Effect of External Posttensioning on Member Forces of Determinate Pratt Pattern Bridge Truss

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Abstract- Transportation on land is the most common one among all the modes of transportation: may be on roads or railways. In India and abroad bridges have been built along roadways and railways in order to make the transportation system more efficient and economical. Some of them are steel truss bridges and majority of which are very old and have been designed as per the codal standards existing at the time of their construction. Problems with these truss bridges are that, they are deteriorated to such extents which are not able to resist the loads for which they are originally designed and/or they may not be able to match with the current loading and traffic requirements. Hence there is a need to strengthen these existing truss bridges. The method to be adopted for strengthening should be cheap and economical with minimum disturbance to the existing traffic. Even though there are different methods of strengthening of bridges, one of the best methods is the posttensioning by high tension steel tendons.

In the present analytical investigation, only the truss portion of the steel truss bridge is undertaken for strengthening. Pratt pattern of the truss is considered as it is one of the commonly used trusses. In order to know the effect of posttensioning on member forces, the truss is externally posttensioned with two-drape tendon layout which is placed below the bottom chord. Stiffness matrix for two-drape tendon is developed and MATLAB computer programs are generated for the posttensioned truss analysis. From the results obtained after analysis, significant reduction in member forces is noticed and the reduction in member forces increases with the increase in the vertical distance between the bottom chord and tendon. If the truss is internally posttensioned by keeping tendon along the bottom chord, there will be reduction of forces only in the bottom chord members; whereas in external posttensioning, there is reduction in almost all the members of the truss and the percentage reduction is also more when compared to that due to internal posttensioning. Hence, to reduce the member forces external posttensioning is more efficient than internal posttensioning.

Index Terms: Bridges, Chord, Posttensioning, Pratt, Tendon, Truss, Two-Drape

I. INTRODUCTION

All over the world, majority of the existing truss bridges are very old and they are in deficient state. In United States itself, more than 80% of the existing steel truss bridges are deficient. Some of the major problems associated with these deficiencies are inability to carry the loads, insufficient lane width and clearances, and corrosion of elements. It may be due lack of proper maintenance, poor design details, “light” original designs. Because of all of these above mentioned facts, the increasing number of steel bridges requiring rehabilitation is a common feature. Also, expenditure of large sums for premature bridge replacement can be avoided if adequate attention is given towards timely rehabilitation.

The process of rehabilitation of deficient bridge may vary depending upon the type and the severity of the problem. Even though, there are different methods of rehabilitation of truss bridges, posttensioning by high-strength steel tendons is adopted in the present work because of its various advantages. Some of the significant advantages are its economy, minimum/no interruption to normal traffic and avoidance of temporary false work.

II. REVIEW OF LITERATURE

Majority of the existing steel bridges in India and abroad are structurally deficient and /or functionally obsolete. Indian railways have approximately 1,20,000 bridges of different types (Krishna and Kumar, 2001) as shown in Table 2.1. It is seen from Table 2.2 that around 43 % of the bridges are over 100 years old, which may need rehabilitation or replacement (Krishna and Kumar, 2001). Table 2.3 shows the details of deficient railway bridges under Indian railways (Jain, 2002).

Likewise there are a large number of road bridges which are aging. Table 2.4 shows the details of major/minor bridges on National Highways (NH), State Highways (SH), and other roads (Jain, 2002). In Table 2.5 statistics of some deficient bridges on Indian National Highways is presented (Jain, 2002).

Table 2.6 gives about deficient road bridges across world. According to Federal Highway Administration (FHWA) of the 5,72,000 highway bridges built before 1940 in United States, over 42 percent are classified as structurally deficient, because of deterioration or distress or because these are functionally obsolete. The estimated cost of rehabilitation and replacement of these bridges is about US $50 billion (Jain, 2002). Out of these, there are 24730 steel truss bridges, 80 percent of which are structurally deficient and/or functionally obsolete. The cost of rehabilitation and replacement of these bridges is about US $2.5 billion as reported by FHWA (Ayyub et al, 1990a, 1990b). Over 20 percent of 60,000 bridges on motorways and trunk routes in the United Kingdom suffer from decay and corrosion. The U.K. spends £35 million on bridge maintenance and repairs annually. In Germany, out of 30,000 prestressed concrete bridges, 600 bridges were damaged as per its survey and the repair cost was estimated at DM 200 millions. France with 6700 bridges (Span greater than 5m) plans to allocate US $40 million annually for 20 years, of which 1/3rd is for routine maintenance and 2/3rd for rehabilitation and strengthening. In Indonesia, about US $450 million was planned for bridge replacement and improvement program. A French survey covering 23 percent bridges on major routes showed that 18 percent bridges require major repairs, 2 percent bridges require reconstruction and 1 percent requires widening and the costs involved were 10 percent, 100 percent and 60 percent of reconstruction cost of respective bridge. A Danish study of some 2000 bridges indicated that the maintenance\replacement cost ratio of bridges varied from 1.3 to 2.5 percent as the average age of bridge increases from 20 to 37 years (Jain, 2002).

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Table 2.1: Types of Bridges on Indian Railways (1,20,000 Bridges of all types and spans)

Steel Girder Bridges	20%
Arch Bridges	19%
Pipe Culverts	19%
Slab Bridges	23%
Other types	19%

Table 2.2: Age of Bridge on Indian Railways

(In Years)	Percentage
>100	42.88
100-90	13.07
90-80	7.23
80-70	7.98
70-60	3.23
60-50	2.07
50-40	4.26
40-30	9.99
30-20	3.49
20-10	1.83
<10	1.83

Table 2.3: Details of Deficient Bridges under Indian Railways

No. of Bridges	No. of Deficient Bridges	Cause of Deficiency	Remarks
1,20,000	20000 (16 .7 %)	Distress	Require rehabilitation and strengthening.

Table 2.4: Details of Major/Minor Bridges and Culverts on NH, SH and Other Roads

No. of Bridges	No. of Deficient Bridges	Cause of Deficiency	Remarks
6500 (Surveyed 23 States)	1100 (16.92 %)	Showed distress	Replacement or need repair and strengthening.

Table 2.5: Statistics of Some Deficient Bridges on Indian National Highways

Road Category	Bridges			Culverts
	Major	Minor	Total	
NH	1996	5316	7012	53907
SH	5893	17553	23446	1,56,457
Other Roads	5643	39115	44758	6,99,605

Table 2.6: Details of Road Bridges, Deficient Road Bridges across World

Country	No. of Bridges	No. of deficient bridges	Cost	Causes of Deficiency
U.S.A.	5,72,000 (Constructed before 1940)	2,40,240 (42 %)	50 billion US Dollars for rehabilitation, replacement, and repair	Structurally or Functionally
U.K.	60,000 (Built on motorways and truck routes)	12,000 (20 %)	Annual 35 million Pounds for Bridge Maintenance, and repairs	Suffer Decay and Corrosion
Germany	30,0000 (PSC Bridges)	600 (2 %)	DM 200 million for repair	Damaged

III. AIM OF THE RESEARCH WORK

The aim of the present analytical study was to study the effect of external posttensioning using high strength steel tendons on member forces. An attempt has also been made to compare the performance of the different external tendon layouts with internal tendon layouts in reducing member forces.

IV. TRUSS ANALYSIS AND RESULTS

Pratt truss which is one of the commonly used patterns in steel truss bridges considered for our study is shown in Fig.1 with geometry and loading. Posttensioning may be internal or external: in internal posttensioning, tendon will be placed within the truss system; whereas in external posttensioning, the tendon is placed outside the truss system. In the present work, external posttensioning is adopted for strengthening the truss. The additional members L_1B_1, L_2B_1,L_6B_7 and L_7B_7 are added and additional joints B_1 and B_7 are created. Pulleys are placed at these additional joints and the external tendons are passing through these pulleys with their ends at joints L_0 and L_7 of the truss. The vertical distance between bottom chord and the tendon position (*h*) is varied, in order to know the effect of *h* on member forces. The tendon location for *h*=2 m, *h*=4 m and *h*= 6 m is shown by dotted line in Fig. 3(a), Fig. 3(b) and Fig. 3(c) respectively. As the tendon changes its direction at two points (joints B_1 and B_7), this configuration of tendon is called two-drape type. The cable cross sectional area is 600 mm^2 with modulus of elasticity of 160 GPa. The cable is posttensioned with an initial stress of 1120 N/mm^2 and the corresponding force is 672 kN. Modulus of elasticity of truss member is 200 GPa.

Each of the truss members is having 2 degree of freedom in local direction and 4 degree of freedom in global direction and the stiffness matrix for these members are available in the literature (Weaver and Gere, 1986). The same stiffness matrix cannot be used for the two-drape tendon, as it is changing its direction at two points along its run. Even though the local degree of freedom for the tendon is also 2, its global degree of freedom is 8 as it is having 4 nodes. Stiffness matrix for tendon is developed using concepts of matrix direct stiffness approach. MATLAB program for the posttensioned truss is developed for linear static analysis assuming the axial force in tendon as constant (i.e., friction at the joints of the cable is ignored). Forces in all the members of the truss are presented in Table 1.

Member	Before Posttensioning	After Posttensioning with External Tendons		
		h=2 m	*h*=4 m	*h*=6 m
L_0L_1	1680	603.8	548.7	530.6
L_1L_2	1680	603.8	548.7	530.6
L_2L_3	2880	1721.1	1432.3	1166.1
L_3L_4	3600	2441.1	2152.3	1886.1
U_1U_2	-2880	-2636	-2376.4	-2118.3
U_2U_3	-3600	-3356	-3096.4	-2838.3
U_3U_4	-3840	-3596	-3336.4	-3078.3
L_0U_1	-2689.3	-2326.6	-2059.4	-1871.6
L_1U_1	600	338.5	245.7	275.1
L_2U_1	1920.9	1893.1	1744.8	1519.3
L_2U_2	-900	-900	-900	-900
L_3U_2	1152.6	1152.6	1152.6	1152.6
L_3U_3	-300	-300	-300	-300
L_4U_3	384.2	384.9	384.2	384.2
L_4U_4	0	0	0	0
L_1B_1	------	-261.5	-354.3	-324.9
L_2B_1	------	-68.76	-248.1	-443.6
Cable	------	905.2	915.5	927.6

V. DISCUSSION OF RESULTS

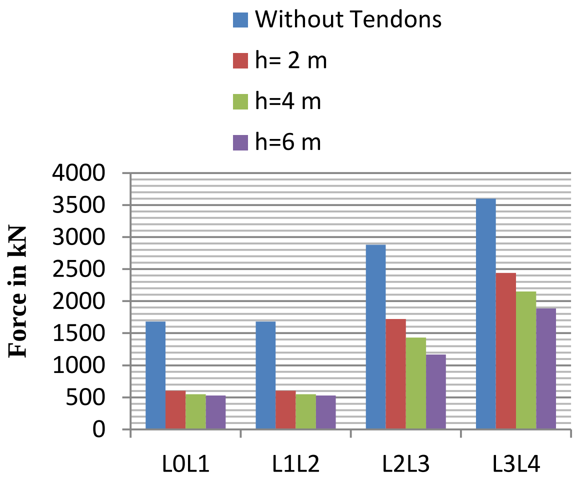

Fig. 4: Tensile Force in Bottom Chord Members of Determinate Pratt Truss before and after External Posttensioning

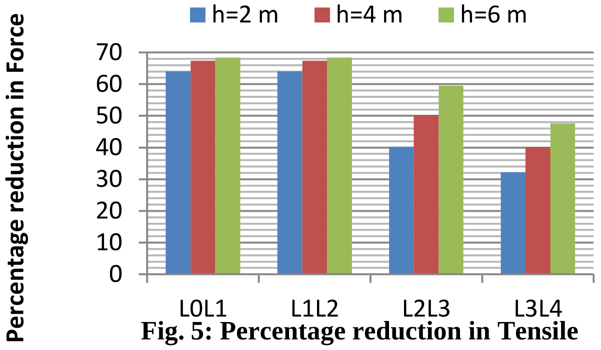

Fig. 5: Percentage reduction in Tensile Force along Bottom Chord members after External Posttensioning by varying *h*

Table 1: Member Forces of Statically Determinate Pratt Truss before and after Posttensioning (in kN)

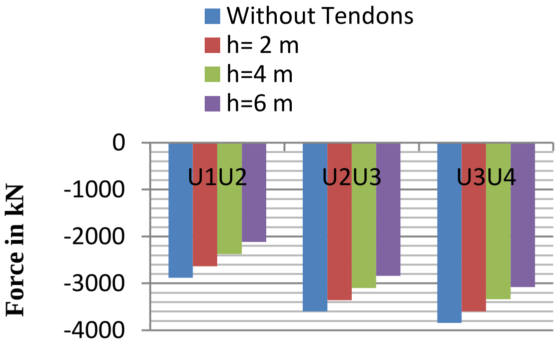

Fig. 6: Compressive Force in Top Chord Members of Determinate Pratt Truss before and after External Posttensioning

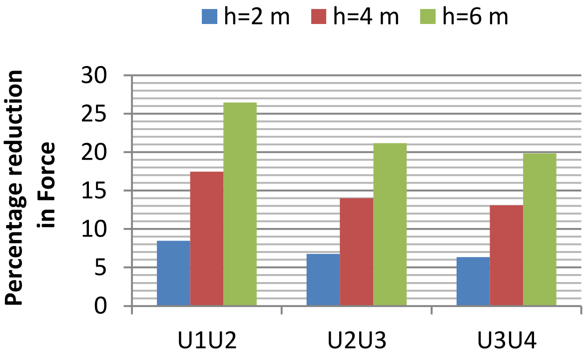

Fig. 7: Percentage reduction in Force along TopChord members after External Posttensioning by varying *h*

In second column of Table 1 member forces before posttensioning are presented and the member forces after external posttensioning are presented in third, fourth and fifth columns for *h*=2 m, *h*=4 m and *h*= 6 m respectively. The tensile forces along the bottom chord and compressive forces along the top chord members are depicted in Fig. 4 and Fig. 6 respectively, and the corresponding percentage reduction in forces is plotted in Fig. 5 and Fig. 7.

Tensile Forces in Bottom Chord Members: By comparing the values of member forces in third, fourth and fifth columns with the corresponding values in second column of Table 1 (also from Fig. 4), it is seen that all the bottom chord member forces have been reduced drastically after external posttensioning. Before posttensioning, force in each of members L_0L_1 and L_1L_2 were 1680.0 kN, L_2L_3 was 2880.0 kN and in L_3L_4 was 3600.0 kN. After post tensioning they have been reduced respectively to:

i. 603.8 kN, 1721.1 kN and 2441.1 kN for h= 2 m; hence the corresponding percentage reduction is 64.1, 40.23 and 32.19.
ii. 548.7 kN, 1432.3 kN and 2152.3 kN for h= 4 m; hence the corresponding percentage reduction is 67.4, 50.26 and 40.21.
iii. 530.6 kN, 1166.1 kN and 1886.1 kN for h= 6 m; hence the corresponding percentage reduction is 68.41, 59.51 and 47.6.

Compressive Forces in Top Chord Members: Reduction in compressive forces of all the top chord members is also noticed after posttensioning. As noticed from Table 1 and from Fig. 6, in members U_1U_2, U_2U_3 and U_3U_4 respectively reduced from 2880.0 kN, 3600.0 kN and 3840.0 kN to:

i. 2636.0 kN, 3356.0 kN and 3596.0 kN for h=2 m; hence the corresponding percentage reduction is 8.47, 6.78 and 6.35.
ii. 2376.4 kN, 3096.4 kN and 3336.4 kN for h=4 m; hence the corresponding percentage reduction is 17.49, 14.00 and 13.11.
iii. 2118.3 kN, 2838.3 kN and 3078.3 kN for h=6 m; hence the corresponding percentage reduction is 26.45, 21.16 and 19.84.

It can be concluded that all the tensile member forces along the bottom chord as well as the compressive forces along the top chord have been drastically reduced after external posttensioning. It is noticed that, the percentage reduction in force is more in the members which are located nearer to the ends of the tendon than those which are located away from the tendon. It is also seen that, the vertical distance between tendon and the bottom chord (h) is having influence on force reduction; the reduction is more as h increases.

Forces in Vertical and Diagonal Members: There is no change of force in vertical members after posttensioning except for member L1U1 which was 600 kN before posttensioning. The tensile force in this member after posttensioning reduced to 338.5 kN, 245.7 kN and 275.1 kN for h=2 m, h=4 m and h=6 m respectively and the corresponding percentage reduction is 43.58, 59.05 and 54.15. Force in some of the diagonal members has been marginally decreased: compression in L0U1 has been changed from 2689.3 kN to 2326.6 kN, 2059.4 kN and 1871.6 kN respectively for h=2 m, h=4 m and h=6 m; whereas tension in L2U1 changed from 1920.9 kN to 1893.1 kN, 1744.8 kN and 1519.3 kN. Hence, reduction in member forces of verticals and diagonals are not very significant when compared to reduction taken place along the top and bottom chord member forces.

The effect of internal posttensioning on member forces has been investigated by Ravindra and Nagaraja (2013). The same determinate Pratt truss considered in our study has been internally posttensioned by positioning the tendon along the bottom chord. From their study, they noticed reduction of forces only in bottom chord members: the percentage reduction is 52.2 in each of L0L1 and, L_1L_2, 30.46 in L_2L_3 and 24.37 in L_3L_4. Hence, it is seen that the percentage reduction in force is more in external posttensioning in comparison with internal posttensioning.

VI. CONCLUSIONS

The significant conclusions arrived at from the present analytical investigation are as follows:

- Tensile force in bottom chord members was significantly reduced after external posttensioning.
- Compressive force in top chord members was also reduced after external posttensioning.
- Reduction in forces of vertical and diagonal members was not very significant when compare to reduction in bottom and top chord member forces.
- Percentage reduction in force of chord members was more in the members which are located nearer to the tendon ends.
- As the vertical distance between tendon and the bottom chord (h) increased, the percentage reduction in force also increased.
- External posttensioning was more effective than internal posttensioning in reducing the member forces.

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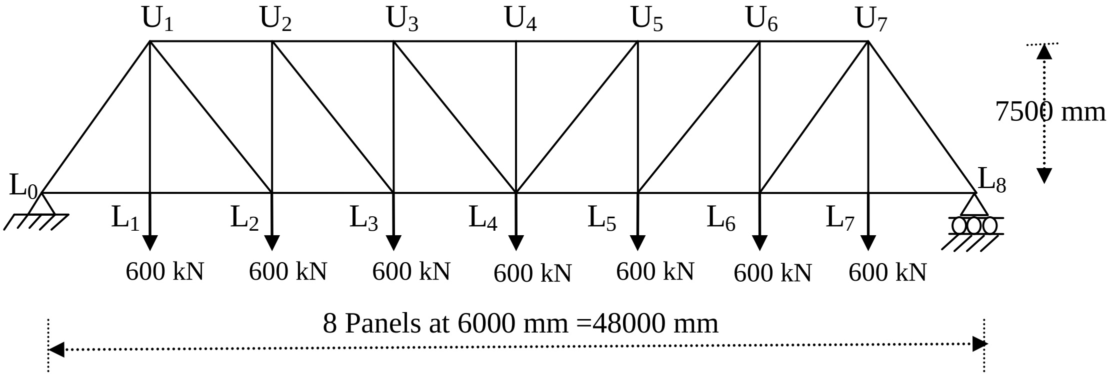

Fig. 1: Geometry and Joint Loads on Statically Determinate Pratt Truss

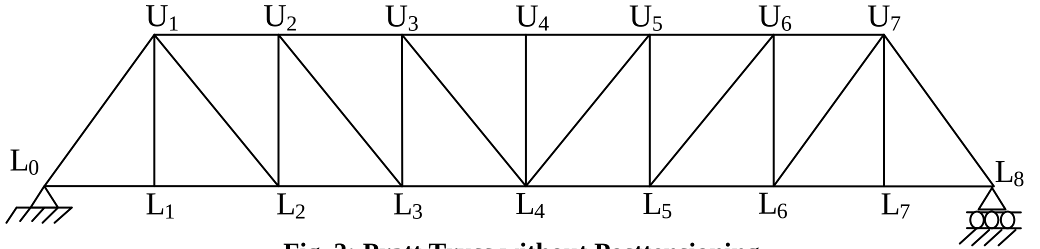

Fig. 2: Pratt Truss without Posttensioning

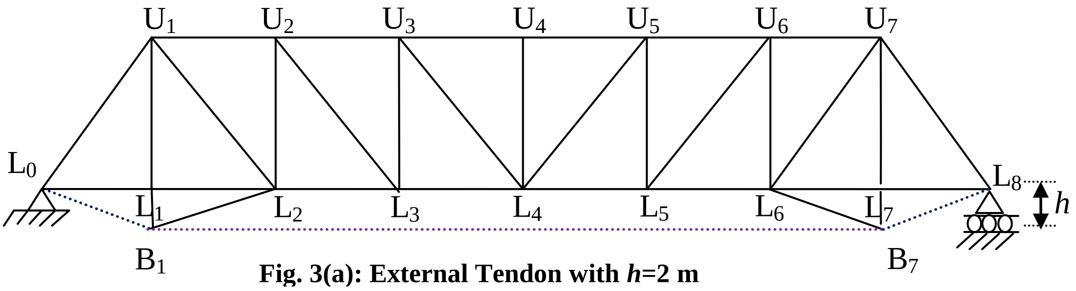

Fig. 3(a): External Tendon with *h*=2 m

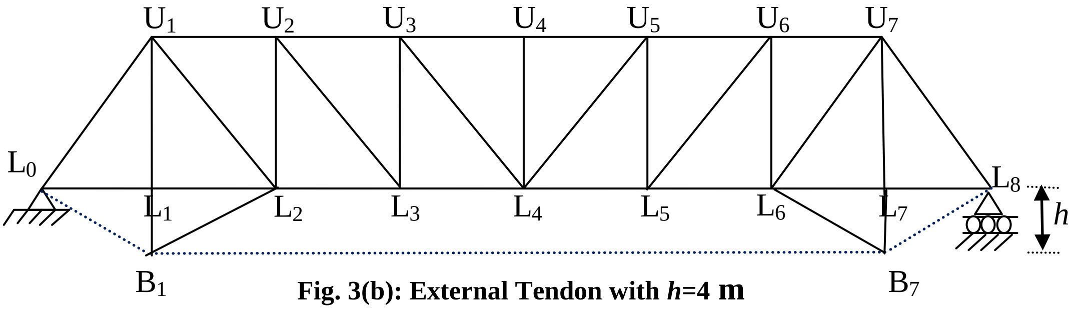

Fig. 3(b): External Tendon with *h*=4 m

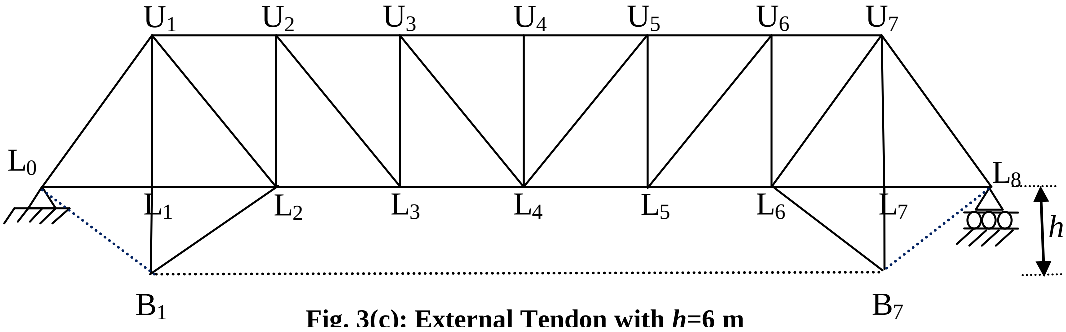

Fig. 3(c): External Tendon with *h*=6 m

Fig. 3: Determinate Pratt Truss Posttensioned with Different External Tendon Layouts