Bridges: Types, Components, Deterioration, Failures, & Preventing Future Failures

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INTRODUCTION

This course examines bridge failures and structural deterioration for the purpose of understanding the elements that cause deterioration in bridge structures and the factors that lead to structural failures. There are several elements that cause the material in bridge structural components to degrade and deteriorate over time, in both steel and RC (reinforced concrete) bridges. The two dominant elements causing deterioration are deicing chemicals (chlorides) and vehicle overloading. These two elements affect all types of bridges and their components. In extreme cases, extensive deterioration potentially leads to structural failure. Of the bridge failures presented in this course, each failure has one or more of these factors which contributed to the bridge collapsing.

Types of Bridges

Seven basic types of bridges represent a majority of the highway, railroad, and pedestrian bridges in North America, and around the world. These include truss, tied-arch, suspension, arch beam, cable-stayed, and cantilever. Each type of bridge fulfills a specific requirement for a specific location. The distribution of stresses, both horizontal and vertical, determines the type of bridge structure required. It is interesting to note many bridge designs have been in practice for several centuries without major changes. For example, the arch bridge was perfected by the Romans over 2000 years ago.

2.1 Arch Bridge

Arch bridges are the oldest bridges in existence, with the Arkadiko bridge in existence today with many still in use. The basic design of the arch bridge allows the arch span to transmit lateral pressure to supporting abutments on a solid Greece, from the thirteenth century BC, still in service. Over 900 Roman arches are in foundation. The simple design of the arch bridge with stone under compression allows for an extremely stable bridge, which explains why older arch bridges are still in existence and in use today, Figures 1 and 2.

An example of older arch bridges still in service is provided in a paper by D. Trajber et al. [1], in which they examine the condition of the bridges and assess the degree and rate of deterioration from anthropogenic and environmental factors, with the goal of providing accurate condition assessments and establishing necessary maintenance. In their paper they state “Historical masonry arch bridges still form an important part of the Croatian transportation network. There are approximately 680 masonry arch bridges and culverts currently being used for railways and roadways.

Figure 1. Roman Alcantara Arch Bridge in Spain

Figure 2. Stari Most Arch Bridge was built in 1557 in Mostar, Bosnia

Many of these bridges are relatively old (more than a hundred years in most cases) but still in use. Increasing vehicle load and speeds as well as deterioration due to anthropogenic and environmental influence have highlighted the need for reliable assessment of their service condition and regular maintenance. The aim of this course is to provide a review of existing masonry arch bridges in Croatia. Firstly, a historical review of bridges is given showing the period in which they were built, indicating the materials and design principles used for their construction. Next, bridge typologies are presented as well as their detailed analysis of geometric characteristics for brickwork bridges. Finally, a short review of damage and its impact on the serviceability of bridges is given. This review presents masonry arch bridges in Croatia and the need for a reliable method of assessing their service condition to provide proper maintenance, repairing, and retrofitting." [1].

2.2 Beam Bridge

One of the simplest types of bridge, Figure 3, is the beam bridge with abutments supporting two or more beams over relatively short spans. The two main beams can have cross beams to add strength and stability. The beam bridge does not transfer load stress as in an arch bridge. Many small and medium beam bridges on main and secondary roads are beam bridges.

Figure 3. Example of a steel beam bridge

2.3 Cable-Stayed Bridge

A cable-stayed bridge, Figure 4, consists of cables connected to load-bearing tower pylons, and the deck below is used to span large distances. By connecting the cables to the pylons, a fan-like pattern is created. In effect, the cable-stayed bridge is a statically indeterminate continuous girder bridge where the dead and live load internal forces are smaller than a girder bridge. With their structural members in tension, the cable-stayed bridge makes more efficient use of materials. In a paper by J. Radic et al. [2] the authors point out that a great number of parameters are required for the shaping of cable-stay bridges, where principal requirements for the shaping of beams, stay cables, and pylons are explained. Cable-stayed bridge design analysis must consider strong interactions between principal load-bearing structural elements. As an example, the principal properties of the Jarun Bridge, a cable-stayed bridge in Croatia, are explained in the light of guidelines for the shaping of cable-stay bridges, and an accent is placed on specific features of this bridge [2].

Figure 4. Cable-stayed bridge Rio Antirrio Bridge in Greece.

2.4 Cantilever Bridge

The cantilever bridge, Figure 5, made from structural steel or pre-stressed concrete, using simple trusses and beams connects two cantilever arms in a suspended span centerpiece with no direct support underneath. Horizontal beams and diagonal bracing support the bridge load with no vertical bracing. The first cantilever bridge in 1866 was the Hassfurt Bridge over the Main River in Germany, with a span of 124 feet, and was considered a major engineering breakthrough in bridge construction at the time. The Canadian bridge Pont de Quebec, Quebec City, Figure 4, which opened in 1919, after 30 years and two collapses, is the longest cantilever bridge in the world. In a paper by Rajeshirke et al., India [3] the authors describe the use of balance cantilever bridges in India, which are widely used in hilly regions, where supporting from the bottom is difficult. The name Balance Cantilever Bridge is a construction methodology that balances out the cantilever portion and is one of the most effective methods of building bridges without the need for falsework. Balanced cantilever bridges are used for special requirements like construction over traffic, short lead time compared to steel, and use of local labor and materials. An extra-dosed bridge is a unique type of bridge between a Girder Bridge and a cable-stayed bridge. As most of the literature covers either balance cantilever bridge or extra dosed bridge, this paper introduces and attempts to summarize the comparative study of balance cantilever and extra dose bridge with its span arrangement, span-by-depth ratio, and pre-stressing of steel [3].

Figure 5. Quebec Bridge

2.5 Suspension Bridge

Developed in the early 1800s, suspension bridges were a marvel in bridge engineering and capable of spanning great lengths. The basic components of a suspension bridge are main cables, towers, and secure anchorages at both ends of the bridge. The deck carrying the dead load and vehicle traffic is hung from the suspension cables with vertical suspenders. The load-carrying members are the main cables as tension members are made of high-strength steel and are efficient in carrying loads. With this suspension cable configuration, the dead weight of the bridge can be reduced making longer spans possible. Early suspension bridges had problems with vibrations and wind loading before the dynamics of wind loading on bridges were understood. John Roebling was the first engineer to build suspension bridges designed for wind loading with the Roebling Bridge in Cincinnati, Ohio, Figure 6, and the Brooklyn Bridge in New York City.

In a paper by Arioglu [4] the author describes "suspension bridges as masterpieces of the engineering profession with conceptually clear cut 5-piece load-bearing systems which are highly hyperstatic and undergo large displacements under loads having nonlinear behavior and are sensitive to horizontal loads, such as wind loading. Suspension bridges are the most elegant, aesthetic, and relatively economical structures of our civilization. Suspension bridge designs are based on mathematical models, using known patterns of physical behavior, but have many unknowns and uncertainties. This paper explores practical mathematical expressions obtained through regression analyses to predict key design parameters of long-span suspension bridges such as main geometric dimensions, material quantities/qualities, and dynamic properties for preliminary design calculations. A large design parameter database matrix for 20 long-span suspension bridges was collected to bring out heuristic approximations through regression analyses. These regression models are used to examine the design parameters of the 1915 Çanakkale Bridge Project, which will break the longest span record with a main span length of 2023 m and the tallest tower record with 318 m (IP Point). It was observed that the dimensions, mass distributions and material qualities selected for the design of the 1915 Çanakkale Bridge agree with the findings of this study." [4]. The key design parameters for regression models used by Arigulo on existing suspension bridges correlated well with the design parameters for the new 1915 Canakkale Bridge over the Dardanelles in Turkey. The bridge opened in March 2022 with a span of 3.7 km and is the longest suspension bridge in the world.

2.6 Truss B

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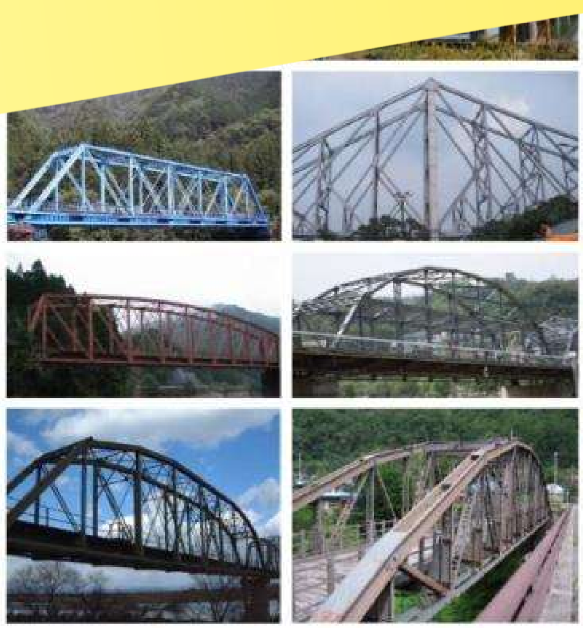

Figure 7. Truss Bridge examples