Chapter 7

CONCLUSIONS

In this research work, effectiveness of strengthening of different truss patterns of bridges, by various internal and external posttensioned tendon layouts was brought out through numerical illustrations.

Based on the results of deterministic analysis of posttensioned steel trusses considered in this analytical investigation, following significant conclusions were drawn:

- In trusses posttensioned with internal tendon layouts which are coinciding with the truss members, after posttensioning, the reduction in only the forces of all the members of the truss on which the tendon is passing was noticed (for example, force in member $L_1L_2$ of determinate Warren truss decreased by 52.47 and 52.91 percent in internal straight and internal two-drape tendon layouts respectively). In internal tendon layout which is not coinciding with any of the truss members, the reduction in forces of some of the bottom chord members was observed (for example, force in member $L_2L_3$ of determinate Warren truss decreased by 14.69 percent), and the increase in compressive force of top chord members was also noticed (for example, force in member $U_2U_3$ of determinate Warren truss increased by 18.36 percent), which is not desirable. Also, change in nature of some of the member forces was noticed (for example, nature of force in member $L_3U_4$ of determinate Howe truss changed from compression to tension), which should be properly accounted for in the design of trusses. Hence, the tendon layouts which are coinciding with truss members should be preferred over tendon layout which is not coinciding with any of the truss members in internal posttensioning.

- After posttensioning of trusses with external tendon layouts, reduction in tensile forces of all the bottom chord members was noticed (for example, force in member $L_1L_2$ of determinate Warren truss decreased by 64.11 percent in external tendon layout with $h=2$ m), and apart from this, reduction in compressive forces of all the top chord members was also observed (for example, force in member...
U₂ of determinate Warren truss decreased by 26.57 percent in external tendon layout with \( h=6 \) m), which was not achieved in internal posttensioning. As the vertical distance between the bottom chord and tendon \((h)\) increases, reduction in member forces were also increased (for example, for member L₁L₂ of determinate Warren truss, the percent reductions were 64.11, 67.42 and 68.51, for \( h=2 \) m, \( h=4 \) m, and \( h=6 \) m respectively). Reduction of tensile forces in bottom chord members were more than their respective reduction in internal tendon layouts, and no change in nature of force was noticed in any of the truss members. Hence, external posttensioned layouts are more efficient than internal tendon layouts in reducing member forces.

- Percentage reduction in bottom and top chord member forces decreased with the increase in distance of the truss members from the tendon ends (for example, in determinate Howe truss after external posttensioning with \( h=4 \) m, the percentage reduction of tensile force in bottom chord members, \( L₀L₁, L₁L₂, L₂L₃ \) and \( L₃L₄ \) was 67.45, 43.59, 41.24 and 38.66 respectively; whereas, in top chord members \( U₁U₂, U₂U₃ \) and \( U₃U₄ \), the percentage reduction of compressive forces was 23.46, 17.93 and 14.34 respectively), in the chord members in which the reduction of force is noticed after posttensioning.

- Horizontal and vertical deflections along top as well as bottom chord joints of all the trusses were reduced after posttensioning which is a favorable condition from serviceability point of view. Similar to behaviour observed in member forces, external tendon layouts are most effective in reducing deflections, as compared to internal tendon layouts (for example, in determinate Pratt truss the percentage reduction in vertical deflection at joint \( L₂ \) of the bottom chord was 16.98, 24.94 and 32.98 in different external tendon layouts, and 9.37, 3.66 and 7.87 in different internal tendon layouts); also, as \( h \) increases, the reduction in deflections were more. In internal posttensioning, tendon layouts which are coinciding with truss members were better than tendon layout which is not coinciding with any of the truss members in reducing deflections. It is noticed that, the maximum vertical deflections are lowest in Warren truss before and even after posttensioning (for example, after external posttensioning with \( h=6 \) m, the
maximum vertical deflection was 57.52 mm in determinate Warren truss; whereas, in determinate Howe and Pratt truss, they were 70.94 mm and 67.94 mm respectively).

- After posttensioning, percentage reduction in vertical deflections of joints decreased with the increase in their distance from ends, in all trusses (for example, in determinate Warren truss, the percentage reduction at joints L₁, L₂, L₃ and L₄ was 35.27, 25.13, 21.88 and 21.36 respectively, after external posttensioning with \( h = 4 \) m).

- Marginal increase in fundamental frequency was noticed in all the trusses after posttensioning (except in internal tendon layout which is not coinciding with truss members in which decrease was noticed in some trusses). The increase was more in external tendon layouts when compared to internal tendon layouts, and also, as \( h \) increases, frequency increased. Among the truss patterns considered in the present study, before and even after posttensioning, the fundamental frequency of Warren truss was more than its corresponding value in Pratt truss, and in Howe truss, it was less than in Pratt truss (for example, in determinate Warren, Howe and Pratt truss patterns, it was 0.2761 cycles/s, 0.2505 cycles/s and 0.2632 cycles/s respectively, after external posttensioning with \( h = 6 \) m).

Based on the results of reliability analysis of posttensioned steel trusses considered in this analytical investigation, following significant conclusions were drawn:

- From sensitivity analysis, it was observed that, the coefficient of variation (COV) of resistance variables is having more influence on reliability index when compared to COV of load variable both in yielding and buckling. This indicates that, it is important to estimate variations in resistance variables more accurately.

- The reliability index of all the bottom as well as top chord members are increased (in turn, probability of failure is decreased) in all the trusses after external posttensioning and the increase was proportional to \( h \) (for example, in determinate Howe truss, the percentage increase in reliability index of bottom
chord member $L_0L_1$ was 61.57, 65.76 and 66.35 for $h=2$ m, $h=4$ m and $h=6$ m respectively in AFOSM method). This clearly indicates the efficacy of external posttensioning of steel trusses.

- In all the trusses, internal posttensioning has lead to an increase in the reliability index of most of the bottom chord member, whereas there was no increase in reliability index of any of the top chord members. Further, reliability index of some of the top chord members were decreased in internal tendon layout which is not coinciding with truss members (for example, in determinate Pratt truss, decrease in reliability index of top chord member $U_1U_2$ was 24.22 percent in AFOSM method), which is not desirable as the probability of failure is increased.

- Member reliability index values obtained by FOSM method were marginally higher (consequently, probabilities of failure were marginally lower) than the corresponding values by RPEM in all the trusses before and even after posttensioning; whereas, in AFOSM method, they were significantly higher than those obtained by FOSM method and RPEM (for example, in member $L_2L_3$ of determinate Howe truss posttensioned with internal straight tendon layout, they were 3.3785, 3.3730 and 3.6041 in FOSM method, RPEM and AFOSM method respectively).

- In all those members in which increase of reliability index was observed after posttensioning, the percentage increase was highest in AFOSM method and lowest in RPEM; whereas, in FOSM, it was slightly more than that in RPEM (for example, in member $L_0L_1$ of determinate Warren truss posttensioned by external tendon layout with $h=6$ m, percentage increase was 33.88, 33.83 and 67.27 in FOSM method, RPEM and AFOSM method respectively).

- In FPEM as well as hybrid reliability analysis, in both yielding and buckling, expectation of performance function increased with increase in number of sigma units $(k)$ and number of $\alpha$-levels, standard deviation of performance function
increased with increase in $k$ and decreased with number of $\alpha$-levels, and reliability index increased with number of $\alpha$-levels and decreased with $k$.

- In yielding, both the expectation and standard deviations obtained by FPEM were less than their corresponding values from hybrid analysis for lower values of $k$, more than their corresponding values for higher values of $k$; whereas in buckling, these values obtained by FPEM were lower than their corresponding values from hybrid analysis for all the values of $k$.

- Reliability index values obtained by FPEM in yielding were more than their corresponding values from hybrid analysis for lower values of $k$, less than their corresponding values for higher values of $k$; whereas in buckling, these values obtained by FPEM are more than their corresponding values from hybrid analysis for all the values of $k$.

- Each of the probability based reliability methods considered in the present study (FOSM method, RPEM and AFOSM method) gives single value of member reliability index and the corresponding probability of failure. But, FPEM and hybrid analysis gives range of values of reliability index and the corresponding probability of failure after accounting the variability and lack of definitions in the uncertain input variables used in the performance function by attaching a degree of membership to the uncertain variables. So, this range of values of reliability index and the corresponding probability of failure provides more information than a single value.

Thus it is evident that, after posttensioning there is a significant reduction in member forces (consequently increase in member reliability index values and decrease in corresponding probability of failure) and joint deflections, leading to a conclusion that, posttensioning is one of the potential methods of strengthening of deficient steel trusses of bridges which can be conveniently adopted to upgrade them.
SCOPE FOR FUTURE STUDY

Based on the research work carried out, it is felt by the author that, the work can be extended to carry out the following aspects:

- Posttensioned steel truss analysis by considering the standard design loadings
  i. For the highway bridges, as specified by the *Indian Road Congress (IRC)*.
  ii. For the railway bridges, taking into consideration the specifications as per *bridge rules* published by Railway board, Ministry of Railways, Government of India.

- Develop methodology to estimate the system reliability of posttensioned steel trusses, apart from the component reliability, and to study the effect of truss patterns and posttensioned tendon layouts on system reliability index.

- Detailed investigations on effect of posttensioning on redundancy of the trusses.

- To account the following non-linearities in the reliability analysis of posttensioned steel trusses:
  i. Material non-linearity.
  ii. Geometric non-linearity.
  iii. Combined material and geometric non-linearities.

- Studies on reliability analysis of posttensioned steel trusses subjected to dynamic loading.

- To further the reliability methodology to quantify the Fuzzy-Randomness in posttensioned steel trusses.