

# A few examples of the advances in bridge engineering

Imam Hossain

*Ammann & Whitney, New York, USA*

**ABSTRACT:** The author, a Bangladeshi Engineer, participated as a Principal Structural Engineer in the analysis, design, construction, erection, and rehabilitation of many world renowned bridges. He faced and solved challenges of road-rail bridges, dynamic forces, bridge vibrations, wind and seismic demands, erection, retrofit and rehabilitation of bridges. The tasks performed during concept, preliminary and final design phases are complex; each shapes the final outcome. Today advanced computer analysis programs are used for all design phases. As an example, the author introduces a bridge design/analysis program called “BRIDGES” and then illustrates the advances in bridge engineering by a few examples from his own design / analysis tasks. Civil engineers of Bangladesh are facing many similar challenges plus a few new ones peculiar to their region. Today’s advanced bridge engineering knowledge is in the public domain. Bangladeshi engineers can easily harness them and face their particular bridge engineering problems.

## 1 INTRODUCTION

A new bridge project is a complex engineering undertaking. In general, socio-economic-political needs initiate a bridge project. Bridge engineers shape the dreams and deliver aesthetically pleasing safe and sound fully functional structures at lowest possible costs.

Today’s Bridge engineers are also rehabilitating and extending the life of important old structures. They are retrofitting and upgrading the design-deficient bridges. They are maintaining and monitoring the performance of the existing bridges.

As always, the bridge engineers are questioning and re-examining the old means and methods, and improving them. They are inventing, creating, and advancing. They are sharing their newly acquired knowledge.

## 2 CONCEPT DEVELOPMENTS

Based on socio-economic-political needs, a tentative bridge site is first selected. Project management framework is then established and principal players are identified. Experts from many diverse fields are summoned to develop the concept. From the past and present data, traffic engineers forecast the future traffic demands. Environmental engineers study the bridge impact and quantify the adverse effect of the bridge on land, water body, marine life, and traditional life style. Other experts evaluate and quantify the potentials and extents of noise, landslides, erosions, floods, scour, site seismicity, wind climate, and geotechnical ground conditions. Project cost, financing, tendering, contracting, and project risks are then addressed. In a favorable scenario, the project is allowed to proceed with preliminary design. For rehabilitation or retrofit of the existing bridges, the concept development process is much simpler.

## 3 PRELIMINARY DESIGNS

Preliminary design is at the heart of successful final outcome. At the start of the preliminary design, geometric requirements such as navigation channels, vertical clearance above highest water level, traffic lanes, sidewalks, and railway tracks etc. are established. All loadings including highway, railway, pedestrian, temperature, wind, stream flow, ship collision and earthquake are quantified. Serviceability and safety limit states are defined.

In preliminary design, a parametric type study considering bridge systems, materials, span dimensions, foundations, constructability etc. are performed. Preliminary design narrows down the possible bridge alternatives to the final one (s). For analysis, both the preliminary and final design uses the same rational state-of-the-art scientific methods of structural mechanics. Preliminary design brings out the characteristic of the alternatives and their responses to the design loads. The sequences of analysis in preliminary and final design are identical except that many secondary bridge elements (bearings, expansion joints etc) are not examined at the preliminary stage. Today all routine analysis and design calculations are performed by a computer.

#### 4 FINAL DESIGNS

In the final design phase, analyses of the selected bridges are refined. All bridge details are examined, analyzed, and designed. The whole analysis and design process including the design criteria, geometry, foundations and their geotechnical aspects, wind stability and constructability are revisited.

The final bridge details are selected. Contract drawings are prepared. In some cases, the final design is checked by an independent checker.

#### 5 A COMPUTER PROGRAM: “BRIDGES”

In today’s engineering, the computer is the work horse. Many commercial bridge design and analysis programs are available but the author uses Ammann & Whitney’s in-house computer program BRIDGES, developed by the author himself. BRIDGES starts with a warning, “Engineers Design Bridges. Computer Programs Do Not.”. Every computer program warns, “The computed Answer may be wrong!” A computer program user must intuitively know the bridge response and have a thorough knowledge of the advanced engineering methods and mechanics. The author is a bridge designer. He is comfortable with BRIDGES because he knows its inner workings.

BRIDGES can analyze and design composite and non-composite girder bridges, plane or three dimensional trusses or frames, grids, cable supported bridges, curved girder bridges, pre-stressed concrete segmental bridges etc. It can handle static, dynamic, and moving loads. It generates its own influence lines and surfaces for live load analysis. Other features of the program include geometric non-linearity, material non-linearity, computation of vibration mode shapes and frequencies, development of moment-curvature relationships, push over analysis, spectral analysis, multi-support time-history analysis, and bridge vibration analysis. It can evaluate member demand/capacity.

BRIDGES was used to design, analyze, study, erect, or rehabilitate many bridges around the world including the New San Francisco Oakland Bay Bridge, George Washington Bridge, Brooklyn Bridge, Williamsburg Bridge, Tagus River Bridge, New Carquinez Bridge, Third Tacoma Narrows Bridge, Storebaelt Bridge, Messina Strait Crossing, Bear Mountain Bridge, Bronx-Whitestone Bridge, Throgs Neck Bridge, Skagit River Crossing, Panama Canal Bridge, Ogdensburg Bridge, Kwang Ahn Bridge, Asan Bay Crossings, Sham Tseng link, Chesapeake Bay Bridges, Second Tacoma Narrows Bridge, Riegelsville Bridge, Forth Road Bridge, Duarte Bridge, Lion’s Gate Bridge, Golden Gate Bridge, Brahmaputra Bridge, Burlington-Bristol Bridge, Blennerhasset Island Bridge and many others.

#### 6 EXAMPLES

Hundreds of impressive examples of recent advancements in bridge engineering are documented in engineering literatures. The author participated as a Principal Structural Engineer in the analysis, design, construction, erection, and rehabilitation of many of the world renowned bridges. Here are four samples from his design / analysis tasks demonstrating advances in bridge engineering:

Example #1: Erection Analysis

Example #2: A Road-Rail Bridge

Example #3: Planning for the Future

Example #4: Record Span (Proposed)

### 6.1 Example #1: Erection Analysis



Figure 1: The New San Francisco-Oakland Bay Bridge, California, USA

The new San Francisco-Oakland Bay Bridge (Figure 1) is designed by others to create a visually impressive structure. These 570 meters long Signature Bridge is an asymmetric self-anchored suspension bridge in a seismically active area. It has a single tower and one continuous cable that loops around the west end of the girders and has both ends anchored at the east end. Two separate orthotropic box girders, connected by wide transverse cross beams, serve as the roadways. A bikeway is provided by a cantilever off the eastbound girder.

The contractor used an advanced computational tool (BRIDGES) to compute all main cable geometry, hanger forces and girder moments through all phases of construction, shop fabricated lengths of main cable strands and hanger ropes, fabricated camber for the bridge girders, load transfer, and computation of bridge dynamic properties and system responses during load transfer. To construct this bridge, the shop fabricated box girder segments will first be assembled and welded on temporary trusses (false work). At this stage, the temporary trusses will be carrying the self weight of the deck. The main cables will then be erected. Loads will then be transferred from the temporary trusses to the main cables in a controlled sequence of operations. As the loads are transferred, the main cable will travel from “Free Cable” position to the final dead load position. Figure 2 shows the computer model used for load transfer analysis. The bridge is expected to open to traffic in 2012.

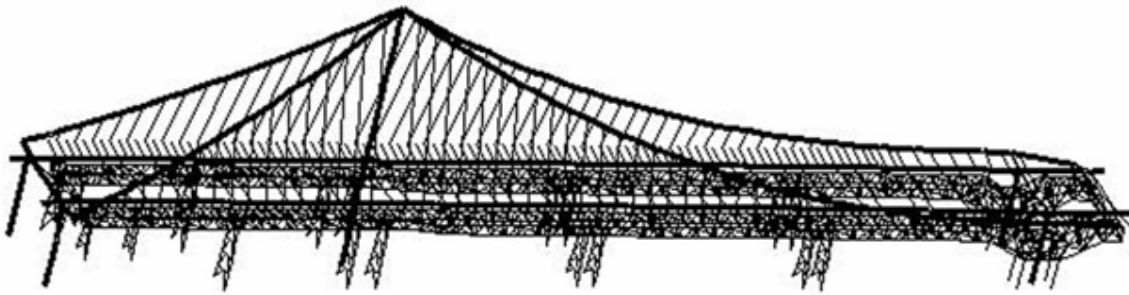


Figure 2: Computer Model, San Francisco-Oakland Bay Bridge & Supporting False Work

### 6.2 Example #2: A Road-Rail Bridge



Figure 3: The Tagus River Bridge, Lisbon, Portugal

The suspension bridge over the Tagus River opened to highway traffic in 1966. The suspended spans are 483 m, 1013 m, and 483 m. The stiffening truss is 2271 m long, and is continuous throughout the suspended spans and three backstay spans. In 1992, Junta Autonoma de Estradas (JAE) of Portugal awarded a design contract to widen the roadway deck and add a new railroad.

In order to carry the new dead and live load, a new second cable system was introduced. The two new cables, supported at new anchorages and extensions to the existing towers and cable bents, are designed to carry all the new additional dead loads. The bridge profile remained unchanged. Both the existing and the new cable systems carry highway and railway loads.

The bridge is designed for two tracks of train loads and six lanes of highway lanes. Wind, earthquake, and human response to bridge vibrations were major analytical tasks. Under the passing trains, the bridge grade changes continuously. Grade and rate of grade change were major train run-ability criteria. Truss movement of 0.8 m at the anchorages required special expansion joints for train run-ability. The computer program BRIDGES animation modules made the bridge virtually come alive and demonstrate its response to moving loads and earthquakes.

Load transfer and erection procedures were developed to permit construction without highway lane closing. Advanced engineering analysis and construction techniques were the keys to the remarkable reconstruction tasks performed on the Bridge over Tagus River. The bridge opened to railway traffic in 1999.

### 6.3 Example #3: Planning for the Future



Figure 4: The Third Tacoma Narrows Bridge, Washington, USA

The first Tacoma Narrows Bridge collapsed in 1940. The Second Tacoma Narrows Bridge, built in 1950, cannot meet the present traffic demand. A Third Tacoma Narrows Bridge was proposed in the 1990's. Considering the age of the Second Tacoma Narrows Bridge, the design of the new 930 m main span bridge includes provision for a new lower deck supported by a future second cable system. The design included complete static and dynamic analysis, wind tunnel testing and multi-support time-history analysis to quantify bridge response to seismic actions. Because the new proposed Third Tacoma Narrows Bridge is only 60 m away from the existing bridge, it had to pass extensive hydrological scour analysis and model tests. The bridge is in an active seismic zone. State-of-the-art bridge engineering knowledge was used in design and construction.

The new Third Tacoma Narrows Bridge opened to traffic in 2007.

#### 6.4 Example #4: Record Span (Proposed)

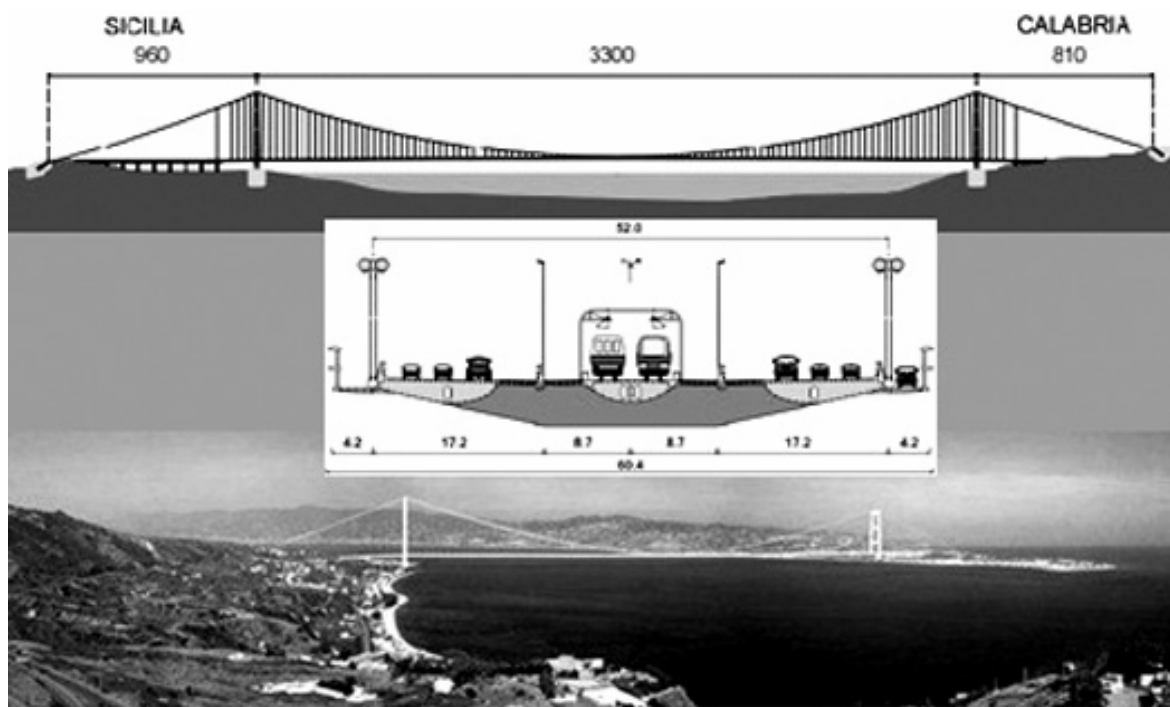


Figure 5: The Messina Strait Bridge, Italy

The author was the Principal Bridge Specialist for an independent review and analysis of the proposed bridge over the Strait of Messina, Italy, in collaboration with a team of international long span bridge experts to advance to a final design/build stage. The main span of the bridge is 3300 meters.

The design of the bridge with this unprecedented span obviously uses advanced bridge engineering technology. The design work included a more realistic highway-railway loading criteria, redefined various limit states and suggested improvements to many standard structural details. Highway-railway run-ability and the bridge response to various design loads including wind and seismic actions were quantified under service and extreme conditions. Details of this advanced engineering work can be found in many papers in engineering journals and the recently published book “The Messina Strait Bridge, A challenge and a Dream by CRC Press”. The Messina Strait Bridge is now poised for the final design/build stage and undergoing final design.

## 7 CONCLUSION

The state-of-the-art of bridge engineering is advancing and more than ever, the engineers at the forefront of these advancements are delivering aesthetically pleasing safe and sound structures at lowest possible costs.

The bridge engineers are also rehabilitating and extending the life of important old structures. They are retrofitting and upgrading the design-deficient bridges. They are maintaining and monitoring the performance of the existing bridges.

Today’s advanced bridge engineering knowledge is in the public domain. Bangladeshi engineers can easily harness this knowledge. All peculiar problems, regional to Bangladesh, must be faced and solved by rational scientific methods.