International Journal of Engineering Technology, Management and Applied Sciences

IJETMAS

www.ijetmas.com July 2015, Volume 3, Issue 7, ISSN 2349-4476

Comparative Parametric Study of Steel Bridge Trusses by Applying External Prestressing

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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 Pre-stressing on the member forces, deflections and total weight of steel of a statically determinate three types of trusses such as Pratt type(Type A), Warren truss(Type B), Lattice Truss(Type C).Pre-stressing technique has been adopted to upgrade the performance of the truss. The truss is pre-stressed with high tensile steel cable and the profile of the cable is straight. The truss is analysed for member forces and deflections using STAAD PRO Software. 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 truss members and there is a reduction in deflection at the centre and material requirement after pre-stressing.

Key words: Bridges, Truss, Pre-stressing, Cable, Member forces, Deflections and STAAD.Pro.

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. Pre-stressing with the high strength steel tendons is the one of the best methods of strengthening of these bridges. The basic concept of pre-stressing 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

Historically, the principle of '*pre-stressing'* 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. Prestressing 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 post tensioning 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 behaviour of the repaired member only and also it increase the dead loads which may not be a favourable and this will overcome by the Prestressing technique.

3.METHODOLOGY

A parametric study without pre-stressing for analysis and design of steel truss using STAAD Pro software is carried out. The same is done with pre-stressing. The results are compared with the results obtained from conventional truss model.

4.ANALYSIS OF TRUSSES AND RESULTS

Statically determinate Pratt type(Type A),Warren(Type B) and Lattice(Type C) bridge trusses are considered for the analytical study. The geometric and loading details of the trusses are given in Figure 1(a), Figure 1(b), Figure 1(c). Truss is prestressed with externally located tendon layout which is passing through the periphery of the truss. The area of cross section of cable is 600 mm^2 with an initial pre- stress of 1120 N/mm^2, and the corresponding prestressing force is 672 kN. Young’s Modulus for the prestressing cable and truss members is 160 GPa and 200 GPa respectively.

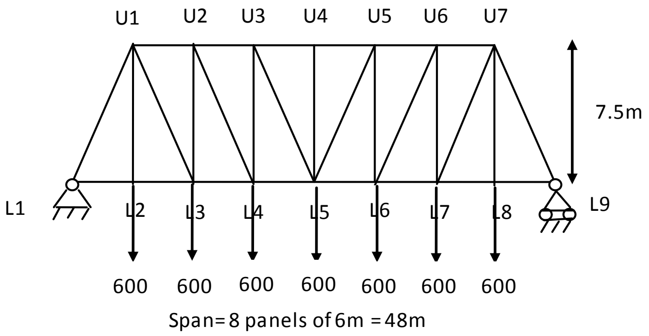

Figure 1(a) Joint Loads of Type A truss (kN)

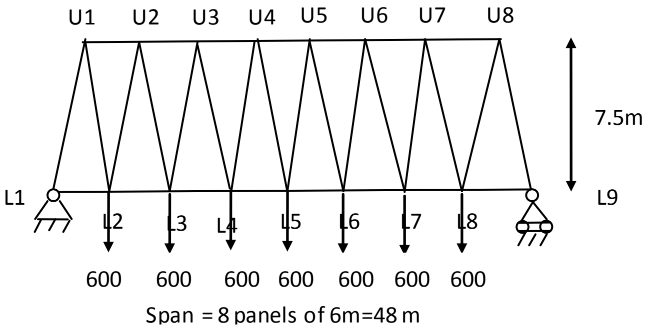

Figure 1(b) Joint Loads of Type B truss (kN)

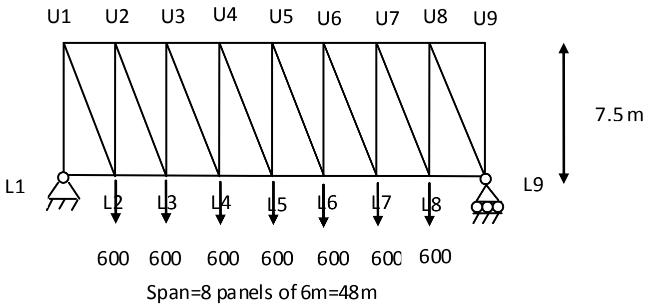

Figure 1(c) Joint loads of Type C truss(kN)

Table 1

Type of truss	**Max Axial Force (kN)**	
	Non-prestressed	prestressed
Type A	3600(T)	2928(T)
	3840(C)	3168(C)
Type B	3720(T)	3048(T)
	3840(C)	3168(C)
Type C	3840(T)	3168(T)
	3840(C)	3168(C)

Table 2

Type of truss	Section provided	
	Non-Prestressed	Prestressed
Type A	ISMC 400	ISMC 350
Type B	ISMC 400	ISMC 350
Type C	ISMC 400	ISMC 350

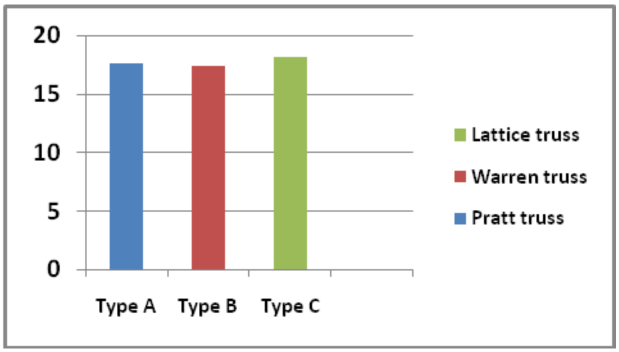

Figure2 comparison of weight of steel in tons Without prestressing

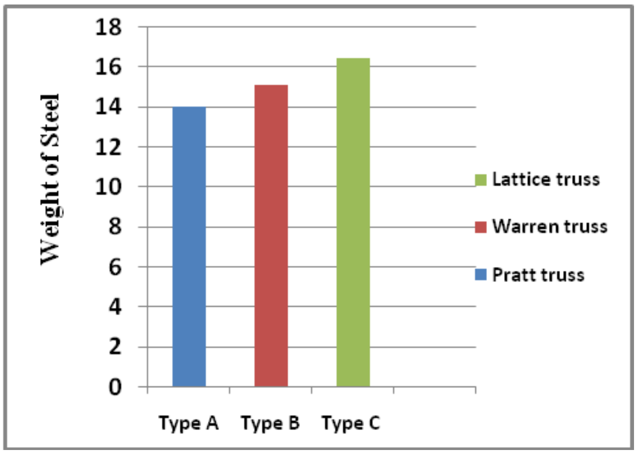

Figure3 comparison of weight of steel in tons With prestressing

Table 3. Weight of Steel (tons)

Member	Type A			Type B			Type C		
	Non prestress	With prestress	% of SavingWt	Non prestress	With prestress	% of SavingWt	Non prestress	With prestress	% of SavingWt
Complete Truss	17.62	14.02	20.4	17.40	15.12	13.11	18.15	16.48	9.0

Table 4. Deflection

	Type A		**TypeB**		**Type C**	
Vertical displacement at Centre in ‘mm’	Non-Prestressed	Prestressed	Non- Prestressed	Prestressed	Non-Prestressed	Prestressed
	42.029	34.482	42.122	34.880	45.433	38.610

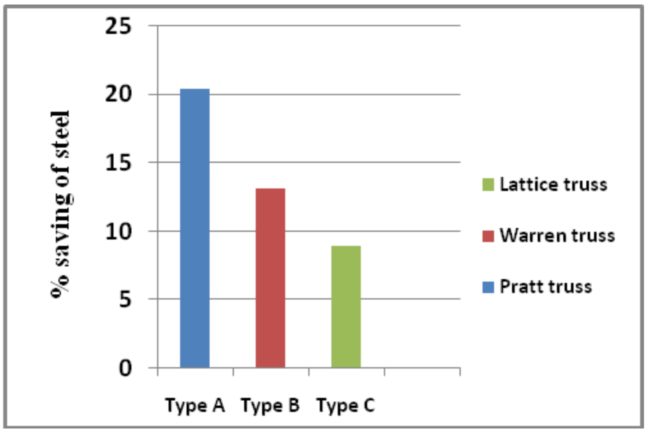

Figure4 comparison of %saving of steel for three Types of trusses

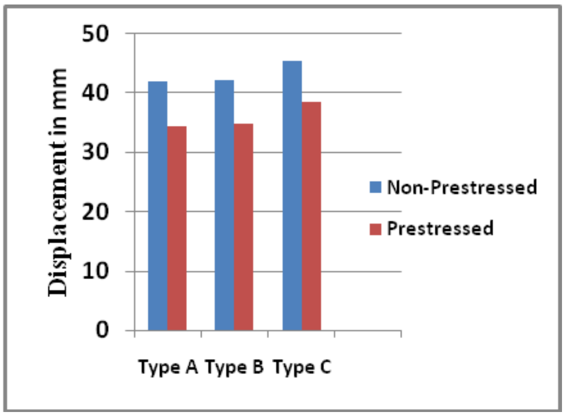

Figure5 Comparison of Vertical Deflection at Centre (before and after prestressing)

5.RESULTS AND DISCUSSIONS

A. Pratt truss (Type A) :

- **1. Member Forces:**

a) Forces in all the bottom chord, top chord members have been significantly reduced after prestressing.

b) In bottom chord members (tension members) the reduction of member forces is from 18 to 40%

c) In Top chord members (compression members) the forces are reduced from 17 to 23%.

d) Forces in the members which are nearer to ends of the cable have significantly reduced in comparison with those which are away from the ends of cable.

e) There is no modification in vertical members.

- **2. Deflections:**

a) Vertical deflections are reduced marginally by 18% after prestressing.

b) Reduction of horizontal deflections is more along bottom chord joints when compared to joints along top chord.

- **3. Quantity of Steel :**

a) Percentage of reduction in weight of steel is 20.4% after prestressing.

B. Warren truss (Type B):

- **1. Member Forces:**

a) Forces in all the bottom chord, top chord members have been significantly reduced after prestressing.

b) In bottom chord members (tension members) the reduction of member forces is from 20 to 80%

c) In Top chord members (compression members) the forces are reduced from 17 to 23%.

d) Forces in the members which are nearer to ends of the cable have significantly reduced in comparison with those which are away from the ends of cable.

e) There is no modification in diagonal members at middle.

- **<u>2. Deflections:</u>**

a) Vertical deflections are reduced marginally by 17% after prestressing.

b) Reduction of horizontal deflections is more along bottom chord joints when compared to joints along top chord.

- **<u>3. Quantity of Steel :</u>**

a) Percentage of reduction in weight of steel is 13.11% after prestressing.

C. Lattice truss (Type C):

- **1. Member Forces:**

a) Forces in all the bottom chord, top chord members have been significantly reduced after prestressing.

b) In bottom chord members (tension members) the reduction of member forces is from 18 to 40%

c) In Top chord members (compression members) the forces are reduced from 17 to 40%.

d) Forces in the members which are nearer to ends of the cable have significantly reduced in comparision with those which are away from the ends of cable.

e) There is no modification in diagonal and vertical members at middle.

- **<u>2. Deflections:</u>**

a) Vertical deflections are reduced marginally by 15% after prestressing.

b) Reduction of horizontal deflections is more along bottom chord joints when compared to

- **<u>3. Quantity of Steel :</u>**

a) Percentage of reduction in weight of steel is 9.0% after prestressing.

<u>6.CONCLUSION</u>

- In the present study considering all the above analytical results and observations of three different configurated truss types the following conclusions have been made:

1) The sections provided for all the three types trusses got reduced from Non- prestressing to prestressing.

2) For the same given span and load, the quantity of steel required is less for *Type B* truss without prestressing.

3) *Type C* requires more steel without prestressing among all the three trusses.

4) When prestressing force is applied the *Type A* gives less requirement of steel for the same span and loading.

5) *Type C* requires more quantity of steel without prestressing and with prestressing as well.

6) Among all the three types of trusses the *Type A* proves to be economical as the percentage saving of steel is more.

7) The percentage saving of steel is very less for *Type C* before and after prestressing.

8) Comparing *Type A* and *Type B* trusses there is no much difference in steel requirement without prestressing.

9) The vertical deflection at the centre is less for *Type A* truss with and without prestressing for the given load compared to remaining type of trusses.

10) *Type C* has more vertical deflection at the centre with and without prestressing comparing to other two types of trusses.

11) By adopting prestressing method to the steel structure about 12-20 % material can be saved.

<u>7.RECOMMENDATIONS</u>

- By considering the above conclusions of three types of bridge trusses, when their span and loading are same, it can be recommended that

1. *Type A i.e Pratt truss* is the most economical one with and without prestressing.
2. Displacement point of view also *Pratt truss* is best suited truss.
3. *Type C i.e Lattice truss* proves to be uneconomical even without prestressing
4. *Warren truss (TypeB)* is best suited for the bridge when prestressing is not applied.

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