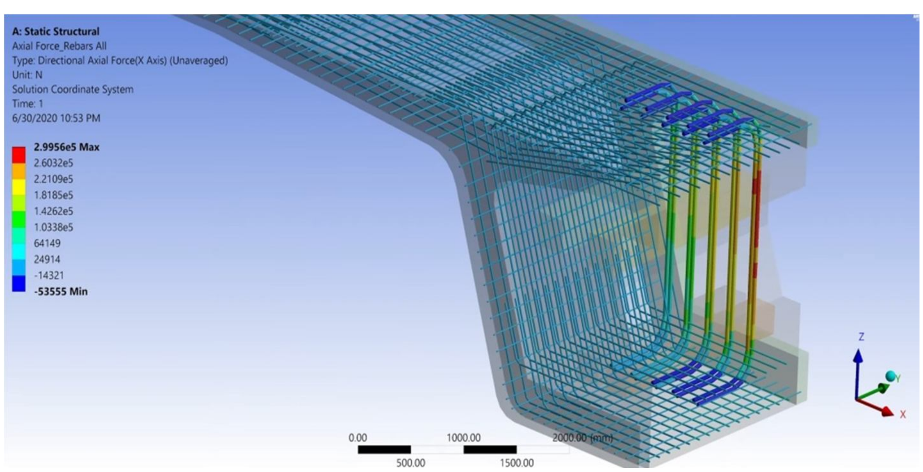

Fig. 6.2 Directional Axial Force

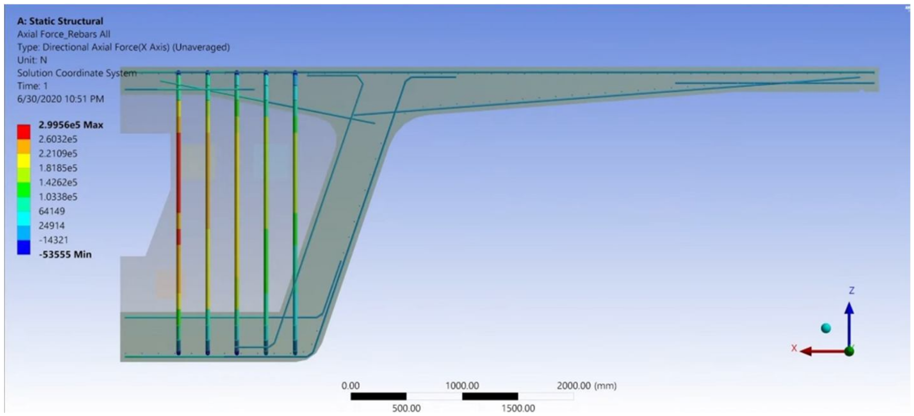

Fig. 6.3 Directional Axial Force

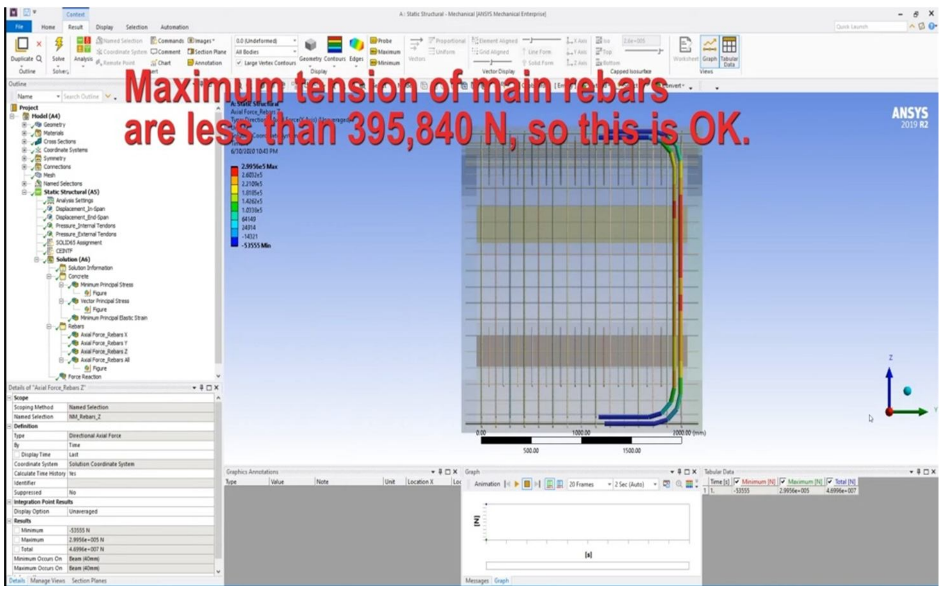

Fig. 6.4 Maximum Tension Main Rebar

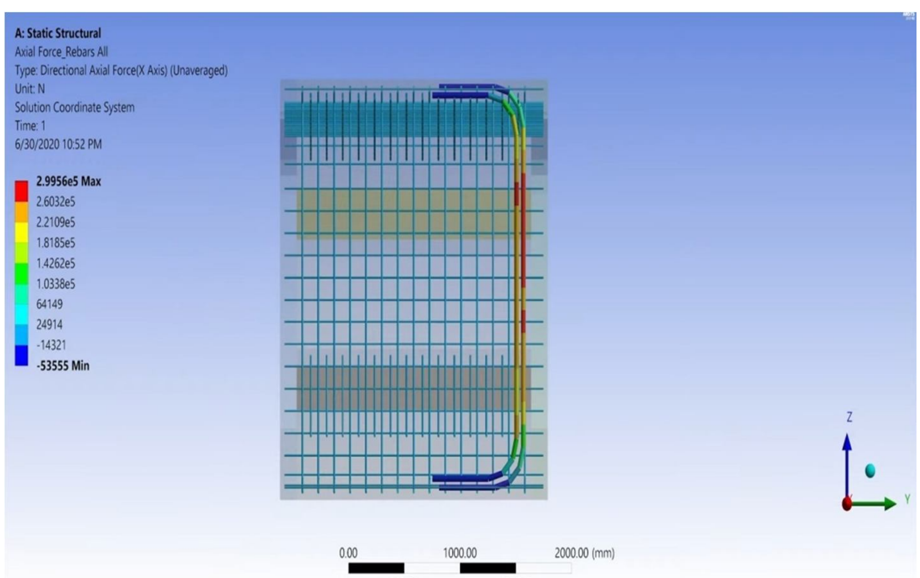

Fig. 6.5 Directional Axial Force

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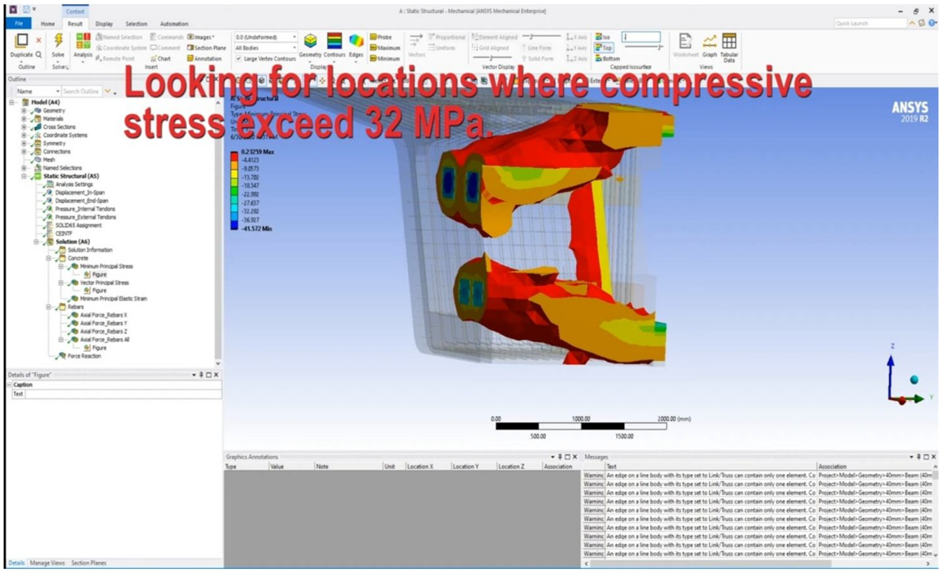

Fig. 6.6 Compressive Stress Location

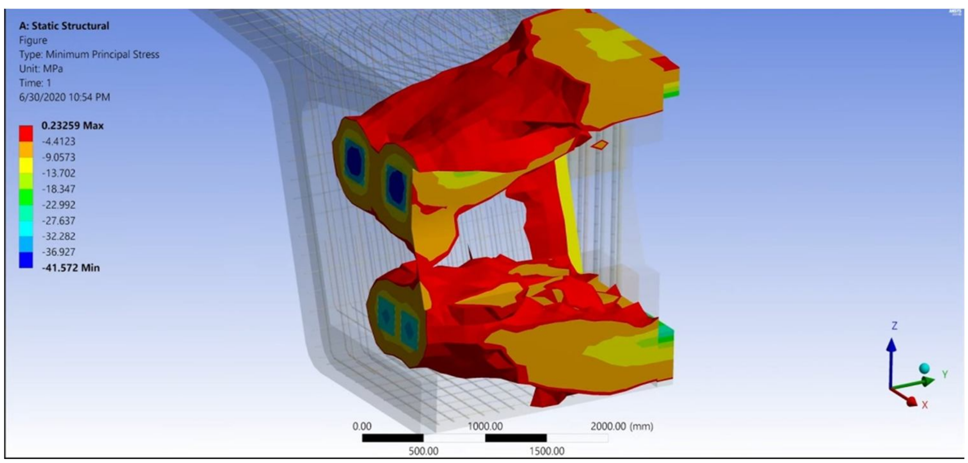

Fig. 6.7 Location Where Compressive Stress Exceed 32 Mpa

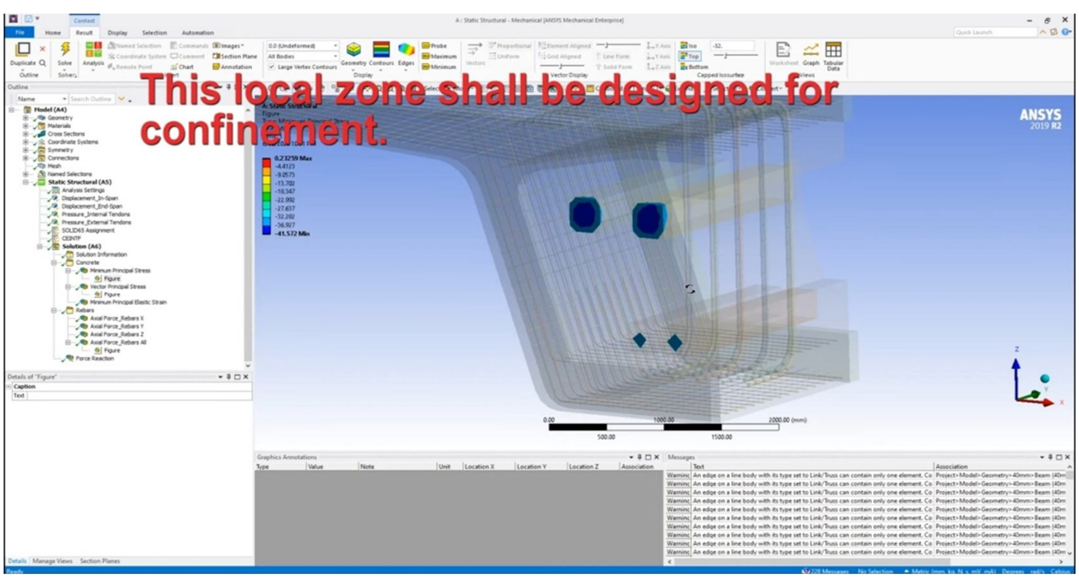

Fig. 6.8 Local Confinement Zone

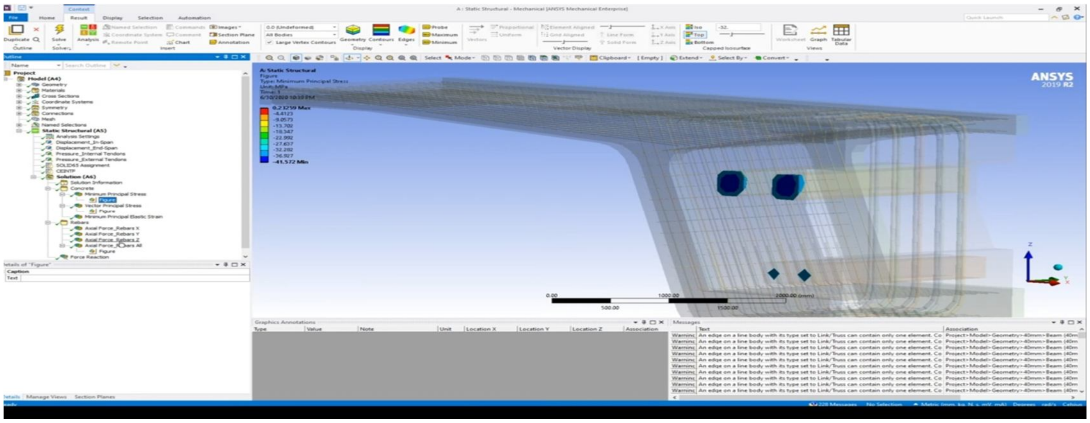

Fig. 6.9 Local Zone design for confinements

6.10 Comparison between Analytical and Software Result

This is the comparison of strut & tie strength of analytical Software Result.

Table 6.1 Comparison between Analytical and Software Result

Sr. No	Descriptions	Analytical Value	Software
1	Strut Strength	32 Mpa	32 Mpa
2	Tie Strength for rebar dia 40 mm	395,840 N	299,560 N

VII. CONCLUSION

1) This research suggests that Prestressed cable anchor can be used successfully to reduce steel congestion in the anchorage zone without decreasing the capacity of the member.
2) Based upon this research, It is recommend that confinement reinforcing (spirals) be used in the local zone and bursting steel (steel ties) be used in the general zone. However, the spacing of this steel can be increased above the current design recommendations and the current ACI 318/19 recommendations for the approximate design method.
3) Based upon the load test results for the parameters used in the test specimens, it was possible to double the tie spacing for the bursting reinforcement.
4) This behavior of test segment over the complete analysis confirms the adequacy of design.
5) The segment showed substantial ductility in deflection and joint opening, structure with post tensioned will give sufficient warning before failure.

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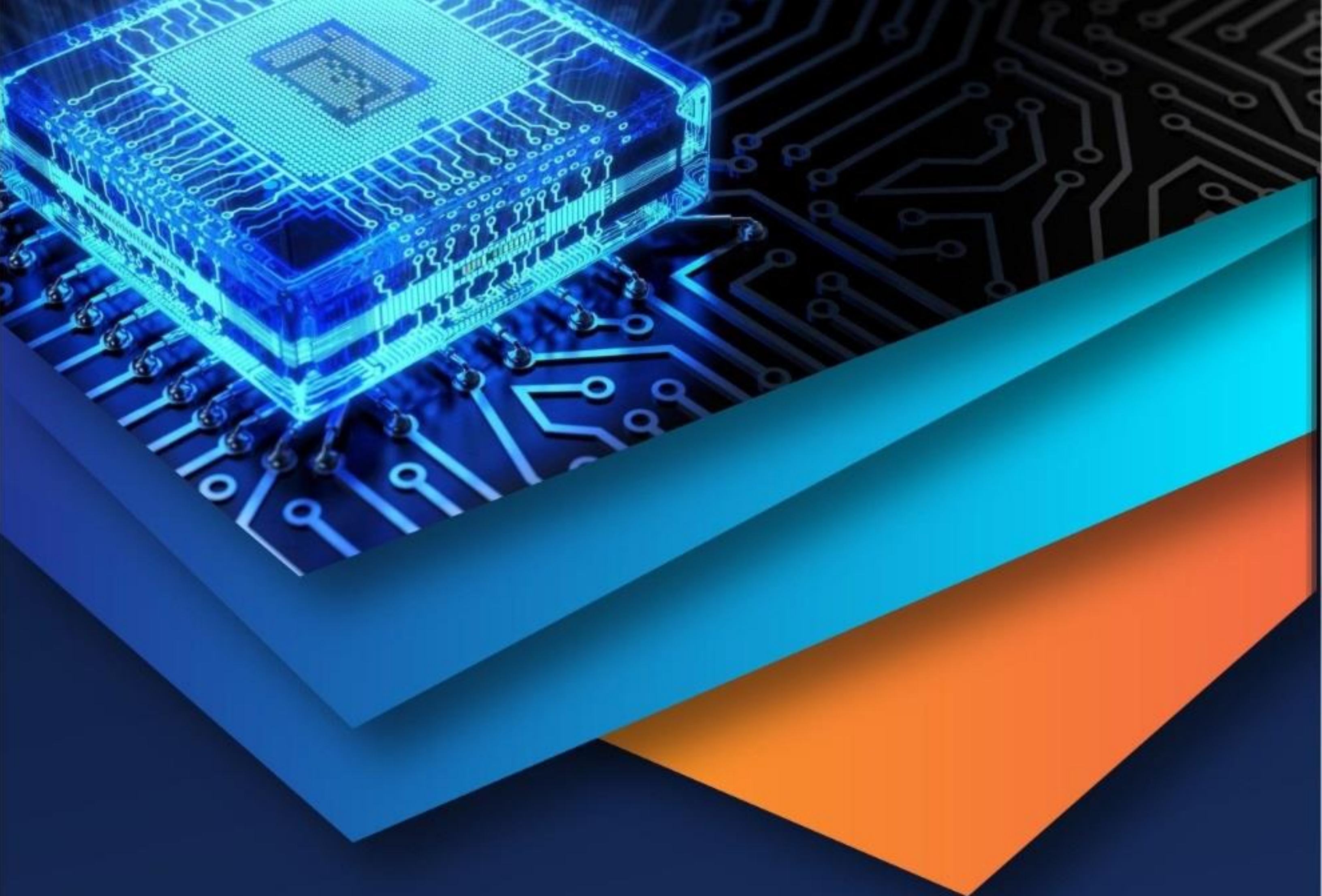

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