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Numerical Analysis for Strengthening Steel Trusses using Post Tensioned Cables

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Different techniques using post tensioned cables are used in strengthening different truss's systems. The main difference between these techniques is the profile and the locations of the post tensioned cables. Comparisons between these techniques are made in order to determine the suitable post tensioning technique for each truss system. The analysis and results are obtained by using ANSYS program.

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NUMERICALANALYSISFORSTRENGTHENINGSTEELTRUSSESUSINGPOSTTENSIONEDCABLES

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Numerical Analysis for Strengthening Steel Trusses using Post Tensioned Cables

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I. Introduction

Post tensioning is one of the most effective methods for strengthening an existing structure to overcome the increase in service load without replacement parts of the structure. The aim of this paper is to study the effect of post tensioning in strengthening different types of steel trusses and find a suitable way to apply post tensioning in each type. Many researchers studied the effect of post tensioning on strengthening different types of structures.

Previously, researchers study the effect of post tensioning on strengthening steel beams, especially those used in bridges. Dunker et al. [1] presented a research which studied the strengthening of existing single-span steel-beam with concrete deck bridges. Klaiber et al. [2] studied the effect of post tensioning on strengthening an existing continuous-span steel-beam with concrete deck bridge. It was concluded that post tensioning is a viable, economical strengthening technique. Ayyub et al. [3] studied the pre-stressing of a composite girder subjected to a positive moment. It was concluded that using strands is preferable than using bars in post-tensioning. Ayyub et al. [4, 5] presented an experimental and analytical study for prestressing composite girder subjected to negative moment. The research shows that using post tensioning decreases the crack in the negative moment region and reduces the required steel material. Phares et al. [6] presented a research on strengthening of steel girder bridges using post tensioned rods of carbon fibre reinforced polymers (CFRP). The research showed the significant effect of using post tensioned CFRP in increasing the load capacity of the bridge. Nazir [7] showed that using post tensioned cable for a pre-stressed arch steel bridge has a great effect in reducing the stress on the arch girder.

As the effect of post tensioning cables in strengthening different types of structure becomes obvious, many researchers [8-11] used post tensioning cables in earthquake-resistant in structural steel moment resisting frame (MRF) system, which is known as self-centering moment-resisting frame (SC-MRF) structural system. This type of connection uses high strength post tensioned cables to pre-compress the beams to the columns and to close the gaps that were developed under earthquake loading, returning the frame to its initial position [12]. Vasdravellis et al. [13] proposed a new self-centering beam-to-column connection. The connection used post tensioned high strength steel bars to provide self-centering capability and designed energy-dissipation (ED) elements that consisted of steel cylindrical pins with an hourglass shape. Mahmoud et al. [14] studied the effect of using eccentric post tensioned cables in strengthening simple frame. Different post tensioning techniques were proposed for strengthening simple steel frames. The result shows that using post tensioning cables in strengthening simple steel frames can increase the load capacity by more than 30 %. Similar result where reported by the research done by Ghannam et al. [15].

Ghannam et al. [16] showed that post tensioned cables can increase the load capacity of box girder steel bridge by 25% with a factor of safety equal to 1.8 and 3.63 according to AASHTO LRFD (17) and ECP No. 201 (18) loading vehicles respectively.

Steel trusses are one of the most important types of structures in our life. Nowadays, steel trusses are used in workshops, factory building, stadiums roof, bus and train stations and bridges. Due to the increase in service load applied to steel trusses, researchers began to study different methods to strengthen steel trusses. Using post tensioned cables in strengthening different types of steel trusses are one of the most efficient and widely acceptable methods.

Ayyub et al. [19] and Ayyub and Ibrahim [20] studied the effect of using post tensioned cables on strengthening steel trusses bridge. Single span bridges with different trusses system were investigated in this

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study. Also the effect of different tendon layout was studied. It was concluded that post tensioning tendon is a cost-effective method to strengthen steel trusses and can increase the redundancy levels as well as the reliability of the truss structures to meet the increase in service loading requirements. Post tensioning also enlarges the elastic range, increases the fatigue resistance and reduces deflection and member's stress. Thus, the remaining life of a truss bridge can be extended. More details will be given about this study in section 2.1 of this paper.

Han and Park [21] studied the elastic behaviour of post tensioned steel trusses with straight and draped tendon profiles. The effect of different parameters on the working load and the deflection of truss were studied. These parameters were: tendon profile, truss type, pre-stressing force and tendon eccentricity. Similar to Ayyub et al. [19] and Ayyub and Ibrahim [20], it was concluded that post tensioning enlarges the elastic range, increases the redundancy and reduces the deflection and member's stress. As a result, the load carrying capacity of the truss was increased. Nowadays, there are lots of applications of post tensioned steel trusses for long span roofs especially in stadiums such as Telstra Stadium in Australia [22].

From the literature, it can be concluded that using post tensioned cables is one of the most effective methods in strengthening different types of buildings and structures. Also it was observed from the literature that the effect of post tensioned cables was not investigated on continuous span steel trusses. This paper studies the effect of post tensioned cables in strengthening double span steel trusses. Warren and N truss system are included in this study. Different post tensioning techniques are investigated to check the ability of these methods in strengthening different types of trusses. The main difference between these techniques is the layout and the profile of the post tensioned cables.

II. Finite Element Analysis

a) *Ayyub et al truss model*

The main objective of this paper it to study the effect of different post tensioned cables profile on strengthening double span steel trusses. The numerical study is performed using ANSYS Finite element (FE) program [23]. It is very important to verify the FE model before proceeding to the main objective of this paper. The FE model is verified against the result obtained by Ayyub et al. [19].

Ayyub et al. [19] studied the effect of using post tensioned cables on strengthening steel trusses bridge. Single span bridges with different trusses system were investigated in this study. Also the effect of different tendon layout was studied. In this study, the analysis of post-tensioned trusses is divided into three steps. In the first step, an analysis is performed using the dead load. In the second step, the analysis is performed using the dead and the posttensioning loads as applied to the truss joints. In last step, an analysis is performed using the live loads including impacts. The stiffness of the tendons is considered only in the third analysis stage. The final solution is achieved by superimposing the second and third step.

In this study three examples were presented. The first example was a statically determinate truss post tensioned internally; the second example was indeterminate truss post tensioned internally and the last example was statically determinate trusses post tensioned externally. It was decided to use the statically determinate trusses that were post tensioned internally and externally for the verification of the FE model. The discretion of the statically determinate trusses is indicated in the following paragraphs.

The detail of the truss that was used in the analysis is described as follows. The truss was a warren single span truss with a height of 11582.4 mm and consists of 8 panels of 8229.6 mm length each. The truss is loaded at 3 point as indicated in Figure 1 the value for dead load was 450 kN and the value for live load and impact was 900 kN, forming a total load of 135o kN as indicated in Figure 1.

Four different cables layout were used to apply post tensioning to the truss. Here, each layout will be referred as a technique. In the 1st technique, a straight cable was used, this cable was coinciding with the lower member joining between the two supports of the truss, and this layout is indicated in Figure 2.

In the 2nd technique, one drape cable was used; this cable was joining between node U0 and U8 passing through node L4 as shown in Figure 3. In the 3rd technique, two drape post tensioned cable was used, this cable begins at node U1 passing through node L2, L6 and ending at node U7 as shown in Figure 4.

In the 4th technique, the cable was post tensioned externally as indicated in Figure 5. Two drape post tensioned cable are anchored at nodes L0 and L8 and pass over two pulleys at nodes D1 and D2. Two vertical members (L1,D1) and (L2, D2), two diagonal members (D1, L2)and(D7, L6) are added to achieve the stability of the truss as shown in Figure 5. The distance between the post tensioned cable and the lower member of the truss was 6319.5 mm.

In the first three techniques, the cables consist of three strands of 15.24 mm diameter and an ultimate tensile strength of 1860 MPa. The cross sectional area of the cables was 548 mm^2. The cables were post tensioned by a force equal to 927 kN giving a post tensioning stress equal to 1674 MPa. This stress corresponds to 85% of the ultimate strength of the strands as indicated by Ayyub et al. [19].

In the 4th technique, the cables consist of two strands of 15.24mm diameter and an ultimate tensile strength of 1722.5 MPa. The cross sectional area of the cables was 361mm^2. The cables were post tensioned by a force equal to 45 kN giving a tensioning stress equal to 1266.4 MPa. This stress corresponds to 70% of the ultimate strength of the strands strands as indicated by Ayyub et al. [19].

b) Finite element model description

Link element (8) is used to model the truss member, beam element (4) is used to model the post tensioned cable. It should be noted that the beam element is used with axial stiffness only with ignoring the bending stiffness. Beam element (4) is used to model the cable to overcome the convergence problem that may occur when using Link element (8) to model the post tensioned cable. Post tensioned load is applied by using Pretension element (179), this element splits the cable in to two part and apply the tension force in each part, and this is the reason of using beam element (4) to model the cable.

The poly that is used in the 3rd and the 4th technique is indicated in Figure 6 (a and b) respectively. In the 3rd technique, a connecting link member is added to connect between the truss joint and the post tensioned cable. It should be noted that the axial stiffness of this added link is very small so that it will not affect on the load distribution in the truss member, also its length is very short. This connecting link is added so that the angle between the drape cable is divided equally. A rotational restrained is assigned to joint connecting the cable to the connecting link.

In the 4th technique, another method was used to model the poly. The same connecting link that is used in the 3rd technique is used here with the same properties and dimensions. However, instead of adding a rational restrains, an additional cable is added at the joint connecting between the cable and the connecting link as indicated in Figure 6 (b), the addition link has also a very small axial stiffness and length. A rotational and transitional restrains are assigned at the end of the additional link.

c) Verification of finite element model

Table 1 Shows the comparison between the result introduced in Ayyub et al. [19] and the result obtained in from the finite element (FE) model of this study. In this table result of selected truss members is presented, each truss member is identified by its number as indicated in Figure 1, The result presented by the FE model of this study is indicated by FE.

The comparison was done according to two loading cases, the first loading case include the primary loads without post tensioned force, this case includes deal load and live load plus impact. This case is indicated by *N*. The other case includes the primary load plus the post tensioned load which is indicate as *N+P*. It should be noted that the cable load in the 4th technique was not presented in Ayyub et al. [19].

From the comparison of the result through different techniques, it can be concluded that there is good agreement between the result presented by Ayyub et al. [19] and the result presented in this study.

III. Strengthening of Continuous Trusses

a) Warren truss

This section studies the effect of post tensioning on double span warren truss. The dimensions of the warren truss are the same as that were used before in verification the model, the truss height is 11582.4 mm. The truss consists of 8 panels, each panel has a length of 8229.6 mm. The analysis is carried under the effect of dead and live load with impact. The total value of each concentrated load is 1350 kN as indicated in Figure 7. Figure 7 shows the numbering system of the truss members in one span. Seven post tensioning techniques are used to strengthen the truss. These seven techniques are described in details in the following sub sections.

i. *Technique of the Warren Truss*

In this technique, the post tensioned cable is coincide with the lower tensioned member as indicated in Figure 8. The cables consists of three strands of 15.24mm diameter and an ultimate tensile strength of 1860MPa. The cross sectional area of the cables is 548mm^2. The cables initially post tensioned by a force equal to 925 kN.

ii. *Technique of the Warren Truss*

In this technique, the post tensioned cable is coincide with the upper tensioned member as indicated in Figure 9. The cross section of the cables and the post tensioning force are the same as the 1st technique.

iii. *Technique of the warren truss*

In this technique, two external draped post tensioned cables are used parallel to the lower chord members. The distance between the cables and the lower truss member is 3159.8 mm. Another post tensioned cable is used coincide with the two upper central chord member as indicated in Figure 10. The post tensioned force for the external draped cable is 143 kN and for the straight cable is 770 kN.

iv. *Technique of the warren truss*

In this technique, straight cable is used coincide with the lower chord members and external straight cable is used parallel to the two upper central chord members as shown in Figure 11. The post tensioned force for the lower straight cable is 201 kN and 770 kN for the upper cable.

v. *Technique of the warren truss*

Straight cable is used coincide with the lower chord members and a straight cable is used coincide with the two upper central chord members as show in

Figure 12. The post tensioned force for the cable is 183 kN and 770 kN for the upper cable.

vi. *Technique of the warren truss*

Two external draped cables are used parallel to the lower chord members and external straight cable is used parallel to the two upper central chord members as shown in Figure 13. The post tensioned force is 156 kN for the lower cable and 770 kN for the upper cable.

vii. *Technique of the warren truss*

In this technique, two draped cables post tensioned by 770 kN are used in each span as indicated in Figure 14.

b) N truss

This section studies the effect of post tensioning on double span warren truss. The dimensions of the N truss are the same as that were used before in verification the model, the truss height is 11582.4 mm. The truss consists of 8 panels, each panel has a length of 8229.6 mm. The analysis is carried under the effect of dead and live load with impact. The total value of each concentrated load is 1350 kN as indicated in Figure 15. Figure 15 shows the numbering system of the truss members in one span. Seven post tensioning techniques are used to strengthen the truss. These seven techniques are described in details in the following sub sections.

i. *Technique of the N truss*

In this technique, the post tensioned cable is used coincide with the lower tensioned member as indicated in Figure 16.

ii. *Technique of the N truss*

In this technique, the post tensioned cable is coincide with the upper tensioned member as indicated in Figure 17.

iii. *Technique of the N truss*

In this technique, two external draped post tensioned cables are used parallel to the lower chord members, The distance between the cables and the lower truss member is 3159.8 mm. Another post tensioned cable is used coincide with the two upper central chord member as indicated in Figure 18. The post tensioned force for the external draped cable is 143 kN and for the straight cable is 770 kN.

iv. *Technique of the N truss*

In this technique, straight cable is used coincide with the lower chord members and external straight cable is used parallel to the two upper central chord members as shown in Figure 19, the distance between the cable and the upper member is 3159.8 mm. The post tensioning force for the lower straight cable is 275 kN and for the upper cable is 770 kN.

v. *Technique of the N truss*

Straight cable is used coincide with the lower chord members and a straight cable is used coincide with the two upper central chord members as show in Figure 20. The post tensioned force for the cable is 169 kN and 770 kN for the upper cable

vi. *Technique of the N truss*

Two external draped cables are used parallel to the lower chord members and external straight cable is used parallel to the two upper central chord members as shown in Figure 21. The post tensioned force is 222 kN for the lower cable and 770 kN for the upper cable

vii. *Technique of the N truss*

In this technique, two draped cables post tensioned by 770 kN are used in each span as indicated in Figure 22.

IV. Results and Discussions

From the previous sections, it can be noticed that in different techniques, the post tensioning force which was applied to the post tensioned cables that were located close to upper chord members was chosen to be 770 kN. This value was chosen in order to eliminate the internal tension force of the two middle upper chord members. The post tensioning force of the cables that are located close to the lower chord member was chosen with different values for different techniques. The value of the post tensioning force of the lower cables was chosen based on which value will give the most reduction of the internal forces of the truss members with keeping the post tensioned force in the upper cable constant as 770 kN.

Table 2 shows the percentage of reductions in the truss members' internal tension and compression forces after using different post tensioning techniques with continuous Warren and N trusses. It should be noted that in Table 2 that, % *Ten.* refer to the total reduction in the internal forces of all tension members, % *Comp.* refer to the total reduction in the internal forces of all compression members. In Table 2, +ve numbers mean a reduction in the truss members' internal force and -ve numbers mean an increase in the truss members' internal force.

It can be concluded from the results obtained in Table 2, that the best technique for strengthening the N truss system, is the 6th techniques, which gives a reduction of 9.84 % of the total internal forces of the tension member and a reduction of 3.19 % of the total internal compression forces. Although the 7th techniques provides a reduction of 21.77 % of the total internal tension forces, however, this techniques cause an increase in the total internal forces of the compression member by 1.42 %.

Also, it can be concluded from the results obtained in Table 2, that the best techniques for strengthening the Warren truss system, are the 3rd and the 5th techniques. 3rd technique gives a reduction of 9.72 % of the total internal forces of the tension member and a reduction of 0.94 % of the total internal compression forces. 5th technique gives a reduction of 9.91% and 0.016 % for the total tension and compression force respectivelly. Although the 7th techniques provides a reduction of 21.63 % of the total internal tension forces, however, this techniques cause an increase in the total internal forces of the compression member by 12.9 %.

V. Conclusions

This paper studies the effect of post tensioned cables in strengthening double span steel trusses. Different truss systems (Warren and N truss system) are included in this study. Different techniques using post tensioned cables are used in strengthening different truss systems. The main difference between these techniques is the profile and the locations of the post tensioned cables. Comparisons between these techniques are made in order to determine the suitable post tensioning technique for each truss system. The analysis and results are obtained by using ANSYS program.

From this study, it can be concluded that post tensioning is an effective method in strengthening different types of steel trusses. Strengthening trusses using post tensioned cables can reduce the internal force in both tension and compression members. However, the reductions of the internal tension forces is more significant than the compression forces.

Each type of truss has a specific post tensioned technique that provides the most percentage of reduction in the trusses internal forces. Generally, post tensioning the cable externally has a significant effect in reducing the internal forces, however, care should be taken when using this technique, as it reduces the clearance under the truss. This may have a negative influence on the using purpose of the truss especially, if this truss was designed as a bridge over a water stream where there is a navigation to pass under the truss bridge.

References Références Referencias

1. Dunker K. F., Klaiber F. W., Beck B. L. and Sanders W.W. Strengthening of existing single-span steel-beam and concrete deck bridges. Final Report Part II. ISU- HR-238, ERI Project 1536, ERIAmes-85231: Engineering Research Institute, Iowa State University, Iowa Department of Transportation Highway Division and the Iowa Highway Research Board. 1985.
2. Klaiber F. W., Dunker K. F., Planck S. M. and Sanders W.W. Strengthening of an existing continuous-span, steel-beam, concrete deck bridge by Post-.Tensioning. Final Report, ISU-ERI-Ames - 90210. Ames: Engineering Research Institute, Iowa State University, Iowa Department of Transportation Highway Division and the Iowa Highway Research Board. 1990.
3. Ayyub, B.M., Sohn Y.G and Saadatmanesh, H. Prestressed composite girder under positive moment. journal of structural Engineering. 1990, 116(11); 2931–2951
4. Ayyub B.M., Sohn, Y.G. and saadatmanesh, H. Prestressed composite girder I: experimental study for negative. journal of structural engineering. 1992, 118(10); 2743-2762.
5. Ayyub, B.M., Sohn, Y.G., and Saadatmanesh, H. Prestressed composite Girder II : Analytical study for negative moment. journal of structural engineering. 1992, 118(10), pp 2763–2782.
6. Phares, B.M., Wipf, T.J., Klaiber, F. W., Abu-Hawash, A. and Lee, Y. Strengthening of steel girder bridges using FRP". Proceedings of the 2003 Mid-Continent Transportation Research Symposium, Ames, Iowa. 2003, pp 1-12.
7. Nazir, C.P. Prestressed steel arch bridge, IE (I) Journal .CV. 2003, 84; 72-76.
8. Petty, G.D. Evaluation of a friction component for a post-tensioned steel connection. Theses and Dissertations, Lehigh University. 1999, Paper 629.
9. Ricles, J.M., Sause, R., Wolski, M., Seo, C-Y. , and Iyama J. Post-tensioned moment connections with a bottom flange friction device for seismic resistant selfcentering steel MRFS, 4th International Conference on Earthquake Engineering Taipei, Taiwan October 12-13, 2006, Paper No. 108.
10. Wang, D. and Filiatrault, A. Numerical and experimental studies of self-centering post-tensioned steel frames, Technical Report MCEER-08-0017, University at Buffalo, State University of New York. 2008.
11. Rojas, C.P., Caballero, V.M., Ricles, J.M., and Sause, R. Plastic limit analysis of self-centering steel moment resisting frames with post-tensioned friction damped connections, The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China.
12. Lin, Y-C, Sause, R., and Ricles, J.M. Seismic performanceof steel self-centering, moment-resisting frame: hybrid simulations under design basis earthquake. Journal of Structural Engineering, 2013, 139(11); 1823–1832.
13. Vasdravellis, G., Karavasilis, T.L., and Uy, B. Large-scale experimental validation of steel posttensioned connections with web hourglass pins. Journal of structural engineering. 2013, 139(6); 1033–1042.
14. Mahmoud, N.S, Badr A., Ssalem F.A. and Ghannam M. Strengthing Steel Frames by Using Post Tensioned Cable. Life Science Journal. 2014, 11(1); 111-116.
15. Ghannam, M., Mahmoud, N.S, Badr A. and Salem F.A. Effect of post tensioning on strengthening different types of steel frames. Journal of King Saud

University – Engineering Sciences. 2016, Article in press.
16. Ghannam, M., Mahmoud, N.S, Badr A. and Salem F.A. Strengthening and repairing of an existing steel bridge using post tensioning. International journal of civil and structural engineering. 2014, 5(2); 91-100.
17. AASHTO LRFD Bridge Design Specifications The American Associates of State High Way and Transportation Officials, Washington, DC. fourth Edition, 2007.
18. Egyptian Code for Calculating Loads and Forces on Structures, code no. ECP 201. Ministry of Housing, Utilities and Urban Communities, Housing and Building National Research Centre, Cairo, Egypt. 2008.
19. Ayyub B.M., Ibrahim A., Schelling D. Posttensioned trusses: analysis and design. Journal of structural engineering. 2008,116(6); 1491-1506.
20. Ayyub, B.M., and Ibrahim, A. Posttensioned trusses: reliability and redundancy. Journal of structural engineering. 1990, 116, (6); 1507-1521.
21. Han, K-B., and Park S-K. Parametric study of truss bridges by the post-tensioning method, Canadian Journal of Civil Engineering. 2005, 32(2); 420-429.
22. Manley K. Innovation Case Study No 9: Post-tensioned steel trusses for long span roofs, A series of innovation case studies, the BRITE Project of the Cooperative Research Centre for Construction Innovation. 2006, pages 8.
23. ANSYS. Verification Manual, Release 10.0. ANSYS, Inc., 275 Technology Drive, Canonsburg, PA 15317, United States. 2005.

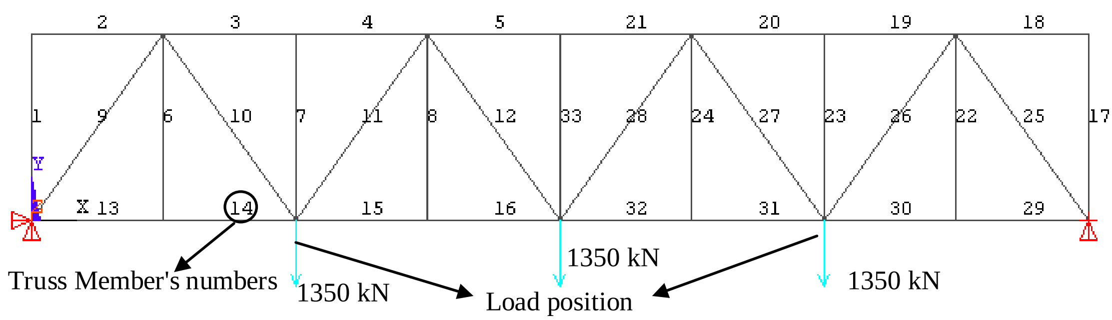


Figure 1: Main truss layout

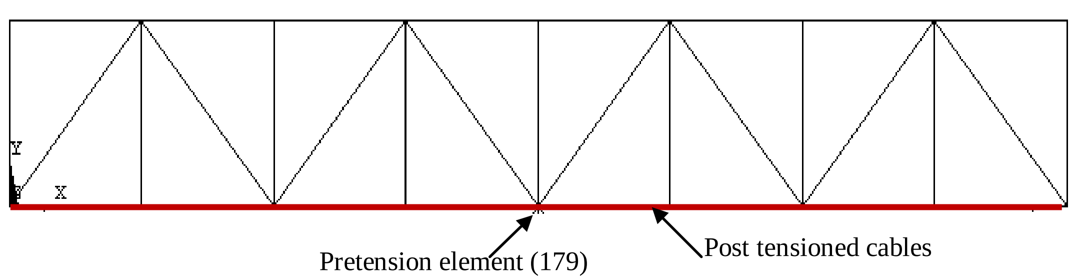


Figure 2: Layout of the 1st technique

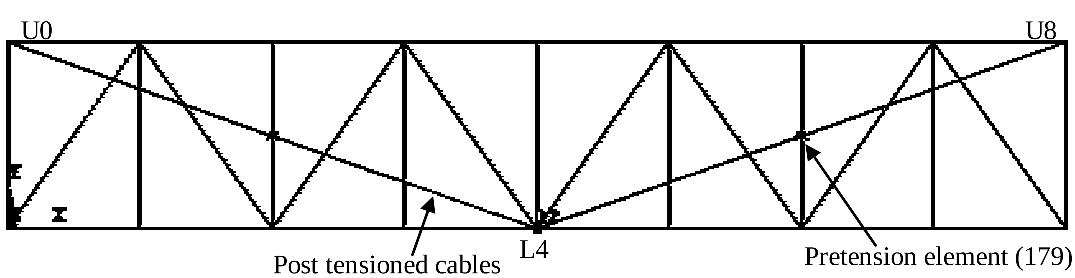


Figure 3: Layout of the 2nd technique

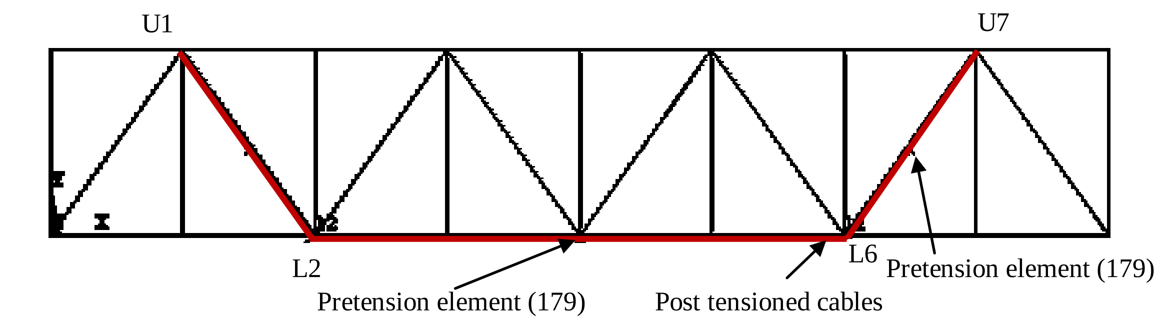


Figure 4: Layout of the 3rd technique

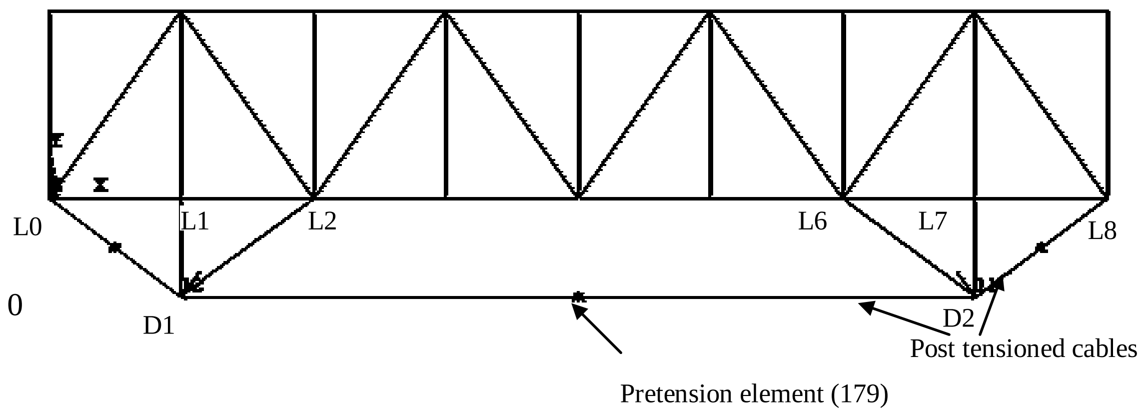
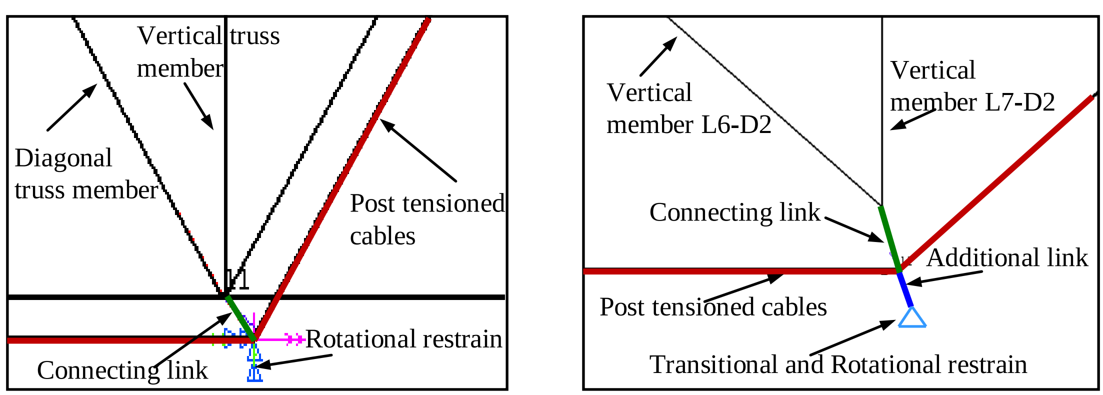


Figure 5: Layout of the 4th technique



(a) 3rd technique (b) 4th technique

Figure 6: Modelling of the poly

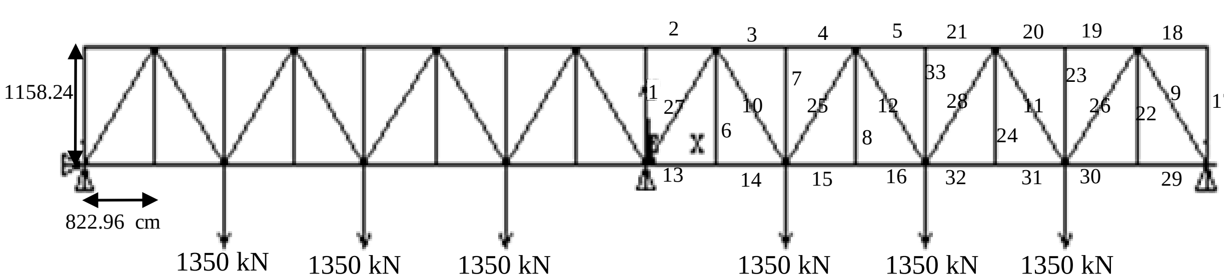


Figure 7: Layout of Warren continuous truss.

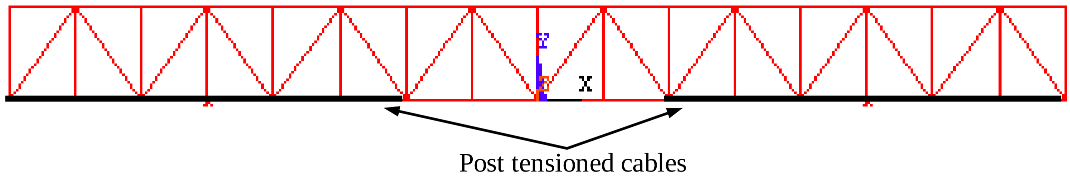


Figure 8: Layout of the 1st technique used for strengthening of the continuous Warren truss

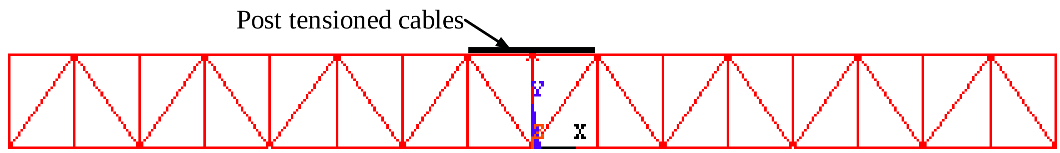


Figure 9: Layout of the 2nd technique used for strengthening of the continuous Warren truss

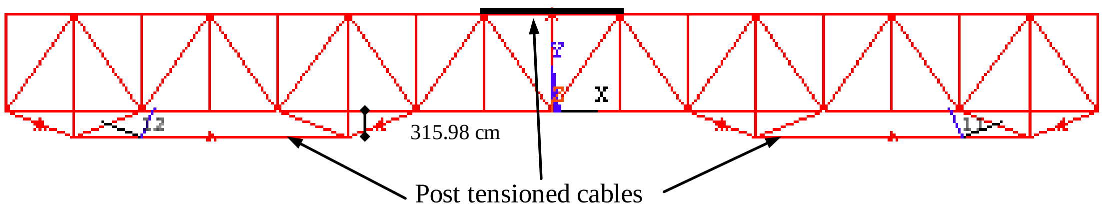


Figure 10: Layout of the 3rd technique used for strengthening of the continuous Warren truss

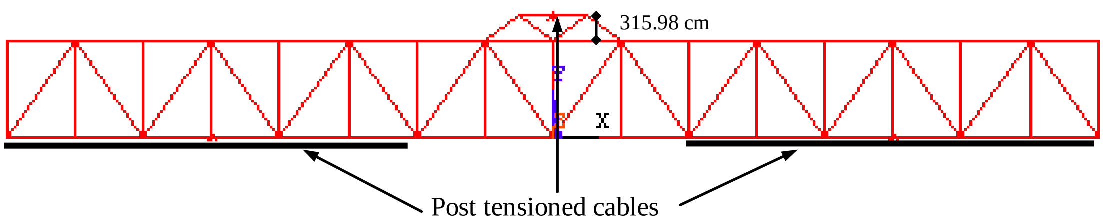


Figure 11: Layout of the 4th technique used for strengthening of the continuous Warren truss

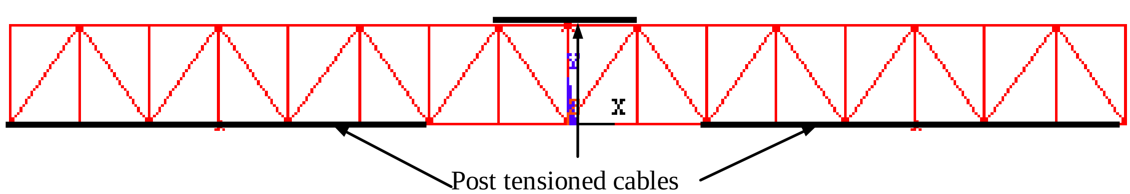


Figure 12: Layout of the 5th technique used for strengthening of the continuous Warren truss

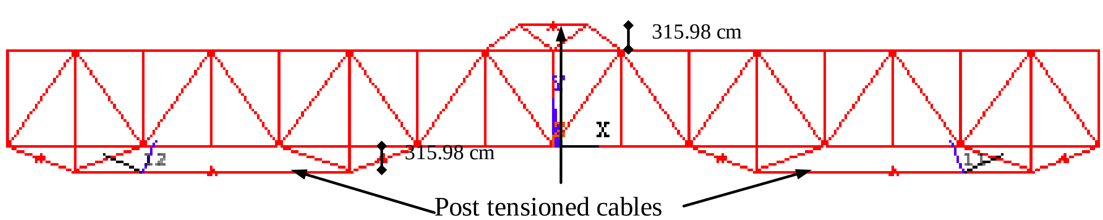


Figure 13: Layout of the 6th technique used for strengthening of the continuous Warren truss

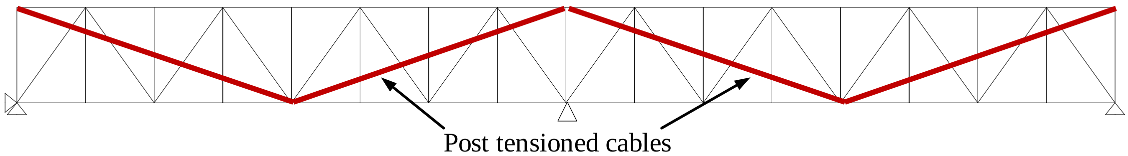


Figure 14: Layout of the 6th technique used for strengthening of the continuous Warren truss

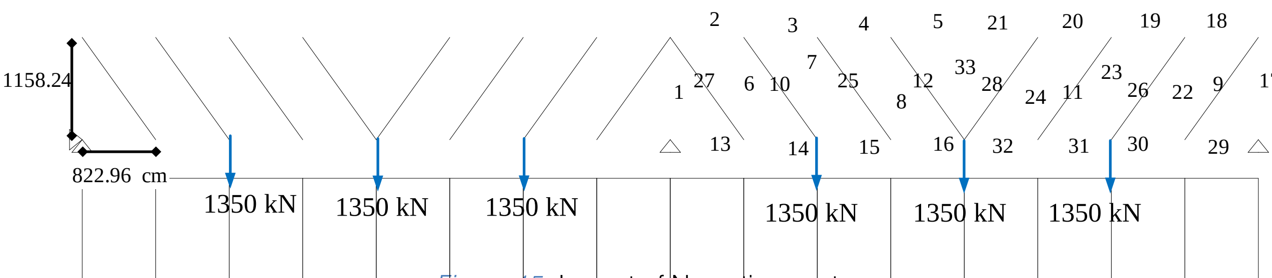


Figure 15: Layout of N continuous truss.

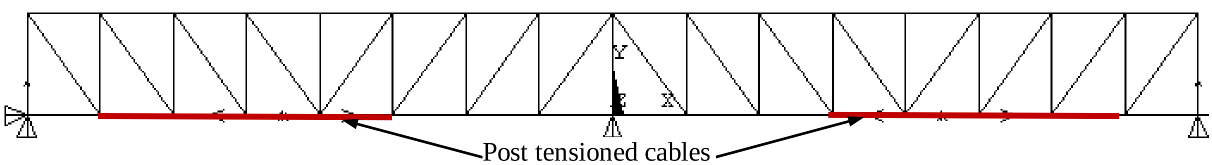


Figure 16: Layout of the 1st technique used for strengthening of the continuous N truss

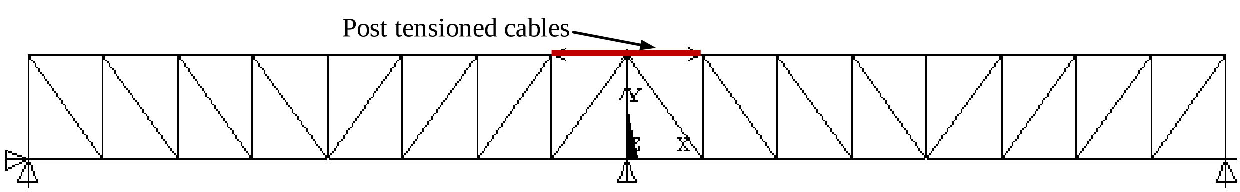


Figure 17: Layout of the 2nd technique used for strengthening of the continuous N truss

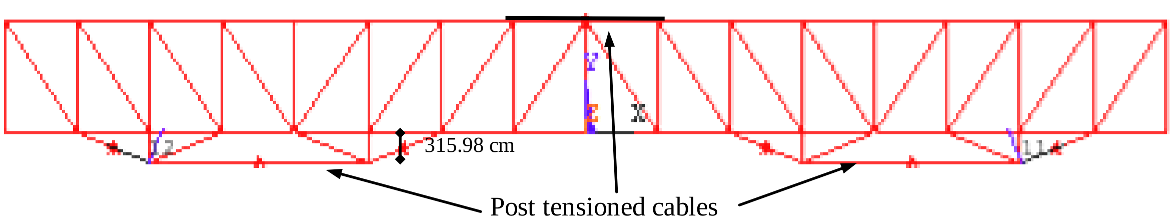


Figure 18: Layout of the 3rd technique used for strengthening of the continuous N truss

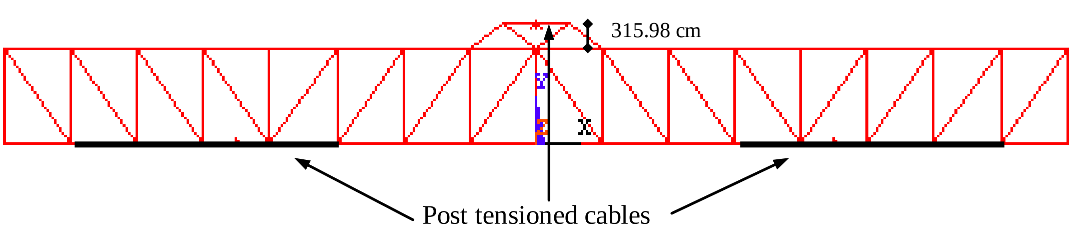


Figure 19: Layout of the 4th technique used for strengthening of the continuous N truss

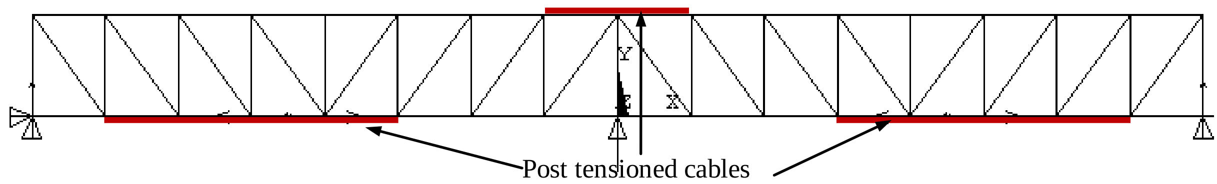


Figure 20: Layout of the 5th technique used for strengthening of the continuous N truss

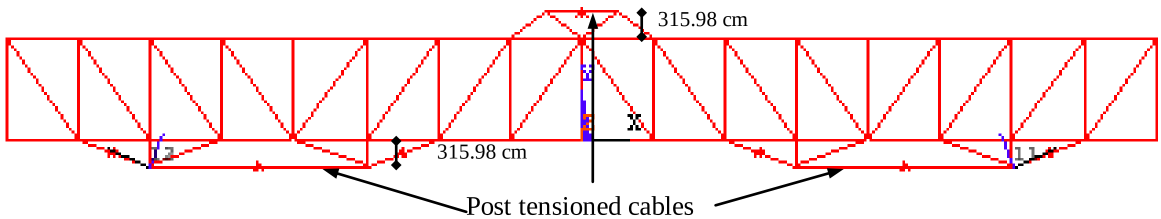


Figure 21: Layout of the 6th technique used for strengthening of the continuous N truss

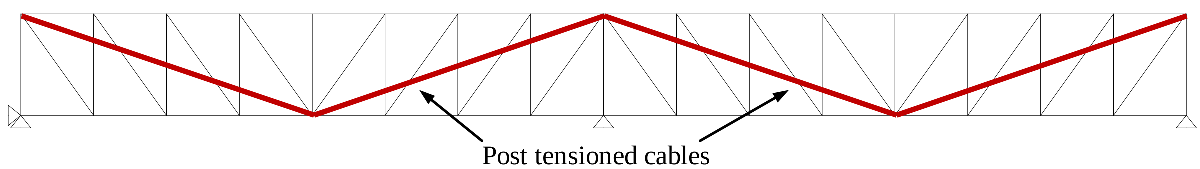


Figure 22: Layout of the 7th technique used for strengthening of the continuous N truss

Table 1: Comparison between the results in Ayyub et al (1990a) and the results obtained by The FE model in this study

Truss Member	*N* (Ayyub et al 1990a) (kN)	*N* (FE) (kN)	*N* + P (Ayyub et al 1990a) (kN)				*N* + P (FE) (kN)			
			1st Technique	2nd Technique	3rd Technique	4th Technique	1st Technique	2nd Technique	3rd Technique	4th Technique
1	0	0	0	-315	0	0	0	-317.26	0	0
2	0	0	0	-900	0	0	0	-901.71	0	0
3	-2880	-2877.62	-2880	-3330	-2880	-2614.5	-2877.62	-3328.47	-2877.71	-2618.73
4	-2880	-2877.62	-2880	-3330	-2880	-2614.5	-2877.62	-3328.47	-2877.71	-2618.73
5	-3838.5	-3836.84	-3838.5	-3838.5	-3838.5	-3573	-3836.84	-3836.84	-3836.88	-3577.86
6	0	0	0	0	0	-220.5	0	0	0	-220.6
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	-2484	-2484.14	-2349	-2097	-2484	-2119.5	-2484.14	-2094.93	-2484.14	-2125.31
10	2484	2484.14	2484	2097	1710	2394	2484.14	2094.93	1533.29	2395.94
11	-828	-828.05	-828	-441	-828	-828	-828.05	-438.84	-828.05	-827.96
12	828	828.05	828	441	828	828	828.05	438.84	828.05	827.96
13	1440	1438.83	477	1215	1440	828	478.98	1213.38	1438.83	839.75
14	1440	1438.83	477	1215	1440	828	478.98	1213.38	1438.83	839.75
15	3357	3357.23	2398.5	2686.5	2380.5	2596.5	2397.38	2680.97	2381.04	2610.05
16	3357	3357.23	2398.5	2686.5	2380.5	2596.5	2397.38	2680.97	2381.04	2610.05
33	0	0	0	0	0	0	0	0	0	0
Cable	………	………	963	954	972	………	959.85	955.89	964.89	487.31

Table 2: Percentage of reductions in truss members' internal forces after using different post tensioning techniques

Truss's system	1st technique		2nd technique		3rd technique		4th technique		5th technique		6th technique		7th technique	
	% Ten.	% Comp.	% Ten.	% Comp.	% Ten.	% Comp.	% Ten.	% Comp.	% Ten.	% Comp.	% Ten.	% Comp.	% Ten.	% Comp.
N system	9.05	-0.65	2.22	0.14	7.63	0.98	9.5	1.66	7.2	0	9.84	3.19	21.77	-1.42
Warren system	12.8	-15.52	2.75	0.33	9.72	0.94	9.58	-1.17	9.91	0.016	9.31	-0.14	21.63	-12.9

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