CHAPTER 1

INTRODUCTION

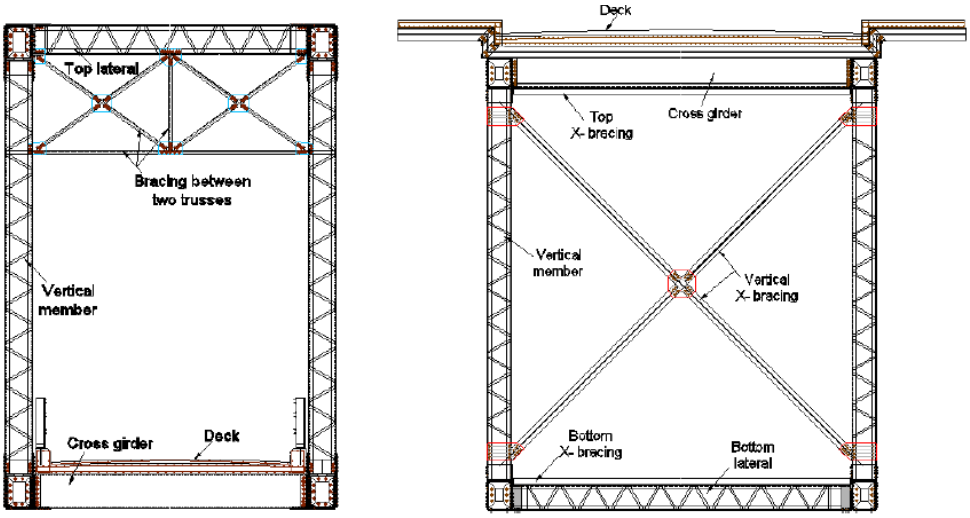
1.1 GENERAL

Any structure, either natural or manmade that provides passage over obstacles such as rivers, canals, valleys, rough terrain, etc. is called a bridge. Bridges are a vital part of surface transportation. The geometry of bridges depends on the site requirement, the nature of surrounding terrain, and the economics involved with the project.

Bridges are categorized into numerous different types depending on the structural arrangement and the materials used. Classification of bridges also depends on the method of transmission and distribution of axial force, shear force, bending moment, and torsional moment. Based on force transfer mechanism, bridges are classified as Truss Bridge, Beam Bridge, Arch Bridge, Tied Arch Bridge, Cantilever Bridge, Suspension Bridge, and Cable-Stayed Bridge.

A truss bridge or open web girder bridge is a bridge system whose superstructure is composed of a truss and connecting elements are under axial load. Elements forming the triangular units are called members of a truss. Members of the truss predominantly carry axial tensile or compressive forces. Truss bridges were popularly constructed throughout the world in the 19th and 20th century and they were the most adopted bridge system between the 1870s to 1930s. Even today construction of truss bridges is in practice mostly in hilly areas.

Truss bridges or open web girder bridges are still common in practice and are economical from small spans of 10m to large spans of 300m. Truss bridges of 50m to 60m spans are most common. Concerning the location of the deck in the truss bridges, these are classified into through type (Figure 1.1.a) and deck type (Figure1.1.b) truss bridges. As the name suggests, in deck-type bridges the deck lies on the top of the truss structure and directly rests on the top chord member joints. Through type truss structures get its name as the vehicle passes through the truss structure, the deck rests on the bottom chord members of the truss. Typical cross-sections of through type bridge and deck type bridge are shown in Figure 1.1.



a. Through type bridge b. Deck type bridge

Figure 1.1 Typical cross sections of through and deck type bridges

Due to analysis constraints, earlier open web girder bridges were analysed as planar pin-jointed structures. However, with the invention of computers, analysis and size of a structure are no more a problem. Members of a truss are connected at the ends with the help of rivets, bolts, or weld. These connections are rigid and not pin connections as required for pin-jointed truss. Therefore, it has now become more relevant to analyse bridge trusses using the space frame approach.

Earlier it was assumed that all truss members are frictionless pin jointed and all loads including self-weight of members are applied at joints. However, in actual practice, it is not possible to construct truss joints as pin joints due to multiple rows of rivets or welding. Therefore, 3D rigid space frame analysis of truss bridges should be carried out to get actual axial forces and bending moments in members. In 3D rigid space frame analysis, it is possible to get six types of forces at each node of truss member, and therefore, apart from checking members against buckling, all members must be checked for interaction ratio due to axial force and bending moments.

1.2 ANALYSIS OF BRIDGE FAILURE

Historically, numerous steel bridges have collapsed while either under construction or in in-service condition. A bridge is termed as a failure if it is not able to serve its purpose. That can be because of a partial collapse of a complete collapse of the structure. Among the causes of failure, overstressing structural components and design defects are the most common ones. Failure due to long-term fatigue and lack of inspection is also observed a lot. Some bridges have also collapsed due to constructional errors or by accidental impacts from ships and trains or some unforeseen events. The conditions, which led to the failure of the bridges, should be understood so that the economic loss and life loss may be avoided. The design guidelines in the coming codes must address such failure conditions and design deficiencies must be corrected. The correct interpretation of the failure of the structure may help in anticipating the correct behaviour of the structure during various loading conditions. It will lead to improved analysis and accurate design and construction practices.

Failure studies in the past have shown a variety of causes for failure. Lessons learned from the failure of each bridge is important, as it may have crossed the limit of existing knowledge. Usually, a primary cause and numerous secondary causes are contributing to failure. The primary cause alone may not cause failure but when joined by secondary causes, the cumulative action may trigger collapse. For making future designs safer, it is important to understand both mechanism of failure and the applicable theory of yielding and fracture. Hence, all structural collapses and especially bridge structure collapses significantly improves the knowledge pool of structural action and material behaviour (Z. Šavor, et al., 2011).

Compared to other bridges, steel girder bridges especially open web steel bridges are more susceptible to collapse. K. Wardhana and F. C. Hadipriono (2003) carried out a statistical study of the failure of 503 bridges in the USA from 1989 to 2000. In their study, it is found the most commonly failed bridges were steel girders with 145 (29%) occurrence and steel truss bridges with 107 (21%) cases. Both these types of bridges constitute over 50% of the total failed bridges studied. Flooding and scouring was also one important cause of the failure of these bridges. Lee et al., (2013) reported that between 1980 to 2012, of all the failed bridges, 59.22% of the bridges were steel bridges. This is a significant number considering only 30.0% of all the constructed bridges are steel bridges.

In India, R. K. Garg (2020) reported that more than 2130 bridges (excluding culverts and pedestrian bridges) have collapsed from 1977 to 2017. The average life of these failed bridges was 34.5 years, which is much lower than the expected design life for these bridges. This untimely collapse of bridges not only disrupts the lives of local people but also creates a burden on the economy of the nation. 123 bridges failed during different stages of construction. Of 2130 failed bridges that they considered, 63% were RCC and PSC bridges, 19% were steel bridges, 6% were bailey bridges, 5% were masonry and 3% were steel suspension bridges. In the study, the reason for the failure showed that 72% of the bridges were left unusable due to the failure of the superstructure and 10% due to failure of substructure among other reasons. The cases of bridge failure have increased in the recent decade, with approximately 129 bridges failed each year during 2007-2017. This distinct pattern of failure of bridges is different from the rest of the world.

In the case of steel bridges, buckling of the compression members was the leading cause of failure. The buckling resulted due to overloading and faulty design or construction practices. One such example of faulty construction practice was the Chauras bridge in Uttrakhand India (Birajdar et al., 2014). The bridge collapsed due to buckling of compression members when the members experienced stresses 16% above the design stress (Figure 1.2). This happened due to unplanned concreting of the deck.

Figure 1.2 Failed Chauras bridge during casting of deck slab. [R. K. Garg et al. (2020)]

1.3 COMPOSITE CONSTRUCTION

Composite construction of RCC floors with open web girders is common in the case of building construction, and with steel plate girders in the case of composite plate girder bridges. Not much literature is available for composite steel truss bridges. Despite the unavailability of proper design guidelines and design standards for composite open web girder bridges, various types of composite open web girder bridges have been constructed in the World.

In India through type, open web girder bridge construction is most popular, and construction of deck type composite steel open web girder bridges is not popular. Hence, further research in this area is required to avail benefits of the composite construction.

In trusses, as the materials are only axially loaded, the materials are well utilized hence making them an efficient structural system (R. P. Johnson, et al., 2001). Steel shows similar strength in both tension and compression. However, the slender compression members may prematurely buckle at stresses much lower than the material strength. In underslung bridges, deck slab if made composite with the top chord will help in preventing the buckling of the top chord. Using a composite concrete deck will not only prevents buckling but will also help in sharing the compressive force in the top chord, making the structure more economical.

The failure stress of concrete is much lower than that of steel. Hence, large cross-sectional area of concrete is provided in the form of a slab. This sustains the compressive force and also eliminates the chance of buckling in compression members. In addition, concrete can carry compression more economically than steel. Hence, a composite deck open web girder bridge fully utilizes constructional materials and may result in an economical and sturdy bridge design. The technology of composite open web girder bridge design is comparatively new in India. Bogibeel bridge, double-deck Railway cum road bridge over river Brahmaputra is one such bridge which was inducted into service in Assam (India) in 2018.

Shear transfer between the concrete deck and the steel truss members is done using shear studs (Figure 1.3). Using shear connectors, if the deck slab is made composite with the top chord compression members of a simply supported open web girder bridge, then lateral buckling of the top chord members can be prevented, and it can support more load at collapse. Therefore, the possibility of the design of composite steel open web girder bridges is explored and a lab experiment highlighting the difference in behavior at failure between composite and non-composite bridges is presented.

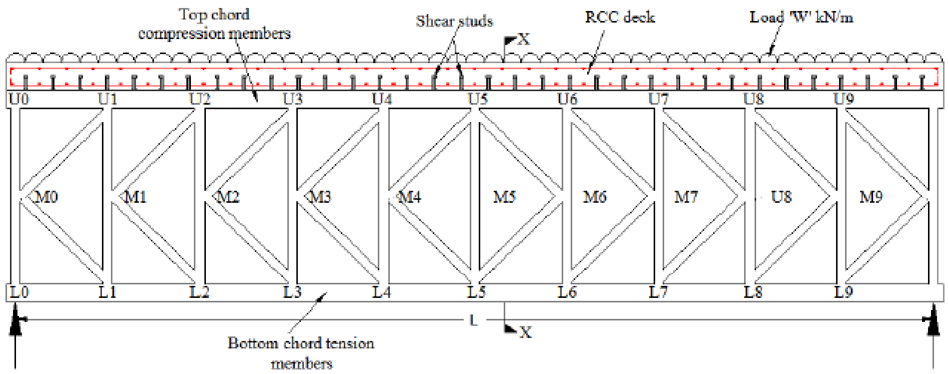


Figure 1.3: Composite deck type steel open web girder bridge

Composite deck in continuous bridges may not be used to full advantage, as negative moments near the supports will cause tension in the deck slab. This cracked deck slab at the supports does not contribute to composite action. Cases of existing continuous composite bridges in the world are compared to establish their usefulness in mountainous regions like the Himalayas. Therefore, continuous composite bridges are not recommended due to the above reasons. Simply supported composite open web girder bridge is further studied for its suitability.

Due to shrinkage strain in the deck slab of a deck-type composite open web girder bridge, composite action between the steel open web girder and the deck slab may start only when shrinkage strain is overcome by the flexural stresses under the live load condition. Thus, the advantage of the composite section in terms of the increased cross-sectional area may be derived only near or after full live load condition. Therefore, the steel open web girder may be designed for service conditions with fatigue for full dead load and live load, and the advantage of the composite section may be available in the overload condition. As a result, under the overload condition, sections of the laterally supported top chord compression members, tension members, and gusset plates need not be increased from the service condition requirement, and cross-sectional areas of only web compression members need to be suitably increased.

1.4 SCOPE OF PRESENT STUDY

In steel bridges, buckling failure of compression members is the most prominent cause of failure of the superstructure, which leads to a sudden collapse of the whole structure. To avoid buckling failure, lateral restrains are required to make the members less slender. An RCC deck made composite with the compression members of the structure can offer a solution to this problem. Well-designed shear connectors can ensure effective shear flow between the RCC deck and steel compression members making them act together. In such an arrangement, the deck slab will also contribute to bear load along with the steel members. Hence reducing the cross-sectional area required for steel members under compression. This reduction in steel area will be economically significant.

The composite concrete deck will also increase the rigidity and stiffness of the structure in vertical as well as in lateral directions. This increased rigidity will improve the response of the bridge against lateral loads of earthquake and wind. This characteristic is also useful in decks of cable-stayed or suspension bridges. Due to increased stiffness, bridges with larger spans are also possible. With increased span length, the requirement for the number of foundations for a multi-span bridge is reduced. This further decreases the cost of the bridge. This kind of composite deck on underslung bridges will be very useful for hilly areas as there is space available for the steel structure under the deck. The effects of newly constructed RCC deck made composite with previously constructed underslung bridges will be interesting to examine. If successful, this will provide an economical way to increase the life and load-carrying capacity of the bridge.

For a detailed understanding of the benefits of a composite deck over an open web steel girder, a study is conducted to understand the following points.

1) Effectiveness of composite construction in resisting buckling of compression members is also to be studied.
2) The effect of shrinkage strain in allowing the participation of composite deck initially needs to be verified.
3) The load sharing between the deck slab and top chord members needs to be quantified. Stress variation in the deck slab is also necessary to identify the behavior.
4) Effect of composite deck on structure's load bearing capacity, stiffness and deflection is also studied.
5) Comparative study of non-composite and composite open web girder bridges is required to be done both experimentally and analytically.

1.5 LAYOUT AND CONTRIBUTION OF THESIS

The thesis is divided into six chapters. A brief introduction and overview of the thesis are provided in chapter 1. Findings available in the literature related to the failure of bridges, developments in composite open web construction technology, and progress in developing shear studs with the present status of various codes are discussed in chapter two.

Details of experiments performed including material tests, model design, testing, and recorded observations are shown in chapter 3. Chapter 4 deals with the numerical analysis of the models used and the comparison of observed data from experiment and numerical model are done for validation of numerical analysis.

Advantages of a composite deck on through type bridges and deck type bridges are shown in chapter 5. In this chapter, a comparison of through and deck type open web steel girder bridges with identical members having composite and non-composite RCC deck is done using STAAD.Pro software. Finally, conclusions of the research work are shown in chapter 6.

The main contribution of the thesis is mentioned below:

1. The research aims to address the issue to buckling in compression members in an underslung truss. In the research, experimental study was conducted to find the benefits of composite deck in resisting the buckling of the compression member.
2. Shrinkage in concrete may also effect the performance of composite action between steel and concrete. The experimental study also clarifies this issue.
3. Comparative numerical study is also done to understand the benefits of composite deck. It is observed as the simply supported composite underslung open web girder bridges are economical solution to bridge spans between 25 m to 100m.