Kenneth Severn Award 2007 Winner

Bridge engineering: turning problems into possibilities

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Keywords: Bridges, Engineering, Millau Viaduct, France, Seismic design, Rion Antirion Bridge, Greece, Dynamic loads, Poems – Brooklyn Bridge, New York, USA

Bridges are a symbol, a metaphor, an icon, a sculpture, a monument, and a way to get from A to B. They are photographed, painted, eulogised, crossed, and climbed. But with bridges meaning many things to many people, what drives their creators? What draws structural engineers of all ages and backgrounds to these ancient and iconic structures? No doubt the drive of each bridge designer is unique, but rarely are structural engineers given more opportunity to overcome complex challenges and meet the needs of a growing society through such daring, elegant, and creative solutions.

Because a bridge is not called to offer shelter or habitation like a building, its structural skeleton is not hidden by architectural additions that can distort space and proportion. Bridges are defined not by what is added to the essential load-bearing structure but by the simple purity of that structure itself. Bridge design provides a unique opportunity for structural engineers to prominently exhibit their creative skill in overcoming nature to provide human transport.

The design of bridges is a creative process because it requires a synergy of artistic and technical skill. In good design form must follow function, and the constraints and demands of each bridge project help to preclude possibilities and often lead naturally to the structural form selected.

Every bridge is unique and brings with it a unique set of challenges and constraints. Creatively overcoming these challenges to produce great works of engineering and architecture is perhaps the core appeal of bridge engineering for structural engineers. Several types of environmental and technical challenges that designers must overcome are presented below with accompanying examples of bridges from around the world. These examples show the often-stunning result when the challenges of the design process are not only overcome, but used as opportunities to utilise new designs, new materials, or new construction techniques. This is at the core of the dynamic and creative process of bridge design: turning problems into possibilities.

Environmental challenges

Because bridges typically link two points separated by geology, the connection between bridges and the natural world is significant. The site of a bridge is often rugged or remote, and the peculiarities of a bridge site both challenge and assist the bridge engineer as they select the form a structure could take. Many of the world's most exciting bridges are defined as much by their structure as by their location, and the result of engineers successfully shaping a bridge to surrounding natural conditions can be breathtaking. The rocky coastline of western California is the perfect setting for the concrete arch bridge shown in Fig 1, with the sheer cliff wall resisting the horizontal forces of the arches. Because the designer carefully blended the structure to the natural site, the two complement each other brilliantly and the end result is one of the most scenic highways in America.

The recently-completed Millau Viaduct is another striking example of structural engineers tailoring a bridge to a site, in this case the picturesque Tarn valley in southern France. Here the immense technical feat of carrying a motorway across a 2460m valley 246m in the air was achieved with a series of seven cable-stayed bridge towers. The depth of the valley limited the number of bridge piers that could economically be used, leading structural engineers towards this cable-stay design. The finished viaduct is the tallest vehicular bridge in the world and is in many ways a natural extension of the landscape in which it is built. It emphasises both the majesty of the natural valley and the creativity of man in building this thin connecting ribbon across the divide.

Technical challenges

Constructability

As in the case of the Millau Viaduct, bridge solutions that rise to meet the environmental constraints of a site often include

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Fig 1. A concrete arch bridge on Route 1 along the California coastline

numerous technological challenges as well. One of the greatest challenges facing structural engineers when designing a bridge is determining how it will be built. Unlike buildings, where construction sequencing is fairly clear, how a bridge will be built is a major consideration during the design phase. Bridge designers work closely with construction contractors during design to ensure that the structure is practically viable. The opportunity to work in these multidisciplinary teams to push the limits of constructability is yet another appeal of bridge design to structural engineers.

For the viaduct near Millau, engineers had to ensure that the bridge they designed could be safely constructed up to 246m above the valley floor. The solution developed involved building the deck segments on land at each end of the bridge, and launching them out over the abutments to each cable-stay tower. This unbelievable feat was accomplished using a proprietary satellite-guided hydraulic ram system that was capable of lifting the deck segments slightly and pushing them forward at a rate of 600mm every 4min. Temporary steel piers were built between the permanent concrete towers to support the deck as it gradually moved across the 2.4km span. Working at the limits of the possible with bridge design and construction techniques, this viaduct is a monument to the creative problem-solving abilities of structural engineers.

Seismic design

While construction is a significant consideration in the design process, engineers are often faced with far more complex technical problems to solve for the bridge itself. The public expects bridges to be safe and to last in their environment. Often bridges must be built in areas with high winds or significant seismic activity, adding a challenging dynamic element to the design process. One recent bridge where structural engineers used seismic challenges as impetus for innovation is the Rion-Antirion Bridge in western Greece. This four tower cable-stayed bridge crosses an active fault and required structural engineers to think creatively of ways to both reduce the seismic energy input and control the response of the bridge to earthquakes.

To reduce and resist earthquake strong motion, special features were included in the bridge foundation and superstructure. The Rion-Antirion Bridge has the largest pier foundations in the world, designed to reduce pressure on the weak soil and provide stability in an earthquake. Each tower is supported by a massive precast concrete disc resting on a bed of crushed gravel. During an earthquake, strong motion is mitigated by the sliding friction between the seabed stone and the concrete foundations, providing a simple damper. The superstructure is robustly designed as well, and the deck contains expansion joints capable of moving a full 5m during an earthquake. The deck is attached to the piers with large dampers to absorb energy and reduce deck movement in a seismic event. Working with researchers and other specialists to develop these innovative technical features is yet another example of the opportunities for creative collaboration available to bridge engineers.

Slenderness

As with earthquakes, other cases of dynamic loading provide designers with complex challenges that must be overcome through intelligent and creative bridge design. Dynamic environmental loading is especially challenging because of its huge variability, and this loading type has provided significant historical lessons for bridge engineers. The Tacoma Narrows bridge disaster in the northwestern US is one of the most infamous modern engineering failures, with the bridge deck being torn apart due to the dynamic effect of a light breeze. Much less disastrous yet infamous in Britain is the 'wobbly' Millennium Footbridge crossing the Thames in London. When first opened, crowds crossing the bridge caused significant swaying of the shallow suspension cables to the point of the bridge being unsafe. Structural engineers spent months working on a complex damping system to eliminate the swaying of the bridge without compromising its aesthetic concept, and were finally able to stabilise and reopen the bridge

Conclusion

Examples such as these show that structural engineers designing bridges are truly working at the edge of the possible, overcoming new challenges that arise with longer spans, thinner decks, and new materials. Using breakthroughs in computing power and analytical software, modern bridge engineers are able to push their designs further using less material, providing structural economy and aesthetic grace. Far from being a static and traditional profession, bridge design today must incorporate advances in materials, construction methods, and analysis tools to provide cutting-edge solutions to modern transportation problems.

There is nothing common or simple about bridge design: every new site, every unique user need offers engineers a new puzzle to work through and overcome. Few professions in the world can boast this diversity, and bridge designers of all eras have used these diverse opportunities to spark the imagination of their contemporaries. Bridges are a focused unity of science and art, and a profound expression of both man's need to organise and innate creative spirit. They are a purely functional yet utterly beautiful unifier of people: physically, culturally, and symbolically. Bridges flow from and encourage what is best in humanity; they are inspired, and inspire. From the first concept sketch to the final ribbon of road uniting what was once divided, there are few richer opportunities for structural engineers than a career in bridge design.

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Fig 2. Blending form with function, the Millau Viaduct seems to soar across the Tarn valley (*photo courtesy Mike Lehmann (Creative CC-BY-SA-2.5)*)
Fig 3. The massive earthquake-resistant piers of the Rion-Antirion Bridge on the northwestern edge of the Peloponnese Peninsula in Greece

4a

4b

Fig 4a, 4b. The Millennium Bridge in London, designed as a slender ribbon of steel across the Thames (*photos: courtesy Ove Arup and Partners, all rights reserved*)

On the Brooklyn Bridge

The river here is laden
with the commerce of the seas
iridescent with oil
moving as ever to the ocean
caught in a temporal groove
from beginning to end
of a downhill journey.

Suspended in a web of steel
between sky and the reflection of sky
I raise my arms in emulation of
the cables' parabolic grace-
Tensile meridians cascade to me
and we capture in timeless genuflection
a stillness beyond the river's teeming flow,
the soar and dive of raucous gulls.

Angel wings on either side of me
ascend to gothic arches and down again
to Brooklyn and Manhattan shores.
The moment stretches out
like a cable strand spun taut and singing
the perfect one unwavering note.

Shep

Nick Burdette is a recent graduate of the University of Illinois (USA) and began a career in bridge design with Ove Arup and Partners in 2006. He has always been fascinated by bridges and is happy to be starting his career at such an exciting time for the bridge design industry, with new materials, construction techniques, and modelling software giving engineers greater freedom for creative expression in their structures than ever before. Nick lives in Birmingham, England with his wife Lauren.

Standards news

The following standards publications (advised in the June 2007 issue of BSI's *Update Standards*) can be ordered from BSI Customer Services, 389 Chiswick High Road, London W4 4AL (tel: 020 8996 9001; fax 020 8996 7001; email: orders@bsi-global.com).

New standards

BS 6349: *Maritime structures*
BS 6349-8: 2007 *Code of practice for the design of Ro-Ro ramps, linkspans and walkways*
no current standard is superseded

BS EN publications

BS EN 1739:2007 *Determination of shear strength for in-plane forces of joints between prefabricated components of autoclaved aerated concrete or lightweight aggregate concrete with open structure*
supersedes BS EN 1739:1998
BS EN 1991: *UK National Annexe to Eurocode 1. Actions on structures*
BS EN 1991-1: *General actions*
BS EN 1991-1-2:2002: *Actions on structures exposed to fire*
no current standard is superseded
BS EN 1991-1-5:2003 *Thermal actions*
no current standard is superseded
BS EN 1993: *Eurocode 3. Design of steel structures*
BS EN 1993-1-6:2007 *Strength and stability of shell structures*
no current standard is superseded
BS EN 1993-1-12:2007 *Additional rules for the extension of EN 1993 up to steel grades S 700*
no current standard is superseded
BS EN 1993-4-1:2007 *Silos*
no current standard is superseded
BS EN 1993-4-2:2007 *Tanks*
no current standard is superseded
BS EN 1993-4-3:2007 *Pipelines*
no current standard is superseded
BS EN 1993-5:2007 *Piling*
no current standard is superseded
BS EN 1997: *Eurocode 7. Geotechnical design*
BS EN 1997-2:2007 *Ground investigation and testing*
supersedes DD ENV 1997-2: 2000 and DD ENV 1997-3: 2000
BS EN 1999: *Eurocode 9. Design of aluminium structures*
BS EN 1999-1-2:2007 *Structural fire design*
supersedes DD ENV 1999-1-2: 2000 which remains current
BS EN 1999-1-4:2007 *Cold-formed structural sheeting*
no current standard is superseded
BS EN 1999-1-5:2007 *Shell structures*
no current standard is superseded
BS EN 14629:2007 *Products and systems for the protection and repair of concrete structures. Test methods. Determination of chloride content in hardened concrete*
no current standard is superseded
BS EN 14991:2007 *Precast concrete products. Foundation elements*
no current standard is superseded

Amendments to British Standards

BS 4449:2005 *Steel for the reinforcement of concrete. Weldable reinforcing steel. Bar, coil and decoiled product. Specification*
AMENDMENT 1 AMD 17103
BS 4482:2005 *Steel wire for the reinforcement of concrete products. Specification*
AMENDMENT 1 AMD 17104
BS 4483:2005 *Steel fabric for the reinforcement of concrete. Specification*
AMENDMENT 1 AMD 17105
BS EN 14545 *Timber structures. Connectors. Requirements*
BS EN 14592 *Timber structures. Dowel-type fasteners. Requirements*

Updated British Standards

BS 476: *Fire tests on building materials and structures*
BS 476-3:2004 *Classification and method of test for external fire exposure to roofs*
AMENDMENT 2. Also incorporates Amendment 1

British Standards proposed for confirmation

BS 4550: *Methods of testing cement*
BS 4550-0:1978 *General introduction*
BS 4550-3: *Methods of testing cement. Physical tests*
BS 4550-3.1:1978 *Introduction*
BS 4550-3.4:1978 *Strength tests*
BS 4550-3.8:1978 *Test for the heat of hydration*
BS 4550-6:1978 *Standard sand for mortar cubes*
BS 5400: *Steel, concrete and composite bridges*
BS 5400-1:1998 *General statements*
BS 5400-4:1990 *Code of practice for the design of concrete bridges*
BS 5400-6:1999 *Specification for materials and workmanship, steel*
BS 5400-7:1978 *Specification for materials and workmanship, concrete, reinforcement and prestressing tendons*
BS 5400-8:1978 *Recommendations for materials and workmanship, concrete, reinforcement and prestressing tendons*
BS 5400-10:1980 *Code of practice for fatigue*
BS 5400-10C:1999 *Steel, concrete and composite bridges*
BS 5642-1:1978 *Specification for window sills of precast concrete, cast stone, clayware, slate and natural stone*
BS 5642-2:1983 *Specification for copings of precast concrete, cast stone, clayware, slate and natural stone*
BS 5911: *Concrete pipes and ancillary concrete products*
BS 5911-1:2002 *Specification for unreinforced and reinforced concrete pipes (including jacking pipes) and fittings with flexible joints (complimentary to BS EN 1916: 2002)*

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