INVESTIGATION OF CONTACT FORCES IN PRECAST CONCRETE TUNNEL LINING SEGMENT

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Abstract - *A stress measurement is a key factor in evaluating the safety and stability of underground engineering, e.g., tunnels, mining or petroleum, underground caverns. Radial and circumferential joints are highly stressed parts in precast concrete tunnel lining segments; therefore to avoid failure provides the adequate structural capacity. When a concentrated load acts on one of the joint faces of the segment, tensile bursting forces develop beneath the applied concentrated load. These tensile bursting forces are perpendicular to the applied load. The radial and circumferential joints of a tunnel segment are designed to prevent failure due to bursting. In this work, analytical work is conducted to analysis the inter-ring transfer mechanism, which includes a three-ring compression-bending test, a single-ring compression-bending test and shear test on circumferential joints. All this analytical work is done in ANSYS Workbench. To prevent failure in segment add meshing in reinforcement and compare all results with traditional reinforcement segment result. This study represents a contribution towards the Investigation of contact forces in precast concrete tunnel lining segment.*

***Key Words*: Bursting load, Stress distribution, Stagger-jointed segmental lining, Full-scale test, Transfer loading mechanism, Finite Element Analysis, ANSYS Workbench.**

1. INTRODUCTION

In underground structures like tunnel, subways, water supply, oil and gas pipeline tunnel lining system gained more popularity. In tunnel lining segment Longitudinal and circumferential joints are mostly stressed and weak part. When concentrated load act on segment joints faces then tensile bursting and splitting forces develop on the intrados or extrados surfaces. To resist the failure or overcome the bursting and splitting forces provide a mesh cap on the longitudinal joints. However, the researcher mostly focused on the numerical and experimental behavior of the circumferential joints. Therefore in this study we focus on the behavior of the longitudinal joints.

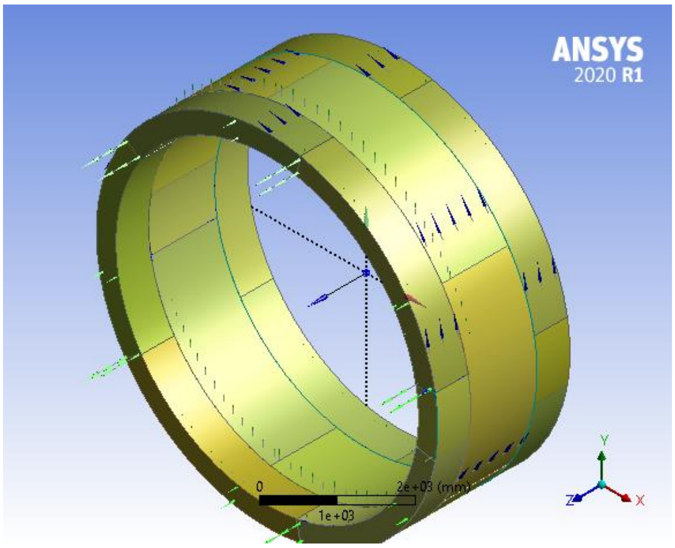

Fig -1: Tunnel lining segment ring

1.1 OBJECTIVE OF THE WORK

- To investigate behaviour of precast concrete tunnel lining segment at contact due to normal stresses.
- To analyze inter-ring transfer mechanism.
- To accurately analysed the joints during design and provide adequate structural capacity to avoid failure.
- To modify Structure to stop cracks in the longitudinal direction of the segments.
- To carry out analytical analysis of PCTL segment with traditional reinforcement.
- To carry out analytical analysis of PCTL segment with cover the traditional reinforcement by meshing.

1.2 AIM OF THE WORK

Investigation of contact forces in precast concrete tunnel lining segment and modify structure to resist crack.

2. MODEL DESCRIPTION

In this analysis, to be representative of shield tunnel with T joints, the specimens used in the analysis are comprised of six segments of the lining structure. These specimens are 350mm thick and 1200mm wide, with a concrete grade of C50. The longitudinal joint and circumferential joints ring connection are made using grade 5.8 M30 bolts and stainless steel mesh is 2mm diameter with 20mm*20mm sizes.

The tests are divided into a major test and ancillary tests: three analytical tests are carried out, a three-ring compression bending test, the major one; and as single-ring compression-bending test and a shear test on circumferential joints, the ancillary ones. For this entire test, segment modeled by using ANSYS Workbench 2021 R1. In my study, we provide mesh cap in the longitudinal joint.

The single-ring compression -bending test revels both the ultimate strength and bending-resistance stiffness referred to longitudinal joints.

2.1 SINGLE-RING POSITIVE MOMENT CONDITION MODEL

This single-ring positive moment segment modeled in ANSYS Workbench. The segments are modeled as rigid concrete beam elements, the bolt modeled as rigid steel element, the mesh modeled as a line body stainless steel element and the reinforcement is modeled as a line body reinforcement element. Two segment connected by longitudinal annular bolts.

Middle Segment Size: 350mm thick, 1000mm length and 1200mm wide

Bolt Size: 36mm Diameter

Mesh: 2mm Diameter (20*20mm)

Concrete grade: C50

Reinforcement grade: HRB 400

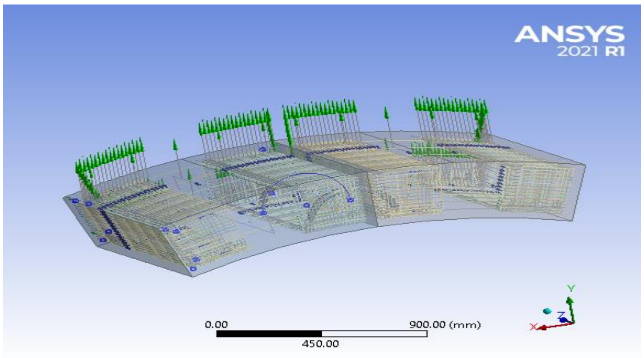

Fig -2: Single ring positive compression bending moment test specimen geometry

2.2 SINGLE-RING NEGATIVE MOMENT CONDITION MODEL

This single-ring positive moment segment modeled in ANSYS Workbench. The segments are modeled as rigid concrete beam elements, the bolt modeled as rigid steel element, the mesh modeled as a line body stainless steel element and the reinforcement is modeled as a line body reinforcement element. Two segment connected by longitudinal annular bolts.

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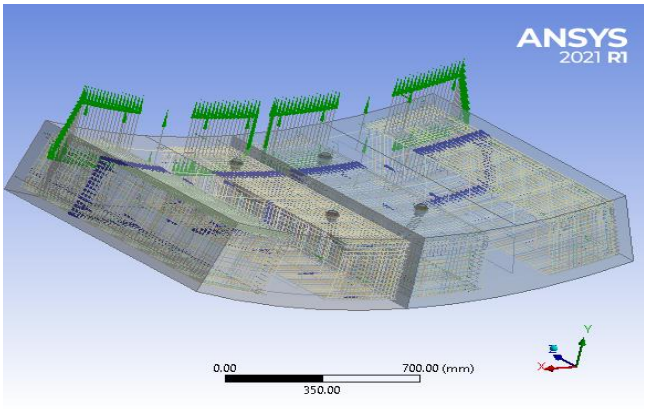

Fig -3 Single ring positive compression bending moment test specimen geometry

2.3 THREE-RING POSITIVE MOMENT CONDITION MODEL

This single-ring positive moment segment modeled in ANSYS Workbench. The segments are modeled as rigid concrete beam elements, the bolt modeled as rigid steel element, the mesh modeled as a line body stainless steel element and the reinforcement is modeled as a line body reinforcement element. Two middle segment connected by longitudinal annular bolts and end segments connected with middle segment by circumferential joints.

Middle Segment Size: 350mm thick, 1000mm length and 1200mm wide

End Segment Size: 350mm thick, 2000mm length and 1200 mm wide

Bolt Size: 36mm Diameter

Mesh: 2mm Diameter (20*20mm)

Concrete grade: C50

Reinforcement grade: HRB 400

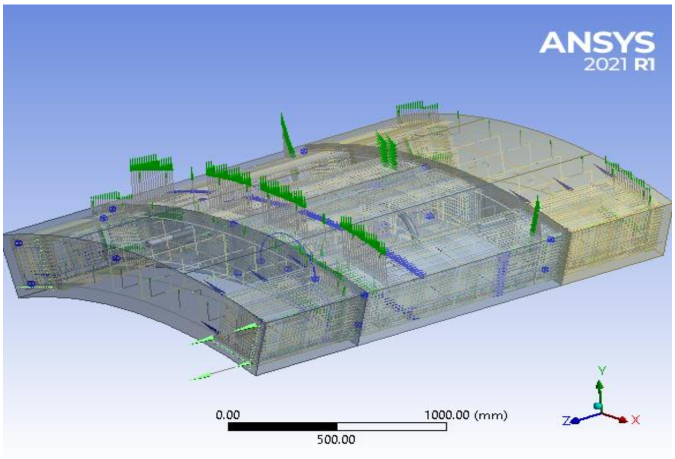

Fig -4 Three ring positive compression bending moment test specimen geometry

2.4 THREE-RING POSITIVE MOMENT CONDITION MODEL

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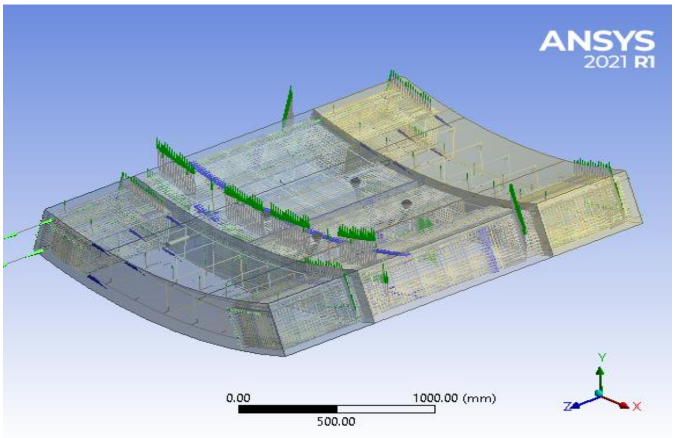

Fig -5 Three ring negative compression bending moment test specimen geometry

3. THE LOADING SCHEME

The loading of compression bending test and support condition are given in Fig. 6, 7, 8, 9. The loading of single-ring positive compression bending test is as shown in Fig. 6. The loading of single-ring negative compression bending test is as shown in Fig. 7. The loading of three-ring positive compression bending test is as shown in Fig. 8. The loading of three-ring negative compression bending test is as shown in Fig. 9. In this loading condition as shown in loading Fig. 6, 7, to apply the moment M to the longitudinal joint a certain horizontal Force N applied to the specimen. For a given N, M=N.e which includes four parts- M_N induced by horizontal force N, M_S induced by the support reaction, M_G induced by the self-weight, M_P induced by the vertical force P. By solving this geometric construction for horizontal force N value we find vertical force P and apply this both value to the segment.

Test	Type of Test	Remarks
Three-ring compression bending test	Positive bending moment conditions	Longitudinal Force: 153kN, 192kN, 307kN, 384kN
	Negative bending moment conditions	Longitudinal Force: 77kN, 96kN, 192kN, 307kN, 384kN
Single-ring compression bending test	Positive bending moment conditions	Eccentricity: 0.3m
	Negative bending moment conditions	Eccentricity: 0.15m
Shear test	Direct shear test	Longitudinal Force:65kN, 82kN, 130kN, 163kN
	Inverse shear test	

Table -1: Loading condition

For three-ring compression bending test and single-ring compression bending test P and N value are same. In three-ring compression bending test additional longitudinal force is apply to the segment. For longitudinal value refer Table no. 1. Positive moment joint is loaded at 0.3m eccentricity and Negative moment loaded at 0.15 eccentricity.

4. RESULT AND DISCUSSION

4.1 VALIDATION OF MODEL

To ensure the accuracy of present work as well as accuracy of model which we use in this study using ANSYS Workbench 2021 R1. Its validation is done by analyzing previously done experimental work. Comparing the experimental results and analytical results obtained from ANSYS, accuracy of work is determined. For validation purpose "INVESTIGATION OF THE STRUCTURAL EFFECT INDUCED BY STAGGER JOINTS IN SEGMENTAL TUNNEL LINING: DIRECT INSIGHT FROM MECHANICAL BEHAVIOUR OF LONGITUDINAL AND CIRCUMFERETIAL JOINTS" by XIAN LIU, ZIBO DONG, WEI SONG, YUN BAI is referred from "TUNNELLING AND UNDERGROUND SPACE TECHNOLOGY"[7].

For validation of model we select one experimental model result and compare this experimental result with our ANSYS model result which has same dimensions, properties, loads and support. We analyze three rings negative bending test in ANSYS Workbench and find rotation angle on longitudinal joint with respect to bending moment and compare this software model result with experimental model result.

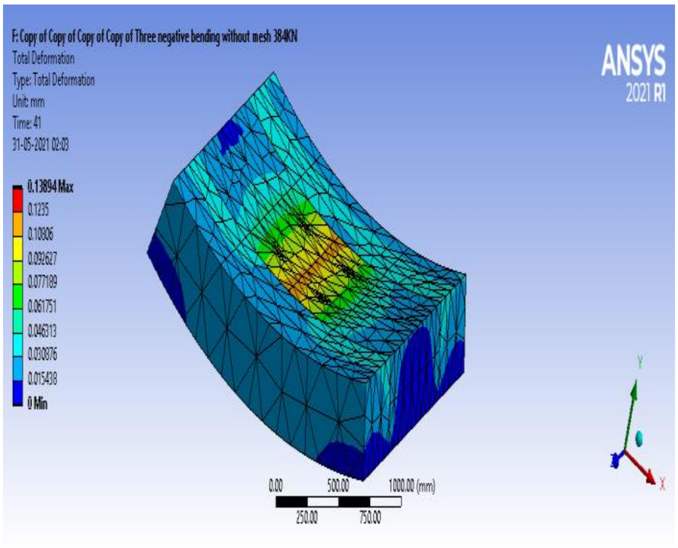

Fig -6 Deflection contours and Deflection values of three-ring negative bending test

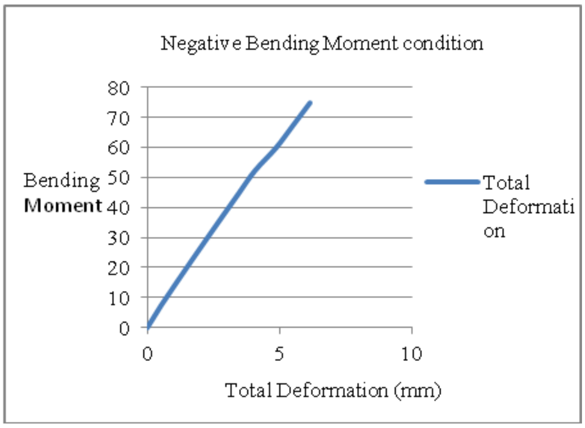

Chart -1: Deformation result of negative bending test ANSYS

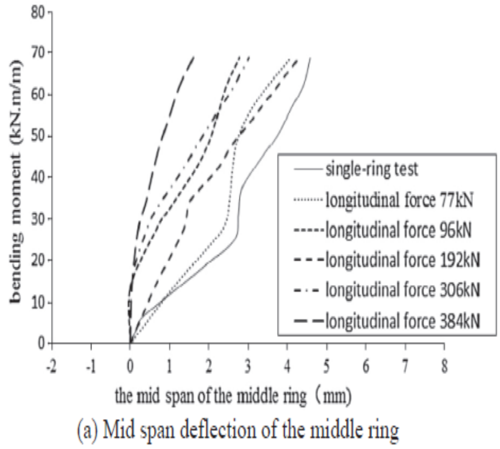

Chart -2: Deformation result of negative bending test experimental

Table -2: Showing deflection result obtain from ANSYS and experiment

Sr. No.	Bending Moment (kN.m)	Experimental deflection (mm)	ANSYS deflection (mm)
1	10	0.7	0.72
2	20	1.5	1.2
3	30	2.5	2.26
4	40	3	3.3
5	50	3.8	4
6	60	4.6	4.8561
7	70	5	5.12

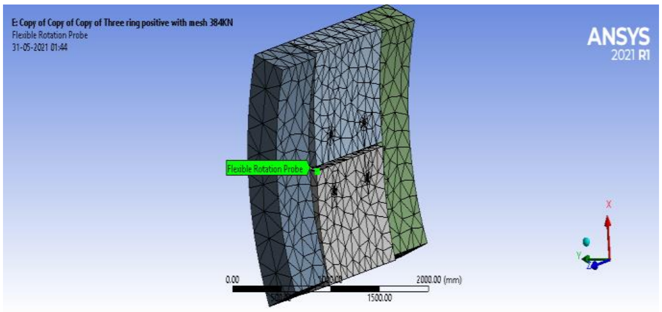

Fig -7 Rotation angle contours and rotation angle values of three-ring negative bending test

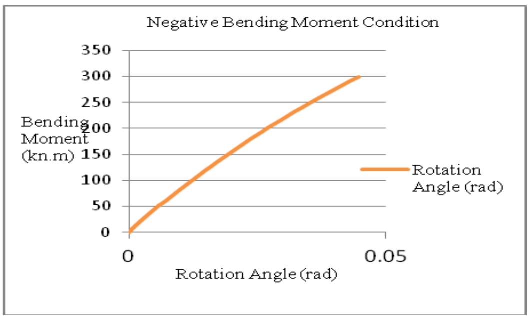

Chart -3: Rotation angle of negative bending test ANSYS

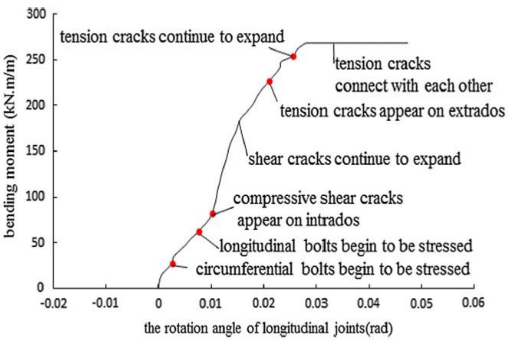

Chart -4: Rotation angle of negative bending test experiment

Table -3: Showing Rotation angle result obtain from ANSYS and experiment

Sr. No.	Rotation angle (rad)	Experimental Rotation angle (rad)	ANSYS Rotation angle (rad)
1	50	0.0055	5.84E-03
2	100	0.0021	1.19E-02
3	150	0.0029	1.92E-02
4	200	0.0025	2.71E-02
5	250	0.0032	3.48E-02

The average percentage of accuracy of result obtained from ANSYS in comparison with experimental results is found out to be 95%. All the analysis for actual work is done with this percentage of accuracy.

4.2 MECHANICAL BEHAVIOUR OF SEGMENT

4.2.1 RESULT OF STRUCTURAL EFFECT INDUCED BY T JOINTS

Table -4: Comparison result of single and three ring positive bending moment test

Sr. No.	BENDING MOMENT (kN.m)	SINGLE RING		THREE RING	
		total deformation (mm)	Rotation angle (rad)	total deformation (mm)	Rotation angle (rad)
1	75	2.7963	0.00436	1.4196	0.0021
2	165	6.2616	0.0098	3.4187	0.00523
3	255	8.7487	0.0157	5.5342	0.00855
4	345	14.147	0.0224	7.8444	0.0122

Chart -5: Deflection results comparison of single and three ring positive bending moment tests

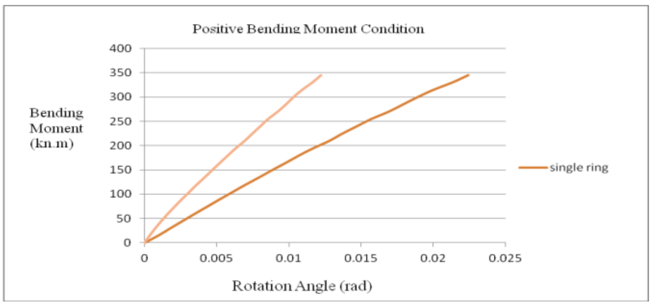

Chart -6: Rotation angle results comparison of single and three ring positive bending moment tests

Provide mesh in the longitudinal joints and analyze the segment result and compare these results. Through a comparison between the single-ring and three-ring compression bending test, it can be concluded that T joint segments have a more obvious structural effect induced by T joints than do cross joint segment. By the rotation angle and deflection of segment the stiffness and strength of longitudinal joint, obtained from the three-ring compression-bending test conducted under positive bending moment condition, are higher than those obtained from the single-ring compression-bending test. The ultimate strength is improved and also the initial rotational stiffness of the longitudinal joints increases.

4.2.2 INFLUENCE OF THE LONGITUDINAL FORCE

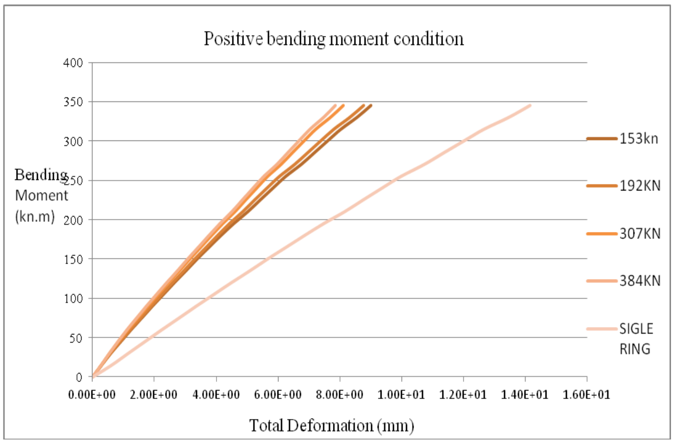

Chart -7: Total deformation results achieved under positive bending moment condition with longitudinal force

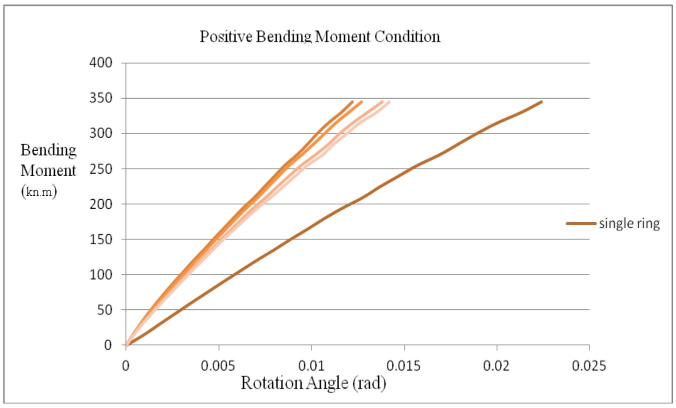

Chart -8: Rotation angle results achieved under positive bending moment condition with diff. longitudinal forces

The influence of the longitudinal load is investigated in terms of longitudinal joint and deflection of the middle ring by comparing with the data derived from the single-ring compression-bending test. Chart. 7 and 8 shows the test results achieved under positive bending moment condition.

A comparison of result indicates that grater longitudinal force give small deflection of the mid span of middle ring and small rotation angle of the longitudinal joints. That's mean that grater longitudinal force gives more constraint to end segments to support middle segment and increase the stiffness of middle ring.

4.2.3 DECREASES CONTACT FORCES ON LONGITUDINAL JOINTS BY ADDING MESH

From analysis we get mechanical behavior, stress transformation data and crack positions of tunnel lining segment. As we know that when concentrated load act on longitudinal joint face then tensile bursting and splitting forces develop in segments joint and develop cracks on intrados and extrados. To control these forces we provide mesh in longitudinal joint.

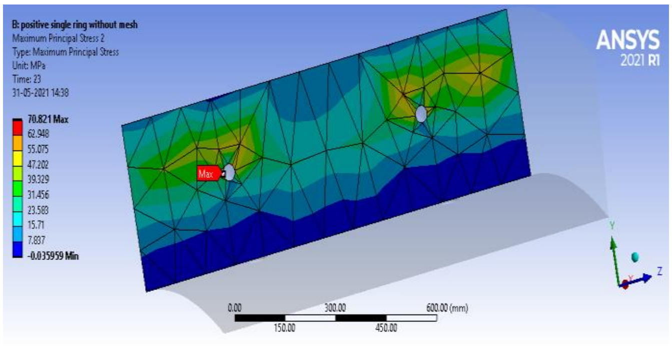

Fig -8 contact force of traditional reinforce segment

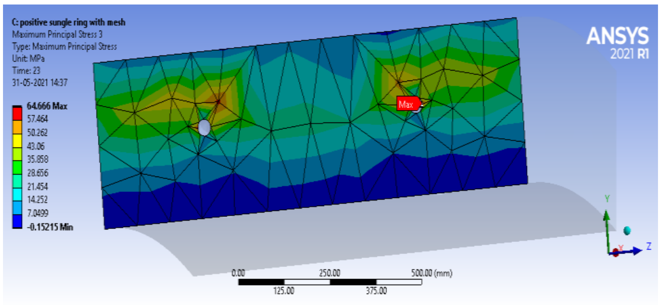

Fig -9 contact force of mesh installed reinforce segment

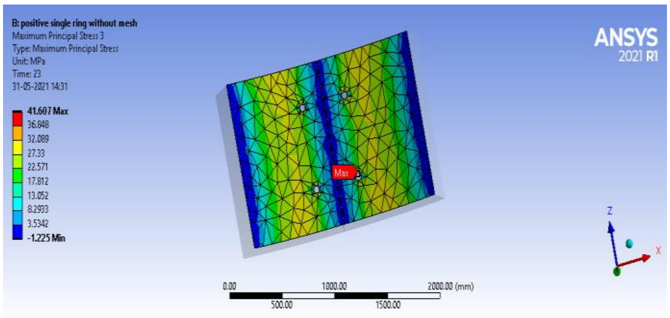

Fig -10 Tension stresses on the intrados of traditional reinforcement segment

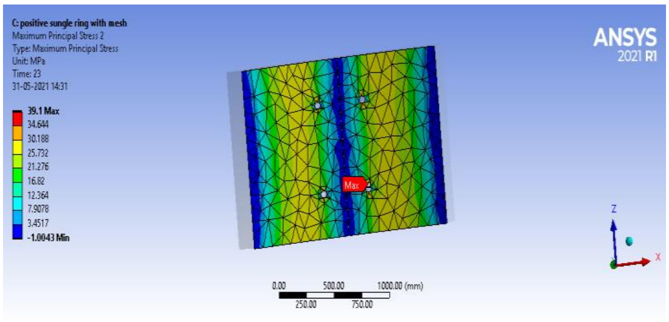

Fig -11 Tension stresses on the intrados of mesh installed segment

Table -5: Stresses comparison result of with or without mesh segment

	TRADITIONAL SEGMENT	MESH INSTALLED SEGMENT
MAX. CONTACT STRESSES	70.824 MPa	64.666 MPa
MAX. TENSION STRESSES ON THE INTRADOS	41.607 MPa	39 Mpa

5. CONCLUSIONS

1. A compression between a three-ring compression bending test and a single-ring compression bending test reveals that the load carrying capacity of three-ring model is more that single-ring model. Single-ring model work like cross joint segment and three-ring model work like T joint segment. Therefore it concluded that T joint segment have more strength than cross joint segment. The stiffness and strength of T joint segments can be better improved in an all-round way, as opposed to cross joint segments.

2. The single-ring test suggested that the longitudinal joints are the weakest parts where failure is concentrated. In the three-ring test, it is found that the longitudinal joints are not only weakest parts; circumferential failure and segment body failure can also be observed.

3. When concentrated load act on longitudinal joint, then tensile bursting and splitting forces in joint portion of segment which create cracks on intrados surface of segment, when we provide mesh with traditional reinforcement in segment then contact stresses and tensile stresses at joints decreases.

This work investigates the mechanical properties of T joint segments through analysis and compare with previous thesis experimental result. And modify the segment by adding mesh in segment longitudinal joints and by bending moment test done on this modify model. In future work we do experimental result on modified segment. And also does analytical full scale test with modified structure.

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