CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 GENERAL

In the past a number of steel truss bridges have failed during various stages of construction or service. In case of truss bridges, failure of gusset plates connecting members of truss, and buckling failure of compression members have been reported to be the most happening failures. In the present research failure case study of Chauras bridge is carried out and strengthening of Garudchatti bridge has been performed. On the basis of this study, few recommendations are made for the design of steel truss bridges at service load and at overload. Recommendations are made for the design of composite truss bridges using shear studs.

From the presented study on failure of Chauras bridge and composite steel truss bridges, the following conclusions can be drawn.

1. Had Chauras bridge not collapsed during construction due to marginally unsafe design of the bridge, in service condition it might have collapsed on completion in future during more severe loading. Therefore, checking of steel truss bridge designs at limit state of strength with appropriate additional load factor for maximum possible loading condition during life time of the bridge is required. Further, it should be ensured that the bridge fails after warning due to sufficient deflection.
2. As evidenced in Chauraas bridge collapse, compression members buckle and suddenly fail without warning. Also, compression members do not have reserve strength like tension members, which have reserve strength beyond yield stress up to ultimate strength. Therefore, for the limit state of strength, design of laterally unsupported compression members should be checked with an additional load factor

of 1.5, increasing the recommended IRC: 6-2010 approximate load factor for (DL+LL) case of 1.5 to 2.25.

As sufficient reserve strength beyond yield stress exists up to the ultimate strength, design of tension members and gusset plates carried out in service condition would be safe at limit state of strength also.

3. As per IRC:24-2010, design of road bridges has to be carried out for limit state of serviceability and checked for limit state of strength and other limit states. In the limit state of serviceability design, the load factor for (DL+LL) case is 1.0 and in the permissible stresses a fatigue factor of 1/1.5 is used. For the limit state of strength design the corresponding load factor is approximately 1.5 and no fatigue factor is used. Therefore, both the approaches result approximately in same design. Further, considering maximum possible loading on a bridge during its lifetime, ever increasing loading standards and corrosion and wear and tear of the bridge, higher load factor at the limit state of strength of 2.25 in place of 1.5 is recommended.
4. In Chauras and Garudchatti bridges, the side to main span ratio was 0.364 which caused lifting at the end supports, leading to Chauras bridge failure during casting of the deck slab. In Garudchatti bridge strengthening, the ends were prevented from lifting by providing additional RCC counterweights on the girder at the supports. Therefore, for new continuous span bridges, it is recommended to adopt proper side to main span ratio so as to avoid girder lifting at the end supports.
5. Gusset plates if properly designed and connected to the members and prevented from buckling can take compressive or tensile stress up to ultimate tensile strength of the plate. In that condition design of joints carried out under service condition would also be safe at limit state of strength.

6. Local buckling depends on width to thickness ratio of individual plate element of the built up compression member. Therefore, dimensioning of built up compression member is vital and it should be strictly done as per provisions stipulated in standard design codes.
7. A number of steel truss bridges have failed in the past during load testing due to sudden buckling of compression members. Therefore, load testing of steel truss bridges for full live load is not recommended unless their design is found safe at limit state of strength for overload condition.
8. In a continuous span bridge, negative moment at the support is approximately twice the sagging moment at the mid span, and it causes tension in the deck slab concrete resulting in no advantage due to the composite action. Despite various available methods for crack control, no effective and feasible method has yet been proposed for steel–concrete composite continuous structures.

   Deck type simply supported composite steel truss bridges have very good advantage due to the composite action. However, due to shrinkage of the deck slab concrete, cross sectional area of concrete does not directly provide strength and stiffness to the bridge until it is overcome by the flexural stresses due to loading.

   Therefore, simply supported medium span (30m to 100m) deck type composite truss bridges have been found to be most suitable, especially for deep valley condition in mountainous regions having high seismicity.
9. Simply supported steel truss bridges of 90.0m span having non-composite and composite decks have been compared. In case of the composite truss bridge designed at the limit state of strength with a load factor of 2.25, cost of superstructure is higher by 10.6% in comparison to the non-composite bridge designed in service condition, whereas its load carrying capacity is higher by 50.0%.

Further, in composite steel truss bridges where top chord compression members are laterally supported, gives sufficient reserve strength at plastic collapse and noticeable deflection before failure.

At the ultimate limit state of collapse in plastic condition, where it is assumed that web failure is prevented, there is a factor of safety of 2.4 in comparison to service condition, and 1.6 in comparison to the limit state of strength condition.

10. In composite steel truss bridges, during the process of hardening of the deck slab, shrinkage strain of the order of 0.0003 takes place, resulting in tensile stress and micro cracking. Even after application of live load, composite action between the deck slab concrete and the steel truss does not take place as strain due to live load is much lower than the concrete shrinkage strain.
11. In the case of open web girder bridges shear flow in elastic condition between the web and the deck slab is concentrated near the truss joints, for which densification of studs near the joints is necessary. However, longitudinal shear distribution in the shear studs becomes uniform in the plastic condition. Uniform spacing of the studs is also required from the truss top chord lateral restraint consideration. Therefore, uniform spacing of the shear studs throughout the truss span is recommended.

    Total longitudinal shear for design of shear studs in service condition for a simply supported composite truss bridge is recommended to be equal to the maximum tensile force in its bottom chord member under (DL+LL) case.
12. Comparative study of through type, deck type, semi deck type and under slung truss bridges for 30.0m span and 90.0m span are carried out from which deck type composite steel truss bridges are found to be superior to the through type bridges.

    Semi deck type truss bridge configuration is introduced for the first time in the present research. From the lateral deflection criterion, it is found that semi deck type bridge is most preferable for the short span bridges. From vertical deflection consideration, semi deck type bridge is also acceptable. From total steel off take consideration, under slung truss bridge is most economical and semi deck type bridge configuration is the second best.

For longer spans, steel off take and deflections in the deck type, semi deck type and under slung truss bridges are nearly same and any of these configurations suitable from site condition consideration may be adopted.

13. Comparison of 90.0m span bridge designs using E250 and E410 grade steel is carried out. Total steel off take and cost of the bridge truss in service condition for the semi deck type bridge using E410 grade steel is 35.0% lower in comparison to the bridge using E250 grade steel. Total steel off take of semi deck type bridge using E 410 grade steel is 42.6% lower at limit state of strength condition.\
14. Maximum vertical deflection under service load condition of E 250 grade steel bridge is lower by 32.0% in comparison to the E 410 grade steel bridge. Bridge deflection for E410 grade steel exceeds by 47.5% from the limiting deflection of 150.0mm. Permissible deflection of the bridge under live load with impact is 112.5mm (L/800) and both E 250 and E 410 grade steel bridges pass this criterion. Since, E 410 grade steel bridge passes the deflection criterion under live load with impact condition, suitable camber may be provided in the bridge and dead load plus live load deflection criterion may be violated. As in the limit state of strength condition, vertical deflection is not a governing criterion, E 410 grade steel bridge is found to be superior. Therefore, by providing sufficient camber for dead load, high tensile structural steel can be used in deck type composite truss bridges.

On the basis of the present research, it is concluded that simply supported semi deck type composite steel truss bridge designed under increased load factor of 2.25 in the limit state of strength condition, has maximum advantage over the traditionally designed non composite steel truss bridges in India in terms of increased strength and stiffness. In the composite steel truss bridges, sudden collapse of the bridge due to buckling of the compression members of the bridge is prevented and significant deflection is ensured before failure of the bridge.

7.2 FUTURE SCOPE OF STUDY

In the present study analysis and design guidelines for composite steel truss bridge are presented. Looking at the present study, following areas of research can be explored.

1. Experimental study on modelling and load testing of composite truss bridge may be carried out.
2. Use of external prestressing using high tensile steel cables for composite steel truss bridge.
3. Finite element analysis of shear studs under fatigue loading taking account of shrinkage strain.
4. New techniques to minimize shrinkage strain in bridge deck to take benefit of composite action in the service load condition.

7.3 AUTHORS CONTRIBUTION AND NOVELTY OF THE WORK

In this research work a new approach for the design of steel truss bridges at limit state of strength for overload condition is proposed. For design of compression members at limit state of strength for overload condition, a load factor of 2.25 is recommended while for tension members a load factor of 1.5 is found to be sufficient.

Thus different load factors for compression members and tension members are recommended.

Due to shrinkage of the concrete, composite action of deck slab with deck type steel girder is possible only at overload condition which is proved by the analysis in the present study.

Sudden collapse is the most catastrophic failure which the truss bridges are encountered with. To avoid such collapse in future, design of deck type composite open web steel girder bridge is beneficial and for which design guidelines are recommended here.

A new type of truss geometry i.e. semi deck type truss configuration is invented through this research work which may be an economical and effective design for seismic prone areas.