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Strengthening Of Determinate Pratt Steel Truss By The Application Of Posttensioning Along Its Bottom Chord

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Abstract:
Majority of the truss bridges in India and abroad are either structurally deficient and/or functionally obsolete. There is a desperate need to enhance the performance of these existing bridges by an appropriate technique which should be economical and with minimum disturbance to the traffic. The aim of the present analytical work is to know the effect of posttensioning on the member forces and deflections of a statically determinate Pratt type of the truss. Pratt type of truss has been considered in our study, as it is one of the most commonly used truss configuration in truss bridges. Because of its relative economy and less disturbance to the traffic, posttensioning technique has been adopted to upgrade the performance of the truss. Bottom chord of the truss is post tensioned with high tensile steel cable and the profile of the cable is straight. The truss is analysed for member forces and deflections using direct stiffness approach of matrix analysis. From the obtained analytical results, it is seen that there is a noticeable improvement in the performance of the structure: Member forces have been reduced significantly in the entire bottom chord members and there is reduction in deflections at all the joints after posttensioning.

Key words: *Bridges, Truss, Bottom Chord, Posttensioning, Cable, Member forces, Deflections*

1.Introduction

One of the vital necessities in the development of any country is the transportation facility. Land mode of transportation through roadways and railways is the most common one. Along roadways and railways bridges have been built in order to save journey time and money. The reduction of commuting time not only saves on precious man-hours but also saves on fuel consumption and depreciation on vehicles, apart from giving added convenience.

Majority of the existing Bridges in India and abroad can be grouped as follows. One group includes structurally deficient bridges that have deteriorated to such a condition that they cannot carry the load for which they were originally designed. The second group includes functionally obsolete bridges that are in good conditions, but whose current loading requirement may exceed the original design load. Therefore, it is necessary to find easy, simple and cost-effective methods to meet current and future loading and traffic requirements.

Three possible solutions to this problem are bridge replacement, posting load restrictions or to strengthen these existing bridges. As the existing bridges are vital assets and preservation of these bridges is necessary form the aspect of historic and cultural heritage, strengthening of these existing bridges is an appropriate solution. Also, proper maintenance of these bridges and timely rehabilitation work may well save substantial capital expenditure of any country. Posttensioning with the high strength steel tendons is the one of the best methods of strengthening of these bridges. The basic concept of prestressing is to introduce the internal stresses of such magnitude and distribution that the stresses resulting from given external loadings are counteracted to a desired level. It can be applied to a single member or group of members and can be in a single stage or in multi stages.

2.Literature Review

Contribution of some of the research works on posttensioning of bridges by previous researchers is summarised below.

Historically, the principle of '*prestressing*' was employed long before the word was coined, and this principle is used today subconsciously in some everyday objects. The Romans countered the problem of arches tending to overthrow piers, by putting a large weight on to the pier in order to counteract the tensile stresses due to the arch thrust. This principle was even exploited architecturally, and gave rise to the typical Roman decoration of statues on piers.

Materials such as cast iron, which are strong in compression but weak in tension, require compressive prestressing to make them more effective. In the 15th century, Leonardo Da Vinci suggested that cast-iron cannons would burst less frequently when fired if the barrels were tightly wound with iron wire; centuries later, the idea was adopted in wire-wound guns. Gadolin (1861) suggested winding artillery barrels with hot high strength wire which, after cooling, would compress the barrel and therefore reduce tensile stresses in it after the charges exploded.

Apart from prestressed concrete, the only application prestressing which has had a reasonable amount of publicity is prestressed steel (Magnel, 1950). One of the earliest works reported by him showed that it will be economical by prestressing truss with high tensile wires and concludes that the cost to stress ratio, for high tensile steel is lower than for mild steel.
Samuley (1955) mentions that prestressing is a physical principle which has been used for thousands of years, although it was not recognized as such and this physical principle is not confined to concrete. From his study, he concludes that, applying the prestressing force on neutral axis is not effective and suggests it to be applied below the neutral axis.
Use of high-strength steel for post tensioning is effective and economical, since the strength of the steel tendons is four to six times greater than that of medium steel although the cost is only two to three times higher (Troitsky, 1990). The economy of steel increases as the difference between the allowable stresses of the steel used for the structure and the high-strength steel for the tendons increases. Post tensioning by tendons made of high-strength steel is widely applied in bridge trusses. Steel bridges that are post tensioned with tendons consist of the following three elements: the structure which is to be strengthened, tendons of high strength steel, and the anchorages & saddles supporting the tendons. For tensioning and anchoring the tendons to the structure there are a number of different systems, some of which are patented (Belenya, 1977).
It has been reported in the literature that tendons used for prestressing usually take one of the following forms: wires, strands & bars (Troitsky, 1990; Belenya, 1977). Tendons may be internal or external: an internal tendon is one which is placed within the truss system; where as an external tendon is placed outside the truss system (Ayyub et al, 1990).
Venkateswara Rao and Prabhakar (1990) presented a comparison of prestressed truss design with conventional truss design. From their design, they have shown that the saving is considerable if prestressing is done for individual truss members.
There are a great variety of geometrical truss patterns used in bridges. Several of the most common truss patterns are Howe truss, Pratt truss, Warren truss, quadrangular Warren truss, Baltimore truss, Camelback truss and K-truss (Kenneth et al., 1992).
Decommissioned steel truss bridge was tested by Aziznamini (2002) in a laboratory and Failure was attributed to the abrupt rupture of a diagonal tension member.
Han and park (2005) mentions that the application of posttensioning is rare in steel structures, even though this technique has been successfully used to improve the performance of the existing concrete structures. The effect of design parameters such as the tendon profile, truss type, prestressing force, and tendon eccentricity on load and deflection of trusses are studied. They concluded that, posttensioning enlarges the elastic range, increases the redundancy, and reduces the deflection and member forces, eventually increasing the load-carrying capacity of truss bridges.
Design of prestressing concentric tendons for strengthening steel truss bridges is briefed by Albrecht and Lenwari (2008). Modes of failures considered by them are tendon yielding, member buckling and member fracture & yielding.
Conventional method of repairing the damaged truss members by adding steel plates merely improves the local behavior of the repaired member only and also it increase the dead loads which may not be a favorable and this will overcome by the posttensioning technique.

3.Objectives

The main objective of the present analytical study is to develop an analysis method for a truss posttensioned with a straight tendon layout and to know the effect of bottom chord posttensioning of a Pratt type truss on member forces and deflections.

4.Analysis Of Truss And Results

Statically determinate Pratt type through bridge truss is considered for this analytical study. The geometric and loading details of the truss are given Figure 1(a). Truss is posttensioned with internally located tendon layout which is passing through the bottom chord between joints L_0 and L_8 as shown in Figure 1(c) and the truss without posttensioning is shown in Figure 1(b). The area of cross section of cable is $600\ mm^2$ with an initial posttensioning stress of 1120 N/mm^2, and the corresponding posttensioning force is 672 kN. Young's Modulus for the posttensioning cable and truss members is 160 GPa and 200 GPa respectively. Column 2 and Column 3 of Table 1 gives the area of cross section and length of each member of the truss respectively

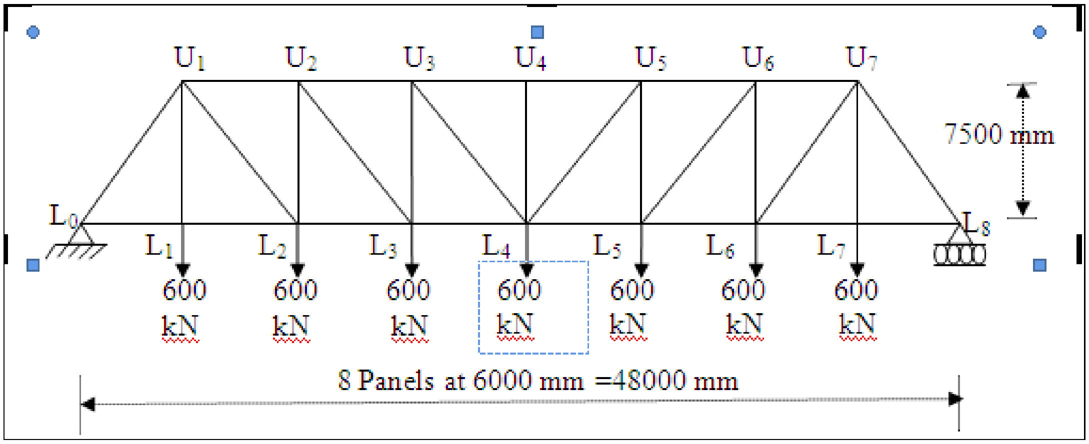

Figure 1(a): Joint Loads On Statically Determinate Pratt Truss

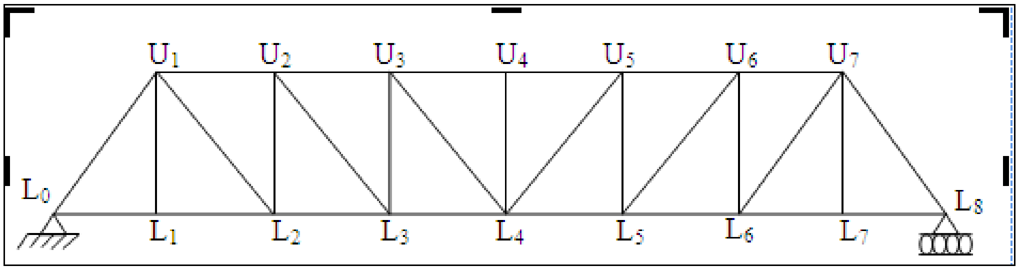

Figure 1(b) : Pratt Truss Without Posttensioning

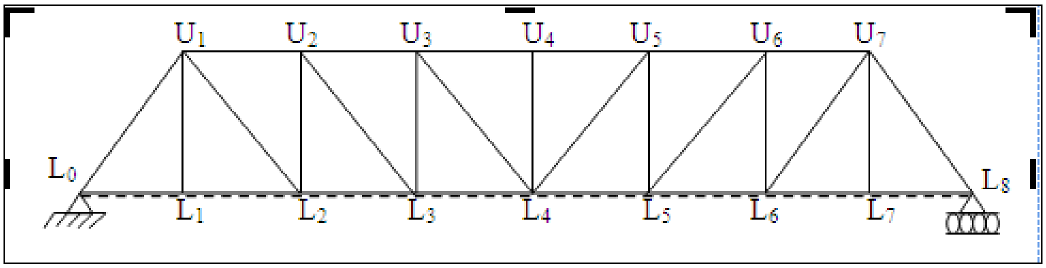

Figure 1(c) : Pratt Truss With Posttensioning Along The Bottom Chord

Table 1

Member	Area (mm^2)	Length (mm)
L_0L_1	25428	6000.00
L_1L_2	25428	6000.00
L_2L_3	25428	6000.00
L_3L_4	25428	6000.00
U_1U_2	23408	5100.00
U_2U_3	23408	5100.00
U_3U_4	23408	5100.00
L_0U_1	23408	9604.69
L_1U_1	3796	7500.00
L_2U_1	12660	9604.69
L_2U_2	9992	7500.00
L_3U_2	7468	9604.69
L_3U_3	5604	7500.00
L_4U_3	3796	9604.69
L_4U_4	2680	7500.00

Table 2

Member	Before Posttensioning	After Posttensioning
L_0L_1	1680.0	802.7
L_1L_2	1680.0	802.7
L_2L_3	2880.0	2002.7
L_3L_4	3600.0	2722.7
U_1U_2	-2880.0	-2880.0
U_2U_3	-3600.0	-3600.0
U_3U_4	-3840.0	-3840.0
L_0U_1	-2689.3	-2689.3
L_1U_1	600.0	600.0
L_2U_1	1920.9	1920.9
L_2U_2	-900.0	-900.0
L_3U_2	1152.6	1152.6
L_3U_3	-300.0	-300.0
L_4U_3	384.2	384.2
L_4U_4	0.0	0.0
Cable	----	877.3

Table 3

Member		Before Posttensioning	After Posttensioning
L_0	x	0.00	0.00
	y	0.00	0.00
L_1	x	1.98	0.95
	y	-32.86	-29.55
L_2	x	3.96	1.89
	y	-52.96	-48.00
L_3	x	7.36	4.26
	y	-76.86	-71.06
L_4	x	11.61	7.47
	y	-89.03	-83.23
L_5	x	15.86	10.68
	y	-76.86	-71.06
L_6	x	19.25	13.04
	y	-52.96	-48.00
L_7	x	21.24	13.99
	y	-32.86	-29.55
L_8	x	23.22	14.94
	y	0.00	0.00
U_1	x	24.84	20.70
	y	-26.93	-23.62
U_2	x	21.14	17.00
	y	-56.34	-51.37
U_3	x	16.53	12.39
	y	-78.87	-73.07
U_4	x	11.61	7.47
	y	-89.03	-83.23
U_5	x	6.69	2.55
	y	-78.87	-73.07
U_6	x	2.07	-2.07
	y	-56.34	-51.37
U_7	x	-1.62	-5.76
	y	-26.93	-23.62

Table 1: Member Data Of Statically Determinate Pratt Truss
&
Table 2: Member Forces Of Statically Determinate Pratt Truss Before And After Posttensioning (In Kn)
&
Table 3: Deflections Of Statically Determinate Pratt Truss Before And After Posttensioning (In Mm)

In the analysis it is assumed that the cable is linearly elastic and axial force is constant throughout its length. Stiffness matrix for straight tendon is generated using direct stiffness approach of matrix analysis and is presented in Appendix. Computer programs for truss analysis in MATLAB are developed and the member forces & deflections are obtained. The results of the member forces are presented in Table 2 and deflections in Table 3.

5.Discussions Of Results

5.1.Member Forces

Only forces in the Left half of the truss have been tabulated, as the values are same for right half also, due to symmetry. Member forces before and after posttensioning are tabulated in Table 2. Brief discussion on effect of posttensioning on member forces in Top chord, bottom chord, vertical and diagonal members are presented below.

5.1.1.Bottom Chord

As seen from the column 2 & column 3 of Table 2 (and also from Figure 2), force in all the bottom chord members L_0L_1, L_1L_2, L_2L_3 & L_3L_4 have been significantly reduced after posttensioning: in each of L_0L_1 & L_1L_2 has been from 1680.0 kN to 802.7 kN, in L_2L_3 from 2880.0 kN to 2002.7 kN & in L_3L_4 from 3600.0 kN to 2722.7 kN. That is, percentage reduction in member force is 52.2 in each of L_0L_1 &, L_1L_2, 30.46 in L_2L_3 & 24.37 in L_3L_4. From this, it is concluded that forces in the members which are nearer to ends of the cables have significantly reduced in comparison with those which are away from the ends of the cable.

5.1.2.Top Chord, Verticals & Diagonals

There is no modification in forces of top chord, vertical & diagonal members even after posttensioning as seen from Column 2 and Column 3 of Table 2.

Hence, it can be concluded that, the forces in only the bottom chord members have been significantly reduced after posttensioning and members which are nearer to the cable ends have significant effect in comparison with the members located away from the cable ends. Also, there is no effect of posttensioning on top chord, vertical and diagonal members.

5.2.Deflections

Horizontal and vertical deflections at all the joints are tabulated in column 2 and column 3 of Table 3 before and after posttensioning. The brief discussions on deflections at all the joints along top and bottom chords of the truss are presented herewith.

5.2.1.Vertical Deflections

Along both the bottom chord and top chord the deflections at all the joints are reduced after posttensioning as seen from column 2 and column 3 of Table 3. Vertical deflections are symmetrical as shown in Figure 3 and are reduced from 32.86 mm, 52.96 mm, 76.86 mm & 89.03 mm to 29.55 mm, 48.00 mm, 71.06 mm & 83.23 mm at bottom joints L_1, L_2, L_3 & L_4 respectively; whereas, at top joints $U_1, U_2\ U_3$ & U_4 also they come down from 26.93 mm 56.34 mm, 78.87 mm & 89.03 mm to 23.62 mm, 51.37 mm, 73.07 mm & 83.23 mm respectively. From the above results, it is seen that, the maximum deflection occurring at mid span is decreased marginally by 6.51 %.

5.2.2.Horizontal Deflections

There is a reduction in the horizontal deflections also. Along the bottom chord the deflections at joints $L_1, L_2, L_3, L_4, L_5, L_6, L_7$ & L_8 have been reduced from 1.98 mm, 3.96 mm, 7.36 mm, 11.61 mm, 15.86 mm, 19.25 mm, 21.24 mm & 23.22 mm to 0.95 mm, 1.89 mm, 4.26 mm, 7.47 mm, 10.68 mm, 13.04 mm, 13.09 mm & 14.94 mm respectively; whereas along the top chord the deflections at joints $U_1, U_2, U_3, U_4, U_5, U_6$ & U_7 changed from 24.84 mm, 21.14 mm, 16.53 mm, 11.61 mm, 6.69 mm, 2.07 mm & -1.62 mm to 20.70 mm, 17.00 mm, 12.39 mm, 7.47 mm, 2.55 mm, -2.07 mm & -5.76 mm respectively. The percentage reduction in horizontal deflection is more along bottom chord joints when compared to joints along top chords and at some of the top chord joints change in nature of deflection is also noticed.

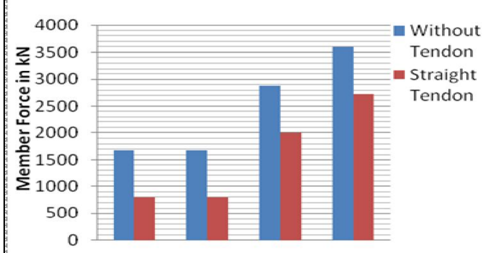

Figure 2: Bottom Chord member Forces of Statically Determinate Pratt Truss before and after Posttensioning

Figure 2

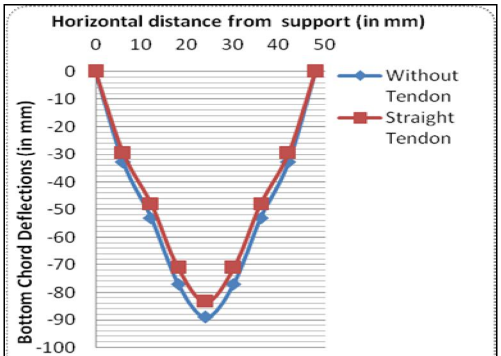

Figure 3: Bottom Chart Vertical Deflections of Statically Determinate Pratt Truss before and after Posttensioning

Figure 3

6.Conclusion

Following are the significant conclusions from our study.

- Forces in only the bottom chord members have been significantly reduced after posttensioning; whereas there is no modification in all the remaining member forces.
- Bottom chord members which are nearer to the cable ends have significant effect in comparison with the members located away from the cable ends.
- Vertical deflections at all the joints of the truss have been decreased due to posttensioning and the decrease in maximum deflection at mid span is by 6.51 %.
- There is reduction in horizontal deflections along both the chords; the percentage reduction in horizontal deflection is more along bottom chord joints when compared to joints along top chords.
- At some of the top chord joints, change in nature of horizontal deflection is also noticed.

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