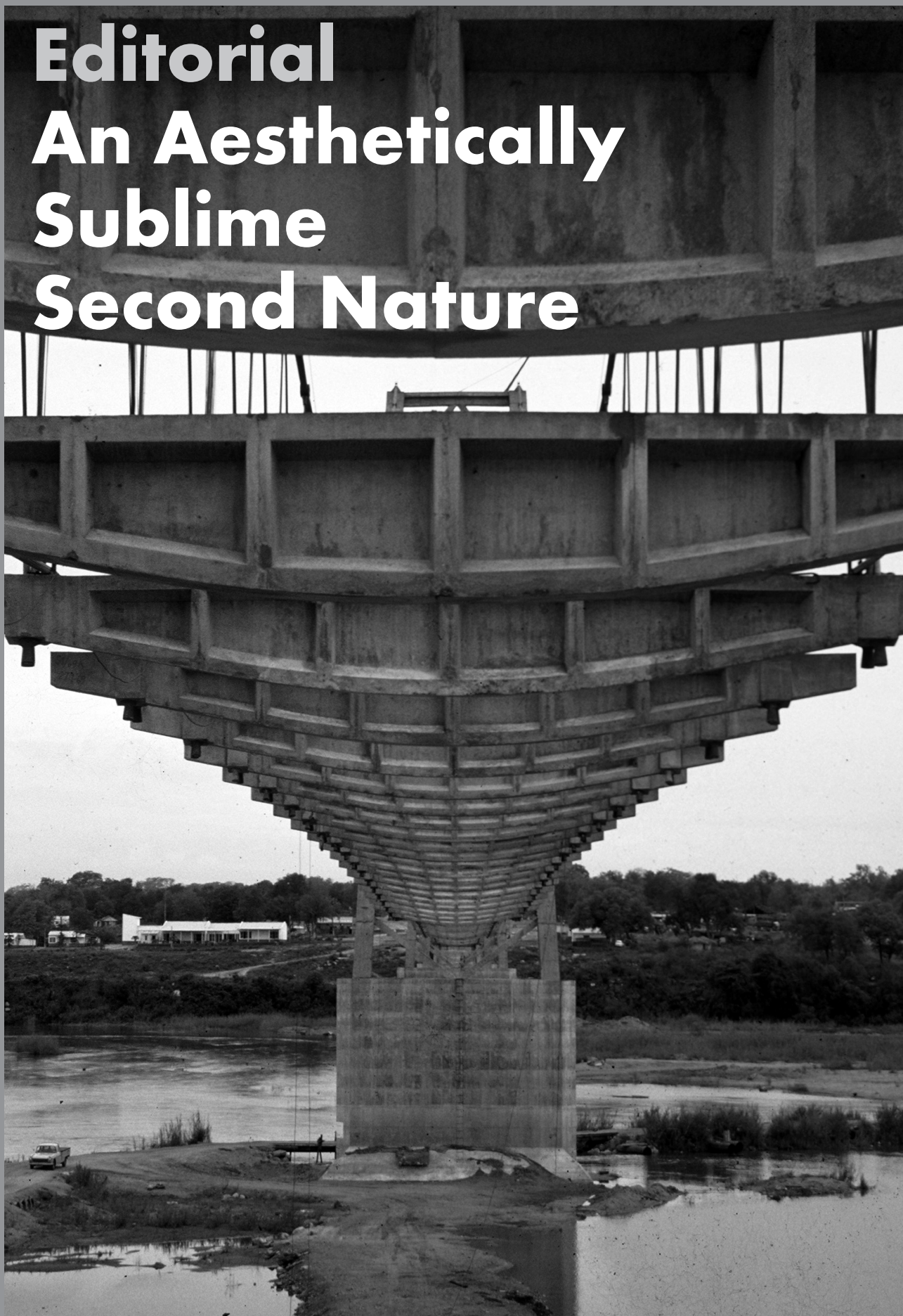


Editorial

An Aesthetically Sublime Second Nature

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THIS **docomomo** Journal is dedicated to a reflection on Bridges and Infrastructures, envisaged as key structures for an enriched comprehension of Modern Movement.

The search on Bridges and Infrastructures has to do with a matter of connecting. To launch bridges seems to be a kind of life requirement, as far as it is the way to connect sides, which means improving relations and energies, desire and intelligence. Bridges and Infrastructures have the function of connecting pieces of land and the role of creating a connected world. The matter is to make links and establish a network. In fact, it is a global network made of *works of art*, which have a physical and material presence balancing between values such as economy and elegance and providing a better life for every man. Seeking audaciously for innovation, research contributes to these large scale structures as it has been improving material capacities and technical creation. It is a huge field that lay infinite possibilities for art and science to perceive changes of social, aesthetic, technical standards and norms, to quote Sir Ove Arup.

The search on Bridges and Infrastructures has to do with a matter of moving. Bridges and infrastructures are fantastic topics to make one go deeper on the reflection that moves us on the universe of Modern Movement. A process that we believe to be an open one, daily set up in accordance to the continuous transformation which is the very character of the modernization process. What Octavio Paz names as the modern tradition: a process of permanent transformation. Primarily, it has to do with mobility, transportation, in a word: movement, with *Space, Time and Architecture*, to quote Giedion. Movement is the most precise (and simultaneously, the most ethereal: *all that is solid melts in the air*, stated Marx) to characterize the Modernity and the Modern Movement in response to the contemporary situation. In fact, the bridge does not define space, it organises space, space envisaged as the place where movement occurs, as a flow way of people, goods, energies, promoting movement and time acceleration. It is the aesthetics of mobility and an inspiration for Modern Movement architecture and its fascination for speed transformation infrastructures, in other words, for tangible and abstract architectural problems as referred to by E. Mock.

Finally, the search on Bridges and Infrastructures has to do with a matter of nature envisaging the landscape as an ongoing medium of exchange. Bridges and the large scale Infrastructures are a kind of an *aesthetically sublime second nature*, as Goethe claimed in his *Italienische Reise*. It is a route, a way, as well as a place and a work of art; it puts together practical devices and intense cultural symbols. A *bridge of dreams* as John Allan suggests, is made of the intuition and innovation desire remembered always by Freyssinet as *a love without limits (un amour sans limite)*. Because one can see it is an aesthetic experience, beyond all the technical requirements that fixed the interaction between man and nature. The progress fulfilled through the Bridges and Infrastructures constitute the large and universal scale laboratories that have been fostering several micro scale solutions, procedures and technologies.

Due to the scientific commitment, the inexhaustible energy, the intense creativity of the guest editors, Kyo Takenouchi and Ola Wedeburnn, who accepted the challenge to work this issue, it was possible to put together a competent, brilliant and generous range of experts around this theme. In fact, the Bridges and Infrastructures issue came up to us as a brainstorm, as a *bridge of desire* that took place between Tokyo and Copenhagen. At the end of a year in which a violent earthquake and tsunami with devastating consequences occurred in Japan, **docomomo** is proud to present this Journal, which symbolically includes the report of **docomomo Japan 150, future and legacy**, the exhibition presented in September at the main Tokyo Subway Station, revealing how important it is for **docomomo** to be close to the public, how vital it is to use bridges and to connect people.

Ana Tostões, Chair of **docomomo** International

Bridges and Infrastructure

By Kyo Takenouchi and Ola Wedeburn

AT present, it is by no means an exaggeration to say that innumerable bridges and infrastructures are able to bring us to the end of the earth, whether these are monuments, scattered in a remote area, recognized or not, situated where mankind intensively has made its effort to extend daily circles of life till the present day. Humans have always been on the move, in primitive ages they went up the hill and down the dale, over and beyond mountains, across streams and wherever obstacles had to be crossed, bridges and roads skilfully came into their hands. Emerging directly on the ground, as fruit of empirical and intuitive knowledge; as comprehensive static and dynamic engineering, state of the art science and creative use of information.

Bridges and Infrastructure

This special issue, *Bridges and Infrastructure*, deals rather briefly with the concept of infrastructure, nevertheless, most of the readers will notice that there is something common between bridges and infrastructure.

In terms of public wealth, infrastructure represents substantial services, prompt, safe and guaranteed supply of electricity, water, gas, information network, etc.; paths and roads to walk on foot, to ride bikes on, and even negotiate on horseback. As trains and motorized traffic have increased the volume of infrastructure, capacity and resources burst; at present it calls for contextual and interdependent engagement, creativity, research, and an eco-friendly network.

Both bridges and infrastructure pass essentially on roadways, pipes, cable lines and so forth. They are continuous structures generally supported by posts, pylons and towers—on abutment and foundations—substructures or sometimes by cable supported systems. When roads above ground reach a river, a valley, or any other similar obstacle it becomes a bridge; by contrast, when they go underground it is in a tunnel. This means that the level of roads merely changes when separated from ground to soar in the air, when passing in a tunnel underground, while bridges radically change the structural system of roads. Technically speaking there is mostly no difference from road as earthwork to road on bridges. In addition most infrastructure is integrated as networks and consequences of urban growth.

History

Generally speaking, the subject Modern Movement could be considered as a project of the enlightenment. The development of bridges is in many ways parallel with the development of mobility and transportation system for goods, travellers, and commuters, etc. Increased frequency and loads of carriages and vehicles following the industrialization brought the need for robust and durable bridges.

When it comes to bridges and infrastructure of the Modern Movement, they can neither be classified solely from a chronological angle nor as structural types and building material. At every opportunity the Modern Movement answers to diversity and transition from the enlightenment to new systems of society in accordance with local, regional and national conditions. As for bridges, it is true that the typical features as expression of Modern Movement are construction materials identified as steel and concrete and developed throughout industrialization. On the other hand bridges are also identified as bare structures, almost as the shape of a skeleton, transparent and exposed to public sights.

Briefly it could be said that while construction materials are identified as characters, such as steel and concrete, structures are rather defined as a concept of typologies. It could be noticed that in the late 1950s an increasing number of bridges with tensile stress structure appear, such as modernized pre-stressed concrete bridges (PC bridges), cable-supported bridges (suspension bridges, cable-stayed bridges), furthermore pre-stressed wooden bridges, and lately stressed ribbon bridges, the latter unfortunately not included in this issue.

Bridges and infrastructure are not to be taken for granted and automatically grasped as monument and objects. They are expression of materials, structure and system that reach beyond matter and construction typologies determined as time and scale.

Thus the methodological approaches that characterize the qualities of *Bridges and Infrastructure* in this issue of the **docomomo** Journal are diverse. The authors have been addressed to reflect on the topic of Modern Movement, which has brought answers of expectation as well as surprises, to which we will return. Meanwhile, after addressing the authors, attempts have been made to



The Kintai Bridge today. Photo by Jens Markus Lindhe.

Kintai-Hashi (Kintai Bridge) drawing by **Katsushika Hokusai**, ca. 1831. Image from the Ohta Memorial Art Museum collection.



sharpen the construction of the theme, through theoretic studies of the topic and with reference to empiric and acknowledged experiences.

An important source to Modern Movement and bridges was found in the book and exhibition *Architecture of Bridges* by Elisabeth B. Mock¹ at the Museum of Modern Art in New York, 1947. It introduces architecture of bridges with a short history and a substantial commented documentation. Mock writes:

Since a bridge does not define space, but cuts through it, it is free of all intricate psychological considerations that must be taken into account when space is moulded or enclosed. Thus, paradoxically, a bridge is at once the most tangible and most abstract of architectural problems [...] Since the reality of the bridge lies in its structure, the art of bridge building lies in the recognition and development of the beauty latent in those structural forms that most effectively exploit the strength and special properties of a given material [...] Man has rarely built less efficiently than he was able, and the history of bridge architecture is essentially the story of his triumph over space through increasingly skilful exploitation of the best materials available to him.

The concern of Elisabeth B. Mock is the development of material and structure. Thus when it comes to consider context her argumentation is weak, if existing at all. When arguing about bridges and space she is almost hostile. Still the book is a unique evidence about the concept of Modern bridges. In addition to the historical and analytic introduction of *Architecture of Bridges* follows the major stock of the book with a well illustrated survey of methodological approach to bridges, based on keywords of material and structural types such as material;

stone, wood, metal arch, suspension cable, metal beam, reinforced concrete, reinforced concrete arch, reinforced concrete beam and rigid frame. Structural types; beams, cantilever, rigid frame or portal frame, arches, fixed, two-hinged, three-hinged, suspension cables.

Very different is the approach of Sir Ove Arup. With the article *Design of Bridges*² he invites with a skill and experience, that almost translocate the reader, to share the emerging concept, to learn about good design by studying it in *statu nascendi*, with presence of almost being there as mind and matter become bridges. In this Journal Jørgen Nissen introduces the text and work of Ove Arup and Arup Associates imagined and unfold in the process and context of bridge constructions.

In the centre of presence there are few limits and many possibilities for art and science, perceiving changes of social, aesthetic, and technical standards and norms. Bridges and infrastructure are evidence to analytic definitions of material and structural character, inseparable from context and processes. As technology changes, bridge and infrastructure concepts change, addressing the reality of public concern as well as private integrity. With the help of passwords and interfaces we enter paths to information complexes, sometimes shared as territories where real and virtual meet to bridge the gap.

In the article *Garden of Microchips* by Toyo Ito,³ Ito refers to the garden of Edo. The text is an interesting reference as well as an introduction to experiences of technology, infrastructure, and reality:

It is easy to point out the violence done by technology and confusion wrought by overlapping of heterogeneous systems in Tokyo today. However, I believe it is far more meaningful to search for new ways to make today's urban space attractive than to bemoan the wretched condition of Tokyo and indulge in nostalgia for the garden city of the past [...] People and cars are not the only moving objects. The flow of diverse forms of energy and information has increased at a tremendous rate, and indeed the flow of such invisible things is coming to dominate urban space.

The ambition with this Journal is to get close to technology, to social possibilities of creative communication, and last but not least to pursue aesthetics, sensual beauty and love for craft and fellowship when sharing the interest in bridges and infrastructure. The most remarkable achievement in recent years is the exhibition *Landscape and Structures* at the Swiss Pavilion of the 12th International Architecture Exhibition in Venice, 2010. The exhibition was presented by Jürg Conzett, initiator and curator of the exhibition, and Martin Linse, photographer. Jürg Conzett highly suggests: "[...] chiefly interested in constructed or engineered work with at the same time high architectural merit-works that involve as intense engagement with issues of engineering and sufficiency on the one hand and are intended to evoke certain responses in the individuals using them on looking at them on the other [...]. The authors' response is that the most interesting solution comes about as a synthesis of engineering and architectural requirements within the conceptual design."⁴

It is reasonable to ask why and how it has been possible within this special issue of the **docomomo** Journal to find these contributions of superb articles. It is obvious that there are no boundaries when it comes to identify types of structure and material, thus introducing the challenge of structural design and conservation technology. There are few limitations to the extensive universe; in reality it is questionable if there are limitations at all, certainly when considering structural design and the Modern Movement.

The articles gathered in this Journal characterize a diversity brought together with a certain, but not demanded, relation to the mission and statement of **docomomo**. The authors have more or less explicit relations to the Modern Movement, architecture, and technology. They all represent a view of special interest and knowledge about bridges and infrastructure.

Jürg Conzett emphasizes the importance to keep up a Modern tradition of scientific engineering, an open critical process. Further, "We need more than this", J. Ruskin's work on synthetic Modernity, and the approaches into a coherent concept.

Denis Zastavni's article about concrete and Robert Maillart's innovations represents a scientific work about structural behaviour and graphic statics.

The alarming condition of the Maracaibo Bridge in Venezuela is the topic of **Hannia Gómez** and **Rino Montiel**. They ask for the need of scientific help as an urgent issue on a topic that calls for action; an important asset for infrastructure in Venezuela.

Pierre Jartoux presents Eugène Freyssinet as a natural born builder, a crack eliminator and developer of structural form under stress.

Carlos García Vázquez speaks about Eduardo Torroja's concrete shell construction, pretension and the Allos Aqueduct.

Rinaldo Capomolla's "Theory of minimal surfaces", deals with membrane and development of infrastructure by Sergio Musmeci and the Renaissance ideal.

Annette Bögle concentrates on Fritz Leonhardt (engineer) and Friedrich Tamms (architect) and the development of cable-stayed bridges, light appearance and the efficient use of materials.

Daijiro Kitagawa presents an introduction of industrial construction in Japan after the great earthquake of 1923. The article addresses Modern structural design, technology, material and aesthetics.

Norihide Imagawa and **Shinsuke Suematsu** find in Modern Japanese bridges a survey and a heritage.

The article "Cable Supported Bridges across Straits in Denmark" by **Niels Jørgen Gimsing** is a story dealing with both bridges and infrastructure connecting the islands and the nation.

Jørgen Nissen speaks about Arup and his concept and birth of bridges, being there during construction in *statu nascendi*.

John Allan, a world within a world, concentrates on the conservation of the penguin pool in London zoo.

Pétur H. Ármannsson focuses on bridges and infrastructure while exploring Iceland and concrete technology.

Henrieta Moravčíková writes on the Piešťany spa and the promenade bridge as a social meeting spot.

Tim Samuelson speaks about the Lincoln Park Passarelle better known as the Rainbow Bridge.

Kieran Ruane deals with the Mizen Footbridge near Cork, conservation and construction authenticity.

And **Mari Hvattum** focuses on infrastructure and changing technology, reality...

Kintai-Hashi: an Example of Conservation, a Sustainable Bridge from the Edo Period

It is obviously exceptional to mention the *Kintai-hashi*, Kintai Bridge, the old wooden arch bridge built in the city of Iwakuni, Hiroshima, in 1673, assigned a national

property of scenic spot in 1922.

The restoration, with minor and major changes to the bridge, is being done with intervals of about 20 years, thus still living for nearly 340 years, time passing, before and through the Modern Movement and today.

Whenever opportunities for the restoration or retrofitting have been met, new technology was adopted with skill and precision of master-hand carpenters, not only solely keeping tradition, but also positive to make them foster. For instance, improvements were done to the islands/piers in the stream in the early 1950s, when hydrodynamic technology was introduced to be enduring to rapid current caused by repeated typhoons. Therefore concrete structure was introduced inside the supports on the islands, tiled by natural stone so the original appearance remained on the outside. The latest restoration was successfully done in 2002–2004, as an example that conservation technology has to learn from the past to live today. The bridge itself is a sort of flexible structure, still solid enough for bearing load. It is certainly an appreciated pedestrian bridge as it has been from the beginning. It is the usual footpath for the daily commuting of citizens. Furthermore, nowadays it is a scenic object for tourists, even though it has served with hunch as a footpath/deck seeming inconvenient to walk on.^{5,6}

Aesthetics of Bridges

It is agreeable to know the explicit theory on the bridge design today, stated by Christian Menn:⁷ “the most important design objectives, common for all bridges, are: 1. Safety, 2. Serviceability, 3. Economy, 4. Elegance.”

Economy and Elegance are not defined in the design standards. These two objectives are to some extent interrelated. And optimal balance between economy and elegance requires a design effort that goes beyond the technical aspects of design and is the true art of the engineer.

The question of aesthetics has been long discussed by bridge engineers and designers. The concept of aesthetic quality is indeed difficult to define. Nonetheless, there are innumerable structures that are treasured or famed by people around the world, structures that somehow exhibit a kind of beauty/elegance, to attract general public attention. A well-designed bridge based on a consistency of conceptual design is often a mark of a successful effort. It should be holistically designed, satisfy certain basic criteria in a well-proportioned and unified structure, so to say as a unity of function (purpose, serviceability), structure (safety), material (the right factor in right place), form (configuration, finish-colour, texture), and possess a certain elegance (aesthetics, harmonization with surroundings), as a social and cultural asset. Most bridge

projects nowadays are in fact influenced by political, social, and economical conditions, foremost technological and engineering knowledge and method in general, furthermore to be environmentally friendly (in other words, sustainable) is a consideration of concern especially in this global era, of course it is indispensable to manage in accordance with the diversity of site conditions as well.

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Kyo Takenouchi

Born in Tokyo, Urban Environmental Designer(JIDA), Senior Professional Civil Engineer (Infrastructure design/JSCE), from 1971 to 1993 chief designer with partnership at M+M Design Office, mid 1993–94 fellowship researcher at Royal Danish Academy of Fine arts (Inst. Structural Science), 1995 set-up and lead her own Design Studio, and now she is a freelance designer and civil-engineer. She has been involved in a number of bridge aesthetic design projects for a long time, some of those works being granted the JSCE/Tanaka Award (Excellent in Bridge Design Work), also prizes from overseas assoc., and so forth. She is the author of several books such as *Aesthetics of Danish Bridges*, Kustakademiet Forlag Arkitektskolen Denmark, 1995; co-author of *Ped-design for footbridges networking towns*, edited by JSCE, Kajima shuppan-kai, 2006; and others.

Ola Wedebrunn

Architect maa, PhD, associate professor at the Royal Danish Academy of Fine Arts in Copenhagen, professor II at the Norwegian University of Science and Technology in Trondheim, and curator for exhibitions on architecture and art, for instance at the Øresund Cultural Bridge and at the climate conference COP 15.

His work involves research and development of architecture and he has published several books and articles about Modern Movement architecture, material, technology, climate and culture. He is coordinator of Docomomo Denmark with certain concern for Nordic and Baltic cooperation. He is a member of the Docomomo Specialist Committee on Technology and ICOMOS ISC 20th century.

Acknowledgements

Last but not least, we, co-editors, would like to send our deep gratitude to each and every contributor who has dedicated her/his precious time to write an article, a magnificent contribution to this **docomomo** Journal 45. Thanks also to **docomomo** International, especially to Ana Tostões, Chair, and Ivan Blasi, Secretary General, who have supported us in such a rare challenging opportunity to work together on this special issue, *Bridges and Infrastructure*, of the valuable **docomomo** half-yearly Journal. We also want to thank Sigrid Jørgensen, M.A., linguist and translator for her contribution translating from German to English. Finally, this special issue could be an open entrance of *momentum* to bring about further beyond the scope of ‘Bridges and Infrastructure’ following the Mission and the Eindhoven Statement of **docomomo** International from now on, showing our wish and gratefulness as co-authors.

Bridges of Modernity

8



THE engineer is an inseparable part of the Modern Movement. He has fulfilled its request of working unprejudiced. But he was driven to his most magnificent works by a mental concentration on technique excluding many other influences. Therefore, John Ruskin called the engineer a human beaver. Rarely the ambition of synthetic Modernism to suspend the difference between culture and civilization was converted. In the writer's opinion, this is no reason to abandon this ambition and engineers should keep up the Modern tradition and continue to work on it.

By Jürg Conzett

THE engineer is an integrated part of Modernity. He has prepared, is grown up with Modernity, and has carried its triumphs and defeats. Unlike the architects, the profession of engineers has no past going back before the modern era. Modern engineering is the unprejudiced mind that invents any new structure, based on a common theory which is the same all over the world. What other discipline has achieved this? There are no dissenters among engineers, no homeopaths questioning the medicine, and even the most inveterate historicist who pretended to construct his arch bridges according to Alberti's methods would certainly check his work in secret with a thrust line. The most vehement disputes about methods, such as the calculation of spatial structures between Otto Mohr and Heinrich Müller-Breslau, seem a hundred years later like a child's play—finally it was only a different number of equations which led to the same, undisputed result.

The developments of the 19th century reveal a characteristic element: the greatest achievements came about in a way where you concentrated more and more on the work of analysis, hereby excluding manifold influences. The precisely calculated works from the late 19th century seem abstract (among others Behrens and Gropius criticized their lack of corporeality when comparing with e.g. Isambard Brunel's opulent works whose ship hulls and bridges were closely related. You might turn Schwedler's truss of the Vistula Bridge at Dirschau (Poland) upside down and still it would stand (tension and compression differ only by plus and minus), what you could never do in case of the Royal Albert Bridge (United Kingdom) with its overlay of tension chains and a compression tube. You could not make precise calculations of the latter bridge, its powers and course which, however, thanks to the robust system did not play an important role, while after several weeks Schwedler identified the secondary stresses of the rods due to the rigid riveted connections of the frame-

work of the Vistula River Bridge. Consequently Culmann demanded the separation of the engineering schools from the schools of architecture so that the candidates were able to devote themselves to the study of projective geometry before they were allowed to solve structural engineering problems. And the splendid isolation of the engineers bore fruit: fantastic buildings, machinery, and *apparatus* which sometimes touched the viewer to tears as David Nye describes it vividly in *American Technological Sublime*.¹

However, the criticism of the engineer began early: in 1853 John Ruskin invites the reader to come to a construction site with the following, impressive passage from *The Stones of Venice*: "Suppose, for instance, we are present at the building of a bridge..." In several paragraphs he, as a great critic of technique, shows us that he knows well about how to build a bridge. First he encourages you to recognize how much the person who drew the curve of the bridge and numbered the stones had to know: "There is no saying how much wit, how much depth of thought, how much fancy, courage presence of mind, and fixed resolution there may have gone to the placing of a single stone of it." And he admires further "this grand power and heart of man in that thing", but, as Ruskin concludes, ultimately, the bridge builder is nothing but a human beaver with an "intricate bestiality—nest or hive building in its highest development. You need something more than this ..."²

Here at last you are able to distinguish between culture and civilization, often provoking you when reading major literary works: from Thomas Mann, Joseph Roth to Simone de Beauvoir there is a list of prominent writers and intellectuals for whom the engineer is a symbol of the hardworking, active, and intellectually limited man. Now these statements by Ruskin and his followers are not simply wrong because how often were the engineers not tools of highly problematic projects, disregarding social, and ecological aspects, be it road construction or the building of power plants, but they show one aspect only. The engineer, like the pioneer, had to concentrate on his works, closed off from disturbing influences, on his way to Modern society; there was no alternative, first the means of Modernity had to be developed.

< Dorfbrücke, Vals, Switzerland. **Conzett, Bronzini, Gartmann** (engineers). Conceptual collaboration: **Peter Zumthor** (architect), 2010.

But then the real goals of Modernism were synthesized: culture and civilization should be one. In the years around 1900 an ongoing discussion about the integration of bridges in urban and natural areas began. On the one hand, discussions by representatives of the *Werkbund* (German association of artists, architects, designers, and industrialists, 1907–34) and the *Heimatschutzbewegung* (a movement concerned with preserving the German regional heritage), led to a wide popularisation of engineering structures, e.g. in the books by Werner Lindner.³ On the other hand, there is a series of more job-specific texts such as that of Hermann Jordan and Eugen Michel, who received the first prize in a competition on the artistic design of iron constructions arranged by the German emperor.⁴ A good example of these discussions is the Hohenzollern Bridge (1911) in Cologne which has become an inseparable part of the city due to its axial location to the cathedral, the static system of the *German arch* and the ascending sequence of their piers and arches with sculptural decorations. That this bridge after the Second World War, against strong opposition in the name of a vulgarized objectivity (*Sachlichkeit*), was robbed of its architectural parts, illustrates the conflict between integrating and divisive tendencies of Modernism.⁵ There were two sides: the iconoclastic impulses while in nearby Düsseldorf the great family of bridges emerged.

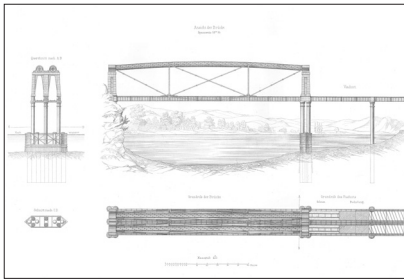
Even where bridge builders behaved conservatively, their works are unerringly Modern: the natural stone arch bridges in the *Alpenstraße* (the German Alpine Road) with their side walls in their curved design; there is no difference between the side walls and adjacent retaining walls, the side walls are also the parapets which are topped with a thin cover plate, a subtle and effective decoration. Conceptually compared to Robert Maillart's bridges there is only small difference since they have the following elements in common: flowing lines, seamless access to parts of the abutments, and integrated parapets.

But then again pioneers appeared. The construction of the post-war highways was rapid and often uncompromising. These outstanding individual performances of the bridge emerged but often the beavers were at work: in 1961 Bruno Zevi called them the "*dittatori dell'asfalto*" in a newspaper article which got very much attention, and in which he criticized the uncoordinated formal lack of concepts in the construction of bridges and tunnels of the *Autostrada del Sole*.⁶ The *Sihlhochstraße* in Zurich, an elegant design of bridge with two parallel point-based hollow boxes stabilizing each other through the elastic deck and lines across the river, symbolized the brutality of modern road construction. Like eighty years ago when in the beginning the urban elevated railways were constructed, the engineers had to concentrate on their

technical work and they did not consider in before how the world would respond to their work. Still the claim of Modernity on a comprehensive quality in the design of the human environment could not be met: the construction of the road network on a large scale happened too rapidly, the social and political pressure on its implementation was too big, and, unprepared for the consequences, the engineers being under heavy pressure had seen no reason to ask more fundamental questions.

The highways which at the same time were unloved and well-tried may have played a role, now that Modernity as such was considered critically from very many sides. Although these works of the engineers, not being able to step out of Modernity, were directly criticized, surprisingly few attempts were made to defend the Modern values from the engineer's perspective. Once Max Bill had written on Robert Maillart, he succeeded in overcoming the pure technical through the intensification of the technical, and Hermann Czech demanded in connection with a lecture by Theodor W. Adorno that one had to be even more factual (*sachlich*). Rarely this attitude, expressed by architects, corresponding to the engineer and his understanding of the engineering career was discussed. Instead, the engineer remained either defensive in his isolated corner of the intricate bestiality, or he confined himself, being interdisciplinary or alone, to produce sculptural forms.

In my opinion, both attitudes are unworthy because they are too superficial, and they satisfy neither spirit nor sense. You need to reply, quoting Ruskin, "We need more than this". I plead for a further work on the synthetic Modernity: this includes a patient, comprehensive analysis of the circumstances, the unbiased investigation of the possible solutions with a large tool box, the critical compression of the approaches into a coherent concept that governs each of the measures. Modern is that this method begins openly, that it considers all aspects of a task, that it produces a result whose parts are so very much related to each other that nothing can be changed. A sign is a certain aesthetic compactness. The interest in the history of your own discipline sharpens your mind, and thanks to education and local experience, it helps you to overcome limits and to find all possible solutions. So in retrospect this design process could be more or less rationally described. This rationality belongs to the engineering profession and it is necessary as a condition of getting a valid result. Whether this rationality is sufficient, however, is a matter of emotion—eventually your emotion tells you when you have completed a design process.



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Notes

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Jürg Conzett

Born in 1956, citizen of Schiers (Grisons, Switzerland). He studied civil engineering at the Eidgenössische Technische Hochschule (ETH) in Lausanne and Zürich and received his diploma in 1980. From 1981 until 1988 he worked as an employee of Architect Peter Zumthor at Haldenstein. Today he leads an engineer's office together with his partners Gianfranco Bronzini and Patrick Gartmann in Chur.

Figure 1. Wye Bridge in Chepstow (Wales), **Isambard Kingdom Brunel**, 1852, destroyed in 1962. The beginnings of Modernity, a bridge with no precedent, with no structural designation. Simultaneity of past and future: a work we have still not reached. Image from *Sammlung ausgeführter Constructionen schmiedeeiserner Brücken*, Mannheim, Verlag Friedrich Bassermann, 1863.

Figure 2. German Alpine Road bridge in Ramsau, according to **Alwin Seifert's** regulations, 1927-1937. The continuous curvature of the bridge body, the continuity of the slope of the side walls at the abutments and arch, and the integration of the bridge parapets make it a work of Modernity. Photo by Jürg Conzett, Chur.

Figure 3. Dorfbrücke, Vals, Switzerland, **Conzett, Bronzini, Gartmann** (engineers), conceptual collaboration: **Peter Zumthor** (architect), 2010. An enriched regionalist Modernism. Through its position and by avoiding the sidewalks, the bridge creates a portion of the village square. The side walls consist of load-bearing gneiss from Vals in conjunction with the concrete slab. Photo by Martin Linsi, Einsiedeln.⁷

Figure 4. Sihlhochstraße in Zurich, **Soutter and Schalcher, Hans Eichenberger** (engineers) and **E. Schindler** (architect), 1974. An elegant structure construction fell into disrepute due to its location. Photo by Martin Linsi, Einsiedeln.⁷

Figure 5. Widening of the Valemberbrücke, Cinuos-chel, Switzerland, **Conzett, Bronzini, Gartmann** (engineers), 2006. A Modern concrete design frames the old bridge using prefabricated supports and upholds at the same time a respectful distance. Photo by Martin Linsi, Einsiedeln.⁷

Figure 6. Goldach Viaduct, Switzerland, **Weder & Prim**, 1971. A powerful work of classical Modernism. Large, elaborately produced spans frame the landscape. The two bridges are defined by their position and the proportions of the pair of pillars. Photo by Martin Linsi, Einsiedeln.⁷

Robert Maillart's Innovative Use of Concrete

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ROBERT Maillart's innovative views concerning the use of concrete come within the scope of the history of structures, structural materials and concrete as a material of structure. It will even lead us far beyond these issues. At the end, the point of view expressed in this article will be the view of a structural designer. When preparing this reflection, I realise that there is no straightforward answer to the question: "What is in fact Maillart's real innovation considering all the contributions he made to the art of engineering?"

Putting forward the different aspects mentioned above as an introduction seems to be a more relevant way to find a contemporary answer taking time and context into account. Consequently the first part of this text is a general presentation of Maillart's works. Following we will make a detour to make what I, and many others, consider to be the most revolutionary aspects of Maillart's practice fully comprehensible. So starting from the historical development of reinforced concrete as a structural material, we will move to the contemporary context to figure out how the intrinsic structural complexity of concrete is managed today. We will see that some difficulties emerge from the behaviour of concrete in relation to the classic theories of mechanics. If some Modern theories find an answer to the problem, it will become obvious that Maillart had already found a convincing way of dealing with these difficulties. We will then return to Maillart's works to answer the question through the status he was to give concrete when it came to structural design and the methods he used to achieve his objectives. I hope this will lead us to consider Maillart's approach as one of the most visionary ever devised.

By Denis Zastavni

Introduction to the Works of Maillart

THE Swiss engineer Robert Maillart was born in 1872 and died in 1940. He worked on more than 300 structures—of which 50 are bridges—between the end of the 19th century and 1940.^{1,2} Initially, Maillart became renowned for new structural forms using reinforced concrete. At a time when concrete was associated with massive material producing and heavy-looking structures, Maillart executed structures with a lightness that had never been seen before. He skillfully produced works of advanced structural executions, reliable and with a high degree of durability. This means that it is a matter of fully rational propositions for structural schemes.

It must be remembered that at the time Maillart was practising, research had been done into the most appropriate structural arrangements with concrete. Maillart's most visible innovation and contribution to research concerns structural forms and systems.

In terms of detail, he invented *Système Maillart* in 1901, a system based on concrete box girder.³

In terms of structure, there are proposals for different structural typologies, for example:

- in arches for bridges:
 - three-hinged arches where he mainly proposed revolutionary forms for the arches;
 - stiffened arches exploiting principle suggested by his former teacher, Wilhelm Ritter;
 - arches with an off-centre thrust line, i.e. arches with high bending forces.
- in bridges: he promoted systems with continuous beams shaped in a singular way.
- in buildings, he promoted a personal vision of the structural arrangement of mushroom-slabs.

Maillart also introduced innovations in other areas. For example, he used graphic statics as a design tool. Indeed, when Karl Culmann devised graphic statics as a consistent discipline, it was with the prospect of using it for analytical purposes.⁴ Maillart mastered the complexity of elaborate structural arrangements by intuitively using contemporary structural principles, in other words long before they were established. He mastered the complexity of the behaviour of reinforced concrete by relying on the specific status he gave the material within a structural scheme.³ Similarly, he managed the complexity of the steel reinforcement needed within a structure by proposing reinforcement patterns that were easily implemented.³

After this first presentation of the main innovations of Maillart, let us return to historical perspectives on reinforced concrete as a structural material.

< Salginatobel Bridge in Schiers, Switzerland, built by Robert Maillart in 1929. Photo by Denis Zastavni.



Figure 1. **Maillart's** reinforced concrete arch Schwandbach Bridge near Berne, built in 1933.

History of Concrete

Maillart is central when it comes to understand the concept and character of concrete. The history of reinforced concrete began in around the mid 19th century. The idea of joining iron to concrete as reinforcement was introduced by Joseph-Louis Lambot and Louis Monier. Structures combining iron and concrete quickly followed with the achievements of François Coignet and William B. Wilkinson. Structural elements, particularly beams, in reinforced concrete began to be patented and developed in around 1880. The first concrete bridges appeared at this time.^{6, 7, 8}

Joseph-Louis Monier, Mathias Koenen and François Hennebique contributed to the perfection of the (internal) design of concrete beams and associated reinforcement patterns. Hennebique's stirrup illustrations appeared in 1892. From then on, the logic of a reinforcement pattern became complete. Meanwhile the history of concrete began far earlier, somewhere at the dawn of history. But a better illustration of the birth of concrete as a new material is found in Lambot's work. In 1848 Lambot used a "coating" of cement on a metallic armature to make a small boat (barque). In 1930, concrete ships were still being produced and used in different contexts. Concrete changed its status: from then on it was able to fully replace

steel and timber. It is light, thin, watertight, even *elastic*.

Designing concrete sections is not the same as calculating them. Various other aspects must be considered to achieve a sensible design. Thinking about suitable forms and sections is one of these aspects. For most concrete designers at the time, it meant reasoning in terms of a system. Most systems were a given association of steel and concrete in a predetermined section. For instance, Hennebique's system came from translation of the form of other materials into concrete ones. To make it viable, he worked empirically to develop an adapted steel reinforcement pattern.

The history of this material is full of attempts at characterising concrete behaviour. Before the 1900s, a series of theoretical modellings was in existence, emphasising various aspects of elastic or plastic collaboration between concrete and steel reinforcement. Some of the methods used, such as Hennebique's, were rather unorthodox.⁶ Even if calculation methods existed, they were far from being widespread. For all these reasons, some countries decided to appoint commissions dedicated to establishing norms. Maillart contributed to Switzerland's national commission⁹ and the Swiss recommendations were the first official ones to be made in Europe.⁶

Contemporary Approaches

Nowadays, those times seem far removed from today's practice: all calculations methods are described in norms and there are marvellous numerical tools to support complexity in design. Concrete structures can be modelled as bars, grids, plates and shells in all possible arrangements and the behaviour of materials can be modelled in a very precise way. For instance, the behaviour of concrete is modelled by use of a parabolic law as described in Eurocode 2.

However some difficulties remain. Concrete has anisotropic properties considering traction compared to compression resistance. As a result of this, concrete cracks so that:

- the mechanical properties of sections change in an unpredictable way, depending on the history of loading.
- the reinforcement of concrete by steel bars is necessary, which in turn...
- changes the mechanical properties of sections

And there is an additional difficulty. In a considerable number of situations, classical theories of mechanics, based on theories of elasticity, do not apply, so that:

- structural analysis requires accurate specialised numerical simulations...
- for which precise mechanical properties are unavailable, leading to a theoretical issue of the legitimacy of numerical simulation.

Even for classical theories of mechanics, there are some insurmountable difficulties. The historical notes that follow come from Jacques Heyman's studies.¹⁰ In 1914, Gábor Kazinczy published in Hungarian the result of tests that he did on steel beams embedded at their ends (encased in concrete):

- he was not able to reproduce the results predicted by mechanical theories for beams with fixed ends considering bending forces.
- he showed a tendency for bending moments to equilibrate along beams.

In 1926, John Baker was commissioned by the British Steel Industry via SSRC (Steel Structure Research Committee) to bring some order into practical steel design, which comprised conflicting rules. Design and analysis were completely elastic processes, at that time. The results of his experimental work was published between 1931 and 1936, and showed that stress measured in real structures bore almost no relation to those produced by the designer's calculations. These results lie at the origin of detailed work on the real behaviour of structures.

Plastic Design

The solution lay in reformatting mechanical theories. In 1938 Nikolas Gvosdev published in Russian the state-

ments and proofs of the two theorems of plasticity (presented during a conference in 1936). His writings remain unknown due to the choice of language in which he published. In 1949 the Americans Greenberg and William Prager established the version known worldwide of the two fundamental theorems of plasticity:¹⁰

- the static theorem, lower-bound or safe theorem.
- the kinematic theorem, upper-bound theorem.

Each of those theorems leads to a specific dimensioning method.

In 1950, Horne established proof of the uniqueness theorem: solutions of the two theorems are identical at the ruin point. For two decades, structural principles relating to plastic behaviour were now being implemented into codes' practices.

Let us express what, in my opinion, is the most important theorem of plasticity—the static theorem:

If a set of bending moments can be found that satisfies the equilibrium at a load factor Q_i , then Q_i is always less than, or at best equal to, the true load factor Q_u , for a perfectly plastic material.

This means that if it is possible for a structure to provide the working of one structural mechanism sufficient to bear the encountered loads, the stability of the structure is guaranteed, whatever the real structural behaviour might be, if the conditions of plasticity are encountered. All this means that:

- a numerical simulation using computers is a possible, and valid, lower-bound solution.
- a simple model is a possible, and valid, lower-bound solution.
- a drawing using graphic statics is a possible, and valid, lower-bound solution.
- an approximate calculation using, apparently excessive, simplifications is a possible, and valid, lower-bound solution.

All these solutions can be equivalent when considering resistance at the ultimate state, collapse.

Let us illustrate briefly this notion of the *perfect plastic material*.

Figure 2 is a stress-strain diagram showing the evolution of the deformation related to applied forces. This diagram is not regular. Steel, after an elastic, regular, linear, zone shown in dashed line, demonstrates a zone of high deformation in continuous grey. The continuous grey zone represents the zone of plasticity on the diagram.

It is simplified in figure 3 which is a diagram used for calculations, where stretching capacities have been voluntarily restricted for safety reasons. So, plasticity is effective, up to a certain point, for metallic materials like steel.

Perfectly plastic materials go a step further: it is possible to stretch the material infinitely without breaking

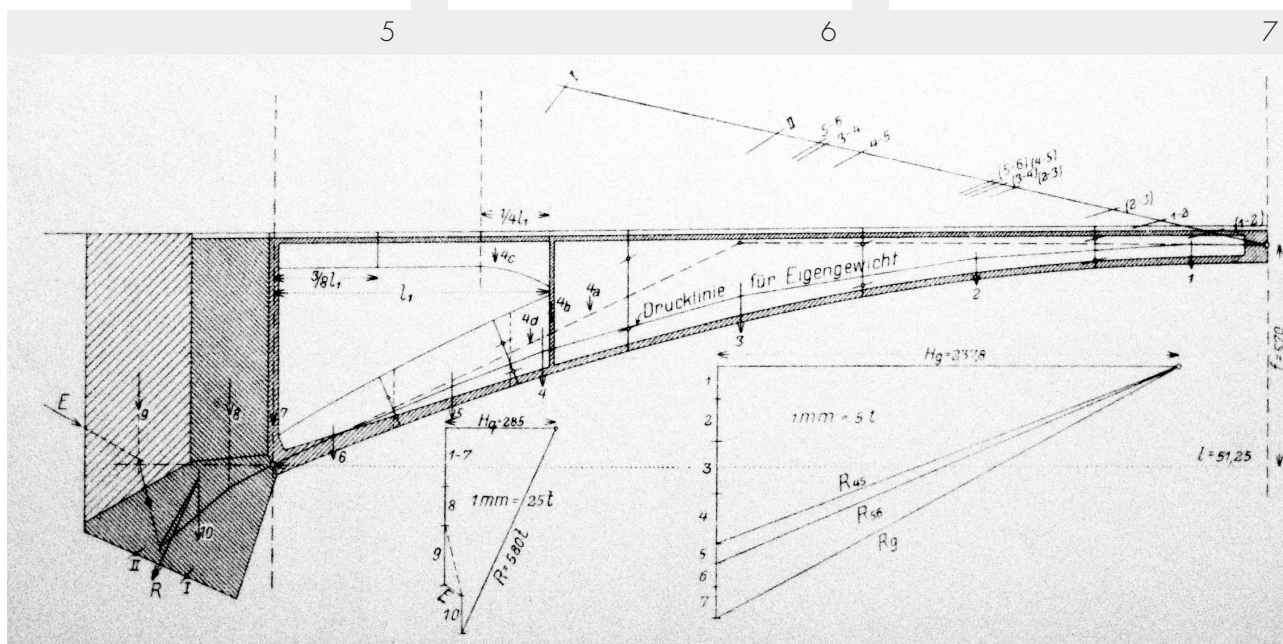
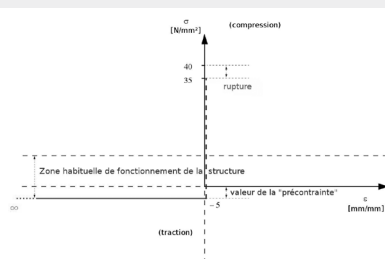
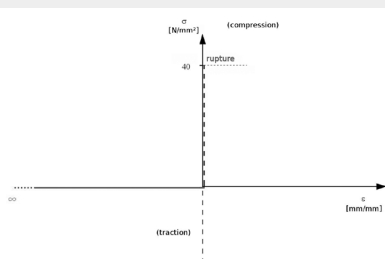
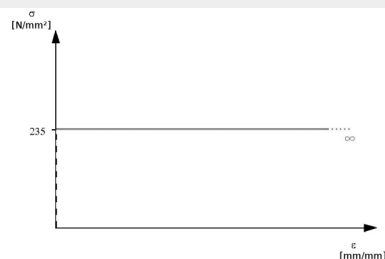
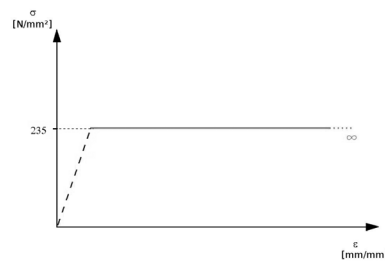
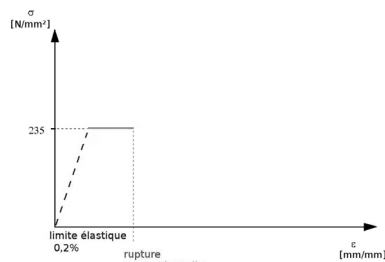
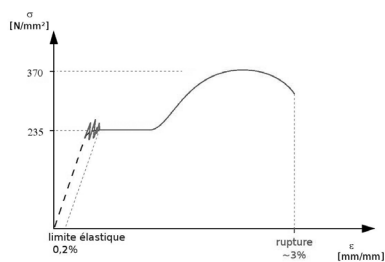


Figure 2. Steel E 235: real diagram.

Figure 3. Steel E 235: diagram for calculations.

Figure 4. Ideal elasto-plastic material.

Figure 5. Ideal rigid-plastic material.

Figure 6. Structural behaviour of masonry (simplified).

Figure 7. Structural behaviour of a masonry acting in compression (simplified).

Figure 8. Tavanasa Bridge: drawing.

[figure 4]. This one has a zone of elasticity; figure 5 no longer has an elastic zone: continuous grey curves being infinite, the whole diagram can be condensed near the origin. These laws can be applied to real material in certain conditions. But what about a brittle material like concrete?

Let us take an extreme example: masonry. With poor mortar inside joints, masonry resists compression, but not in traction: you can infinitely displace a piece of masonry taken from the whole [figure 6]. Things change when a certain amount of pre-stressing is encountered. And it is indeed the case when its own weight or compression forces pre-stress masonries.

In figure 7, the lower zone corresponds to the stresses due to pre-compression or pre-stressing.

This graph is very similar to that of a perfect plastic material. So we see that the law of a perfectly plastic material could apply to a brittle material like masonry, or unreinforced concrete.¹¹ And some ductility can be joined to concrete by using steel reinforcement. So it seems that the only reasonable theory to apply to concrete is indeed the principles of plastic design.

We are now ready to embrace all of Maillart's innovative views applied to concrete design.

Maillart's Innovations

For his own use Maillart defined a set of implicit rules or views for concrete structures and their structural behaviour:

- he saw in concrete an artificial, moulded stone and applied principles of masonry to it.
- despite that, steel reinforcement permitted him to work in more depth on joints and, almost systematically in a secondary phase, on the bending abilities of structures.
- concrete tends to be monolithic so that the principle of integration, or continuity, between elements is the rule for designing sections.
- but cracks are unavoidable, capable of acting as joints so that it is possible to articulate discontinuous rigid sections and interrupt continuity.

With this elementary structural vocabulary established, we are ready to review the principles of Maillart's structural design.

The Zuoz Bridge of 1901 is Maillart's first real invention with his proposition for a concrete box girder, the first ever built.³ At the origin of the form is a U-shape arch, derived from the principle of masonry vaulting. From the outset, a U shape is already a different conception compared to his colleagues' massive unreinforced or reinforced rectangular sections.

In line with the recommendations of some of the leading intellectuals of structural practices of the time, even concrete arches had to be hinged to avoid damages so three hinges were added to the arch. Thereafter, his principle of integrating sections simply led to the creation of a rigid connection between the arch and walls bearing the deck, and thereafter with the deck itself. Rigidly connected walls were indeed cheaper than columns or the stone façades usually suspended on both sides that these longitudinal walls replace.

The first concrete box girder was created even though there was no way of calculating the whole structure, according to ETH professor Wilhelm Ritter, who failed the task of mathematically checking the structure, but agreed with Maillart's principle.³ Maillart therefore had to disregard or leave aside any awkward elements to check the stability of the whole. It means that Maillart first defined

the independent mechanisms (arch, deck's slab, deck's beams, etc.) and associated them in a whole. Secondly, he only considered some specific elements within a complex arrangement; in other words, he only referred to one static scheme inside the real structure.

Put in yet another way, this intuitive way of proceeding was very close to Modern plastic approaches while using the lower bound theorem.¹² It had not been used in the most elegant and considered approach as employed by Maillart for the Zuoz Bridge design, but things were to become more convincing and rational in later works.

The Tavanasa Bridge of 1905 [figure 8] reinforced the position he took in Zuoz. Attention was no longer given to reconstituting a façade along the bridge, and this time changing inertia was conscientiously applied to the bridge profile according to the principle of the three-hinged arch. So, sections were further refined according to their structural function, leading to hybrids, sometimes between U-shapes and double T-shapes, sometimes between box girders and open sections.

Things began to evolve with Maillart's later structures and particularly with his stiffened arch bridges.

The stiffened arch bridge is the supplementary association of a funicular arch with a rigid deck fulfilling the role of a stiffening girder for the arch [figure 9]. This is the perfect inversion of the principles of a suspension bridge, as suggested by Wilhelm Ritter.¹³ It was also a new application of the lower-bound theorem of plasticity: two different and effective elementary structural systems inside the whole structure.

To design a structure like this, the principle is simple: design a sufficiently high stiffness ratio of different elements against bending [figure 11] and also design a sufficiently high stiffness ratio against compression forces. But the importance of these ratios is inverted when comparing elements involved in bending or compression resistances respectively. The stiffness ratio against bending is attained with the dimensions of the section, their mechanical properties to be precise. The stiffness ratio concerning compression forces is attained geometrically rather than mechanically. The correct arrangement of members is the key to develop high resistance using axial forces. It is not a measurable dimension like stiffness against bending. At the same time, this *stiffness ratio* against compression forces is only fully valid for one configuration of loads, unlike stiffness properties considering bending. And unlike stiffness against bending, the issue is rather one of balancing compression forces to the disadvantage of bending forces.

By correctly defining the stiffness ratio between the arch and the deck, the mechanism is effective without producing undesirable interactions, despite the complexity

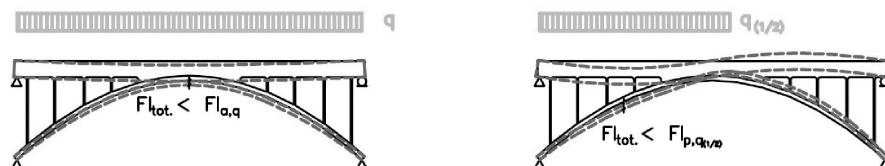
Beams (deck) deformation



Arch deformation



Deformation of arch and deck associated



Bending moments

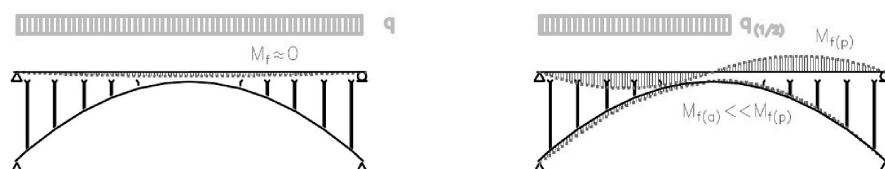


Figure 9. Principles of **Maillart's** stiffened arch bridges.

of the structure [figure 10]. This is precisely the condition that enables a real material to be employed instead of a perfectly plastic material in using the lower-bound theorem. This condition conveys the fact that where structural behaviour is relatively close to the one that exists naturally in the structure, large preliminary deformations do not need to occur in the structure before the theoretical behaviour can be activated thanks to a geometrical modification, relying the possibility of this deformation on the structure's plastic capacities. The best way of matching theoretical behaviour to the one that exists naturally in the structure is to define the geometry intentionally through its design to activate preferentially the intended theoretical behaviour. These ratios for compression forces are similar considering the section areas but the deck is 19 to 22 times stiffer than the arch when bending is taken into consideration. Therefore, elementary graphic procedures, to guarantee geometrical stiffness in compression, i.e. a funicular line, and the correct stiffness ratio are sufficient for designing such a bridge [figure 12]. The principle is structurally efficient and suitable for an efficient way of building a bridge in the early 20th century; in short, it is highly rational. On the first occasion when this principle was interpreted, specifically for the Valtschielbach Bridge of 1924 [figure 13], the arch line remains circular but the

funicular thrust line remains very close to the axis of the thin arch's line. Considering the accuracy of the geometry, things will change later.

Geometric rules evolved slightly with the Salginatobel Bridge [figure 14]. Here we observe the convergent influences of the previous three-hinged arch bridges and the stiffened arch bridges of Maillart. However structural behaviour is strictly defined as seen in his previous hinged bridges. More in-depth work has been conducted on the definition of the section. Meanwhile mechanically speaking it remains a symmetrical box-girder section. But a recursive use of working drawings of graphic statics allowed Maillart to carry out detailed work on designing cross-sections.¹⁴ Indeed, proportions and mechanical characteristics continuously evolve along the bridge. And later, the geometries of arches were studied to be perfectly funicular for the compression forces according to one reference loading case, as with the Schwandbach Bridge for instance [figure 1].

Up to this point, it could be considered that I am undertaking a kind of interpretative review of Maillart's work. Indeed, I am offering an interpretation of the structural mechanism at work in Maillart's bridges or structures. However what is a particular and constituent part of his methods is that these behavioural principles were

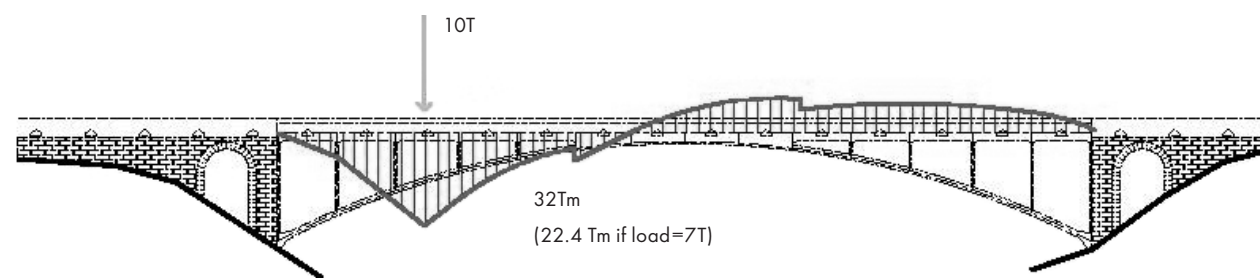


Figure 10a. Valschielbach Bridge: bending moments.

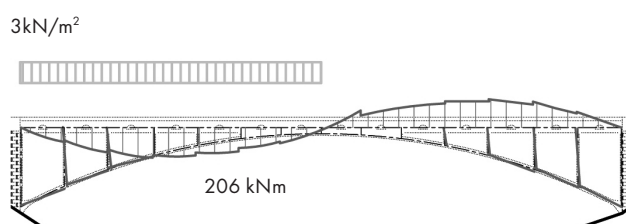


Figure 10b. Valschielbach Bridge: bending moments.

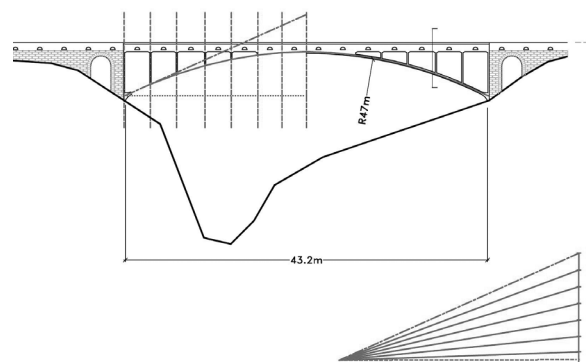


Figure 12. Sketch of the arch of **Maillart's** Valschiel Bridge (1925) using graphic statics: the arch is semi-circular but thrust line remains inside.

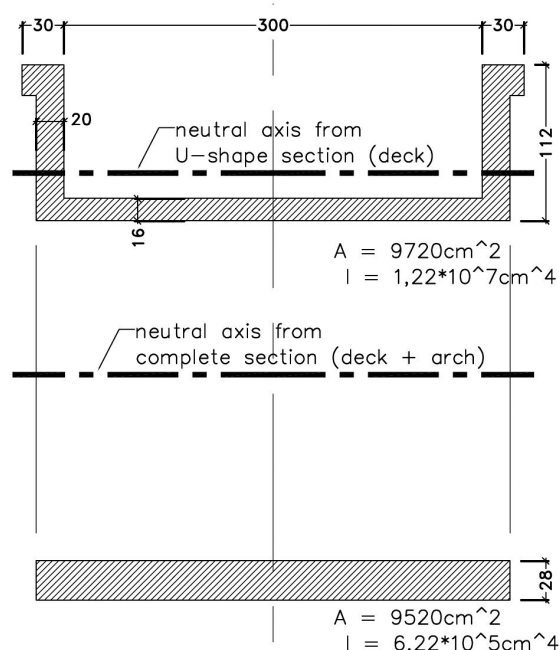


Figure 11. Valschielbach Bridge: stiffness ratios.

initially defined in his design procedures. This is easy to demonstrate when looking at his design calculations. In a way, these behavioural principles for the structure are at the core of his work on structural design. The structural form is, so to speak, constructed around them.

Similarly, one may think that Maillart was forced to use graphic statics as the only available tool to calculate his structure. Indeed, we encounter working drawings of

graphic statics almost systematically along with the files that still exist in the archives. But the history of engineering sciences is initially full of algebraic methods or methods using differential analysis. Indeed, his contemporaries despised what they considered to be Maillart's unorthodox way of performing structural analysis.^{3,9} This is certainly due to a poor understanding of Maillart's structural systems, and obviously Maillart disregarded these analytical methods being inappropriate to calculate his structures.

On the contrary, we may observe Maillart using graphic statics again and again on the same structure with the same loading case, mainly dead load, to draw the same elevation every time to ensure that he has attained the right form to enable the determined structural behaviour to be effective.¹⁴ Thus graphic statics is not analysis, it is morphogenesis.

We see that Maillart continuously used graphic statics for different purposes. Beyond working on establishing loading paths intended for materialisation in the concrete structure, he also used graphic statics to correct geometries to be able to equilibrate forces in a structural design. For the design of the Chiasso Shed, traces of a funicular can be recovered from the geometry and it is no longer possible to explain the geometry without resorting to constructing equilibriums using graphic statics.¹⁵

Even the reinforcement pattern will contribute to characterising the geometrical definition of the elements of the structure. In the Chiasso Shed, for instance:



Figure 13. Valschielbach Bridge, 1925.



Figure 14. Salginatobel Bridge, 1929.

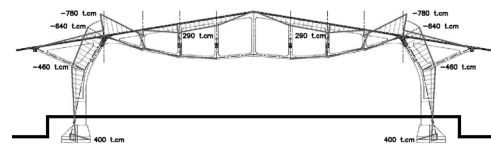


Figure 15. Chiasso Shed (1924): bending-moments.

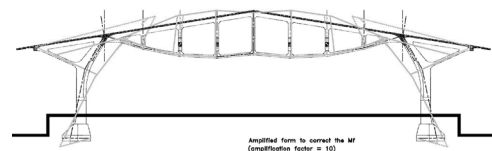


Figure 16. Chiasso Shed (1924): A correction of the geometry to set bending to zero under maximal loading means translating nodes to maximum 5 cm. Any correction is meaningless.

- in funicular members, steel reinforcement is just sufficient to respond to axial forces.
- in the junction-columns it is no more than technological.
- the upper T beam concentrates both bending-stiffness properties and reinforcement steel.⁵

And where is the analytical part of the design?

Essentially at the very beginning when the structural behaviour is devised, before the structure exists and before it is calculated; analysis is used incidentally to accompany the geometrical definition of sections during the form's design; and lastly it is used to write the design calculations.

Indeed, analysis is unnecessary if the result is known:

there is no need to undertake a large degree of structural analysis to grasp the intrinsic nature of the structural behaviour. Initially devising the structure's behavioural principles, related to the application of the static theorem of plastic design, does this before the form even exists.

By the use of numerical simulation it is possible to evaluate the quality of the structural response to loadings. Naturally Maillart did not have an analytical result like this at his disposal, and of course, this is an elastic simulation; this means it is another type of approximation, a new static configuration within the scope of the application of the lower-bound theorem of plasticity. But even

there, we see on figure 15, the behaviour in bending is consistent with the one of stiffened structures. Indeed this corresponds to the method used for designing this structure, i.e. a complex variation of stiffened arches integrating principles of mushrooms-slabs!

Figure 16 shows the correction to apply to the geometry to be sure that any bending forces are eliminated, i.e. to optimise the configuration by retaining only the most efficient forces, that is compression or traction. The figure shows these corrections multiplied by ten. The maximum correction is 5cm, this means 1mm on the working drawing at a scale of 1 to 20, so it is impracticable geometrically speaking.⁵ For a structure with a span of 23.6 m, this corresponds to a tolerance of 1/472. It means we could consider this structure as being perfect... even without considering the impreciseness due to the use of a real material that will crack.

Conclusion

In summary, we have reviewed Maillart's use of some graphical methods. Graphic statics are used to:

- organize the load paths and thrust lines.
- draw funicular curves or equilibrium schemes for form-finding.
- study the magnitude of forces along force trajectories or schemes.

One can extend the use of graphic statics by converting bending to thrust lines for interpretation and eventual corrections, corrections that prove not to be of use to the Chiasso project. We could also compare the kind of method that is used today in plastic design to manage zones where Bernoulli's hypothesis does not apply, non-linearity in strain distribution: the Strut-and-Tie Models.^{16, 17} And we will be forced to note that it is very similar to Maillart's method of managing equilibrium at the scale of the structure. This again demonstrates the great relevance of his approach.

First of all, it has been concluded that Maillart's approach is simplification supported by graphics. And we recognize the strong connections with contemporary principles of plastic design. For Maillart, concrete is used firstly as a *thrust material*. Due to his conception of this material as such, great structural efficiency is achieved with few cracks and therefore little damage over time. Maillart was also a builder, integrating aspects taken from construction into his design, making his projects particularly cost-effective. He paid attention to aesthetics, controlled and steered technical rules according to how the projects would look. When all is said and done, by using these methods, he managed to produce works of great architectural quality and relevance. To me, certainly among the cleverest ever devised.

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Denis Zastavni

Studied architecture and engineering at the University of Louvain-la-Neuve (UCL), Belgium, where he also studied some philosophy. He has worked as a structural engineer and architect for over ten years. For six years he was an assistant at the university, running sessions on concrete calculation, technological aspects in architecture and teaching architectural design studios. His PhD was on Robert Maillart's design methods. His main publications are on structural design, pedagogical approaches in teaching structure and technology, and Robert Maillart's designs. For the past year he has been working as an assistant professor at UCL, teaching structure, material and architectural technology. His current research is focused on structural design approaches and tools and on deepening his knowledge of Robert Maillart's structural methods.

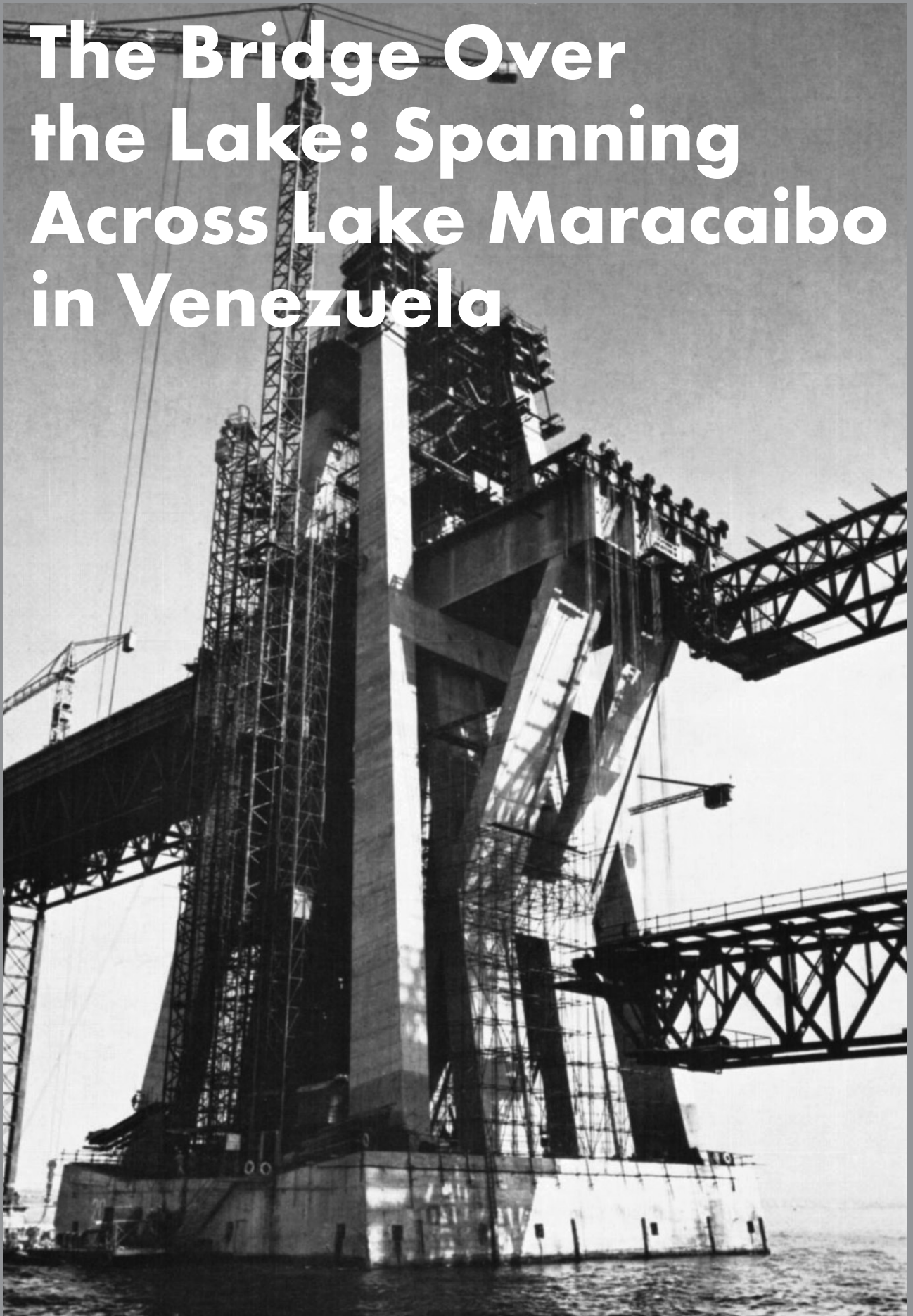
© Figure 1 from ETH Collections.

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© Figure 8 from Robert Maillart in *Schweizerische Bauzeitung*.

The Bridge Over the Lake: Spanning Across Lake Maracaibo in Venezuela

22



THE General Rafael Urdaneta Bridge spanning over Lake Maracaibo in Venezuela (1958–1962), designed by Ing. Professor Riccardo Morandi, a masterpiece of Modern engineering, is now a Modern Landmark at Risk. The remarkable and little known story of the construction of this structure “could not be accomplished by a handful of men. From planning to financing, from design to construction, a great number of Venezuelan and European engineers worked jointly in Wiesbaden, Caracas, Rome, Maracaibo, Zürich, Paris, and Lisbon. In this way, one of the most outstanding structures of our time was erected within the stipulated—and brief—construction time.”¹

By Hannia Gómez and Rino Montiel

“When I am going to Maracaibo and begin the bridge to cross, I feel such a strong emotion that my mind begins to and begin the bridge blur strong emotion.”⁶

Maracaibo 15

A Lake Façade

THE city of Maracaibo has in the Bridge across Lake Maracaibo, Venezuela, (or “Bridge Over the Lake,” as it is commonly known), a monumental Modern city gate of territorial importance like no other city in Venezuela, and maybe in the world.

The bridge can always be seen from the city of Maracaibo. Its unforgettable architecture draws a modern skyline on the lake surface, completing the horizontal and extended skyline of the city itself. The bridge is the main sign of the Modernity of Maracaibo: it is its façade on the lake, and its upmost Modern landmark.

This masterpiece, built in the period 1958–1962, “was recognized at its time as one of the greatest works of modern engineering, enhancing its majesty the fact that it crosses the lake of Maracaibo, the largest in South America and a large reservoir of oil fields.”³ It is the subject of enduring national pride, having been designated on July 16, 2001, as a Good of Cultural Interest of Zulia State, and listed as a National Landmark on August 21, 2002.

Almost a decade after these landmark designations, the dramatic decay of its overall structure and the increasing difficulties to preserve its original qualities situates it as a Modern Monument at Risk, in heavy need of attracting the international attention of the scientific community.

Building a Bridge Across Time

The most important record and unique compilation of the history of Bridge General Rafael Urdaneta was published in a non-commercial book in 1963 in Germany by Dr. Ing. Hanns Simons, Heinz Wind, and W. Hans Moser.

It is called *The Bridge Spanning Lake Maracaibo in Venezuela: The General Rafael Urdaneta Bridge*.⁴ Most of the information and illustrations that we include here come from that book which is a landmark in itself.

Every single step of the construction process is there described thoroughly with wonderful drawing schemes and photographs. Running through the pages is like jumping back to an era of excellence, courage and building genius.

Bridge Will Assist Communications and Economic Development

By 1961, Venezuela “had an annual petroleum production of 150 million tons, and in the Western World it was second only to the United States as a producer, ranking first as a petroleum exporter. 70% of the oil produced came from the Maracaibo area.” The reserves at that time were “among the richest in the world.”⁵

Until 1956, “Maracaibo, remained physically distanced from Venezuela. Zulia State’s economy was fundamentally based on port activity, and it was easier to travel to the islands of Aruba and Curaçao than to Caracas, the capital city.”⁶ In the rest of the country “the development of industry and agriculture, and the exploitation of mineral resources were hampered by the long distances to be travelled in difficult terrain. Consequently, economic development essentially called for the construction of new, and the improvement of existing communications.” In addition, “new and improved communications with neighboring countries were required to provide transportation facilities. Improvement of the Pan-American Highway, comprising the Lake Maracaibo Bridge, ranked high among the tasks to be handled.”⁷ The bridge was an important solution to link to the international road network.

What was called at the time “The Oil Country” on the east shore would be “finally connected with Maracaibo. Venezuela’s major oil-fields are located in the eastern part of Zulia. There—between Cabimas and Mene Grande—petroleum from the inland and offshore wells is collected and piped, field-processed and transferred to oil tankers. The oil companies have their head offices,

< General Rafael Urdaneta Bridge.

A service girder is being raised into position.

wharves, repair shops and utilities at Maracaibo, where, on the western shore of the lake, are also situated the harbor facilities and the international airport".⁸

From Planning to Contact Award

Never before a bridge of such proportions had been built as a reinforced and prestressed concrete structure. Its total length of 8,678 m, five 235 m main spans and 45 m headroom launched this bridge in the late 1950s as the longest bridge of this kind in the world.

In the initial stage, the Venezuelan Government "carried out extensive investigations to determine the most favorable point for crossing the lake, be it by bridge or tunnel." Five routes were tested. "Routes A to E were tested with regards to topography of the lake bottom, type of subsoil, navigation requirements and, in particular, in respect of connection with Maracaibo's traffic system. From all these, Route D provided the best solution in that it gave a direct connection between the new international airport and the oil-fields on the east shore of Lake Maracaibo. A further advantage of this route is that it runs at right angles to the shipway direction of current, which makes navigation under the bridge much simpler."

Having thus established the most suitable location, "the Government of Venezuela in 1956 called for bids for a 9,000-metre-long structure along Route D. Bidders were invited to offer a bridge or a tunnel, or a combination thereof. The structure has to have four highway lanes, a single-track railroad and openings."⁹

It was in this way that "from different parts of the world proposal began to arrive: tunnel and bridge projects or their varied combinations."¹⁰

First international Tender Action (1956)

Ten firms were invited to tender. They submitted eighteen varied designs. Four of these designs "would permit a continuous flow of road and rail traffic, regardless of shipping."¹¹ The other designs "provided level railway

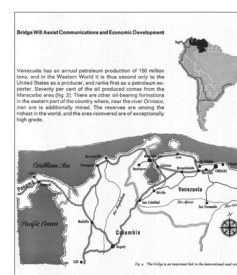
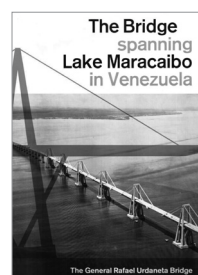


Figure 1. The bridge across the lake can be always seen from the city of Maracaibo, Venezuela.

Figure 2. Satellite view of Maracaibo with the General Rafael Urdaneta Bridge, Venezuela, <http://www.skyscrapercity.com/>

Figure 3. Cover of the book compiled by Dr. Ing. Hanns Simons, Heinz Wind, and W. Hans Moser, *The Bridge Spanning Lake Maracaibo in Venezuela: The General Rafael Urdaneta Bridge*, Wiesbaden-Berlin, The Bauverlag GmbH, 1963.

Figure 4. The bridge is an important link to the international road network.



and road approach sections as far as the central spans. For rail traffic there was then a vertical lift bridge, and for road traffic a tunnel or a separate bridge to link the approach sections.”¹²

The story of this incredible competition of designs is in itself an issue for further analysis, waiting still to be told.

Second International Tender Action (1957)

The tenders submitted during the first action had to be abandoned, “because of fresh stipulations about the shipping and highway authorities. Accordingly, in 1957 the Venezuelan Government invited the same selected firms to submit new bids in order to take account of the changed conditions.

It was specified that the free central span of the bridge should have a 400 m waterway, and that on either side of this there should be five openings each giving a waterway of 150 m. It was also specified that these eleven openings should have a 45 m vertical clearance and be located above the natural shipping channel.

Twelve bids were submitted; they ranged from 284 million to 760 million Bolivars (at that time the exchange rate was 3.35 Bolivars to the American dollar). With one

exception, all the designs provided for a steelwork superstructure. Only one tender submission was based on an all-reinforced and prestressed concrete structure.”¹³

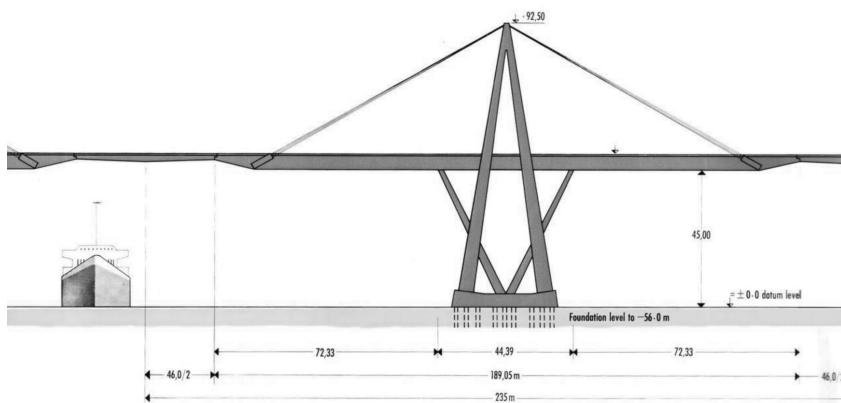
The government commission recommended the acceptance of this bid because:

1. Greatly reduced maintenance costs. Because of the climatic conditions in the Maracaibo area, the annual upkeep of a steel structure was estimated at two million Bolivars.
2. The visual appeal of the design.
3. Less foreign exchange would have to be spent on imported materials.
4. A large number of Venezuelan engineers and skilled labor would be given the opportunity of acquiring experience in prestressed concrete fabric.

Thus, on May 25, 1957, the Venezuelan Government approved the design and accepted the bid of 329,580,136 Bolivars. The finalized contract was signed in Caracas, on August 15, 1957.”¹⁴

The Men Behind The Design

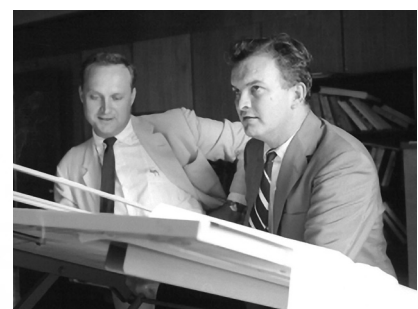
But, who were the bid winners? The Venezuelan Ministry of Public Works awarded the contract for the design



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Figure 5. The 235 m main spans. The deck is 50 m above the lake level.

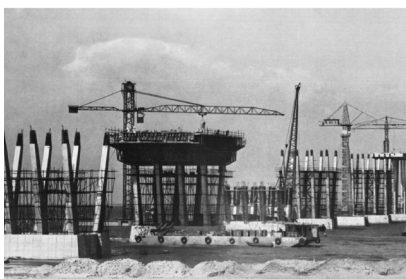
Figure 6. Professor **Riccardo Morandi**, engineer (Rome 1902-1989), Photographer and date unknown, <http://www.civilengclub.com/>.

Figure 7. **Precomprimido C.A.** founders, engineers **Oscar Benedetti** and **Juan Otaola Paván**, circa 1950. *Universidad Católica Andrés Bello*, Caracas.

Figure 8. Professor Ing. **Morandi's** design for the second tender.



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and construction of the new bridge "to the Consortium *Puente Maracaibo*. The Consortium comprised Precomprimido C.A., from Caracas, Venezuela, and Julius Berger A.G., from Wiesbaden, Germany. Firms associated with included Grün & Bilfinger A.G., Mannheim, Philipp Holzmann A.G., Frankfurt a. M., and Wayss & Freytag K.G., Frankfurt a.M., all of Germany. Most importantly, a design by Professor Ing. Riccardo Morandi, Rome, "served as the basis for the structural analysis and detail plans."¹⁵

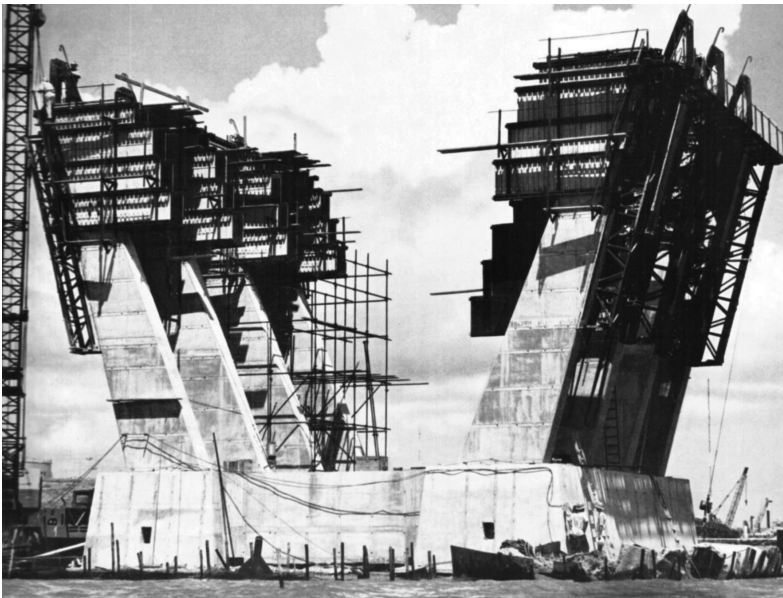
World-known Professor Morandi was born in Rome in 1902 and graduated in Engineering also in Rome in 1927. He was an internationally acclaimed engineer, "who practiced as an international counselor in Building Construction Techniques and as a Professor in charge of Bridge Form and Structure courses at the *Facoltà di Architettura dell'Università di Firenze*. Before winning the international competition for the bridge over lake Maracaibo, he had won in Venezuela in 1951 an international competition to build a bridge in the zone of Pagüita in Caracas and had built a bridge over the Tuy River, close to the capital."¹⁶

Precomprimido C.A. is since 1951 "Venezuela's most important engineering and construction company. Its

founders, engineers Juan Otaola Paván and Oscar Benedetti, were pioneers in Venezuela in the construction of highly engineered works. Theirs was the first company to use prestressed concrete in the country. Among their other Caracas important engineering works are the New Republic Viaduct (also with Riccardo Morandi, 1954) and the famous La Gaviota Bridge (1955)."¹⁷

The Consortium was also conformed by the renowned German enterprise founded in 1890, Julius Berger A.G., and engaged Professor J. Kérisel, Paris, "to handle the particularly complex aspects of soil mechanics. The National Laboratory of Portugal, Lisbon, was commissioned by the Venezuelan Government to carry out model tests to prove the fundamental principles and structural analysis results. The examination of the structural analysis and working drawings prepared by the Consortium and the control of design were entrusted to the late Professor P. Lardy, G. Schnitter, and Dr. F. Stüssi, of the Swiss Federal Polytechnic Zürich. The excellent co-operation of all concerned made it possible to complete the prodigious construction, including all design work, within the contract time of forty months."¹⁸

An immediate start was made on equipping the site.



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Figure 9. Site seen from the air.

Figure 10. Concreting pier cap.

Figure 11. Structures 22, 23, 24 and 25 under construction.

Figure 12. Handling a 6-metre-long pile.

Figure 13. The Ajax 250 T floating crane handles 46.60 m precast girders.

Figure 14. Climbing shuttering for V-shaped piers in place.

Figure 15. The Giraffe 125 T floating crane places a service girder on one of the two highest piers of the 85 m spans.

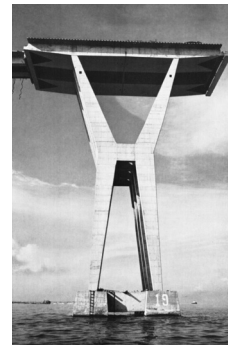
Figure 16. Trestle pier towers 49.50 m into the sky.

Figure 17. Bridge ropes were pulled on the catwalks up to the roller saddle and down the other side.

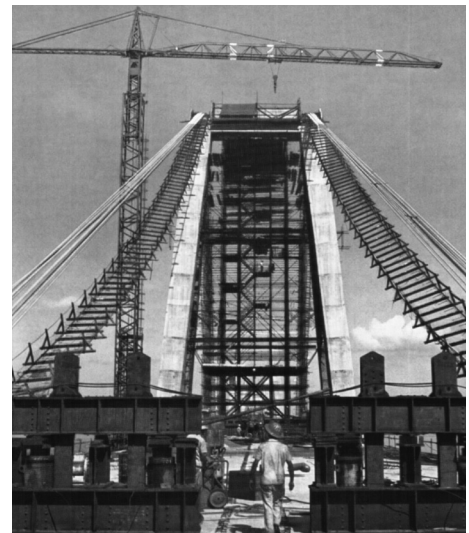
Figure 18. View of center spans.



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Nevertheless, in January 1958, operations had to be suspended because a new government came in to power. The dictatorship of General Marcos Pérez Jiménez had come to an end after a major popular rebellion. On February 13, 1959 Rómulo Betancourt takes office to rule the country for the second time, in a term that "was marked by the development of the oil industry in Venezuela with its adherence to OPEC", and the building great civil works.¹⁹ It was his duty "to inaugurate the work on August 14, 1962."²⁰

Fortunately in the meanwhile, the Ministry of Public Works managed "to discuss with the contractors ways of reducing the construction costs. As there would have been no immediate need for a railroad track across Lake Maracaibo, it was decided that this part of the project should be dropped. Also, at the request of shipping interests, the proportions of the main spans were amended.

The design was revised to give five openings, each having a 200 m width of waterway, and the original 400-metre-wide central opening was deleted; the vertical clearance was to be 45 m.

In April 1959 work was started."²¹

Principles of Winning Design

Maracaibo is not situated in a seismic area, but it is not immune to shock waves from earthquakes in adjacent regions. As is written in the book, "the employer required

that, should one span of the bridge be affected by an earthquake disturbance, the adjoining spans would not also suffer damage. Therefore, the design provided for all members to be of the statically determinate type.

In order to complete the 8, 678-metre-long bridge in the short contract time, it was essential that, wherever possible, uniform members should be used. This enabled numerous units to be prefabricated at a plant on shore, specially equipped for the purpose.

Starting from the low eastern shore, the structure features a 406-metre-long embankment, after which come twenty 36.60 m spans. This effective span was decided upon for the railway and road bridge, and had to be adhered to because the foundations had been completed when it was decided that the bridge should be for road traffic only. Then follows a section having seventy-seven 46.60-metre-spans, initially, this is 5.5 m above water level and then rises at a gradient of 0.45% and ultimately at a gradient of 2.47% to reach a height of 24 m. Up to this point the 46.60-metre-spans provide openings of balanced proportions. But if this span had been retained for the next section of the bridge, extending to a height of 50 m, the design would have been monotonous and the piers disproportionately high.

Therefore, the span was increased to 85 m, and instead of plain piers, V and H trestle piers were employed; on top of them were mounted 39-metre-long caps, thereby permitting the continued use of the 46.60-metre-girders as suspended spans. As the height of the bridge increases, the V shape of the trestle piers is gradually transformed to an H by lengthening the pier legs in their lower parts. The size of the caps, V-sections of the piers and cross beams remains constant. Consequently, only minor changes were required in the centering, shuttering and reinforcement, from one pier to another. This facilitated and accelerated the construction operations.

Two special trussed steel centering were fabricated for the caps. They had high-quality plywood shuttering. The shuttering and practically all the reinforcement were assembled on these centering on land, and a complete service girder was placed in position with the aid of large floating cranes. It was extremely difficult to bridge the navigation openings of 200-metre-waterway and 45-metre-headroom by a reinforced concrete structure.

To this end, for the first time in the world, five large tied cantilever bridges of concrete, having 235 m spans, were designed and constructed. The inclined ropes for the cantilevered girders pass over 92.5-metre-high reinforced concrete towers. Extensive investigations and calculations were necessary to determine the complex system of forces in the ropes, cantilevered portions and reinforced concrete towers."²²

Bridge Administration (1962–1990)

Forty months after the works had begun, the bridge was ready to start operating.²³

From 1962 until 1990, "the management of the bridge was done by the National Government through the Ministry of Finance, who performed the activities of collection and administration of funds, and by the Ministry of Public Works, responsible for maintaining the structure.

In December 1989, the Congress of Venezuela transferred directly to the states the conservation and use of all the roads, bridges and highways in their territories. On July 26, 1991, the Zulia State Legislative Assembly enacted the "Law according to which the Zulia State assumes the Conservation, Management and Use of the bridge General Rafael Urdaneta over Lake Maracaibo."²⁴

Preservation Policies (1990–2009)

According to a concern for keeping in optimum condition the bridge structure, the Zulia State Government assumed as a priority the allocation of investments for the rehabilitation and continuous improvement of the bridge's conditions.

The main objective was to restore the structure to its "brand new" condition, taking into account the bridge's original load capacity and levels of service."²⁵

Maracaibo Bridge is Falling Down

In May 2009, the Venezuelan Government decided to re-centralize again the management of the bridge. Since then, an increasing deterioration began. This decay lasts until today. Minor and major maintenance "is only performed to correct problems and as a reaction to crisis."²⁶

In 2010, the *Colegio de Ingenieros de Venezuela* publicly expressed its alarm. It said that the bridge is in an emergency, "due to a crack in its structure which has yielded several centimeters." In this regard, they asked for its immediate closing: "a comprehensive review of the entire structure is required, and can no longer be postponed." And they warned that "a partial collapse might occur." The main problem is "the degradation of concrete in several of the bridge parts" and the decay of the ropes. Also, "the falling parts of concrete pieces, leaving the steel uncovered."²⁷ Corrosion damage is practically everywhere.

Traffic in the bridge over the lake has increased enormously, but as the control scales are damaged, no one surveys the number of vehicles going upon it today. A very dramatic situation for a structure designed for a maximum of 20,000 vehicles per day, which now is said to be having 40,000 per day.

Local fishermen and marines from the Lake Maracaibo also do their own alarm call to the national and inter-

national community: “If you see the bridge from below, you would not want to pass over it.”

Notes

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3. Remark from engineer Rino Montiel, ex-Director of the General Rafael Urdaneta Bridge.
4. Simons, Wind and Moser, *Op.Cit.*, 1963, 19.
5. Simons, Wind and Moser, *Ibid*, 1963, 5.
6. Rino Montiel.
7. *Idem*, 1963, 5.
8. *Idem*, 1963, 6.
9. *Idem*, 1963, 7.
10. Rino Montiel.
11. Simons, Wind and Moser, *Op.Cit.*, 1963, 8.
12. Simons, Wind and Moser, *Ibid*, 1963, 9.
13. *Idem*, 1963, 9.
14. *Idem*, 1963, 10.
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22. Simons, Wind and Moser, *Ibid*, 1963, 12–14.
23. *Idem*, 1963, 120–121
24. Rino Montiel.
25. Rino Montiel.
26. Rino Montiel.
27. “Expertos piden declarar en emergencia al Puente sobre el Lago de Maracaibo” <http://ovario.wordpress.com/2010/02/19/expertos-piden-declarar-en-emergencia-al-puente-sobre-el-lago-de-maracaibo/>

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Hannia Gómez

President/founder of the Caracas-based foundations *Centro de la Ciudad* and *Fundación de la Memoria Urbana*. She studied Architecture at the FAU *Universidad Central de Venezuela* in Caracas and Urban Design at the GSAPP Columbia University in New York City. She is author of the books *El Cerrito: Gio Ponti’s masterpiece in Caracas* (2009) and *Gego, Architect* (2007), and of numerous texts dealing with architectural and urban culture. A writer, architecture critic and curator, she is also founder and Vice president of the Venezuelan Chapter of **docomomo**.

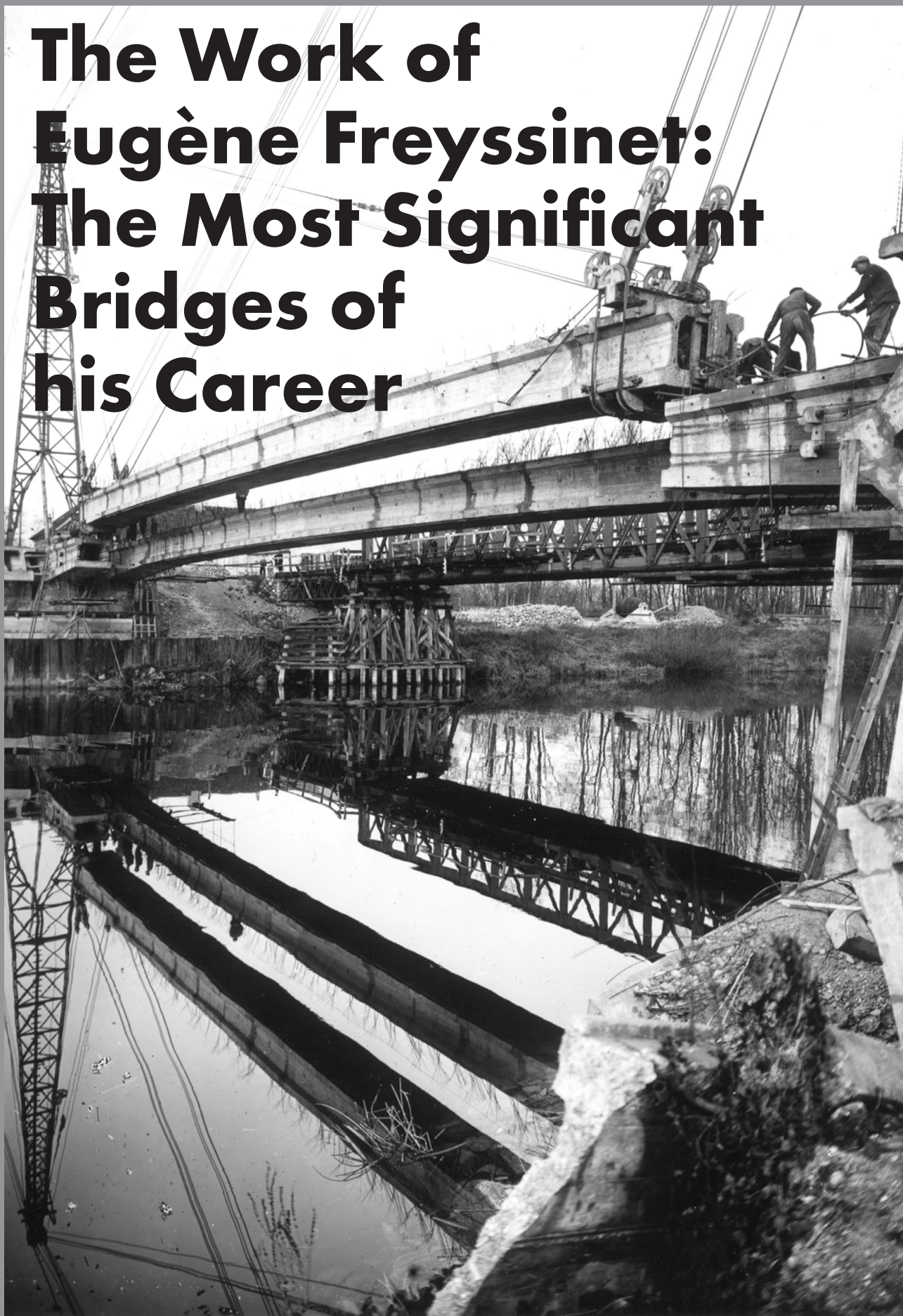
Rino Montiel

Civil Engineer and a MS in Business Administration and Project Management from the *Universidad del Zulia* and the *Universidad Rafael Urdaneta*, Maracaibo. He worked for twenty-one years at PDVSA (Petróleos de Venezuela S.A). For a four-year period he was Director of the Bridge over Lake Maracaibo. He currently works with the Government of Zulia State.

The authors want to give special thanks to architects Jasmine Lizcano, Director of the *Centro Rafael Urdaneta* in Maracaibo, Zulia State, and Frank Alcock, grandson of engineer Gustavo San Román, who participated with his firm VICA in the tender actions for this bridge, both **docomomo** Venezuela members.

The Work of Eugène Freyssinet: The Most Significant Bridges of his Career

30



FROM 1904, when his career began, until 1962, when he died, Eugène Freyssinet did not stop building or advising on all aspects related with his work. To give an idea of his interest in the field of bridges, we selected the following: the Veurdre and Plougastel bridges as reinforced concrete examples and the Luzancy, the Marne and the Caracas La Guaira highway bridges as prestressed concrete works. In these brief descriptions, rather than the technical nature of the design, we have focused on intuition and innovation which made these works models and which inspired many engineers to continue working respecting quality.

By Pierre Jartoux

"I AM a natural-born builder!" expressed Eugène Freyssinet in the late 40s, when he remembered the successes of his career while lecturing or writing articles. His roots from Corrèze, his studies at the *École des Ponts et Chaussées* (School of Civil Engineering)—where he was taught everything that Séjourné had developed making magnificent stone vaults—became an intellectual heritage that predisposed him to this profession. His engineering career began in the early 20th century—Portland cement had been invented by Vicat more than a century before, mortar had been used by Monier¹ to erect light constructions replacing wood, and in the late 19th century, Hennebique realized the first real concrete structures and Coignet built a bridge over the Seine, the *Viaduc de la Vanne*. This new material, the mechanical properties of which were barely known except for its ability to set and harden over time and that it could replace stone, captivated the young engineer during his first job for the public works in Vichy. What attracted him was the moldability, the simplicity of its fabrication and its low cost. His origins from Auvergne—origins usually linked in France to extol the virtues of economy and even of avarice—could not fail to point out this quality. He used this material from a builder's point of view—he made some small bridges over the Bourbonnais streams—but especially from a scientific point of view. In 1903, while visiting the consoles of the *Rue de Rome* in Paris over the *Gare St. Lazare*, built by his master Rabut, he had become aware of one of concrete's significant insufficiencies: the cracking in the strained parts of a structure. Being a practical engineer, he drew two conclusions which underlie his long career. The first one was that concrete should not be used other than in structural forms, undergoing only compressive stresses, something that he systematically did using the vault form until 1930 and getting the most out of it—successfully beating world records and making structures

such as the Veurdre Bridge on the Allier River (1911) and the Plougastel Bridge, officially Albert Louppe Bridge (1930). The second conclusion was the determination to control and eliminate cracking which became possible with the invention of prestressed concrete, a new material which would "revolutionize the Art of Building." He built numerous bridges with prestressed concrete among which we have chosen the most striking ones: the Luzancy Bridge on the Marne River (1942–46), the bridges over the Marne (1947–51), and finally the three bridges on the Caracas–La Guaira Highway (1951–53).

The Veurdre Bridge

From 1907 to 1911, the Veurdre Bridge had occupied my mind almost constantly. I had always loved it more than any other of my bridges, and from all of those that the war destroyed it was the only one that caused me real grief. What I can say about it is similar to what Mistral said about Mireille in his Epistle to Lamartine: "It's my heart and soul. It is the flower of my years."

After such a confession, more than 40 years after its construction, it was important to begin our article with the saga of this work. It was an adventure in which one of two players was the entrepreneur François Mercier. When the need to replace the existing three-section suspension bridge appeared, the Administration prepared a masonry project. Mercier discovered in Freyssinet's office a similar work for the site of Boutiron, upstream of Vichy, a simple exercise that had been made without the prejudices of the daily tasks of the *Service Vicinal* Engineer. After thinking for a few minutes he declared "I like this project and I want you to carry it out in full freedom and at your own risk. It's easy to arrange: I offer the Department the reconstruction of its three bridges—Boutiron, Châtel-de-Neuvre and Veurdre—according to your project for which I am responsible together with the needs for studies and construction. For each bridge, I request a lump sum equal to one third of the amount provided for the sole Veurdre Bridge, payable at once if the tests are satisfactory. If unsuccessful, I will rebuild each bridge according to the draft prepared by the Administration; the

< The installation of the central preassembled beam on the on-site prefabrication grounds. Luzancy Bridge by Eugène Freyssinet.

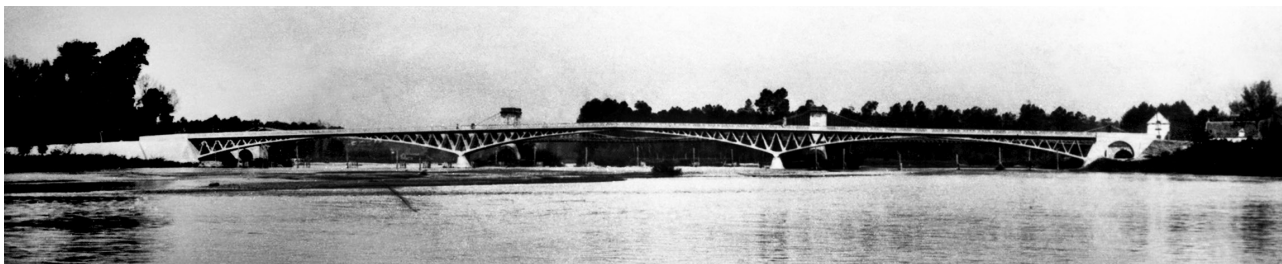


Figure 1. General view of the Veudre Bridge.

Department cannot refuse such an offer.” And indeed, it did not refuse the offer allowing him to build the three bridges for the sum of 630.000 francs, planned to only carry out the Veudre Bridge. A century later, which architect, engineer, would not want to face such a challenge, with such a sponsor? It was an enormous responsibility and risk-taking task for this young engineer just in his 30s. Referring to this moment he would further on say, “At least three times in my life I faced a bold push to the extreme, ignoring the greatest risks.”

During the 3 years before this adventure, Freyssinet had already had the intuition that this famous concrete, so simple to use, had some hidden properties which reserved a few unpleasant surprises to an audacious user such as him: shrinkage and creep under load over time. Regulation at that time did not give specific information about these phenomena and how to take them into account. Freyssinet discovered—it is one of his great merits—that concrete was not an elastic material but an elastic-plastic one and the designer had to take this into account in his calculations. Before starting the project’s preliminary studies and in order to understand these phe-

nomena, he demanded to make a test. And what a test!

A 50-metre-span, 2-metre-high segmental arch, a true work of art that can be loaded with a small narrow-gauge train traveling in the vicinity: it is the Test Arch of the Veudre Bridge. It has remained preserved almost miraculously, in the ground where it was built, now a vegetable garden along the RN7 at Moulins. Why are we giving the details of this test? Because it contains the seeds of many of Freyssinet’s achievements developed during the remainder of his long career:

- Creep in concrete
- Improvement of concrete strength by increasing the smoothness of cement grinding
- Construction using prefabricated elements
- Concrete prestress with post-tension!

Measuring the value of the loaded concrete creep shrinking was obviously the main reason for building this huge test. The measures taken in 1908 were not sufficient to avoid the disappointments that occurred a few months later on the bridge itself, as we will explain later on.

He sensed the importance of the grain size role in cement; both to fill gaps in the structure aggregates—sand—and to improve the rheology of fresh concrete in order to completely core fill on-site and make it more durable. With additional crushing he improved the grinding fineness before mixing. From that moment onwards he obtained “remarkably easy-to-handle concrete without an excess of water and with a regular 90-days strength of 400 kg/cm² (40 MPa), having the capacity to considerably elongate before breaking due to yield strength.”

By building this arch he was able to experiment with prefabricated construction, saving on-site time and enabling the structure to be very quickly loaded during the testing program. This was actually done, “but the execution proved that this idea was ahead of the possibilities of the time.” He was only able to use this method at the Luzancy Bridge in 1942. Today we are aware of the success of this construction method.

Finally, the first production of a prestressed concrete beam using post-tension arrived. “for many years [...] I was obsessed with the idea of prestress: I used it to

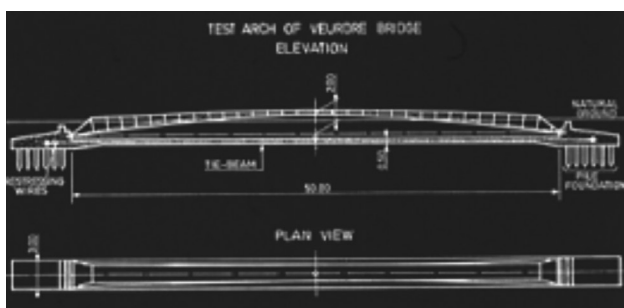


Figure 2. Test Arch. Elevation.



Figure 3. Test Arch expertise.



Figure 4. The prestressed bars

connect the two abutments with a concrete cable of approximately 150 dm^2 , precompressed between the two abutments [...] under a permanent load of about 2500T." In fact it is the first prestressed beam built well before the patent registration in 1928. In 1993 an expertise proved that the prestress was still active.

The urgency of the fulfillment did not allow him to use decentering jacks acting at the middle hinge of each arch. "In the Test Arch I replaced them with steel corners sunk into the mass [...] With the set of corners I was able to raise the arch over the curve, freely begin to buckle to the left and to the right, and finally restore the straightness of the axis."

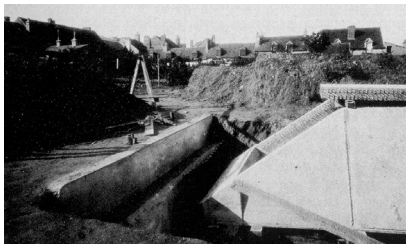


Figure 5. The end of the arch and one of the prefabricated elements before being placed.



Figure 6. The articulation during its excavation in 1993.

The construction of the Veudre Bridge had begun at the same time. In 1910 it was finished and ready to support the load tests. Given the very specific conditions of the tender, the construction had raised a great controversy supported by the local press. It was the first time that Freyssinet's innovations caught people's interest, backed by journalists keen to fill their columns with the story of a disaster: "The tests were a triumph. A hill overlooking the bridge on the right bank was occupied by thousands of spectators, waiting since dawn to witness the fall of the work which had been announced by a daily paper from Nevers under the orders of an unwise competitor. Their hopes were disappointed [...] and nothing but the planned deflection [occurred]."



Figure 7. The Veudre Bridge immediately after its construction.

Destroyed in 1944, we have no detailed documents of its construction. Fortunately, the Boutiron Bridge, its younger brother completed a year later, is still in use and in very good shape as the pictures testify.



Figure 8. The Boutiron Bridge today.

Like the Veudre Bridge, this work has three spans of about 72.50 m, with the arch lowered to 1/15; note that the Alexandre III Bridge in Paris, made of steel, with a similar span and built a few years earlier, has the same profile which gives a good idea of the achievement! The photos show the perfection of its execution and the attention put into the detail such as in the fillet area between beams. By then, Freyssinet had not yet invented the mechanical vibration of the formworks in order to compact the concrete and, of course, poker vibrators did not exist.



Figure 9. Detail of original railings and a concrete section of 6x6cm intact after 100 years. What a lesson!

To complete this description of the Veudre Bridge, it is essential to discuss the incident that took place a few months after the brilliant reception of the work mentioned before. Freyssinet explained it with so much suspense that it is necessary to read the full version. Thus begins the story: "At the end of spring 1911, more than 13 cm of deformation appeared at the middle hinge of each arch [...]" After one of Freyssinet's secret rapid tests, he understood the phenomenon and decided to act immediately without telling the administrations and scientific boards, as the bridge threatened to collapse due to a huge decrease in concrete's elastic modulus caused by creep. With the

help of four men on which he relied—and without interrupting the traffic—he installed his decentering jacks in the middle hinge of each arch, above the normal position, in order to cause compression in the arch moving it in the direction opposite to which gravity pulled, jacking up the bridge to its original position and blocking the third articulation of the arch, something imposed by the regulations of the time! The bridge performed perfectly until it was destroyed by war. Boutiron is there to show the relevance of the analysis of this incident.

We have described at length Freyssinet's first major bridge because it contains the seeds of many of the ideas with which he would continue beating record after record, and which "would revolutionize the art of building" for nearly half a century, as he stated later.

The Plougastel Bridge officially called Pont Albert Louppe

This is the last work designed by Freyssinet in the *Béton Armé* (Reinforced Concrete) period of his career. The project was done between 1923 and 1930 and during these years Freyssinet registered a patent for the prestress method (1928)—until his death in 1962 he would focus on developing applications of this new construction system. Again, his innovative and cheap proposal faced strong opposition from steel manufacturers. The Committee had already endorsed the project but Albert Louppe, Board member and Chairman of the General Council of

Finistère, demanded that each of the designers should defend their project in front of the Council. Freyssinet intervened and would later say, "My words were clear, I had no trouble tearing to pieces the false arguments from those who opposed to my project and I obtained the almost unanimous approval of the Commission." His project was built and it bore the name of Albert Louppe.

The General Council was aware of the need of this project since 1882 because the inhabitants of the Brest region who needed to cross the estuary of the Elorn to go from north to south of the department had to make a 30 km detour. A 900-metre-long bridge was necessary and in 1923 the decision to build it was taken. The last major concrete bridge is a highlight in Freyssinet's career. Not only its three 186-metre-long spans constituted a new world record, but its construction methods fascinate us as technicians.

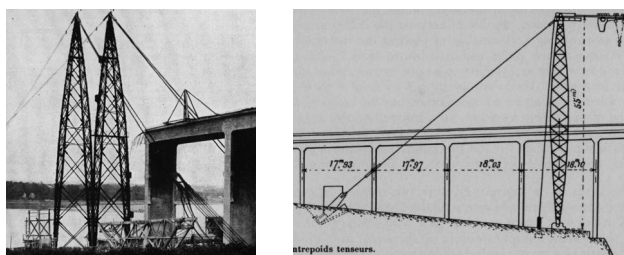
After the problems with Veudre, knowledge on the effects of creep was not yet sufficient. To make sure the right values had been taken into account in the calculations, Freyssinet began making new tests.

A floating reusable wood-nailed-centering underpinned by a steel cable—a real work of art itself with its 150-metre-span—was built and set up in place taking advantage of the high tide and taking the formwork away when the tide was low.

Figure 10. The formwork being moved to the second span.



The supply of concrete for the structure was achieved with a blondin designed by Freyssinet because no manufacturer had accepted the challenge of making such a device. Something also remarkable was the 55-metre-high wooden derricks with two articulations which supported the wire cable carrier. Undisputed master of concrete construction, Freyssinet had no equal when building in wood, sometimes combining it with concrete when there was the need to transfer a high concentration of forces.



Figures 11, 12. The 55-metres-high wooden derricks.

Inaugurated on September 10, 1930 by the President of the French Republic, Gaston Doumergue, it was blessed on Sunday October 12, 1930 by Bishop Adolphe Duparc. A crowd estimated between 40,000 and 50,000 people had invaded the bridge and its surroundings to celebrate the event.

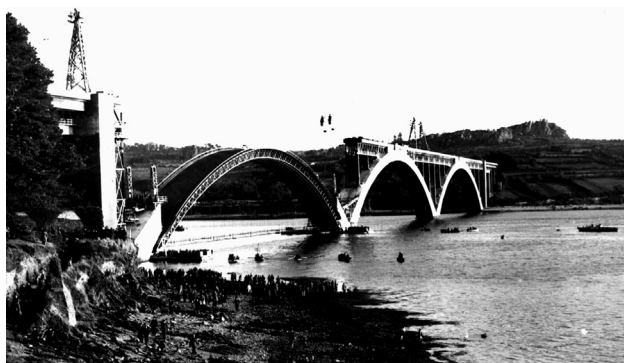


Figure 13. The bridge being rebuilt.

Unfortunately the bridge was decommissioned in August 1944 once the Germans had destroyed the first span on the Brest side. Post-war economy and the cost of repair meant that the bridge was not opened again until 1949. Twenty years after the initial construction, no other technique appeared to be better than the one developed by Freyssinet. However, the original two-way deck turned to be insufficient to the increasing traffic and in 1961 the width was extended to 12 m to allow three lanes with two 1-metre-wide sidewalks. This new organization also proved inadequate and very quickly, in the late 80s, the decision to build the Elorn cable-stayed

bridge was taken. Authorities wishing to retain the imposing work, part of the landscape of the Bay of Elorn, decided to keep it. Unfortunately its presence together with the westerly winds of the estuary area formed Karmann vortices in the bridge's area, putting its stability into risk. It was necessary to streamline the three spans of the bridge making a not nice aesthetic effect but allowing the bridge to survive. The Albert Louppe Bridge is now reserved for pedestrians and agricultural machinery.

After the opening of the Plougastel Bridge, Eugène Freyssinet wrote a few sentences which can be considered unexpected for a builder:

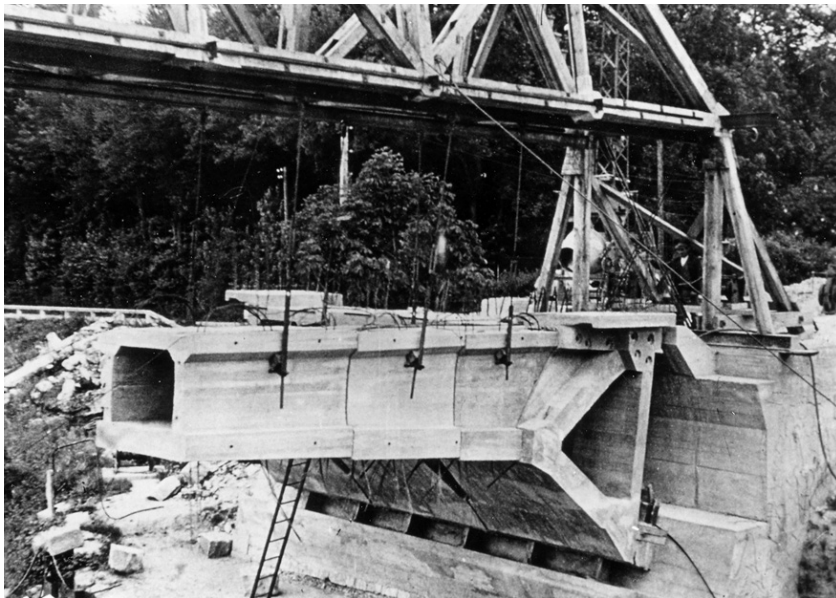
In Brittany, the light is a fairy who always plays covering nature with changing coats; sometimes lead, sometimes silver or pearl or something intangible and bright. In the evenings, when making the tests for the Louppe Albert Bridge, light lay on the bay's most magnificent treasures. And each line of the bridge turned into a long string of unreal light, adding more beauty to the whole wonderful work, proving that the fairy of the harbor had already adopted the child that men had imposed, and knew how to weave clothes which were beautiful enough to hide all the shortcomings of the work.

The structure that can be seen under the deck was intended for the train although it was never used. On top of the central part of the first span we can see the suppression of the railings, an improved aerodynamic element which in the western side consists of a fairing which facilitates the flow of air around the central point.

The Luzancy Bridge

A series of works which use the spectacular new bases introduced by prestress begin with this bridge. The modest work with a span of only 55 m and a width of 8 m is of exceptional elegance. It also deals with a series of new techniques which slowly evolved since 1928 when the patent *Procédé de fabrication de pièces en béton armé* (Method to produce reinforced concrete pieces) was registered, today's description of "prestress". These new techniques had already been tried in the consolidation of the Le Havre maritime terminal and by the *Entreprises Campenon Bernard* works in Algeria. Started in 1942, works were interrupted by the war and the construction would not resume until 1945. Freyssinet utilized this stop to refine the construction method.

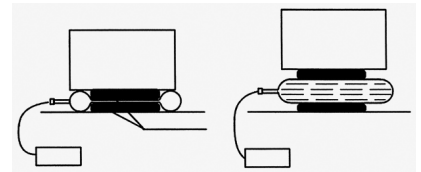
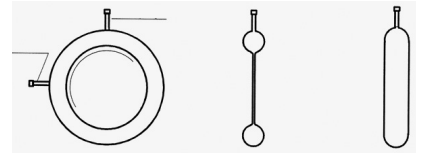
The banks of the Marne which are not very resistant seemed rather unfavorable to handle the load of an arch-shaped bridge. Freyssinet, aware of this situation, anticipated adjustable abutments using flat jacks—bags made of steel sheets that could be inflated with a liquid pressure to 15MPa. This was perhaps the most wonderful tool he invented.



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Figure 14. Abutment with active interposition of flat jacks in support of the crutch.

Figure 15. The beam was set using a wood centering with concrete nodes. Installation of a cantilevered segment on one of the bridge's ends.

Figure 16. Flat cylinder. The diagrams show the design and how it is used to lift a load.

Figure 17. The installation of the central preassembled beam on the on-site prefabrication grounds.

Figures 18, 19. Precast segments at the working grounds. Note the concrete "candles"—used to lay the segments before preload-assembling—which reproduce exactly the longitudinal profile.

Figure 20. Recent view of the Luzancy Bridge. Note the excellent preservation of the railing and the transverse prestress anchor bosses.

Before the project was stopped, he imagined using a centering made out of a wooden beam with concrete nodes to set the precast segments. This piece of wood broke after the first uses and he abandoned this approach and developed another system using derricks and carrier cables. Reminiscent of Plougastel, it used the same wooden derricks due to the lack of steel for such applications at the end of the war. Note however that the beam system was taken up again in steel construction, 25 years later, by Jean Muller, his youngest student.

The bridge was prefabricated using several segments in which each cell underwent very powerful vibration that compacted the concrete to such a point that it allowed the mold to be removed 24 hours later. Since 1934, with the exception of the Le Havre passenger terminal, the building of posts or pipes in Algeria became a perfectly well-controlled technique.

Figures 14 and 15 show how Freyssinet, in 1941, envisioned the use of the beam setting—allowing both the installation of the segments and their suspension before their fixing—using prestressed cables. After abandoning this system, figure 17 shows how, once the work was taken up again in 1945, Freyssinet used carrier cables and a preassembled beam.

Figures 18 and 19 show two areas of the on-site prefabrication grounds with precast segments and a preassembled central beam. The assembly is done by introducing a final prestress more or less centered and fit in the four holes that can be seen in figure 19.

This first work which used precast segments could not assure the perfect combination of two consecutive segments as can be done today. The on-site preassembly required to ensure a caulk joint combination which needed a high-dose mortar (800 kg/m^3), without much water (moist soil texture), around 2-centimeters-thick and strongly compacted using a hammer. This allowed applying the prestress force immediately. The five bridges over the Marne, built some years later with more industrialized systems, used this same technique.

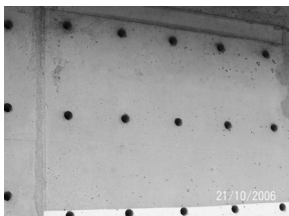
Structurally, Freyssinet wanted this work to be a real exercise that would demonstrate all possible prestress contributions to the stability and durability of a bridge. The bridge was prestressed in the three directions. During construction, the segments were given a prestressed grip using 3 mm diameter wires stretched on the formwork prior to pouring the concrete. Both ends of the cantilevered beams sitting on the abutments were held in place by a temporary external prestress. The central part was prestressed on-site with twelve 5 mm diameter cables strung through the holes waiting for concreting. When all the segments were set up, the overall stability cables were positioned from the top deck at the ends of the bridge

continuing obliquely through the sloping holes in the segments and finally weaving under the bridge in order to place them in grooves which were covered with mortar after tension was introduced. After all these operations had been done, the transverse prestressing on the upper and lower sides took place—the anchor bosses visible on both sides show the presence of prestress. Finally, prefabricated pavement pieces with railings were set tightly against each other using flat jacks inserted in a few joints to ensure perfect continuity. These sidewalk elements were then tightened to the structure using vertical prestress which gave as a result a structural solidarity considered in the longitudinal bending strength of the bridge. The result of this real corsetage of the bridge is a great over time conservation as evidenced by recent photos. Although nearly perfect, there are still two criticisms that can be done after half a century. The first is that the prestress system used is so complex that the labor cost would be impossible today and those who conceived the bridges over the Marne took it into account only some years later. The second concerns the protection of prestress cables. Studying all the constructions carried out by Freyssinet or under his control, it is difficult to take it as an execution quality defect, but with regard to the cable protection we must acknowledge that he failed and underestimated the problem. This only concerned very few of his early works thus his young students and future employees persuaded him to improve the protection of the cables. In the 70s the Luzancy Bridge's cables under the deck corroded and it was necessary to replace the prestress with new cables which flow freely through the beams and were very adequately protected against corrosion. We can be certain now that the bridge is promised a long life.

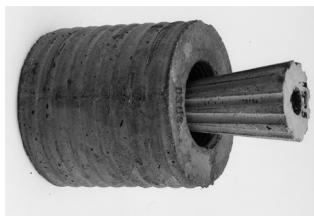
The Five Bridges on the Marne

These five bridges are called Anet, Trilbardou, Esbly, Ussy and Changis-Saint-Jean. If Freyssinet defined the scheme inspired by that of Luzancy, it was actually Jean Chaudesaigues, then Director of Studies at Campenon Bernard, who spearheaded the studies. The completion of these bridges, substantially identical, was industrialized in a prefabrication factory in the vicinity of Esbly and the prefabricated elements were transported to the construction site using barges on the Marne. The project was simplified and instead of a box girder he used six I-beams stiffened transversely with six prestressed transverse struts. The deck was transversely prestressed only on the upper slab with 2 cables made of twelve 5mm-diameter-strands every 1.25 m. The bridges have a 74-metre-span and an 8-metre-wide deck with two 1-meter-sidewalks.

As in Luzancy, the deck is made of beams on crutches



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Figure 21. Esbly Bridge. Detail of an edge beam web showing the smooth surface of the concrete and on the left, the trace of a struck joint.

Figure 22. The concrete anchor 12Ø5, outer cylinder $h=100$ mm, $\varnothing 96$ mm, outer cylinder $l=74$ mm, $\varnothing 40$ mm, permanent prestress force= 250 kN.

Figure 23. Anet Bridge.

Figure 24. Trilbardou Bridge.



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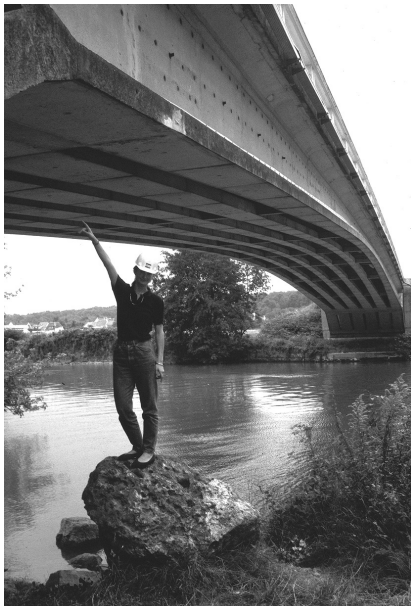
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producing a major pressure on the abutments. The abutments of the old bridges had been strengthened to resist the horizontal thrust of about 1800T. Flat jacks were also interposed between the crutch supports and the abutments to compensate any possible land movements.

What is very new compared to Luzancy, are the arrangements for the production of the beam segments. There were about 20 times more pieces, which meant a series of industrial process involving multiple molds and especially a need to reduce the time to reach sufficient strength before they were released. The method devel-

oped for the posts in 1930, resumed in Algeria for the pipes of the Oued Fodda, was repeated: concreting with intense vibration, compression and drying with steam. A 250 kg/cm^2 resistance was achieved 90 minutes after casting.

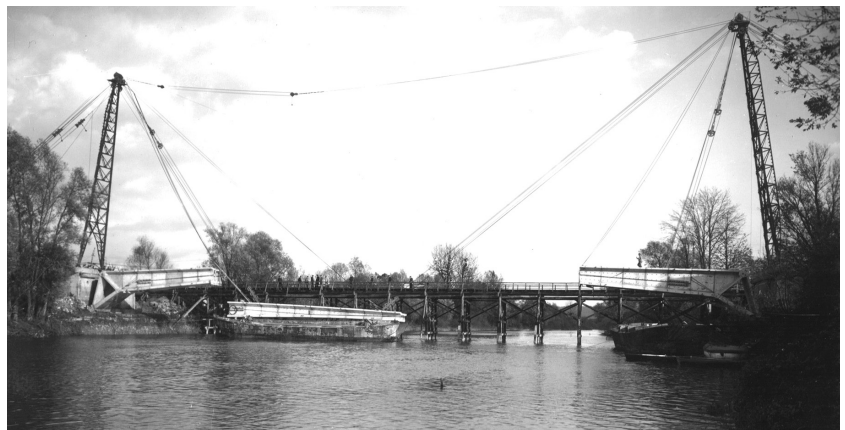
Another important innovation was the introduction of vertical prestress on the beams' web. The deck of the beam (top part) and the heel were first cast separately on the vertical mold—the vertical steel stirrups were in place at the right length, and anchored in the two parts while being concreted. After curing, the web was concreted



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Figure 25. Esbly over the Marne Bridge.

Figure 26. Esbly Bridge. Positioning of an element with the help of a cable transporter.

Figure 27. Changis-Saint-Jean over the Marne Bridge.

Figure 28. Ussy over the Marne Bridge.

All photos of these works were taken on bridges which are older than 50 years. Note their conservation which is the result of a careful implementation and compression effect given by prestress.



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after separating the top and bottom parts with a jack system that tensed the abutments. The web forms were prepared and it was concreted with great care as it was only 10 cm thick and 2.5 m high!

The following steps were similar to what had been done in Luzancy. First the two beam ends were assembled using external provisional prestress, then the central part was assembled on-site and the caulk joints were done before introducing the longitudinal prestress. The whole piece was then placed on barges lead to the bridge site and installed with the carrier cable developed for Lu-

zancy. The photos, which have been taken recently, show that these works are in an excellent state of preservation. Initially, the road did not have a sealing layer and one of them, located near a gravel quarry, endured heavy traffic which the designers had not counted with.

The Three Bridges of the La Guaira — Caracas Highway

These are the last important works built by Campenon Bernard in which Freyssinet was personally involved. He was more than 70 years old but still had the tenacity and

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strength that enabled him, throughout his life, to passionately defend a project he was convinced was feasible both regarding quality and economy. On a very long drawing board he designed to the largest possible scale the arches and their construction method of the bridges so no detail escaped the sagacity of his thinking. Up to his last works, he remained faithful to the principle he had set in his early career stage "I drew the work in great detail, convinced that a work is good or bad depending on its details."

He designed these works but again it was one of his students—the youngest—John Muller, who was responsible for the implementation studies. The bridge consists of a concrete arch and a deck made of prestressed beams—a synthesis of a builder who dedicated his life to innovative structural typologies and their construction methods. These three bridges are no exception, and the 60-metre-deep gorges which had to be crossed precluded the construction of a full centering. Finally the end of the cable-stayed arch formwork was built from the two large viaduct piles. The construction of the arches was then begun with a first cable-stayed centering but, in order to restrict the weight, only the lower slab and the segments' web were built. This disposition was enough to convey the compression forces to the supports—these compression forces appear from the central centering element and the final concreting. The same method was used with a new piece of cable-stayed centering bearing the progress of the arch to 25% of the length on both sides of the articulation of the two starting points of the arch.



Figure 29. Two of the bridges with a 150-metre-long span upon finishing the highway.

Thus began the last and most spectacular phase of the construction, the construction of the central arch with a nearly 75-metre-span, built in the lower part of the gorge using the nailed wood technique that had been used to reconstruct the destroyed Plougastel span. Similarly, the centering was underpinned by a cable, making

it a relatively light structure, although the weight is about 200T and it had to be raised about fifty meters to its final position.

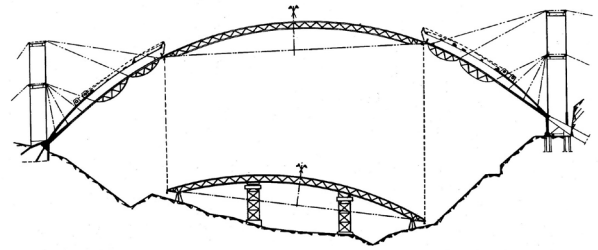


Figure 30. Scheme of the centering.

Figure 32 does not show the crowd of incredulous journalists scoop searching that, it seems, gathered at the bottom of the gorge during the first operation, hoping to capture the disaster that might accompany this phase, deemed risky even if it had been meticulously prepared. No doubt that day Freyssinet must have remembered the disaster that could have taken place due to the decentering of Veurdre! The innovative techniques developed by Freyssinet and then by his followers continued being surprising because of their audacity. After the decentering of the roof of the velodrome built for the Montreal 1976 Olympic Games—designed by Taillebert and studied by Freyssinet International—doubts on success had again gathered many journalists which were more than skeptical regarding the accuracy of engineering calculations.

These three bridges performed very well since their construction. However, one of the three was demolished after a landslide which affected one of the abutments, making the arch buckle. These kind of tectonic movements completely escape preliminary soil tests done prior to the construction of a large bridge like this one. This accident does not change the relevance of foreseeing methods adopted by innovative designers who must always be aware of their responsibility vis-à-vis the users. Freyssinet was one of them, one who brought these values to the highest level of performance: "Using the community's resources in the best way is not the builder's simplest way to gain fame or fortune or elegance of mind. It is an absolute obligation."

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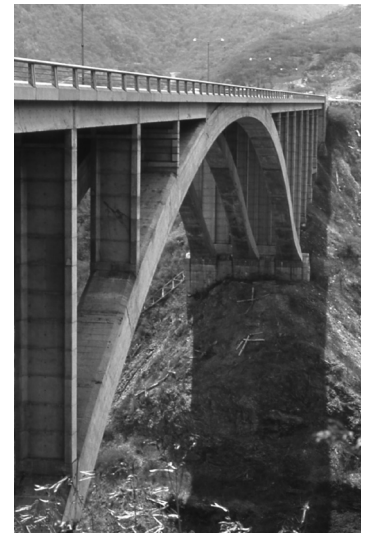
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Figure 31. The middle centering ready to be lifted. The built part shows the segment webs without the upper slab.

Figure 32. The middle centering being lifted.

Figure 33. One of the 3 bridges of the La Guaira-Caracas highway.

Pierre Jartoux

Born in 1937, he is a mechanical engineer graduated at the *École des Arts et Métiers*, civil engineer, graduated from the *Centre des Hautes Études de la Construction*. His career has been connected to the Freyssinet Group: civil engineering studies office; testing on material prestressing section; material manufacturing factory; and research department on new materials (prestressing anchors and braces). Since his retirement, he became involved in the activities of the Association Freyssinet and currently serves on the *Conseil d'Administration*.

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Figure 34. Eugène Freyssinet (1879-1962).

Eduardo Torroja: The Allos Aqueduct



EDUARDO Torroja Miret graduated as an engineer in 1923. That same year, after a bloodless coup d'état, General Primo de Rivera assumed the control of government in Spain and launched a modernizing economic program clearly based on infrastructure: development of the telephone network, modernization of ports, tramway system expansion, creation of 800 km of railroads, extension and paving of over 15,000 km of roads...

By Carlos García Vázquez

SPANISH engineers faced the challenge from very conservative positions, educated as they were in the harsh canons of the Madrid *Escuela de Caminos y Canales* (Civil Engineering Faculty), founded in 1802 and which had inherited the strictly technicist, regulatory and economic spirit of the *École de Ponts et Chaussées* in France. Many of them despised reinforced concrete, both technically and aesthetically. Hennebique's patent had been introduced in Spain in the late 19th century by José Eugenio Ribera, engineer and owner of Hidrocivil. Certainly, the monolithic system of the patent's frames did not leave much creativity leeway. Other obstacles also had to be taken into account: first, the precariousness of calculation systems (the resolution to a surface structure involved tens of equations with tens of unknown factors to be solved without using computers), and secondly, the absence of structural testing centers in Spain (the smallest design heterodoxy involved making expensive models). Under these circumstances, experimentation did not deal with reinforced concrete.

This bleak scenario was abruptly diluted in 1930. A systematic research process led to the application of photoelasticity in numerical calculation, the marketing of strain gages, the appearance of inductive sensors, the development of movement and deformation measuring methods... This series of innovations sparked two revolutions: pre-tensioned concrete and concrete shells. The first was patented by engineer Eugène Freyssinet in 1928, although it was not definitely recognized until 1934, when it was applied to the consolidation of the Maritime Station in Le Havre. Conceptually it was very different from reinforced concrete because the reinforcement bars bore the tensile stress while in pre-tensioned concrete rebar was previously tensioned to induce compressive stress to concrete, preventing tensile stress afterwards.

Eduardo Torroja was the leading figure of the second revolution, that of concrete shells. His contribution consisted in replacing the Hennebique beam and pillar porticos with a very thin shell of up to 1/600 of slenderness.

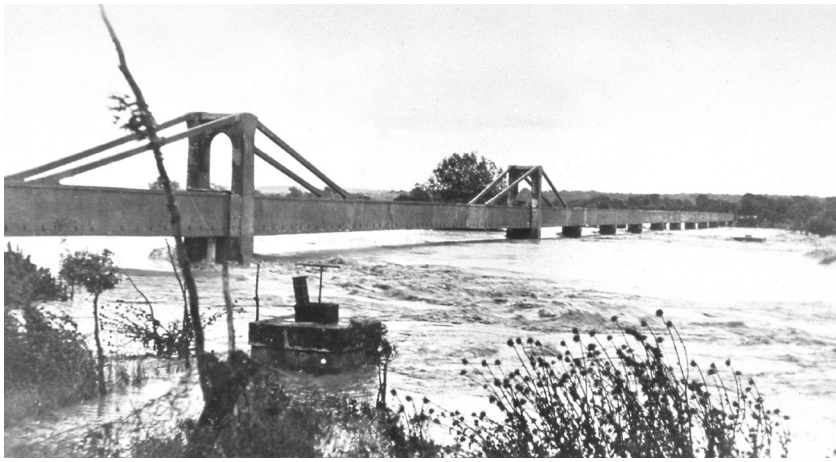
A radical conceptual upturn emerged affecting the basis of architectural composition: slabs supplanted the classic duality between structure and building enclosure in favor of a continuous and enveloping veil which exerted both functions at the same time. This also opened a new horizon for concrete, one that had always been latent but remained unexplored due to technical difficulties: moldability.

The works of Freyssinet and Torroja—and also those of engineers Robert Maillart and Pier Luigi Nervi—were essential to the popularization of concrete use between architects. The Plougastel Bridge (Freyssinet, 1930), the Salginatobel Bridge (Maillart, 1930), the hangars in Orvieto (Nervi, 1935) and the Recoletos *pelota* court (Torroja, 1935) transferred the poetics that had been fascinating architecture and avant-garde art for decades to engineering; the poetics of evanescence. This explains the huge international prestige that Torroja enjoyed at that time. Sigfried Giedion detected in his plates the “way to proceed” and Frank Lloyd Wright called him “the greatest living engineer.”

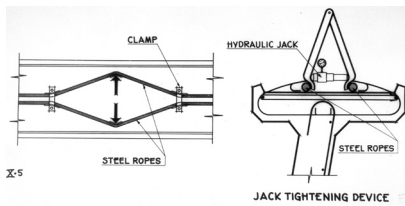
His masterpieces had been erected between 1927 and 1936, in collaboration with the best Spanish architects: the so-called *Generación del 25*, precursor of Modernity. He built the Algeciras Market (1933) with Manuel Sánchez Arcas, the *Frontón de Recoletos* (Madrid, 1935) with Secundino Zuazo, and the Zarzuela Hippodrome (Madrid, 1935) with Carlos Arniches and Martín Domínguez. The brilliance of all these works lay in the use of concrete shells designed by Torroja.

However, the projects on which we will focus on in this article were related to the other great structural success of that moment: pre-tensed concrete. Freyssinet stated that Torroja had never understood its conceptual essence. He had proclaimed that, despite its greater sophistication, it was not better than reinforced concrete (agreeing with Maillart and Nervi), and he used it in an unorthodox way (we do not know whether by choice or due to the country's technological shortcomings).

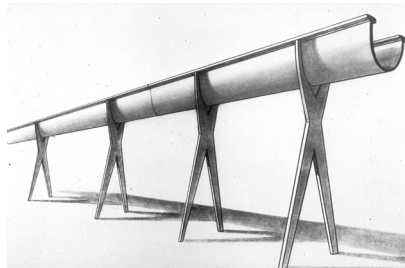
The first time Torroja experimented with something similar to pre-tensioned concrete was in the Tempul Aqueduct, built in 1927 over the Guadalete River, which had



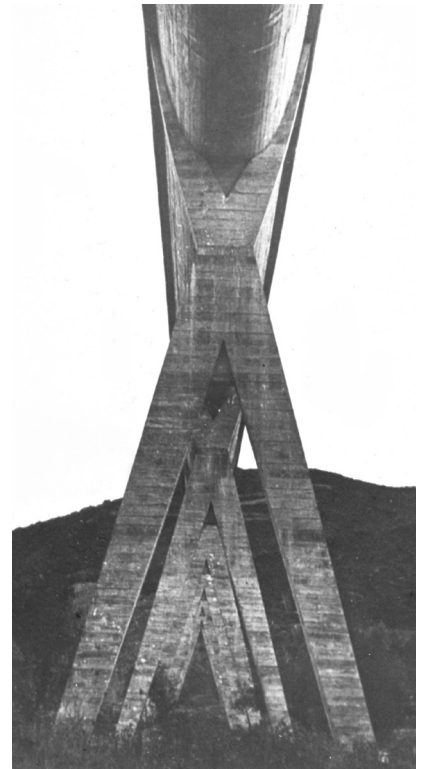
The Tempul Aqueduct during a flash flood.



Alloz Aqueduct jack tightening device.



Alloz Aqueduct drawing.



The Alloz Aqueduct piers and channel.

to supply water to Jerez de la Frontera. Water circulated through two 280-meter-long pipes housed inside a reinforced concrete box. The initial project planned to settle them on top of four piers, two located on the riverside and two on the riverbed, but the poor soil made Torroja remove the latter. He resolved the 60-meter-suspended deck span over the river by using two cable-stayed cantilevered decks connected to the riverside piers using a helical arrangement of 37-high-strength steel cables stranded together.

To avoid the high elongation that would occur in these 55-meter-long struts when put under stress, he used what we could call a “pre-technological” pre-tensioned system. He supported both stays on saddles on top of the piers, allowing them to move and behave independently. Once the concrete was poured and solidified, he raised them with hydraulic jacks to get the proper tension. He then proceeded to pour the concrete into the gap between the saddles and the tower-heads (the stays were also concreted in place to avoid corrosion). With this rather traditional system, Torroja became familiar with the concept of pre-tensed concrete.

More than a decade later he would use this system again. The Alloz aqueduct was built in 1939 over the Salado River in Navarra. Unlike in Tempul, in this case water was not going to circulate through pipes but on a concrete open-topped channel, which meant dealing

with the essential risk of all aqueducts: leakage or, in other words, fissures. Torroja attempted to settle the problem by subjecting the inside part of the channel (which would be in contact with water) to a bi-directional compression. To achieve it he complemented his pre-tensioned proposal with a supportive design. The channel, which has a parabolic cross-section (form that ensures a good hydraulic profile), was supported on a cruciform structure similar to compass-shaped piers. Its 450 m length was segmented into 40 m sections supported by two separate pillars which stood 20 m apart with a cantilever of 10 m at each end. This established a longitudinal negative or null bending moment diagram in which no part of the viaduct was in sagging, and hence the bottom edge of the channel was always in longitudinal compression, avoiding cracking where water’s pressure was stronger.

To achieve the same result in the upper part, Torroja decided to longitudinally post-tension the edges. He carved a recess in each one and placed a pair of twisted cables similar to those used in Tempul. To anchor them to the concrete, he separated the filaments and bent the ends into a hook form. The pre-tensioned system was also somewhat artisanal as he introduced transverse jacks between the pairs of cables, and by jacking the cables apart, lengthened and hence stressed the cables. By using this system he submitted the outer face of the channel to a longitudinal compression in all the cross sec-

tions. Finally, to ensure the transverse compression on the inside, Torroja connected the parabola's top flanges with bars placed at roughly 4 m intervals on top of the water. By tightening turnbuckles on the bars and drawing the two flanges slightly together, the inner face of the channel became compressed towards the bottom part (again, where it is most needed).

The result was a totally compressed piece, in all its length and both inside and outside, a simple and inexpensive piece which never cracked nor presented leaks. It is also a beautiful piece, a centipede with giant and delicate legs which seems to tiptoe over the territory.

The Allos Aqueduct gives evidence of Torroja's peculiar engineering ideas, his consideration that the ultimate goal of structures is aesthetic and not functional: "works are not built to withstand [...] their resistance is a key condition, but it is not the only ultimate purpose, not even its primary purpose." In another occasion he claimed: "the creation of form is the result of a great flash of inspiration, the epilogue to a drama." This chaste engineer liked to skirt the abyss of irrationality, sensitiveness, subjectiveness; his radically technical training saved him from succumbing to it.

Architects intellectualized Torroja's difficult to define universe. Frank Lloyd Wright said "of all the engineers I know, Torroja has expressed the principles of organic construction better than anybody else." Pedro Miguel Sosa, referring to his structures, said "he does not design them to withstand gravitational actions in a passive or inert way but, instead, he handles their geometry and causes, in an active way, forces or deformations so that materials support appropriate tensions according to their resistance behavior."¹ This essentially organicist attitude turned structures into expectant beings, beings which are "in a permanent state of alert, not inert to gravity, but in constant response to the need for balance and endurance."²

Torroja's intense engineering sensitivity was enough to shape his beauty aspiration. According to his structural plexo-tensional definition, the aim was to "incorporate to our spirit, as a second nature, the intuition of resistance phenomena, and, trying to capture the essence of physical phenomena, that is, make tensions visible, materialize them so that intuition becomes easier."

Only somebody like him could assume such a challenge, endowed as he was with a remarkable ability to assimilate the principles of tension in structures. It was as if, in the case of the Allos Aqueduct, he had felt the water friction, the channel deformation, the stretching of the edges, the bending of the supports and the compression of the pillars in his own body—a tension distribution feeling which he was able to defuse just before the infrastructure was put under stress, but which he also showed because

he was shaping it as a "living" artifact, condemned to survive in permanent challenge with a flow of tensions.

Torroja's brilliant career was cut short with the Spanish Civil War (1936–1939). The architectural quality of his work declined swiftly after the war although his activities as a government employee (*Jefatura de Puentes* of the Ministry of Public Works), teacher (School of Civil Engineering in Madrid), researcher (*Instituto de la Construcción y del Cemento*) and writer (he was the author of *Razón y ser de los tipos estructurales*, published in 1957 and immediately translated into English and German), allowed him to continue leading the efforts to overcome the craftwork culture and to incorporate construction to the country's industrialization process.

Eduardo Torroja died in 1961, at the beginning of the decade that marked the definitive decline of reinforced concrete shells as a result of a more expensive labor cost.

Notes

1. VV.AA. *Eduardo Torroja, la vigencia de un legado*, Valencia, Universidad Politécnica de Valencia, 2002, 167.
2. Tarragó, Salvador, *La modernidad en la obra de Eduardo Torroja*, Madrid, Ediciones Turner, 1979, 36.

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All images from *Las Estructuras de Eduardo Torroja*, Madrid, Ministerio de Fomento, 1999.

Photos by M. García Moya. Drawing by G. Echegaray.

Structure and Form: The Theory of 'Minimal Surfaces' and the Bridge over the Basento River by Sergio Musmeci

46



SERGIO MUSMECI occupies a very important position in the history of late 20th century Italian engineering. Born in Rome in 1926, he initially graduated in civil engineering and later in aeronautical engineering. Following an apprenticeship with Pier Luigi Nervi, in whose office he worked from 1949 to 1951, and with Riccardo Morandi, he later opened his own engineering and architecture office together with his wife, the architect Zenaide Zanini. He taught at the University of Rome, initially as an assistant to the course in Rational Mechanics and Graphic Statics, and later as professor of Bridges and Large Structures.

By Rinaldo Capomolla

WITH his activities as a scholar and designer, Musmeci sought to bring a new impulse to Italian engineering in light of its rapid development immediately after the Second World War. He observed that the reconstruction and completion of the country's infrastructural network, given its vastness, was leading engineering to progressively repeat tired and simplified structural models; it was his belief that this trend could be inverted only by completely redefining the very objectives and methods of structural design.

Methods of calculation—Musmeci claimed—had made great strides, though they remained wholly inadequate for orienting engineering in the selection of the optimum form to be applied to a structure. “When we make basic design decisions—he stated—we are in the same conditions as a Renaissance architect: we possess intuition, experience and a sensitivity towards statics, though nothing places in a condition to choose...with awareness and responsibility”. For Musmeci the form of a structure was not to be defined by the designer based on his personal experience, but was rather to be “deduced from a process of optimising its static regime”.

These ideas placed Musmeci at the antipodes of Nervi's way of thinking, a master considered as the benchmark of Italian engineering at the time. Nervi believed that it was not possible to ask static calculations to provide more than they could give or, better still, the more space that was given to sophisticated mathematical calculations the more the architectural-engineering invention would suffer. For Musmeci, instead, only the calculation, if considered less a tool for verifying structural safety, and more as an instrument for selecting the ‘optimum form’, could broaden the inventive potentialities of engineering, offering a vaster repertoire of truly new, and thus unimaginable forms, though entirely rational.

The Theory of Minimal Surfaces

This optimum form was to have corresponded with objective, even if not absolute criteria, established *a priori* by the designer. Musmeci, in particular, held that the principal criteria of choice should be the “structural minimum”: a criteria that would have allowed for the identification of the form of a structure capable of opposing external forces using the minimum volume of material. In any case, he believed that the designer had to be familiar with this “minimal structural form”, even if he would be free to adopt it or not based on his personal evaluation of the real circumstances of construction.

However, the mathematical methods for identifying the form of minimum volume structures presented serious analytical difficulties. As a result Musmeci turned his attention to structures with minimum surfaces (“minimal surfaces”), whose form could be calculated with less difficulty and, above all, could be visualised using models realised with soap bubbles. In fact, these latter, once their edges have been defined, spread spontaneously along a minimal surface and assume a state of tension that is particularly favourable because it is isotropic and constant at each point.

From the forms of these equally tensioned surfaces of soap bubbles it is possible to immediately derive the forms of analogous equally compressed surfaces, because the positioning in space of the minimal surfaces neither depends upon nor presents any sign of tension—traction or compression as the case may be—nor of its value, but only the geometry of its edges. An equally compressed surface fully exploits the mechanical properties of a constituent material that can thus be used not only in its minimum extension, but also in very thin elements (and thus with minimum volume).

The difference between Musmeci's equally compressed shells and classical thin shells is evident: they are not only subject also to traction, but present a scarce adherence between the form, usually simple (cylinder, sphere, conoid, hypar, etc.), and the static regime: this is demonstrated by the strong perturbations in the tensions

along the perimeter and their significant variability from point to point.

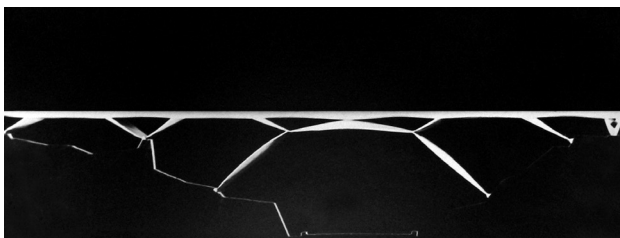
The Shell Bridges

Prior to defining this theory, Musmeci already pursued a particular way of designing: instead of defining the form of the structure in all of its parts and then calculating the tensions, he established a property that the tensions would have to demonstrate and considered the form of the structure that this would have realised an unknown. One example of this approach is to be found in the bridge over the Astico River (1956) in the province of Vicenza [figure 1], whose highly articulated form was designed to obtain a harmonious insertion within the natural landscape and to best exploit the properties of concrete. The bridge is comprised of a deck integrally connected to a series of arches resting one atop the other. The deck, supported only in a few points, is necessarily very rigid in its resistance to bending, such that the arches can be reduced to thin slabs (between 35 and 45 cm in thickness), slightly curved in the transversal direction to keep them from twisting. When developing this solution Musmeci was inspired by Maillart's bridges, which he considered exemplary for their "perfect integration between static efficiency and formal expression". All the same, Musmeci soon focused his studies on double curving thin shells be-

cause, unlike the arches of Maillart, which are subject to compression only along their central axis, in shells the force of compression acts in two directions and makes the most efficient use of the properties of concrete.

The first application of the theory of minimal surfaces to the design of the bridge came with Musmeci's proposal for a structure spanning the Tiber River in Rome, near Tor di Quinto (1957) [figure 2]: a bridge whose road deck is supported on six double curving shells subject to uniform compression. After attempting to define their optimum form using mathematics, without obtaining satisfying results, he reverted to the use of a model made of soap film and later a model in rubber pulled by forces proportional to the constraining actions calculated.

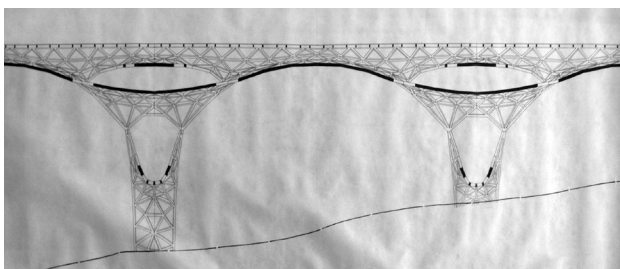
Musmeci also used the same mathematical and experimental studies in the design of a bridge over the Lao River, in the province of Cosenza (1964) [figure 3]. Though he obtained a very different formal result: while in the bridge over the Tiber the supports and deck were statically integrated, though geometrically distinct, here the underside of the deck and the piers are fused to form a single, continuous and equally compressed surface. This project is also of interest for another reason, as it confronts one of the crucial problems of complex geometry: their construction. Musmeci transformed the curved surface into a grid of rectilinear concrete struts to be poured in steel



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Figure 1. Model of the bridge over the Astico River.

Figure 2. Model of the bridge over the Tiber River.

Figure 3. Longitudinal section of the bridge over the Lao River.

Figure 4. Model of the bridge over the Strait of Messina.

Figure 5. The bridge over the Basento River.

jackets. This idea was later proposed and perfected in the design of the lengthy bridge over the Niger River, in Nigeria (1977).

Of his other shell bridges, mention is made here only of that in Shiraz, Iran (1975–76), a long viaduct that remained on paper, its deck supported by an elegant undulating concrete ribbon, and the viaduct over the Via Appia Antica in Rome (1980–85), constructed using a limited number of drawings and a model realised only a few months prior to the engineer's death on March 5, 1981.

At first glance, the preference given to exclusively compressed structures may cause some confusion regarding Musmeci's use of tensile structures in some of his projects. However, this is clarified by the fact that these elements realise a perfect correspondence between form and the static regime. Of the tensile structures he designed, the most daring is without a doubt the bridge over the Strait of Messina [figure 4]: a long-span suspended bridge (3,000 m) that was awarded *ex aequo* the ideas competition held in 1969. Musmeci looked with great interest at tensile structures not only because they are complex systems of cables that, working in synergy, perform their static duties with the maximum efficiency, but also because they are a structural and formal prototype that, by analogy, may suggest the form to be given to compressed shells in concrete: an idea that Musmeci would

exploit in the design of his most famous bridge spanning the Basento River, in Potenza (1967–1975).

The Bridge over the Basento River

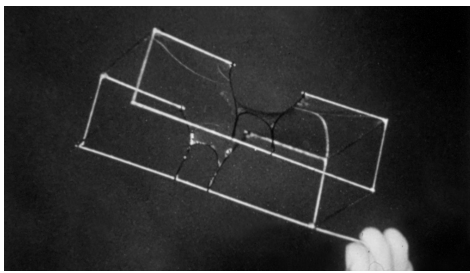
This is the only bridge based on the theory of minimal surfaces that Musmeci managed to build. It is not the concentration of an extravagant idea or an extemporaneous creative gesture, but an original reflection on the foundations, the practice and the aims of structural design. This condition makes it one of the most representative fruits of Italian structural research after the Second World War.

The bridge is composed of four continuous reinforced concrete arches, one every 69.20 m, comprised of double curving shells supporting the deck, also in reinforced concrete [figure 5].

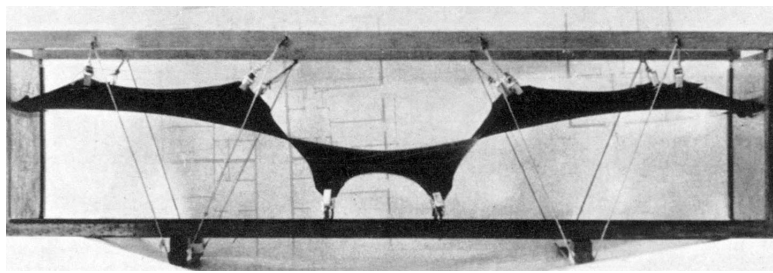
The arches are similar to those of the bridge over the Lao River, in turn the development of an idea that was previously formulated in the design of the roof of the *Palazzo del Lavoro* in Turin (1959).

The development of the project is particularly interesting, as it reveals how Musmeci, placing his trust in his own personal talent as an engineer and working without collaborators, did not hesitate to launch himself into an adventure of design and construction filled with unknowns, and employing procedures of static verification that would now be considered inadequate.

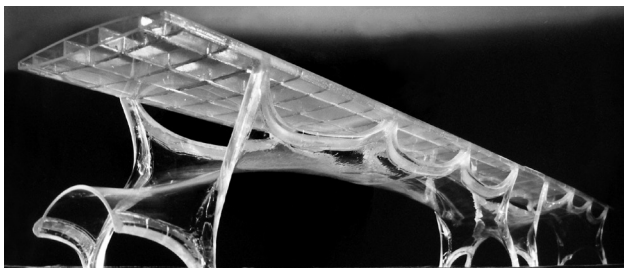




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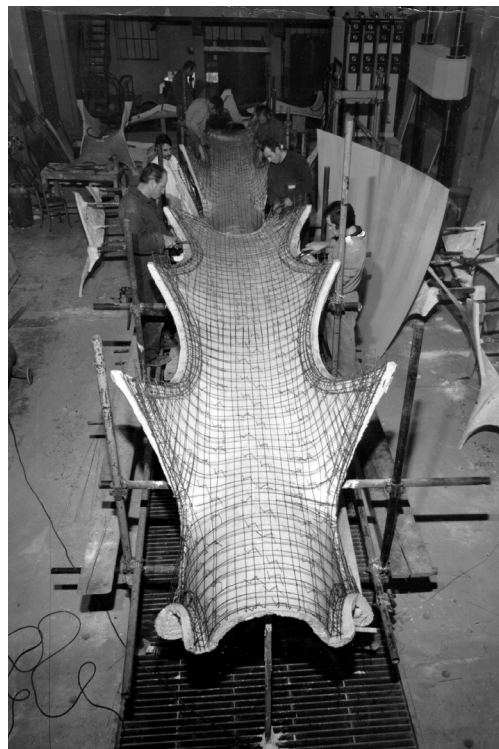


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Figures 6, 7, 8, 9. Models in soap film, rubber, perspex and concrete.



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He initially constructed rudimentary models in soap film [figure 6]; this was followed by the realisation of a model of two semi-arches using a sheet of rubber, pulled by forces applied at the points where the real structure would be subjected to forces of compression from the deck and foundations [figure 7]. The model, in a state of tension very similar to that of the soap film, consented him to measure the geometry of the surfaces and to summarily evaluate the state of tension of the membrane.

In 1967, based on these tests and a calculation of the arches, schematically compared to a planar system of rectilinear and curvilinear beams connected by hinges, he prepared the general design.

In order to have more precise indications regarding the static behaviour of the bridge Musmeci commissioned a 1.4-meter-long perspex model, which he used to measure deformations under various loading conditions [figure 8].

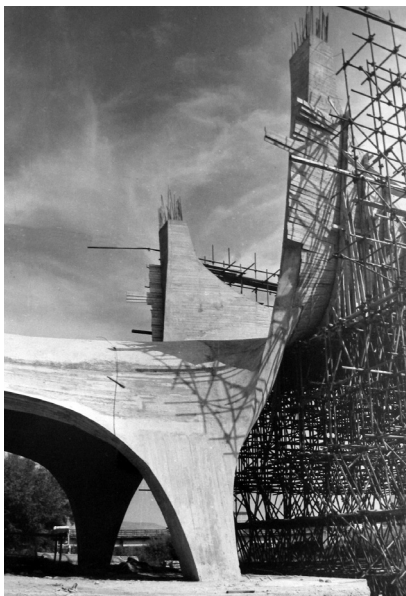
In the meantime, he managed to approximately determine the geometry of the surface of the bridge, utilising a procedure for the calculation of the form of soap films developed by Rudolf Trostel and published in the first issue of *Zugbeanspruchte Konstruktionen* by Frei Otto (1962).

Based on these tests and calculations, during the early months of 1969 Musmeci completed the working drawings, which presented a few differences in terms of details with respect to the general design, in particular an increase in the curvatures and thicknesses of the vaults: the original thickness, of only 30 cm, was conserved in correspondence with a narrow band along the longitudinal axis, while it grows progressively towards the free edges. This change means that the behaviour of the vaults

moves away from the theoretical model of the shell under uniform compression and towards that of a succession of four arches.

When the contractor began construction of the bridge at the end of 1970, he immediately became aware of having underestimated the difficulties related to its realisation: he initially claimed that the project was unbuildable, requesting substantial modifications and threatening to break the contract, however, after obtaining a significant increase to the project budget, he changed his mind. The Italian Ministry of Public Works was also sceptical about the feasibility of the design and requested further test, this time using a concrete model. A model of two bays was realised, some 14 m in length; it was a perfect reproduction of the bridge to be built, right down to the reinforcing bars [figure 9]. While revealing the need for further adjustments, the tests, completed in March of 1971, eliminated any doubts.

Construction began the same year, and straightaway



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revealed all of its complexities: it was very complicated to construct formwork capable of following the vast variations to the curvatures of the surfaces; it was difficult to shape the reinforcing bars in skewed curves; finally, it was anything but simple to pour the concrete, above all in the sections with steep inclines [figure 10].

The bridge was inspected and tested on May 22, 1975 and the job site was finally closed.

The built work [figures 11–14] imposes itself with the abstract lightness of a membrane stretched between the foundations and the deck and, simultaneously and ambiguously, with the hyperbolic realism of a massive body comprised of compressed arches that twist and bend to support the weight of the deck and transfer it to the foundations. However, more than the adherence of the result to its theoretical premises, the greatest value of this bridge—recognised by Musmeci himself after its completion—is to be found in the successful metamorphosis of a vague initial idea into a concrete and vigorous “architectural event”.

Figure 10. The bridge under construction

Figures 11, 12, 13, 14. Images of the bridge today: partial views; view of the pedestrian passage between the vaults and the deck; view of one of the bases of the bridge.

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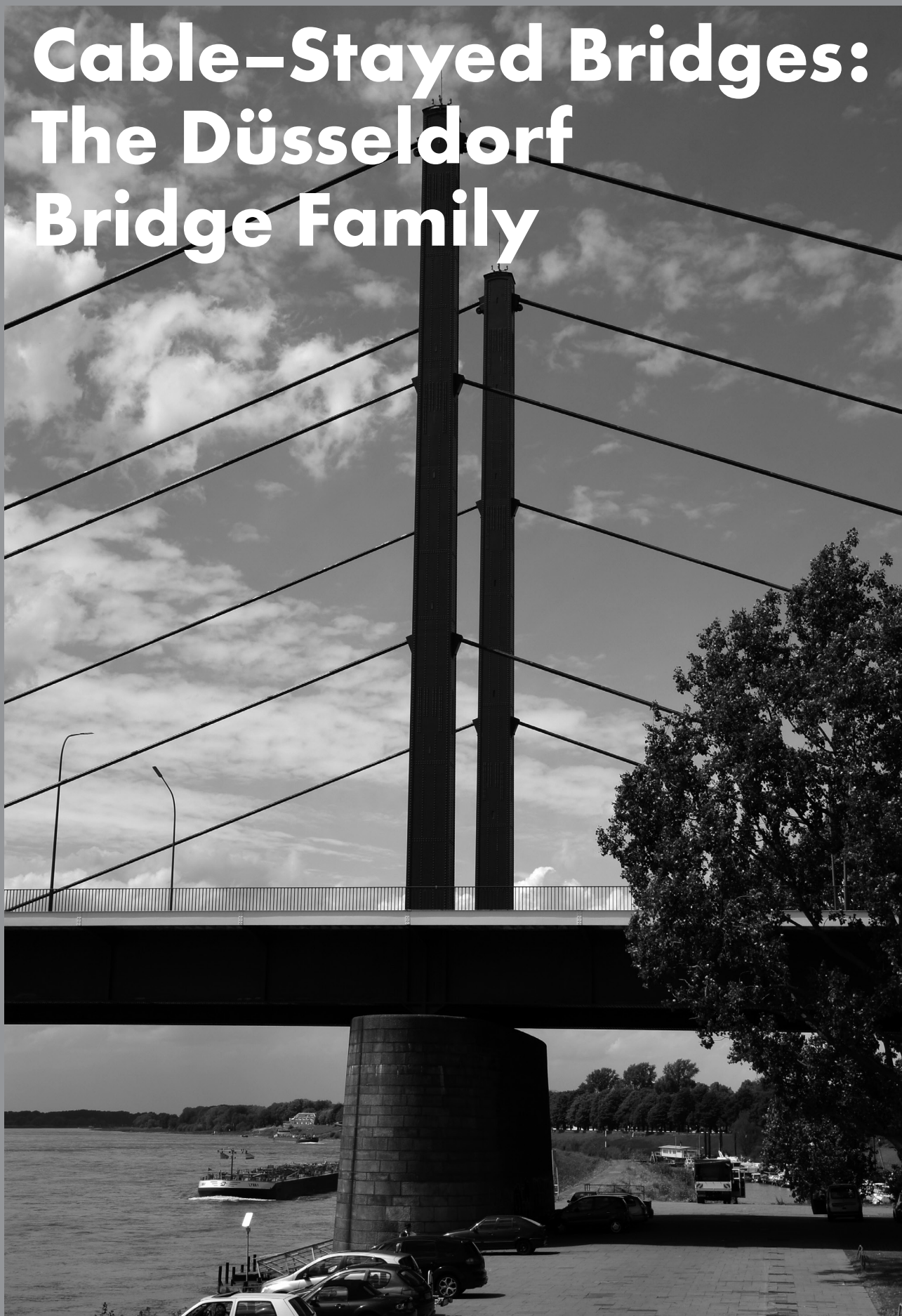
The author wants to give special thanks to the MAXXI Architettura Centro Archivi in Rome for its gentle concession to publish photographs and drawings from the Sergio Musmeci and Zenaide Zanini archives.

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Cable-Stayed Bridges: The Düsseldorf Bridge Family

52



THE heart of the famous Düsseldorf Bridge Family are the three cable-stayed bridges built between the late 50s and early 70s of the last century. They mark the beginning of the development of Modern cable-stayed bridges, but not only from a technological point of view. Instead they develop the aesthetical potential once the new structural type has become favorable all over the world.

By Annette Bögle

SPANNING light and elegance over the Rhine river bend in Düsseldorf, these three cable-stayed bridges became famous as the Düsseldorf Bridge Family and marked the beginning of the development of Modern cable-stayed bridges. But the principle of using cables to hang up the walkway and the use of tension elements instead of compression and bending elements with the aim of reaching wider spans is quite old. Indigenous bridges still use natural growing materials like lianas for suspensions. The stay-cable as structural principle is also well known from sailing boats with their spatial guyed masts. Likewise the striking element of a cable-stayed bridge is the mast with diagonal cables, anchored directly on the mast and a suspended bridge deck in both directions.

Early realized bridges with stay cables are quite often a combination of suspension and stay cables of which the Brooklyn Bridge by John August Roebling is one of the most famous examples. Here additional stay cables stiffen the bridge deck against wind impact and heavy traffic load and give the bridge a singular appearance with a high recognition value. But it was not before mid 20th century that the structural potential of this principle was fully detected and developed as a Modern rational structural principle, particularly consequence of the increasing industrialization of the building trade.

The first stay-cable bridges have only few (1 to 3 or 4) stay cables. In this case the deck is only supported on few points which results in a correspondingly larger depth of the beam. Instead more cables with smaller distance simplify the structure of the deck as well as the construction method. Consequently quite large spans can be built with an exceptional slender deck. To arrange the cables there are numerous possibilities, but two extremes can be described. Technically, the most efficient one is the fan shape with all cables meeting at the top of the tower. The other extreme is the harp shape where all cables are parallel and equally distributed over the height of the tower.

The Strömsund Bridge, built in 1956 in Sweden, gets the credit to be the first Modern cable-stayed bridge. The bridge hangs from two cables on each side, building a fan. From different angles this leads to an irritating appearance of the cable. It seems that the design of this bridge focuses on the development of a new structural type, for example with pre-tensioned stay cables, but from the aesthetic point of view the bridge just shows the known language of suspension bridges and is not further developed. On the way to a distinct structural aesthetic expression, the design of the Düsseldorf Bridge Family seems to be more important.

As in many cities, the Second World War left tremendous marks in Düsseldorf and the existing bridges over the River Rhine did not last beyond its end. This in particular had an immense impact on infrastructure and economy as Düsseldorf connects important economical centers from east to west and along the Rhine River from north to south. Consequently not only the simple connection of the river banks was very important for the city, but also a reasonable link to the whole road network. Furthermore all bridges had to be reconstructed in a time where high quality material, especially high grade steel, was very scarce, making the design of material-efficient bridges mandatory. The responsible architect of the urban concept of the first three bridges, Friedrich Tamms, required a slender and elegant design avoiding any mighty or powerful gestures, also focusing on the design of cable-stayed bridges.

The boundary conditions were dominated by the river traffic: navigation required a big clearance and the quite lively river traffic was not to be disturbed during construction. With these conditions, the most favorable typology at that time was the newly developed structural type of the cable-stayed bridge which allowed the light appearance, efficient use of materials, large spans and cantilevered erection. With the design and construction of these bridges, the leading engineer Fritz Leonhardt gained fundamental knowledge on the structural behavior of cable-stayed bridges. In this way the Düsseldorf Bridge Family can be seen as the starting point of the development and establishment of this worldwide fascinating bridge type.

< Theodor Heuss Bridge, Düsseldorf, 1957. Photo by Nicolas Janberg.



Figure 1. The impressive net generated by the vertical hangers and the diagonal stay cables of the Brooklyn Bridge, New York, by **John August Roebling**, 1883.

Figure 2. Kniebrücke (Knee Bridge), Düsseldorf, 1969.

Figure 3. Theodor Heuss Bridge known as the North Bridge, the first member of the Bridge Family. Düsseldorf, 1957.

Figure 4. Oberkassler Bridge, the third bridge which forms the core of the Bridge Family. Düsseldorf, 1973.

© Photos by Nicolas Janberg.

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Not by accident Leonhardt became involved in the design of these bridges. He had been working with Tamms before the war at the office for construction management of the *Reichsautobahn*. Leonhardt was not only enthusiastic about bridge building, furthermore in the early 30s he had the opportunity to travel through the United States and to study the most Modern suspension bridges like the just finished George Washington Bridge in New York and to meet the responsible designer Othmar Amman; both certainly an impulse for his fascination for any cable suspended bridge in particular and his sustainable interest in a holistic design of bridges which goes beyond the solely calculation of bridge design.

Today 7 bridges belong to the Bridge Family, but the heart consists of the three cable-stayed bridges built between the late 50s and the mid-70s. Even if during this long time period there has been much progress in design and construction, the original urban and aesthetic concepts of Tamms were realized for all bridges with all of their recognizable values. Although each of them is in a slightly different situation and function they speak a similar structural language as they all use harp-shaped stay cables. The harp-arrangement was chosen to avoid any entanglement of the cables which would appear e.g. if the cables met at the top of the mast in a radiating way.

The Theodor Heuss Bridge—among many local peo-



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ple still known as North Bridge—was built in 1957 as the first member of the Bridge Family. Instead of the common pylons of suspension bridges in form of a gateway, here two pairs of slender masts characterize the symmetric bridge with a main span of 260 m. The aerodynamically shaped deck is held by only three parallel cables on each side of the masts, thus the deck has to be comparably thick. But the harp arrangement of the cables avoids any irritating view through a maze of cables. Furthermore the few cables disappear from a distance and the bridge seems to be slender and strong at the same time.

The slender freestanding steel masts taper till the top and do not need any cross beams, thus the lateral stiffness is quite small. But as the deck is stiff and the masts are only 40 m high, it is sufficient. The detailed analysis of the load bearing behavior of this bridge and its construction allowed the clarification of the principle of stay-cable bridge structural behavior.

The next bridge being built in the riverbend was the *Kniebrücke* (Knee Bridge). The design was finished in the 50s but was not realized before 1969 and then with only minor changes. To achieve an accent opposite to the high-rise buildings on the right river bank the bridge is unsymmetrical with only one pair of masts towards the left side. The 114-meter-high masts and the 4 parallel cables are arranged outside the deck. To avoid cross beams, the masts have a T-shaped cross section. Here each stay cable is anchored directly to the columns of the adjunct floodland bridge which lead to a stiff suspension in the main 320 m span and allows this unbelievable slender deck.

Located between these two described bridges the Oberkassler Bridge was built in 1973. The design of this bridge was strongly influenced by the construction process. The bridge had to be built next to an existing auxiliary bridge and then, as the first cable-stayed bridge,

shifted laterally into the final position. Therefore only one mast was chosen and placed in the middle to create a symmetrical bridge. The four parallel cables are symmetrical to the mast which has the advantage of a total balanced bridge under dead load. In this case, as well as during the shifting process, the anchorage of the back stay cables in the columns in the floodlands is not needed.

With these three bridges, the core of the Düsseldorf Bridge Family was erected. The city is proud of its harmonious appearance and identifies itself with its bridges. This once more proves the importance of structural design in general and of the contribution of Fritz Leonhardt and his team to structural design in particular. Furthermore Leonhardt influenced the engineering community not only through his design, but also as a teacher, lecturer and through his publications. Not only to focus on simple feasibility but also develop aesthetic quality along with technical innovations is the important message for today's engineering coming from Fritz Leonhardt and his Düsseldorf Bridge Family.

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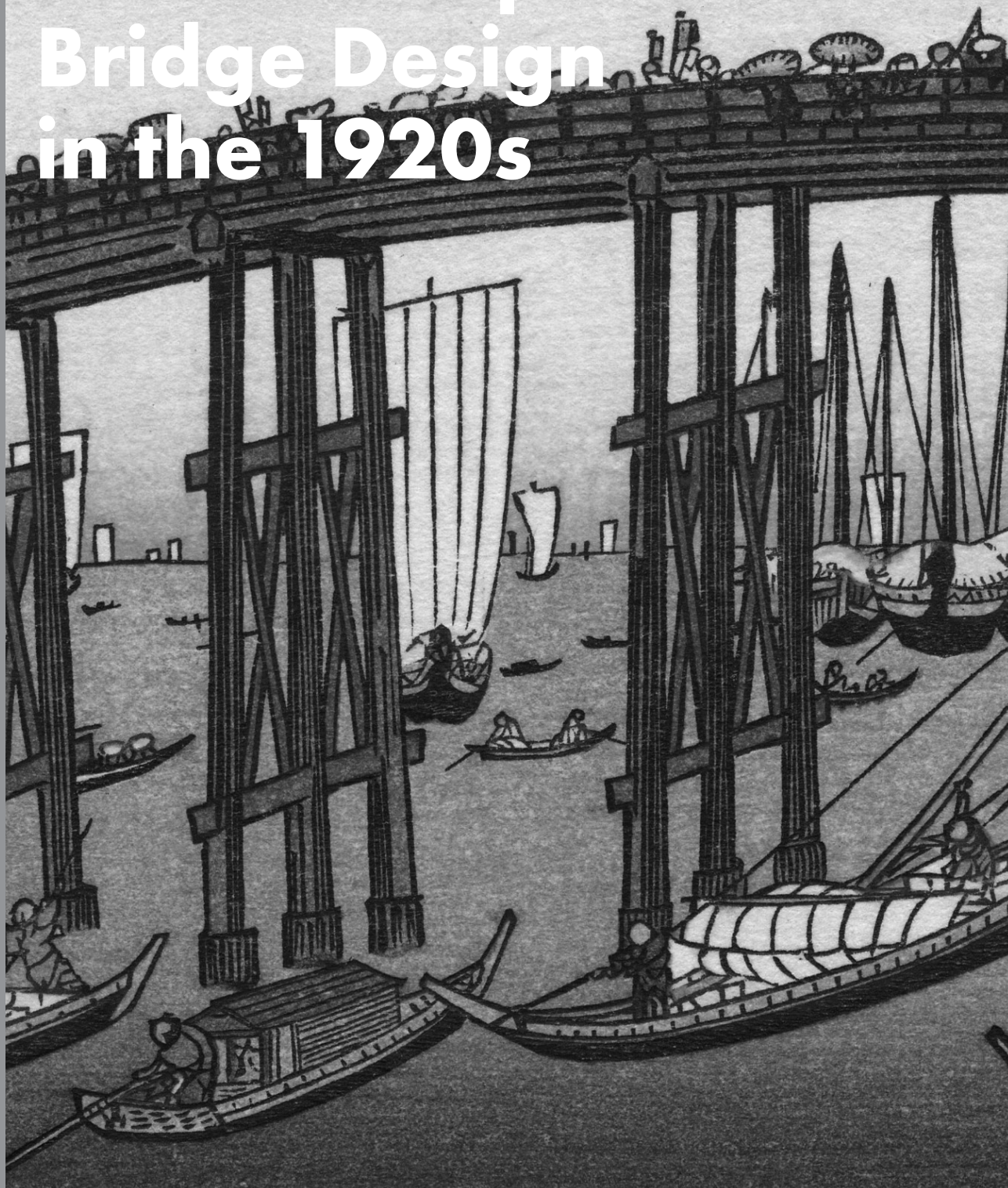
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Eitai and Kiyosu Bridges over the Sumida: Japanese Bridge Design in the 1920s

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AFTER the earthquake of 1923 which devastated Tokyo, Japanese engineers worked on reconstruction to generate a new Modern landscape in the capital, taking into account various arguments ranging from science to culture. The construction process of the Eitai and Kiyosu bridges over the Sumida River are indicative of this development. This paper will describe this process to better understand Japanese bridge design in 1920s in terms of technology and aesthetics.

By Daijiro Kitagawa

THE Sumida, the main river flowing through Tokyo, has always been a key place for Japanese bridge builders and engineers to display the technological progress of the times. Close to the seaport, the bridges had to span a large mouth of the river without impeding the passage of boats or ships [figure 1]. In terms of design, the imposing scale of these new structures expressed the power of a metropolis. Before, the connection between the banks of large rivers had been commonly ensured by small ferryboats.

The introduction of Modern industrial technologies, which began in the middle of 19th century, brought radical changes to the form of civil structures. The Sumida, along with the Yodo River in Osaka, was among the first major Japanese rivers to be equipped with metallic road bridges. In particular, one of the first steel road bridges in the country, consisting of 200 foot trusses, was built in 1897 at the very mouth of the Sumida¹ [figure 2]. The hybrid landscape along the river, which was composed of traditional buildings and 'westernized' bridges, symbolized the modernization of Tokyo.

In the same spirit of modernization, from 1920 a new urban planning for a Greater Tokyo began to be examined. During the same period, a cultural movement yearning for new urban aesthetics also occurred. This movement was influenced, among other things, by the City Beautiful Movement in the US. However, urban improvement of the capital became all the more urgent and indispensable in light of the devastating earthquake of 1923 that reached a magnitude 8.2 on the Richter scale, and of the ensuing fires that caused extensive damage to the city. Concerning the bridges, among the 657 that existed in Tokyo, a total of 69 structures were damaged and 289 burned down.

The challenges for civil engineers were no longer simply to satisfy the political, economic and cultural requirements of a fast-growing society, but to make the 'Imperial city' more resistant against natural disasters. Once again, the Sumida became a space to showcase engineering

achievements, especially through the erection of the Eitai and Kiyosu bridges.²

Towards a Quake-Resistant Bridge

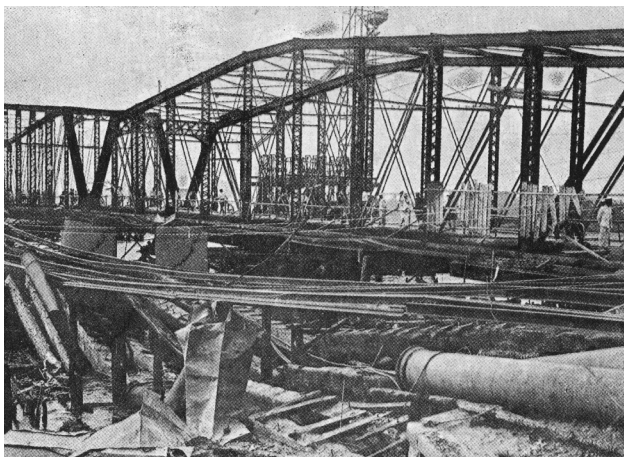
The Eitai and Kiyosu bridges [figures 3, 4] were among the 115 bridges constructed by the National Bureau of Reconstruction during the recovery process in Tokyo.³ Interestingly, all these structures have a common technical feature: none opted for a truss type. For steel bridges, the structures adopted a plate girder to main beam regardless of their span. One of the lessons learned from the disaster was indeed to secure the rigidity of members and joints to avoid any possible deformation of the structures caused by strong vibrations.

Comparative drawings for the bridges over the Sumida in 1924 show that this idea was not unanimous from the beginning of the project [figure 5]. Nonetheless, the technical conviction of chief engineer Yutaka Tanaka was decisive in leading the Bureau to select n° 5 for the Eitai (and not n° 3 or n° 4), and n° 6 for Kiyosu (and not n° 1 or n° 2).

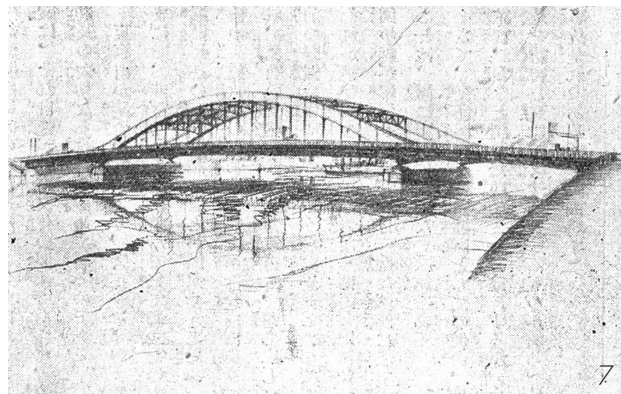
Apart from this general point, what were the technical advantages of two bridges?⁴ Firstly, the use of the pneumatic caisson method should be highlighted. The ground conditions were not favorable to place a massive structure. Therefore, the Bureau decided to summon Junzo Masago, an engineer that had worked at several firms in the US after graduating from Washington University. He was hired to carry out the work in collaboration with American Engineers at the Foundation Company. Seeing that it had taken so long to implement a similar project previously in Korea in the Japanese-Governed period, the Bureau expected American assistance would enable them to shorten the construction time and accelerate the recovery process. Even if this application of the pneumatic caisson method came late, it was nevertheless meaningful in the history of engineering in Japan, for this full-scale experience triggered its generalization all over the country.

Yet, the problem of the soft ground was not completely resolved by improving the foundations. To address this issue, Tanaka and his superior Enzo Ota, Director-General of the Engineering Department of the Bureau, adopted a

< Figure 1. The timber Eitai Bridge, mid-19th century. Source: JSCE.



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tied arch system for the Eitai bridge and a self-anchored system for the Kiyosu Bridge to remove excessive horizontal stress to both banks. A cantilever system was also used in both these cases to attenuate vertical loads to the anchors.

Finally, 'Ducol steel', a high-tensile manganese steel, was used for the first time for these bridges. This material had been developed in 1921 for the building of battle-ships by the Royal Navy of the UK. The Bureau, having researched all engineering fields, applied this technology to both bridges to lighten and strengthen the structures.

In Search of Modern Bridge Aesthetics

It is interesting to note that these technical challenges were closely linked to aesthetic issues. From the beginning of 20th century, several Japanese engineers had become interested in the question of the beauty of Modern bridges alongside the pursuit of cutting-edge technology. This discussion ranged from philosophical to practical issues.⁵

Ota dreamed of giving a new form to Japanese civilization through reconstruction works. He thus organized an informal working group of artists and writers—Ryunosuke Akutagawa among others—to obtain proposals for a

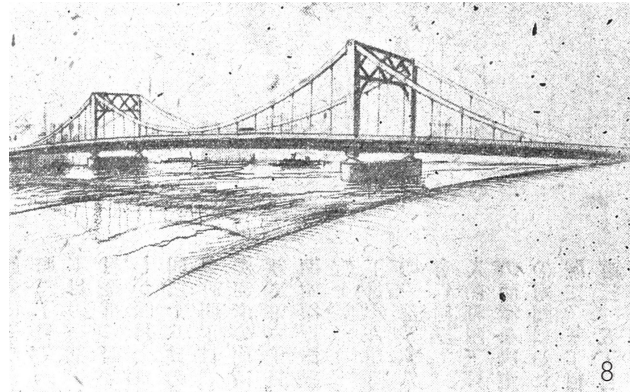
Figure 2. The Eitai Bridge of 1897, damaged by the earthquake and fire in 1923. Source: JSCE.

Figure 3. The Eitai Bridge, constructed in 1924–1926.
Photo by Daijiro Kitagawa.

Figure 4. The Kiyosu Bridge, constructed in 1925–1928.
Photo by Daijiro Kitagawa.

Figure 7. Drawing of the Eitai Bridge, probably done by **Takizo Okamura**, future **Bunzo Yamaguchi**. Source: *Gendai Tsushin*, 1925.

Figure 8. Drawing of the Kiyosu Bridge, probably done by **Takizo Okamura**, future **Bunzo Yamaguchi**. Source: *Gendai Tsushin*, 1925.



new bridge style for Tokyo. Mamoru Yamada and Bunzo Yamaguchi, two architects from the Ministry of Post and Telecommunication known as members of the Japanese 'Sezession' group, had also joined the Bureau to participate in the enterprise. Meanwhile, over 2,000 pictures of bridges all over the world were collected, probably at the request of Ota, to serve as a database of bridge design.

Although most of the informal proposals were unrealistic and as such, difficult to materialize, the many discussions among artists, architects and engineers had finally led to the formulation of a principle.

*Get rid of false belief that a decorative bridge be beautiful! The intrinsic beauty resulting from mechanics theory is major part of bridge aesthetics. [...] From a standpoint of the 'Spirit of Reconstruction' too, we should abandon frivolous and unwholesome decorations as well as decadent tastes, and go back to the right way of the design of civil structures."*⁶

The rejection of trusses could be explained from this idea of the 'Spirit of Reconstruction' as well. In the case of the Eitai Bridge, its massive solid rib arch was an expression of power, which a truss bridge—a 'big bird cage' according to Ota—could not fully render. The Kiyosu's firm

form of chains stiffened by plate girder was also intended to represent gracefulness without giving the impression of being 'frivolous' or 'decadent' through the use of intricate compositions of thin members. In terms of mechanics, the Bureau adopted a real parabolic arch, inverted or not, instead of a false parabola formed from different sections of circle, as had been commonly applied until that time. In addition, the same sag was employed for the arch of the Eitai and for the chain of the Kiyosu to emphasize a clear contrast between the form of these two bridges, which were located side by side.

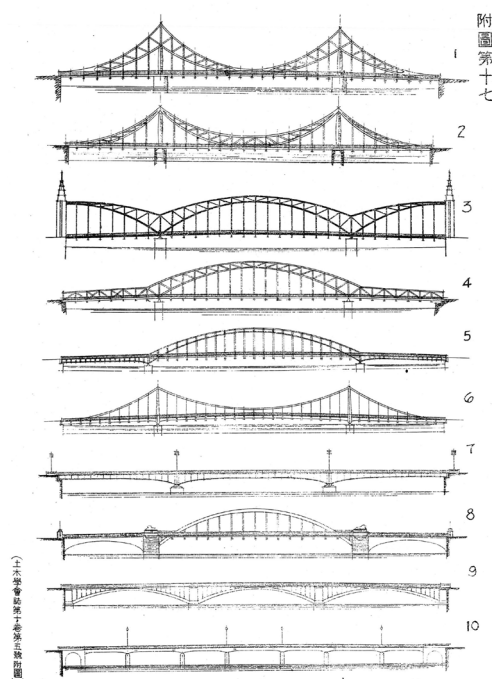
Nonetheless, for the Kiyosu, the above-mentioned principle only played a secondary role in leading the design. This suspension bridge had an obvious model in Cologne, the *Hindenburgbrücke*⁷ [figure 6]. At a conference in 1928, Tanaka said that he had read an article on the competition for this bridge when he was a student at the University of Tokyo and felt the advent of a new age of bridge design.⁸ The only architectural efforts were to make the main beam more slender in order to better express its elegance, taking advantage of the performance of Ducol steel⁹ [figures 7, 8].

Conclusion

Oscillating between an imperative of quick recovery of national political and economic centre¹⁰ and a desire to create a new, more modern and original Japanese civilization, engineers and architects may not have achieved their purpose entirely in this enterprise, considered by many to be the greatest that Modern Tokyo had ever seen. After the suicide of Ota, who was involved in a bribery scandal, his initial wish was materialized in a less visionary way under the direction of Tanaka, as he focused more on practical issues.

Nonetheless, these two bridges remain important references for the Sumida, in particular during the planning of the Kachidoki bascule bridge below the Eitai from 1930. The initial decorative design would have been more suitable for the main entrance of the would-be World Fair in 1940 [figure 9]. In the end, however, it was modified in favor of a harmonization with the sober Eitai Bridge. This occurred after the probable writer of *Spirit of Reconstruction*, Katsutake Naruse, was nominated as supervisor of this construction [figure 10].

The influence of these bridges reaches far beyond the area of the Sumida. Evidence of the prior use of plate girders in steel bridges can be widely observed in Japanese engineering works until the end of the Second World War. Even afterwards, they have inspired some engineers to better articulate technological developments with aesthetic issues. In this sense, the Eitai and Kiyosu bridges can be considered as a precious heritage of our



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Modern urban landscape, demonstrating with utmost clarity the idea of Japanese bridge design in the 1920s.

Notes

1. Concerning railway bridges, the first large steel structure was constructed in 1887 in another part of Japan. Railway engineering was always ahead of road structures at the beginning of the Japanese modernization.
2. Kitagawa, Daijiro, "Classic of Modern bridge design in Japan", *Bridge and Foundation*, Tokyo, 05/2007. Nakai, Yu, *Thought of bridge design in Modern Japan*, University of Tokyo Press, 2005. (Both in Japanese).
3. In total, 425 new bridges were built after the earthquake in Tokyo. The rest was charged by the City of Tokyo.
4. As for the financial aspect, a sixth of the budget for the construction of all 115 bridges was devoted to these two bridges.
5. As a continuation of discussions, Modern Japanese-style bridge was searched in the 1930s and 1940s under an atmosphere of nationalism.
6. *Reconstruction works of Imperial city Tokyo*, The Bureau of Reconstruction, 1931. Original text in Japanese.
7. This competition was rather controversial, as described by Roland May in his paper. Roland May, "Discovering Construction as an Art—The 'Cologne Bridge Quarrel'", *Proceedings of the Third International Congress on Construction History*, Cottbus, 2009.
8. Tanaka, Yutaka "Bridges over the Sumida", *Journal of Public works and Architecture*, vol. 6-1, 1928. (in Japanese).
9. R.I.A., *Architect Bunzo Yamaguchi*, Tokyo, Sagami-Shobo, 1982. (in Japanese).
10. The recovery works, including the construction of 425 bridges, were concluded in 1931.

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Figure 5. Comparative drawings for bridge design over the Sumida by the Bureau of Reconstruction in 1924. Source: Enzo Ota, "About reconstruction works of Imperial city Tokyo", Journal of JSCE, vol. 10-5, 1924.

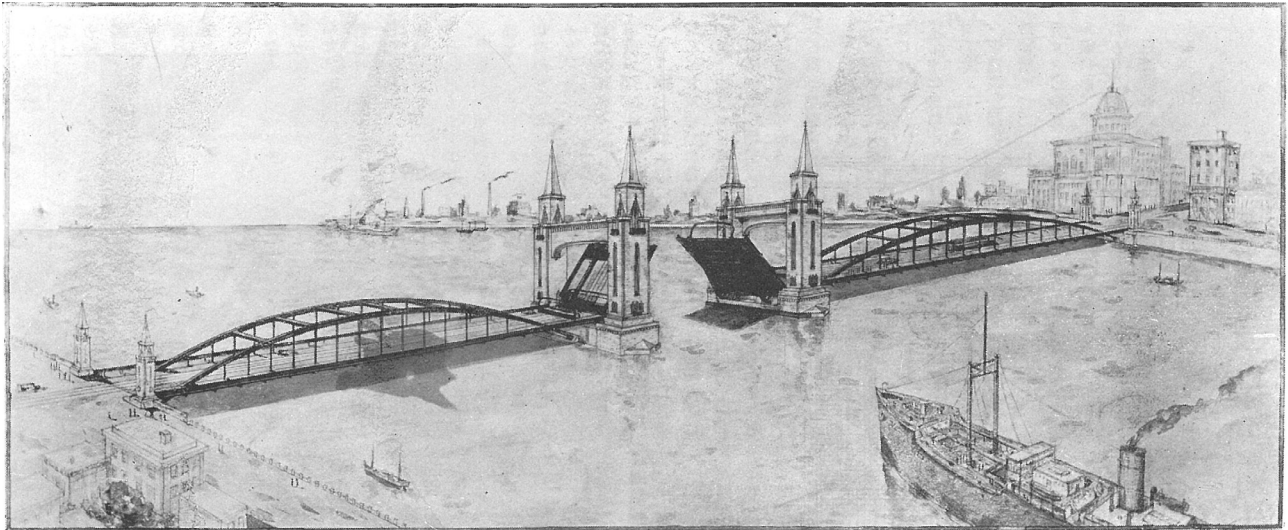
Figure 6. The *Hindenburgbrücke* over the Rhine, constructed in 1913–1915 by **M.A.N./Grün&Bilinger/Carl Moritz**. Source: Heribert Reiners, *1000 Jahre Rheinischer Kunst*, 1925.

Figure 9. Plan of the Kachidoki Bridge in 1930. Source: *Doboku-Kenchiku Gaho*, 1930.

Figure 10. The Kachidoki Bridge, constructed in 1932–1940. Photo by Daijiro Kitagawa.



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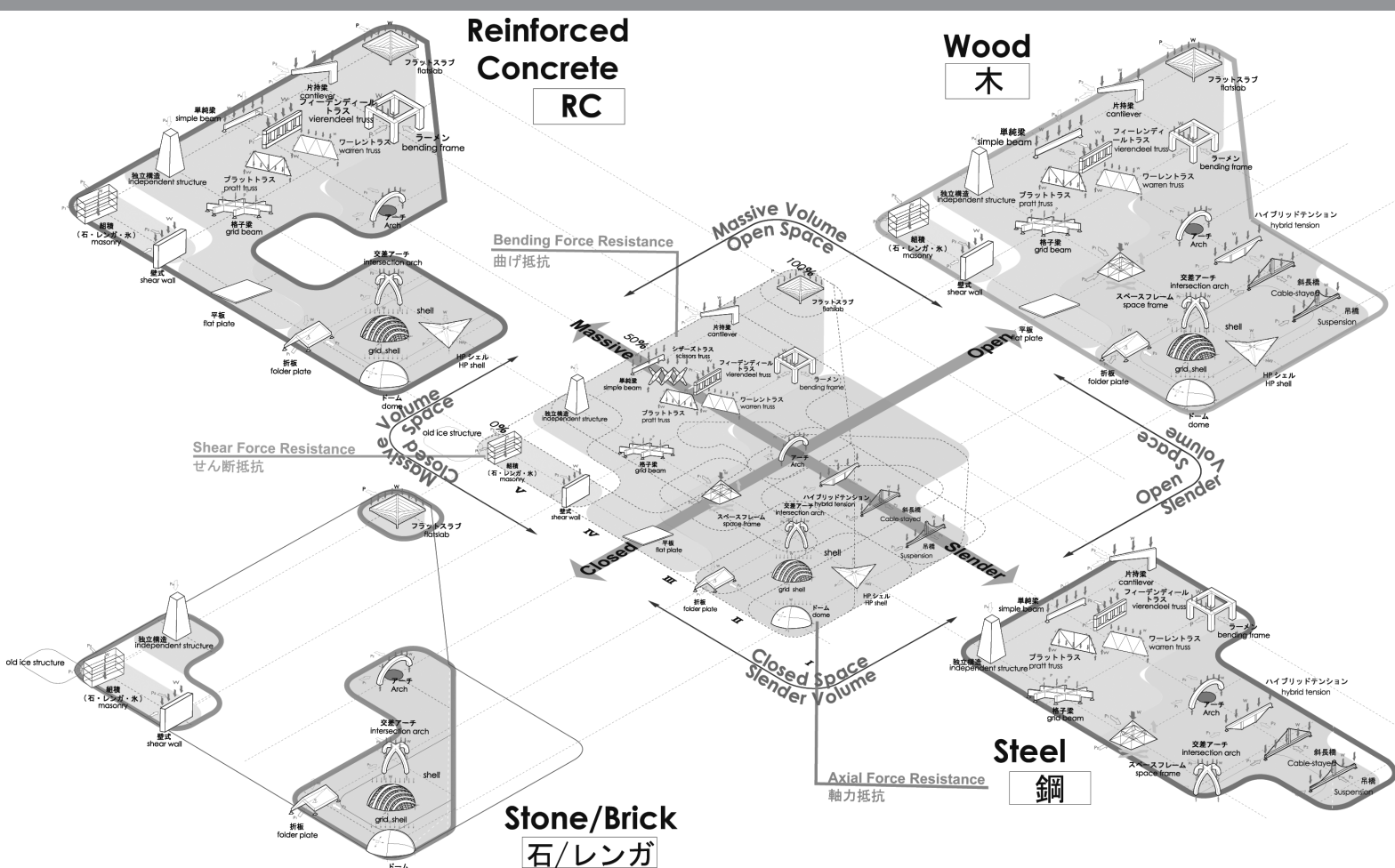
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Finding Modern Japanese Bridges: Stone, Wood and Steel



Frame acknowledgement between material and form. Drawing by © Norihide Imagawa.

IN Japan where many earthquakes occur there is a certain standpoint about long-life architecture and bridges. The relation between material and form is important for this standpoint. The reason is not only that materials have their own character, for example, physical and chemical properties, but also that form has its own individual character as load-bearing system. Without the relation between material and form, long-life architecture and bridges can't be realized.

By Norihide Imagawa and Shinsuke Suematsu

WHEN we recognize construction space, we use the design acknowledgement diagram between space and framework. This diagram expresses with Cartesian coordinate the sense of openness and massiveness about more than 20 kinds of basic framework designed in past and present.

The load-bearing systems of form include three mechanical properties as follows; axial force resistance, bending force resistance and shear force resistance.

The materials of constructions and bridges include stone, wood, iron, and concrete. Each character of these materials is as follows;

Stone	Axial force resistance
Wood	Axial force resistance, bending and shear force resistance
Iron	Bending force resistance
RC	Axial force resistance and bending force resistance

The load-bearing systems of bridges are as follows;

Arch, Cable-stayed and Suspension	Axial force resistance
Girder, truss and bending-frame	Bending force resistance
Masonry	Shear force resistance

These relations between material and form are understood by the frame acknowledgement between material and form.

Some bridges represented by each material are to be handed on to the next generation and estimated according to five points as follows:

1. *Material resistance corresponds exactly to form resistance.*
This means that it can be ensured consistency between resistance systems appropriated for material characters and form.
2. No disturbance of the environment.
It matches its environment or not.
3. Beautiful proportion and form.
It has the balance bridge's structure and beauty of form.
4. Continuity of function, connection of places between bridges.
This means that the bridge has a role for its community and a continuity of space.
5. Characteristics of bridge and construction method.
Is the bridge suitable for its location or not? Consideration of economic efficiency of bridges.

Some bridges as we shortly will discuss are still as Modern bridges in existence and selected as designated bridges and cultural heritage by government or prefecture.

Ryuzu-bashi Bridge

Kitsuki-shi, Oita.
Material: Stone. Stone Girder Bridge. L: 61.5m. W: 3.0m
Completion: 1912



© Photo from Japan society of civil engineers.

This oldest Japanese sinkable bridge in existence was awarded as civil engineering heritage in 2007 by Japan society of civil engineers. The material resistance system, stone, corresponds to the resistance structure of its form, a girder bridge. This bridge blends in with the surrounding nature and does not disturb the surrounding nature. Normally the bridge insists on its own structure, but this bridge accommodates itself to its environment. It shows its significant existence and situation. It is special worth to mention that this bridge excels frame acknowledgement in 3 points (1, 2 and 4).

Torii-bashi Bridge

Innai town, Usa-shi, Oita.
Material: Stone. Five Arch Stone Bridge. L: 55.2m. W: 4.4m
Completion: 1916
Design: Seiichiro Tsuru, Stonemason: Shinnosuke Matsuda



© Photo from Kyusyu Construction Public Utility Association.

Innai town has the most number of stone bridges. The river which flows from south to north and its branch form a deep valley so villages are

scattered along the river and wooden bridges are swept away by rapid flows. Shinnosuke Matsuda, called King of stone bridge, was a master builder that had learned the technique of arch bridges. He designed the Torii-bashi Bridge with various spans and different heights. The 1951 Ruth typhoon made the river overflow and the water level dropped 12 m. There was no damage to the bridge thanks to the good ground and bridge pier designed for the feature of water flow. The resistance system of its material, stone, corresponds with the resistance structure of its form, arch. This bridge has an indispensable presence of the stone bridge family and as a sightseeing resource. This bridge excels the frame acknowledgement in 5 points (1, 2, 3, 4 and 5).

Megane-bashi Bridge

Nagasaki-shi, Nagasaki.

Material: stone. Double Arch Stone Bridge. L: 23.2m. W: 4.70m

Completion: 1634. Collapse of the bridge by flood: 1647

Half collapse of bridge by Nagasaki heavy rain and mudflow: 1982



© Photo from Shinsuke Suematsu.

This bridge is appointed national cultural asset and is famous as one of the oldest stone bridges in Japan utilizing a traditional Chinese construction technique. The bridge was severely damaged by Nagasaki heavy rain and mudflow 1982, therefore the rebuild bridge was located between tunnel waterways on both sides to protect it for the next flood. The resistance system of its material, stone, corresponds with the resistance structure of its form, arch. It is a pioneer of presence of stone bridge family and has an important role in this area. It is worthy of special mention that this bridge excels the frame acknowledgement in four points (1, 2, 3 and 4).

Tamaru-bashi Bridge

Uchiko town, Kita-gun, Ehime.

Material: Wood. Wood Girder Bridge roofing with cedar bark reinforced by using angle brace. L: 15m. W: 2m

Completion: 1943



© Photo by Youichiro Shigeyama.

This bridge was awarded as heritage of civil engineering 2002 by Japan society of civil engineers. The resistance system of its material, wood, corresponds with the resistance structure of form, girder reinforced by the use of angle brace. Every wood bridge roofing except for this bridge across the Fumoto river has been swept away. The inhabitants of the district has refurbished this bridge and has controlled it carefully. This wooden bridge has an indispensable presence of existence that doesn't disturb the landscape. This bridge excels the frame acknowledgement in 2 points (1 and 2).

Hourai-bashi Bridge

Shimada-shi, Shizuoka.

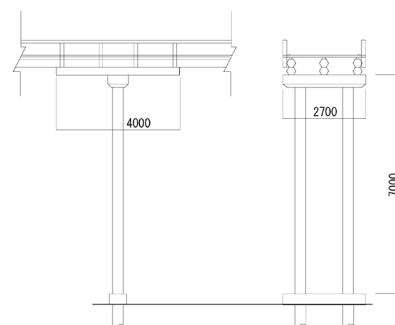
Material: Wood. Wood Girder Bridge. L: 897.4m. W: 2.7m

Completion: 1897. Modification of concrete pier: 1965

Post-disaster construction and damage repair: 2005



© Photos by Youichiro Shigeyama. © Drawing by Shinsuke Suematsu.



This bridge has been recorded in the Guinness Book of World Records as the longest wooden footbridge. The resistance system of its material, wood, corresponds with the resistance structure of its form, girder. Although this bridge has passed away by rise of water level, it has been restored every time. Its piers were replaced with concrete piles after the overflow of river in 1965. For the harmony with the landscape, the concrete piles were covered with wooden panels. This wood bridge fits exactly into the landscape. This bridge excels the frame of acknowledgement in 3 points (1, 2 and 4).

Hachiman-bashi Bridge (Dansei-bashi Bridge)

Koutou-ku.

Material: Wrought iron, Cast iron. Single Span Bowstring Truss Bridge.

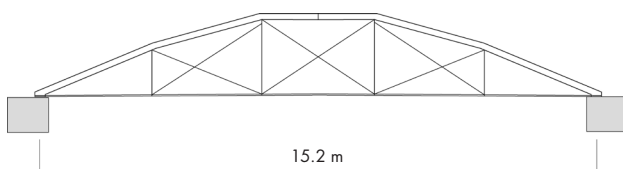
L: 15.2m. W: 2m

Completion: 1878 Momiji-gawa. Relocation: 1929, Fuka-gawa

Design: Souichirou Matsumoto



© Images by Shinsuke Suematsu.



This bridge has been appointed a national cultural asset and a Japan historic civil engineering landmark by American society of civil engineers. Akabane factory, ministry of land infrastructure, manufactured originally this bridge on the basis of American engineering patent. It bridges across Momiji River as a symbol of cultural enlightenment. The new Dansei Bridge was constructed on the north of the old Dansei Bridge according to revised city development in 1912. The old Dansei Bridge was laid in ruins according to the earthquake disaster reconstruction for the great Kanto earthquake in 1923 and was relocated in Fuka-gawa. The arch members of this bridge are manufactured with wrought iron and tension members are of cast iron. At transition period from wrought iron to cast iron, to put the right material in the right member, the resistance system of the material corresponds to the resistance structure of its form, bowstring truss bridge. This bridge excels the frame acknowledgement in 1 point (1).

Naidaijin-kyo Bridge

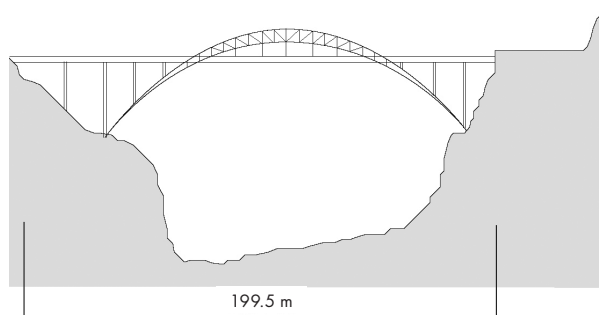
Misato town, Shimomashiki-gun.

Material: Steel. Truss Arch Bridge. L: 199.5m. W: 5.5m

Completion: 1963. Design: Kumamoto regional forestry office



© Photo by Norihide Imagawa. © Drawing by Shinsuke Suematsu.



This bridge was constructed across the Naidaijin valley to support the development of local forest resources. At the time it was the longest arch bridge in the East, later renewed in railing and paint. Crossing the Midori River is also the Ayunose Bridge which has Y-formed piers and cable-stayed form and the Tsujyun Bridge, famous as a stone navigable aqueduct and a sightseeing resource. The resistance system of the material, steel, corresponds with the resistance structure of its form, truss arch bridge. The design and the fine form like floating on air display various looks in response to seasons change of surroundings. This bridge excels the frame acknowledgement in 3 points (1, 2 and 3).

Minamikouchi-bashi Bridge

Kitakyusyu-shi, Fukuoka.

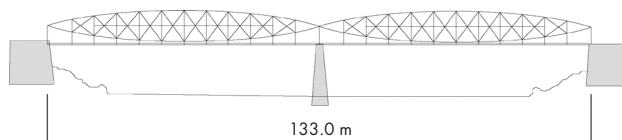
Material: Steel. Lenticular Truss Steel Bridge. L: 133m. W: 3.1m

Completion: 1926. Design: Hisanori Numata, Motojiro Adachi, Saburo

Nishijima (Yahata steel plant)



© Drawing by Shinsuke Suematsu.



This bridge is the only one across the reservoir that ensures stable water supplies for Yahata factory. It is appointed national cultural asset and the heritage of civil engineering 2000 by Japan society of civil engineers. The form of the structure is composed of two curved-chord trusses turning up and down and the vertical members from which the deck is hung. The resistance system of its material, steel, corresponds with the resistance structure of its form, truss arch bridge with rational components. It is red colored as symbol and contrast favorably to the blue sky and the green forest. This bridge excels the frame acknowledgement in 3 points (1, 3 and 5).

Eitai-bashi Bridge

Cyuuu-ku, Tokyo.

Material: Steel. Tied Arch Steel Bridge. L: 184.7m. W: 25m

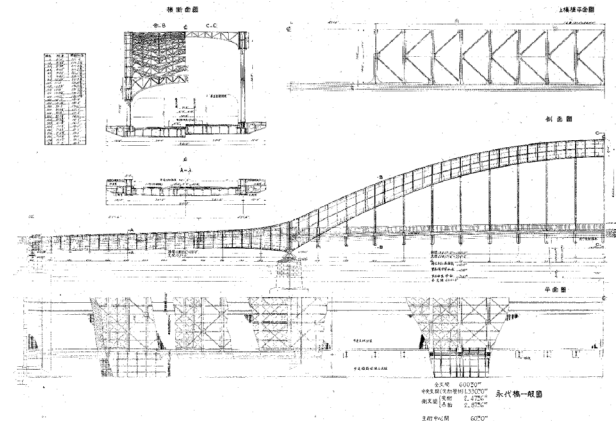
Completion: 1926. Design: Yutaka Tanaka (original), Yoshitada Takenaka, (Mamoru Yamada, Bunzo Yamaguchi), Tokyo reconstruction bureau.

Manufacture: Kobe Kawasaki dockyard.

Construction: Futomarugumi, Hazamagumi



© Photo by Shinsuke Suematsu.



Kiyosu-bashi Bridge

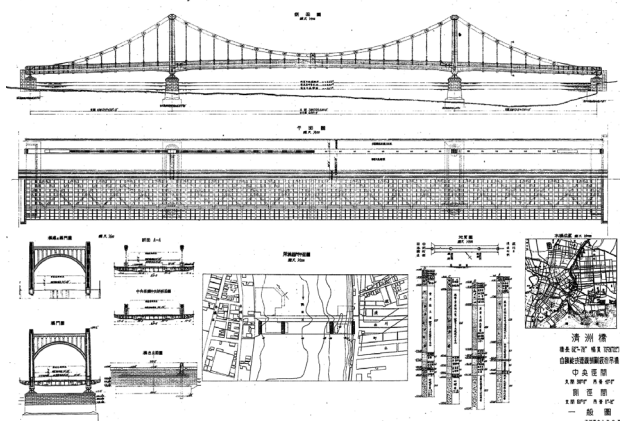
Cyuuu-ku, Tokyo.

Material: Steel. Suspension Steel Bridge. L: 186.3m. W: 22m

Completion: 1928. Design: Seiichi Suzuki (Mamoru Yamada, Bunzo Yamaguchi), Tokyo reconstruction bureau. Manufacture: Kobe Kawasaki dockyard



Photo by © Shinsuke Suematsu.



These two bridges are appointed national cultural asset and heritage of civil engineering 2000 by Japan society of civil engineers. Eitai Bridge has been called the gate of Teito Tokyo and Kiyosu Bridge was called the flower of earthquake disaster reconstruction. These bridges took the central role in Tokyo reconstruction as the Twin Gates. The design introduced new technologies, for example to use high-strength steel like the

German bridges. The resistance system of the materials of the bridges, steel and high-strength steel, corresponds with the resistance structure of its forms, tied arch and suspension. These are not only the main bridges across the Sumida River, but also symbols of Tokyo city. This bridge excels the frame acknowledgement in 5 points (1, 2, 3, 4 and 5).

Hijiri-bashi Bridge

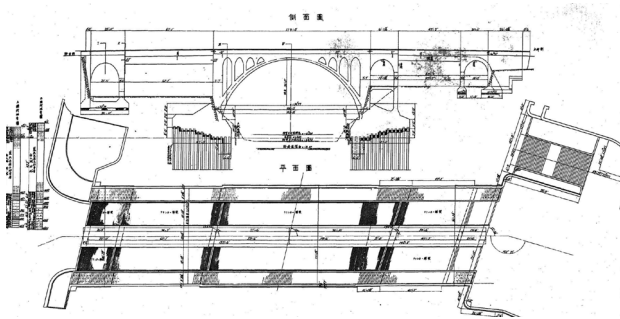
Chiyoda-ku, Tokyo.

Material: R. Concrete. Arch Bridge. L: 92.5m. W: 22.0m

Completion: 1927. Design: Mamoru Yamada, Katsutake Naruse



Photo by © Shinsuke Suematsu.



A Teito reconstruction after the Great Kanto earthquake by Mamoru Yamada, a Japanese Modern architect. The design, modelled with bold parabola, is in large part thanks to him. The resistance system of the reinforced concrete corresponds to the resistance structure of its form, arch. This bridge is not only an image of the site, but also a part of the arterial roadway. It excels the frame acknowledgement in 3 points (1, 3 and 4).

Bandai-bashi Bridge

Niigata-shi, Niigata.

Material: R. Concrete. Six Arch Bridge. L: 306.9m. W: 21.9m

Completion: 1886. Wooden bridge: 1909, 1929

Design: Takeo Fukuda, Mamoru Yamada, Yutaka Tanaka (supervisor),
Reconstruction bureau, Ministry of interior



© Ministry of Land, Infrastructure and Transport.

Appointed national cultural asset and well-established as symbol of Niigata, the reinforced concrete resistance system corresponds with the resistance of its form, arch. In addition, this design is made with consideration to strength and aesthetic form by rolling back at the center of arch drawn loose parabola. The foundations were built with the pneumatic caisson method for the first time with only Japanese people. The Niigata Earthquake in 1964 made part of the bridge sink only 10 cm. The original illuminating lamp was restored by local citizens with zeal. The importance of this bridge is rediscovered by the local area. This bridge excels the frame acknowledgement in 5 points (1, 2, 3, 4 and 5).

In conclusion, the bridges with each material which should be handed on to the next generation can be realized as long-life constructions because they have the balance of material and form: stone for axial resistance; wood for axial and bending resistance; steel for bending resistance; concrete for axial and bending resistance. Through maintenance of steel and concrete and with wood replacement, bridges can gain long-life authenticity. We can plot these 13 bridges on the frame acknowledgement between material and form.

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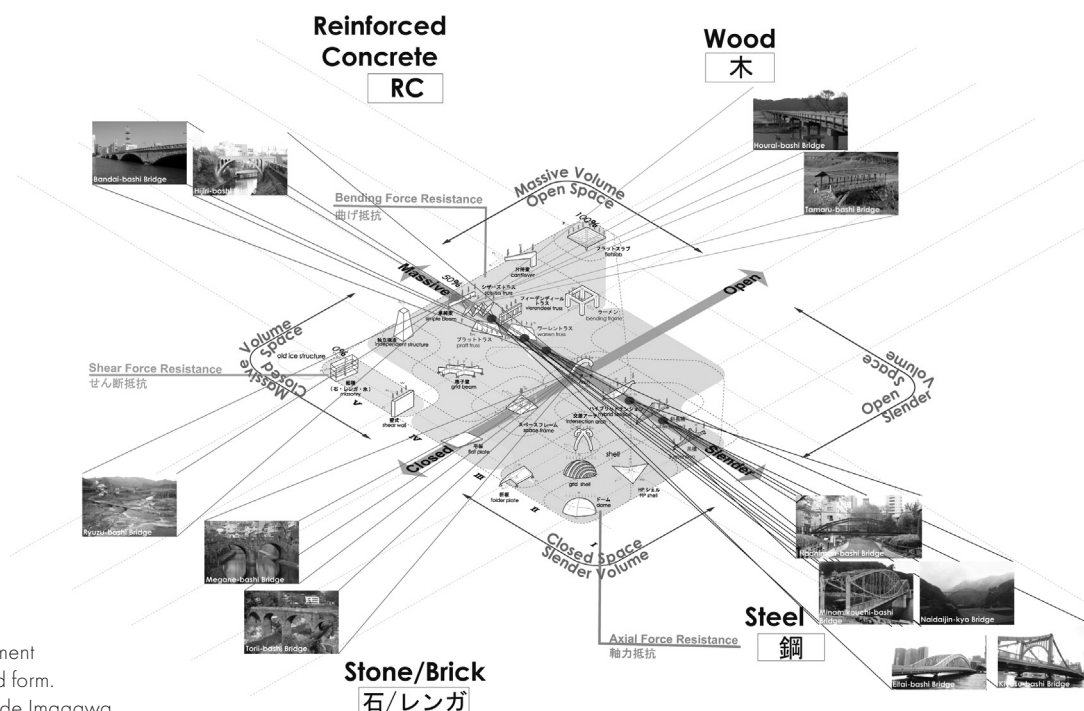
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Norihide Imagawa

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Shinsuke Suematsu

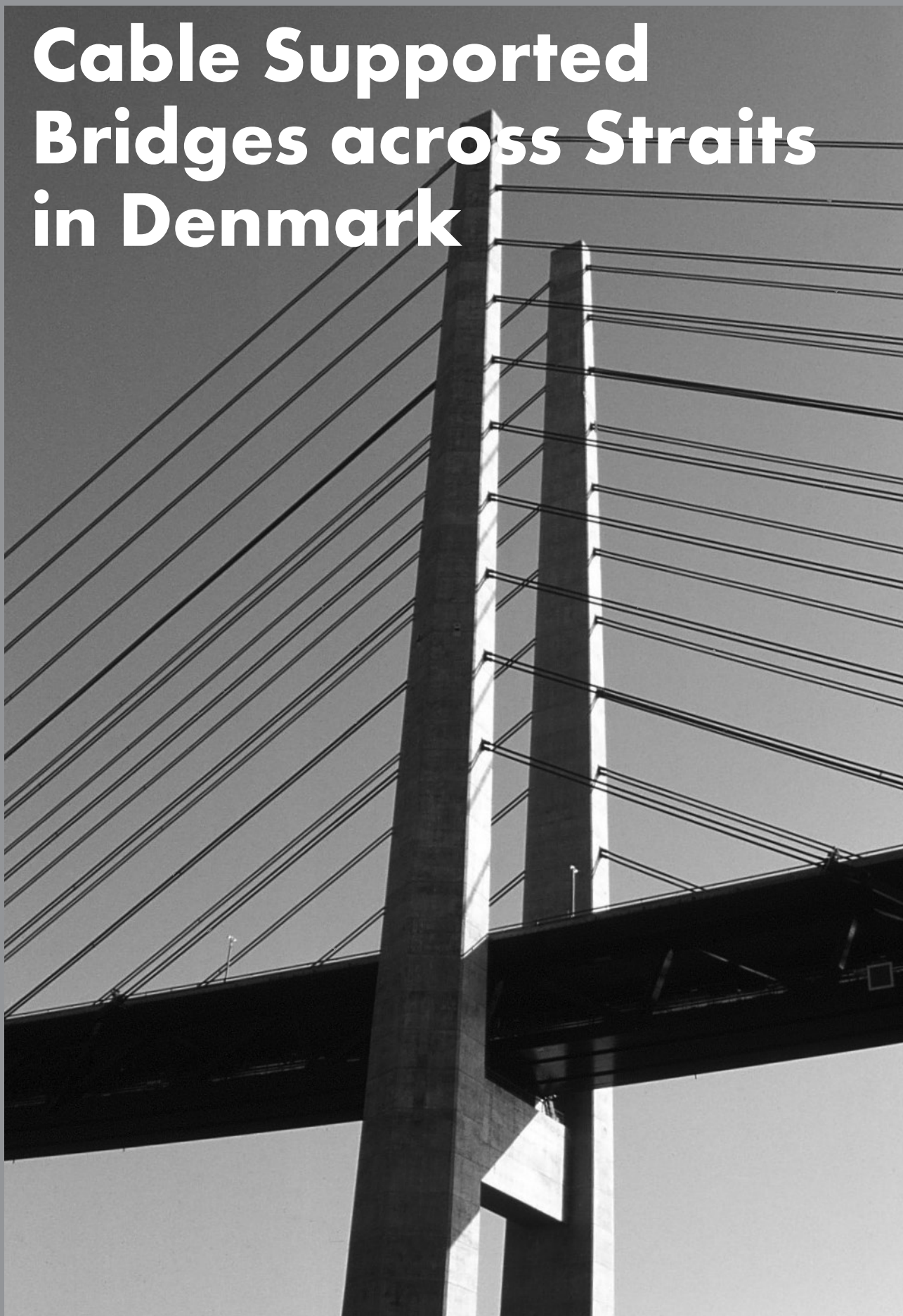
Assistant structural engineer at TIS&PARTNERS Co. Ltd.



Frame acknowledgement
between material and form.
Drawing by © Norihide Imagawa.

Cable Supported Bridges across Straits in Denmark

68



THE *Jylland* (Jutland) peninsula and the approximately 278 islands that form Denmark have had bridge connections since the Middle Ages. The most notable bridges of the 20th century are the high level bridges such as the Lillebælt Bridge from 1935 and the Storstrøm Bridge from 1937. Cable supported bridges and cable-stayed bridges have been making up the most significant infrastructural aspects which cross the seaways of the Baltic Sea.

By Niels Jørgen Gimsing

Bridges in Denmark – Historical Development

DENMARK consists of the peninsula of *Jylland* (Jutland) extending north from Germany and 78 inhabited islands (plus more than 200 small uninhabited islands). The capital of the country, Copenhagen, is situated on the largest island, *Sjælland* (Zealand), [figure 1].

In the Middle Ages wooden bridges were built in large numbers across brooks of moderate widths but none of these bridges has survived to our time. Remains of a few medieval stone bridges have been located in *Jylland* and it has been determined that the technique in constructing the vaults was similar to that used when building the vast number of village churches in the 12th and 13th centuries.

Up till around 1770 the majority of road bridges were still built of wood but after that time natural stone was used to obtain more reliable and durable bridges forming a part of a national net of highways. The stone bridges which were all of moderate size were generally composed of rough-hewed stone beams and piers as illustrated by the Immervad Bridge from 1786 [figure 2].

Major bridges across the straits separating the island kingdom were not built until the 1930s.

The most notable bridges were the high level bridges: Lillebælt Bridge from 1935 [figure 3] and the Storstrøm Bridge from 1937 [figure 4]. With its length of 3.2 km the Storstrøm Bridge was at completion the longest bridge in Europe, and it remained the longest road and rail bridge for a period of 60 years until it was surpassed by the West Bridge of the *Storebælt* (Great Belt) Link in Denmark.

For the Lillebælt Bridge the early designs from the beginning of the 20th century included suspension bridges as well as cantilever truss bridges. When the detailed design started in the 1920s only truss bridges were considered.

The bridges from the 1930s and early 1940s were generally built with a steel superstructure in the form of riveted plate girders, trusses or arches. In a few bridges the approach spans were made as concrete arches e.g. in the Queen Alexandrine Bridge [figure 5].

After World War II and the subsequent post-war period characterized by lack of resources the bridge building program was gradually revived in 1952, but initially

only bridges of relatively modest size were actually constructed.

From 1970 to the mid 1980s a number of major bridges were built across straits as part of the new domestic motorway network. Some of these bridges were actually built as parallel bridges across the straits where bridges with narrow roadways of only 5.6 m width had been built in the 1930s.

Second Lillebælt Bridge

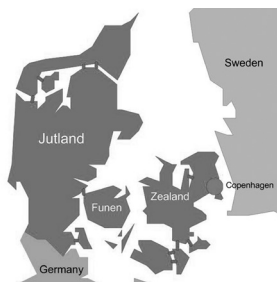
The second Lillebælt Bridge was opened to traffic in 1970 as the first major suspension bridge in Denmark [figure 10]. It gave a much needed improvement of the traffic capacity that had hitherto been offered by the narrow dual lane roadway on the first bridge from 1935.

The second Lillebælt Bridge was initially designed with a stiffening truss in accordance with the American tradition, but after the streamlined box girder design had been introduced for the Severn Bridge in the UK it was decided to use a similar concept for the Danish suspension bridge. So the Second Lillebælt Bridge became the second suspension bridge in the world to have a deck formed as a streamlined box in steel [figure 8].

The first bridge was built close to the location where the width of the strait is minimum, but the desire to have a more smooth alignment of the motorway resulted in a location of the new bridge where the Little Belt is about 50% wider. To also improve navigational conditions it was decided to build the new bridge with a main span of 600 m almost three times the main span of 220 m in the 1935 truss bridge.

At the time when the second Lillebælt Bridge reached the detailed design phase it was only realistic to consider a suspension bridge for a span of 600 m. Cable stayed bridges had at that time only been built with a span of up to about 300 m so it would have been a major step to go to twice that span. However, with the bridge technology of today it is very likely that the second Lillebælt Bridge would have been built as a cable stayed bridge.

The Second Little Belt Bridge also became the second major suspension bridge (span > 500 m) in the world with pylons made of concrete [figure 6].



1



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Figure 1. Strait crossing bridges built in Denmark up till World War II.

Figure 2. Immervad Bridge in Jutland.

Figure 3. The Little Belt Bridge from 1935.

Figure 4. Storstrøm Bridge, 1937.

Figure 5. The Queen Alexandrine Bridge, 1943.

Figure 6. The Second Little Belt Suspension Bridge, 1970.

Figure 7. The Second Little Belt Suspension Bridge with the underground anchor block.

Figure 8. The Second Little Belt Suspension Bridge, a streamlined box in steel.

Figure 9. Second Little Belt Suspension Bridge splay chamber.

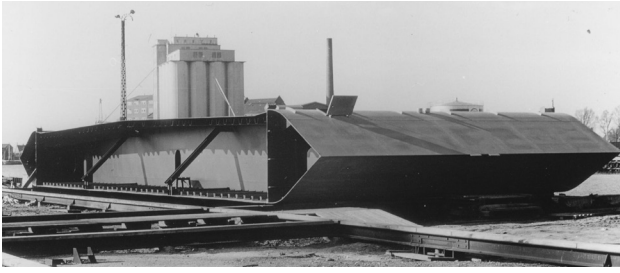
Figure 10. Second Little Belt Suspension Bridge.

Figure 11. The Farø Bridge (southern crossing).

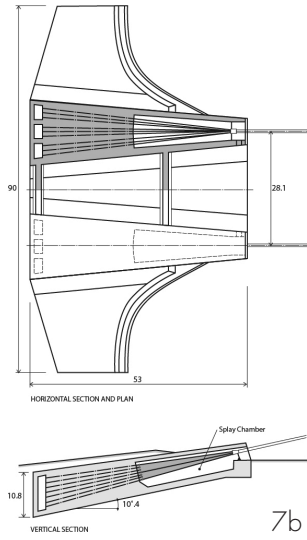
Figure 12. Design from 1936 for a Great Belt Bridge.



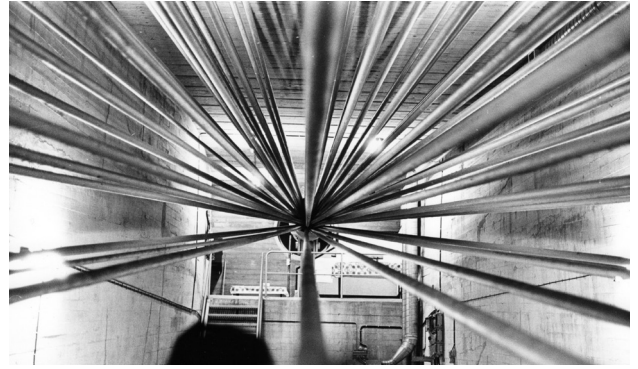
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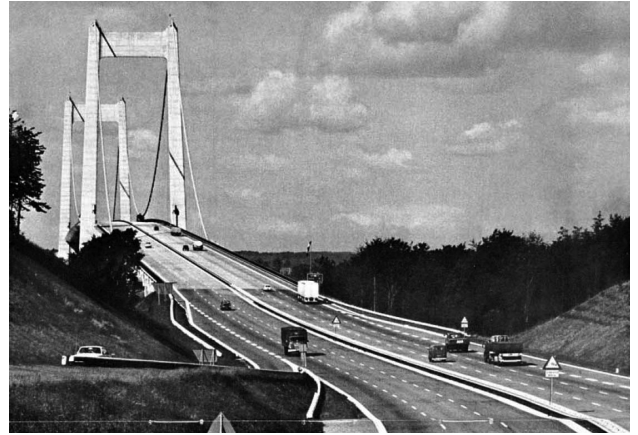
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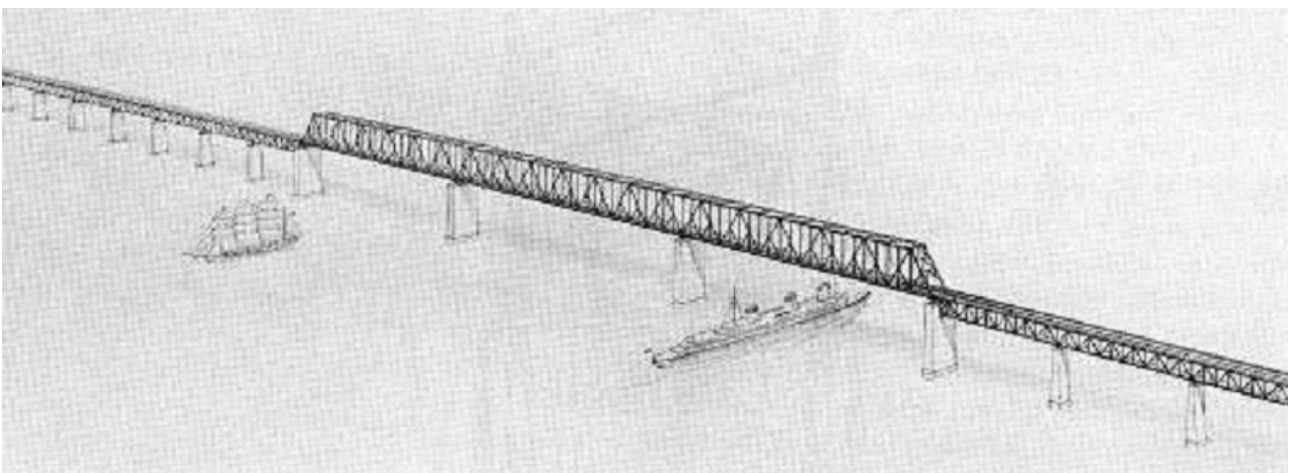
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Since the late 1960s steel bridges in Denmark have been constructed with all joints welded both in the factory and on site. This is in contrast to many other countries where field joints more commonly have been bolted. By the use of welded joints it is possible to get an airtight interior of steel box girders and this was for the Lillebælt Suspension Bridge used to achieve a very efficient corrosion protection of all interior steel surfaces. By adding a dehumidification plant inside the steel box it was possible to keep the relative air humidity below 40% and at that relative humidity no corrosion will form on the steel surfaces.

The principle of dehumidifying the air inside box girders was developed by the engineers C. Ostenfeld & W. Jønsson (later renamed COWIconsult) during the design of the Lillebælt Suspension Bridge where the system has now been successfully in operation for more than 40 years.

Today dehumidification is applied all over the world as an efficient tool to protect interior steel surfaces against corrosion. Also a large number of box girder bridges originally built without dehumidification have later been retrofitted to improve the corrosion protection and avoid the complicated process of interior maintenance of steel surfaces.

A special problem facing the designers of the Lillebælt Suspension Bridge had relation to the design of the anchor blocks as they had to be founded on glacial tills with a relatively small shear strength. As huge and dominating anchor blocks were undesirable above the ground for aesthetical reasons it was chosen to construct underground anchor blocks [figure 7]. This anchor block is almost entirely buried below the surface, and by sloping the underside of the block approximately 10° it was possible to achieve that the resulting force between concrete and soil acted almost perpendicular to the interface.

The anchor block is shaped like a snow plough, and it consists of a continuous bottom slab, 1.5 m thick, with 2 anchor housings on top. Outside these housings the bottom slab is provided with a 4-metre-high front edge that can develop a considerable passive earth pressure in case the anchor block should start to slide. However, the calculated safety against sliding is about 2 even in the worst case.

Inside the anchor housings the strands of the cable are flared in the splay chamber [figure 9] and connected through sockets to threaded rods. As it is generally difficult to establish an efficient corrosion protection of the individual strands near the splay collar, a dehumidification of the entire splay chamber was used for the very first time in the anchor blocks of the Little Belt Bridge.

Farø Bridges

As a supplement to the Storstrøm Bridge from 1937 the two consecutive Farø Bridges were completed in 1985 to carry a four lane motorway across from Sjælland to Falster. The tender design prepared by the owner, the Danish Road Directorate, called for a bridge with a continuous, multi-span concrete box girder in the northern Sjælland-Farø bridge and in the approach spans of the southern Farø-Falster Bridge where the main span was designed as a cable-stayed bridge. However, the successful contractor had based his bid on an alternative design with a superstructure in steel [figure 11]. That proved to be a competitive solution mainly because the 80 m full span box girder units could be fabricated at a shipyard and erected in one piece.

The two Farø Bridges comprise a 1,696 m long northern bridge between Zealand and the small island of Farø and a 1,726 m long southern bridge between Farø and Falster. Both bridges have a continuous superstructure from abutment to abutment, i.e. with no expansion joints inside the steel superstructure but only at the transition to the abutment. Most of the spans are 80 m long but across the navigation channel between Farø and Falster a cable stayed bridge with a 290 m long main span is found.

The deck of the cable stayed bridge is supported by a central fan-shaped cable system supported onto a diamond shaped pylon in concrete. The pylon shape was chosen to avoid the additional width of the central motorway reserve required if a vertical pylon in the cable plane should have been used, and to limit the width of the caisson below the water surface. The configuration of the Farø Bridge pylon actually marks the first application of a genuine diamond shape that has subsequently been widely used all over the world.

The 290m long main span is flanked on either side by 100 m long side spans. As the fans are of equal length in the main span and side span the anchor piers are not positioned at the end of the side span fans but at the deck anchorage of the second stay cable from the top. This activates efficiently the three stays at the end of the side span fan as backstays so a heavy single backstay is avoided.

The interior of the Farø Bridge deck is also corrosion protected by dehumidification—a feature that for this bridge proved to be decisive for the choice of a superstructure in steel rather than in concrete.

Storebælt Bridge

With the bridges built in the 1930s the main parts of Denmark were linked together in two units, one comprised of the Jylland peninsula and the second largest island, Fyn (Funen) and the other of the main island, Sjælland, and the islands to the south. So, one bridge was

missing to link the entire country together: a bridge across the *Storebælt* (Great Belt) between *Sjælland* and *Fyn*.

To build that bridge was a task of quite a different magnitude than the other bridges of the 1930s as the width of *Storebælt* from coast to coast is 18 km—almost six times the length of the *Storstrøm* Bridge from 1937. Furthermore, a *Storebælt* Bridge would cross the international navigation channel from the Baltic Sea to the North Sea so it had to be built to allow passage of the largest ocean-going vessels.

The first realistic plans to construct a *Storebælt* Bridge were presented in the late 1930s [figure 12], and preparatory works such as soil investigations were planned to start in 1940 but the outbreak of World War II made it impossible to proceed with the project at that time.

It was not until 1987 that the Danish Parliament took the final decision to start the construction of a fixed traffic link across *Storebælt*. Due to the location of a small island, *Sprogø*, in the middle of *Storebælt* the link was to be composed of two bridges and a tunnel.

Across the Eastern Channel with the international navigation channel the link consists of a high level motorway bridge and a bored railway tunnel whereas the Western Channel is crossed by a low level bridge carrying both road and rail traffic.

The most impressive part of the *Storebælt* Link is undoubtedly the 6.8 km long East Bridge with a main span designed as a suspension bridge. That span was at the completion in June 1998 the second longest span in the world—surpassed only by the span of the *Akashi Kaikyo* Bridge in Japan.

The suspension bridge has a length of 2,694 m between the anchor blocks: a main span of 1,624 m

flanked by two side spans each measuring 535 m.

The steel box girder forming the deck of the suspension bridge is 4.34 m deep and 31.0 m wide.

The box girder is supported vertically at the anchor blocks and by the vertical hangers from the main cables. At the pylons the deck is only supported in the lateral direction but free to move vertically. At midspan the main cables are fixed to the box girder through a long central clamp. Together with installation of large hydraulic buffers between the box girder and the anchor blocks the central clamp improves the stiffness under short term, asymmetric load and increases the frequency of asymmetric vibration modes. In case of long term movements, e.g. from temperature change the longitudinal buffers do not give resistance.

As the box girder is continuous over the full length of 2,694 m and no vertical support was needed then it became unnecessary to add a cross beam between the two pylon legs immediately below the deck. The omission of the cross beam below the deck also clearly illustrates the fact that the deck of a suspension bridge is supported by the cable system and do not carry the global load by bending to the pylons. Without a cross beam at deck level it was possible to position the lower deck beam at midheight of the 254 metre high pylons [figure 13].

During the conceptual design of the East Bridge emphasis was laid on arriving at a clean and pleasing appearance as seen in the configuration of the pylons. But also the anchor blocks were treated aesthetically to arrive at a more elegant form than found in many of the existing massive looking anchor blocks. With its location at mid sea it was attempted to give the East Bridge anchor blocks a more transparent look [figure 14].



Figure 14. The East Bridge anchor block.

Figure 13. The 254 meter high concrete pylon of the East Bridge.



Øresund Bridge

Overlapping with the construction of the Storebælt Bridges was the construction of the Øresund Bridge between Denmark and Sweden. Here the superstructure is designed as a double deck truss with two railway tracks on the lower deck and a four lane motorway on the upper deck [figure 15]. The total length of the bridge is 7.8 km which made it the longest bridge in the world for both road and rail traffic at the time. At completion in 2000 the main span of 490 m was also the longest in the world for a cable-stayed bridge carrying both road and rail traffic.

Across the navigation channel the Øresund Bridge comprises a cable stayed bridge with a total continuous length from expansion joint to expansion joint of 1,102 m. The continuous truss is supported by harp-shaped cable systems except for the outer regions close to the expansion joints. The anchor piers closest to the pylons render vertical support inside the side span harps and that has a pronounced influence on the stiffness of the system.

The main span deck consists of a transversally prestressed concrete slab acting compositely with the top chords of two vertical steel trusses. The lower railway floor is made entirely in steel in the form of a shallow multi-cell box [figure 16].

All truss members are box shaped with interior dehumidification.

Due to the design of the pylons as free-standing posts above the roadway the cable planes have to be vertical and positioned in some distance from the edges of the

roadway slab. To transfer the load from the main trusses to the cable anchorages triangular brackets or “outriggers” are added outside the trusses. To make it possible to connect the outriggers efficiently to the main trusses the geometry of the diagonal bracing is changed from the approach span where all diagonals are of the same length to a system with long diagonals in the direction of the stay cables and short diagonals in between so that the node distance is kept constant [figure 17].

With the overall design leading to vertical cable planes outside the deck it was possible to let the pylons consist of vertical free-standing posts above the deck. By ensuring that the centroid of the pylon is positioned in the vertical cable planes the cross section of the pylon is subjected to pure uniform compression from dead load and vertical traffic load acting on the deck.

Innovative design features of the Danish Cable Supported Bridges

As it has been described above the cable supported bridges built in Denmark have in several cases introduced new design features, as it is outlined below:

- Continuous superstructures without change of deck shape from approach to main spans (Farø and Øresund Bridges)
- Intermediate pier support in the side span fans/harps (Farø and Øresund Bridges)
- Dehumidification of the interior in steel box girders (Lillebælt, Farø, Storebælt and Øresund Bridges)



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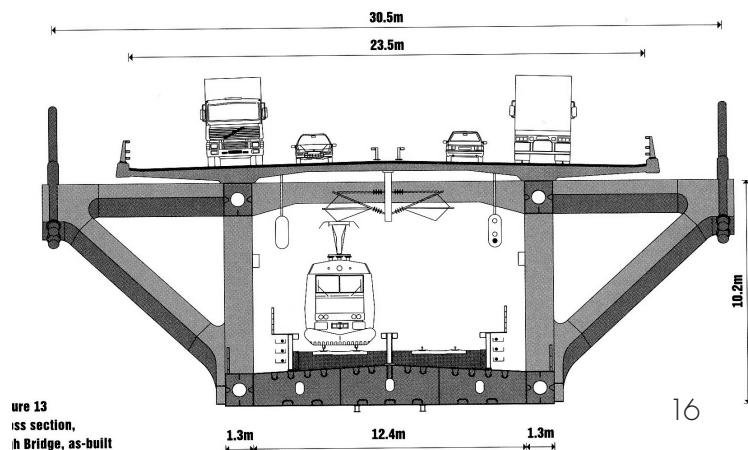
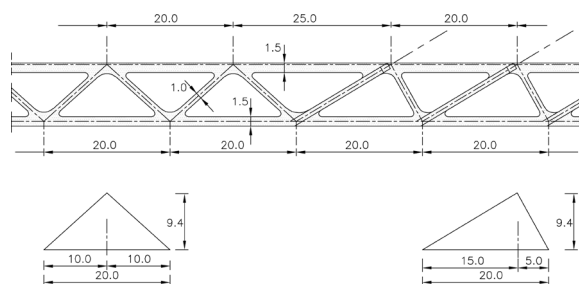


Figure 13
Cross section,
Øresund Bridge, as-built

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Figure 15. The Øresund main bridge.

Figure 16. Cross section of the main span in the Øresund Bridge.

Figure 17. Change of truss geometry from approach bridge to cable stayed bridge.

- Dehumidification of the interior in main cable saddles (Storebælt Bridge)
- Dehumidification of the interior in splay chambers (Lillebælt and Storebælt Bridges)
- Concrete pylons (Lillebælt, Farø, Storebælt and Øresund Bridges)
- Diamond shaped pylons (Farø Bridge)
- Portal shaped pylons without a cross beam below the deck and only two above (Storebælt Bridge)
- Free-standing concrete pylon legs above the bridge deck (Øresund Bridge)
- Anchor blocks with reduced visual impact (Lillebælt and Storebælt Bridges).

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Grant by the Japan Society for the Promotion of Science for a five weeks' lecture tour to Japanese universities, research institutes and engineering societies.

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Editor of the Storebælt Publications: *East Tunnel, West Bridge, East Bridge, Concrete Technology*, and the Øresund Technical Publications: *The Bridge, The Tunnel, Dredging & Reclamation*.

Advisory jobs: Transport Scotland on the design of the Forth Replacement Crossing (cable stayed bridge with two 650 m main spans); Stonecutters Bridge, Hong Kong; Øresund Bridge; Storebælt East Bridge; International Design Board for the Messina Strait Bridge; Gibraltar Strait Bridge studies.

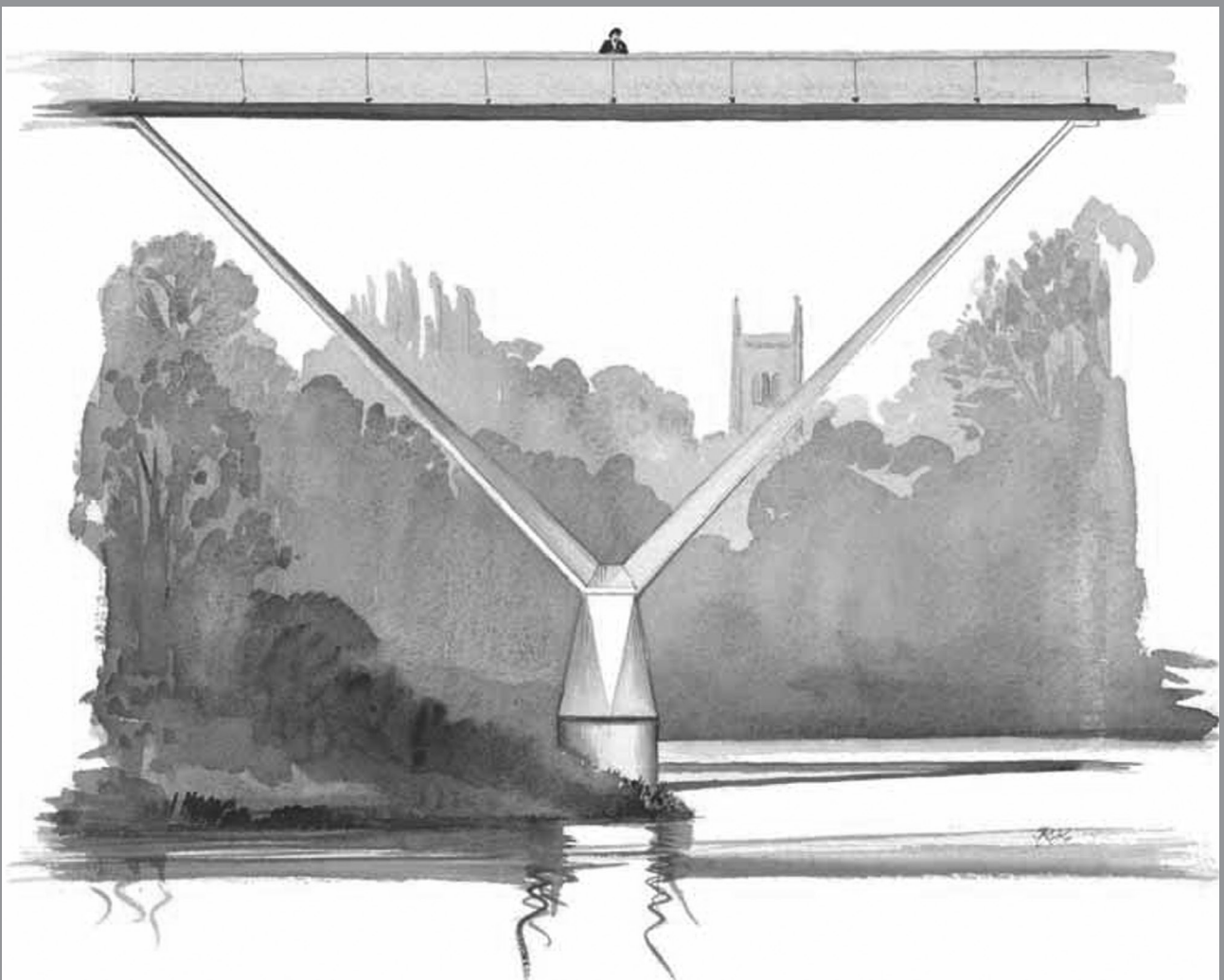
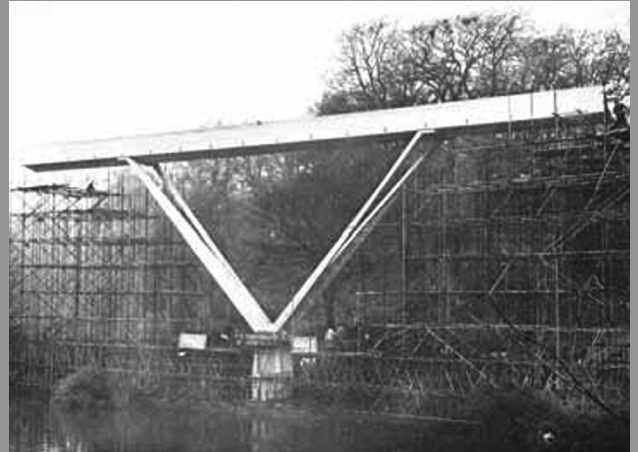
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Sir Ove Arup: The Design of Bridges¹



OVE ARUP (1895-1988) once said in a BBC interview that the two structures that had given him most satisfaction were the Highpoint flats in North London (1935) and the Kingsgate footbridge, Durham, Yorkshire (1963), as “both are rather perfect examples of the complete integration of architecture, structure and method of construction”.

By Jørgen Nissen

BUT before Kingsgate Ove had designed other bridges. Although they were for real none was built, for reasons unconnected with their design. But he wrote about them in an article that appeared in the *Arup London Newsletter* 21 and 22, February and April 1964, written a few years earlier so that Kingsgate only comes in with a few final lines, almost as an after thought.

In 1961 Ove had shown sketches of some of his bridge designs to his CIBA friend the Italian architect Ernesto Rogers (1909-1969), who was then editor of the architecture magazine *Casabella*. The article “Cinqueponti” duly appeared in June 1961. Ove changed it lightly two years later, and a shortened version, “Trois projets de ponts”, appeared in the October/November 1963 issue of *L’Architecture d’Aujourd’hui*. The *London Newsletter* editor, Rosemary Devine, reverted to the longer English original for the Arup publication (but to a then very small internal audience).

It is a fascinating article, well worth studying even now almost 50 years later, and not only by bridge engineers. In it Ove lucidly describes what he meant by what he would later call “total architecture”—which, what ever we call it now, is very much what we are about. He wrote extensively about “total architecture” through out his career, but usually in the abstract, almost philosophically. Here, uniquely in his writings, he is addressing the subject in specific contexts, with real if unbuilt examples, revealing step-by-step how his thoughts progressed.

He says it all at the start, emphasising that he is writing about bridges: “... a more rewarding field for the study of unity between architecture and structure. A bridge is architecture with a clear and simply formulated function. All one has to worry about is the stability, durability, cost, and appearance.” And as for appearance: “there will always remain a number of more or less arbitrary decisions, which have to be made on purely aesthetic or sculptural grounds. I suggest, however, that the best result is obtained if there are very few of such arbitrary deci-

sions to be made, in other words, if decisions affecting proportion and form at the same time make structural and constructional sense”.

In spite of writing for an audience of architects—or perhaps because of it—he did not offer any thoughts on how these decisions should be taken. He did not need to. He was writing about the engineering. In the earlier *Casabella* version he had included a small footbridge at Bowring Park, St Johns, Newfoundland, but he almost apologises for it at the end of the paper: “it does not really belong in this series because the method of construction is not in any way out of the ordinary and in fact, the whole object is small and insignificant and presents no structural and constructional difficulties. But the appearance was important—it always should be anyhow. This is therefore a case of satisfying function and structure in a pleasing and neat manner—construction is of lesser importance.”

And when he refers to Kingsgate at the end he adds: “Although appearance was of major importance in this case, the form was largely influenced by structural and constructional considerations”. He did work with the architect Yuzo Mikami on this bridge and it is a great pity that he could not include a full account here and so close the argument.

A few years later, in 1971, Ove was asked by the Institution of Civil Engineers to advise on “how to improve the appearance of engineering structures...if architects are not to muscle in on the Engineer’s domain” (sic!)... and “please write a paper which will teach engineers how to design beautiful and efficient structures”. True to character, he wrote a fairly long paper explaining why he could not write such a paper, concluding: “you cannot make rules or principles for what is beautiful, but you may be able to learn by examples of good design—by studying it in *statu nascendi*”. He does just that in this article. All four bridges were to be built over water and therefore called for particular engineering expertise. Ove had that expertise; he had been chief designer for contractors specialising in marine structures for nearly 20 years: “We were designers and contractors in one, design and construction were naturally integrated. Now the bulk of designers are mostly unacquainted with the problems on site.”

The construction methods he proposes are complex,

< Kingsgate Bridge in Durham by Ove Arup, under construction and watercolor. Completed in 1963.

but as ever Ove explains them in simple direct language. He is aware of the danger of writing expost but he writes about it as it is, not leaving out ideas that had to be aborted and only including the successful ones. The construction methods are all quite sophisticated and would have been innovative at the time but feasible. His partner Geoffrey Wood (1911–2007), who had a great deal of experience of working in Africa, did argue that the Ghana bridges required technology not then available in Africa. But Ove insisted that they had been “designed down to the last detail”. So they had, but then maybe the local contractors did not yet have an Ove.

Would we do the same today? We might. But technology has moved on; we now have at our disposal stronger and more durable materials, more precise controls and better methods of analysis and forecasting, more sophisticated construction methods, etc. The limits of what we can now do have expanded. And society has greater expectations; environmental and social issues are significant and Ove’s “more or less arbitrary decisions” now weigh heavier in the balance sheet.

He would have approved. His approach is as relevant now as it ever was, even if the input to the process and therefore the outcomes may be different. It is a pity that these four bridges were never built, but he did at least leave us the best: the delightful Kingsgate bridge and our approach to “holistic design”.

After the article was written, the Ministry of Transport, then England’s main client for bridges, announced its first-ever design competition, for the Calder Bridge in Yorkshire. 110 designs were submitted, five of them from Arup (*London Newsletters* 19–22, January–May 1964), a team from Povl Ahm’s group including Yuzo Mikami as architect won a special prize. This led directly to the award in 1965 of our first bridge project by the Ministry, the Gateshead Viaduct, and the Highways and Bridge group in London was born. Ove took an interest—and sometimes more than an interest—in some of our subsequent bridges, particularly the Jesmond Dene Bridge in Newcastle, close to his birthplace. The design was almost ready for tender when the project was cancelled following public pressure not to demolish the existing wrought iron Armstrong Bridge built in 1878. This is in fact a striking bridge and is now listed.

Kylesku Bridge in the Scottish Highlands

The Kylesku Bridge has one of the most remote and dramatic and beautiful sites in the British Isles—a unique site worthy of a unique bridge:

Bridge design is an intimate mixture of design and construction resolving a ‘chaos of facts and circumstances into a unique and beautiful unified whole’. Using the examples of bridges

designed throughout the world, the authors make the case that while a bridge engineer will seek unity, consistency, scale and proportion, and an eye for detail, the overriding factor in bridge design is the importance of the site, its precise shape, and the views from it.²

A Little Background

The west coast road between Ullapool and Scourie at the northwestern tip of Scotland is interrupted at Kylestrome by a deep sea loch. The bridge replaced a ferry that operated from dawn to dusk. After dark, which comes early during the winter, travellers had to make a 110 miles long detour if they wanted to cross the loch. The Highlands Regional Council therefore took the initiative to upgrade the road link under the Crofter Counties Scheme and included a bridge at Kylesku in the project.

A bridge would make travel available around the clock and so improve contact between the scattered local communities and help them to co-operate and explore the tourist potential of the area.

The Road

The topography in the area is exceptional. Rock faces rise steeply from deep sea lochs on the severely indented coastline in a dramatic landscape that poses an exciting challenge to road designers.

Great care was taken in fitting the road as closely as possible to the contours to preserve the character of the landscape, and by avoiding to make deep cuts in the granite the new works were made to act in sympathy with the land forms.

As a result, the road winds its way through the hills in a continuous series of curves. One of these is at the crossing of the sea loch at Kylesku.

The Bridge

The width of the loch at the crossing is at about 135 m and the bridge is 278 m long between abutments. It is a serious bridge, and to propose that it should be curved in plan was very unusual at the time. The received wisdom then was simply that road bridges are straight.

The clearance under the bridge was set to 24 m by the Department of Trade, apparently to allow the Royal Yacht Britannia to pass under the bridge when it were to be opened by the Queen! Nevertheless, the two beautiful inland sea lochs attract cruise vessels and yachtsmen who now have a very attractive entrance to the lochs.

The form of the bridge is intimately linked with the method of construction.

The sea loch is narrow and very deep at the bridge site, and tides through the narrows are very strong, ruling out any falsework over the water. But the generous height above the banks was used to create an understructure



Images of Kylesku Bridge when it was built in 1984 and today.



with inclined legs that reduced the spans of the deck, as at Ove Arup's Kingsgate Bridge at Durham. The deck is a relatively shallow and economical hollow box girder made from prestressed concrete.

Exposed to very high 100 mph winds, the structure is very stable and expresses that stability.

Building the road and the bridge was a major and challenging undertaking. The remote site and the climate with its severe winters and very high winds (measured in excess of 100mph) called for sophisticated construction techniques and made access and deliveries of materials difficult and expensive. In spite of this, the bridge was completed within the planned time frame.

The bridge was built in three stages. The two landward spans were built first from the abutments to the landward legs of the piers, and they were then completed between the landward and seaward legs of the piers. In both stages the *in situ* structure was supported on major temporary works founded on the rock. Finally, the 85m centre span was cast on a temporary jetty at shore, floated out, lifted into position and stressed back to complete the structure. The bridge is made from concrete to make it practically maintenance free in this remote area but easy access is still provided for inspection and maintenance.

Was it Worth it?

Queen Elizabeth II formally opened the bridge in August 1984. It has been a great success. It has not only received many awards for design and construction but it has also, and more importantly, dramatically changed the lives of the people living in the area. Community activities such as education are now shared across the region, small co-operative industries based on fishing and agriculture have been established and a lively tourist industry has developed.

Even the road and the bridge have become tourist targets in their own right as witnessed by the large number of photographs uploaded on Flickr.

The drive along the winding road is interesting and extremely pleasant and at the bridge the continuously changing views for drivers and hikers give them a closer rapport with the surrounding nature than they would have on a straight bridge.

This was Arup's first curved bridge and we have since made use of curves on bridges whenever it has been appropriate—as for example most famously and at a much larger scale at the Øresund Bridge between Denmark and Sweden.

On Total Design

Arup is about Total Design. This is an example of Total Design at its best—all important factors—the relation to the site, structure, construction, appearance, economy—were taken into account right from the start. And in this case the major factors turned out to be the site and construction.

Notes

1. From foreword from article in The Arup Journal 2/2009.
2. Introduction to "Total design of bridges" by Bill Smyth and Jørgen Nissen in *Arups on Engineering*, Ernst & Sohn, 1996.

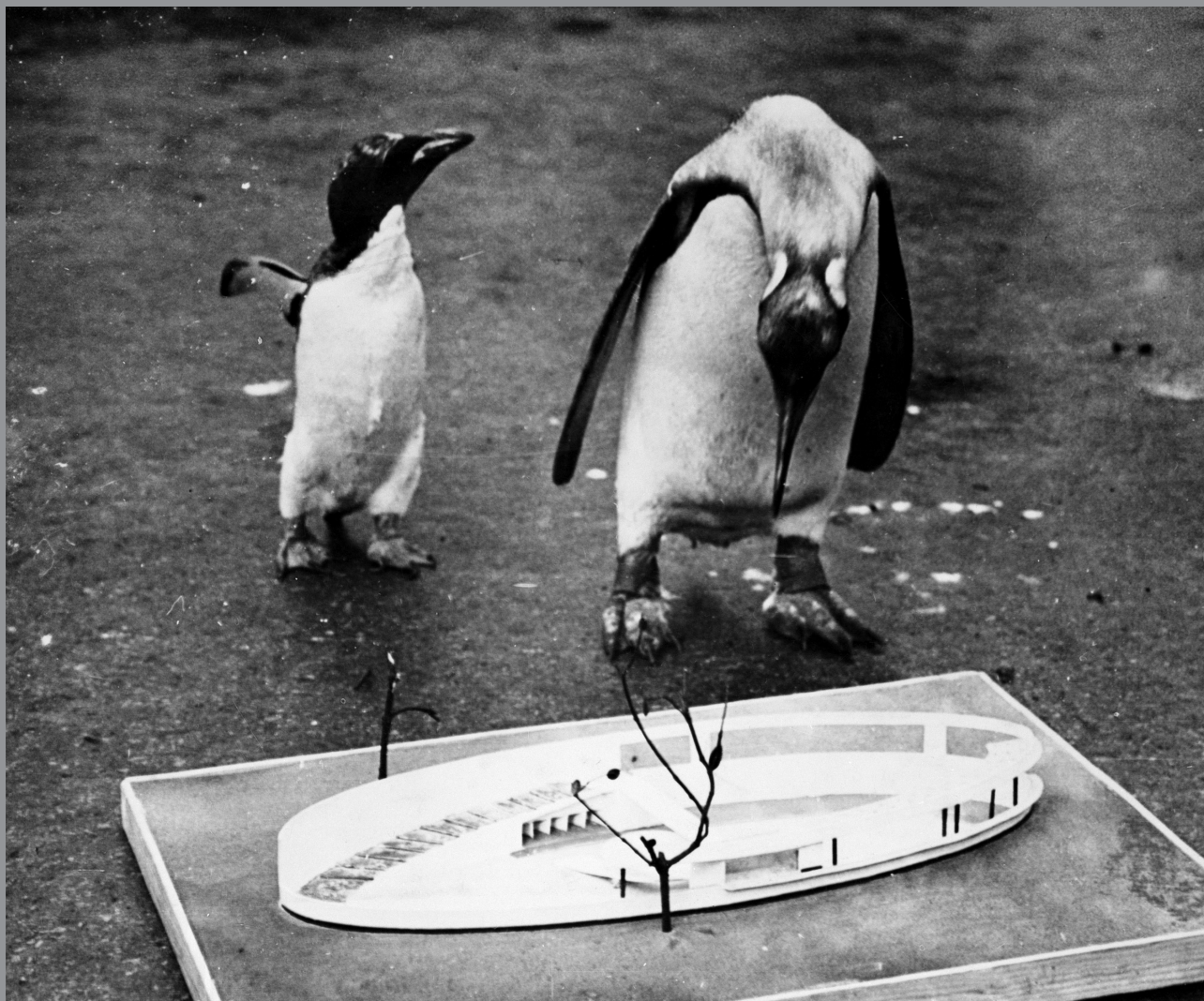
Jørgen Nissen

Joined Arup in 1962, at first designing shell structures. He was one of the prize-winning Calder Bridge competition team and later in attendance at the birth of the Highways and Bridges group. He was made a director in 1977, a main board director in 1984 and a trustee in 1992. He retired from the board in 1999 and as a trustee in 2004. He is now a consultant to Arup.

All illustrations © Arup. The original drawings and photographs were no longer available, and so for this republication of "The design of bridges" the prints in the 1964 *London Newsletter* edition had to be scanned, making some compromise inevitable in image quality.

Bridge of Dreams: The Penguin Pool, London Zoo

80



THE Penguin Pool at London Zoo 1934, designed by Berthold Lubetkin & Tecton is one of the iconic landmarks of modern architecture. This article tells the story of its creation, the structural secrets of its audacious spiral ramps and its varying fortunes in the evolution of the zoo as an institution for the display of captive animals. The Penguin Pool, visited and admired by thousands over the 75 years since its completion, also stands as a poignant emblem of the dreams and disappointments of modern architecture.

By John Allan

THERE can be few visitors to London Zoo who have not gazed at the Penguin Pool—Berthold Lubetkin's iconic *jeu d'esprit* of 1934—and dreamed of walking upon its miraculously unsupported ramps. This tiny aquatic sculpture—it could hardly be called a building—has captivated who see it, and through its worldwide publication, many who have not. Apparently so simple, yet like so much of Lubetkin's work, the Penguin Pool is densely coded with stories, references and ultimately—dreams. But where did it come from and how does it work?

By the time of Lubetkin's arrival in England in 1931 and the formation of his atelier Tecton the following year the early concept of the zoo as a collection of exotic curiosities for spectacle and entertainment had been superseded by ideals of public education and scientific study. This new approach with its naturalistic style of animal accommodation was promoted by the early 20th century work of German zoologist Carl Hagenbeck and could be regarded as the progressive orthodoxy with which Lubetkin's more conceptual manner would be contrasted. While basing his solutions on no less scientific investigation, Lubetkin's distinctive contribution was his pursuit of a more abstract or idiomatic mode of display. The series of buildings he designed for London Zoo in the 1930s coincided with one of its most vigorous periods of expansion, when the institution's profile was at its zenith and long before the advent of television brought natural history into everyone's living room.

Lubetkin's association with the Zoo proved to be as pivotal as it was unlikely. Born in Tiflis, Georgia in 1901 and moving to Moscow and Petersburg where he was to experience the turmoil and excitement of the 1917 Revolution, Lubetkin was fired by the revolutionary art of the Constructivists and developed an unshakable conviction in the interdependence of social progress and radical architecture. Leaving Russia in 1921 in search of greater technical expertise he proceeded to travel Europe in a fabulous decade of auto-didactic adventures. These had

taken him to Berlin, Warsaw and finally Paris where he had studied under Auguste Perret, worked with the USSR Trades Delegation and then realised his first significant building, an apartment block of extraordinary architectural precocity for a designer not yet 30 years old.

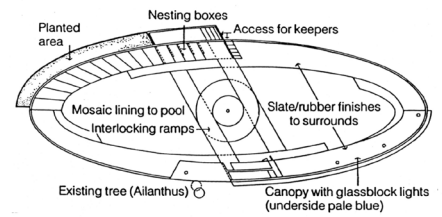
With no further prospects in Paris Lubetkin had come to London in search of work but after months of frustrated commissions was on the point of departure when his first real assignment appeared with the invitation to design a new Gorilla House for London Zoo. This was hardly the challenge of creating 'homes for heroes' that had first attracted him to England, but in the immediate vacuum of unemployment it was, as one of his Tecton partners later recalled, 'simply a lifesaver'. Indeed Lubetkin would remain in England for the rest of his life, dying in Bristol in 1990—a naturalised British citizen.

With its cylindrical form and combining a rotating roof, sliding screens and revolving walls to provide a variable environment for animals and visitors in summer and winter, the Gorilla House caused a stir and even before it was completed Lubetkin had been commissioned to design what would become his most celebrated zoological project, a new exhibit for Antarctic penguins.

The Penguin Pool with its elliptical plan, coiled interlocking ramps and expressive 'diametry' (Lubetkin's term for symmetry across a diagonal axis) took his geometrical preoccupations still further. The pool was conceived as a freestanding sculpture on an open site, its only contextual reference being a nearby *ailanthus altissima* which Lubetkin insisted be retained as a vestigial natural foil to his geometric abstraction. Contrary to the convention of simulating natural surroundings for captive animals, Lubetkin's objective was not literally to recreate the avian habitat of an emperor penguin but rather to suggest a metaphor for Antarctica in a miniature cameo that both expressed the animals' natural characteristics and also fully acknowledged, indeed celebrated, the human artifice involved. The enclosure's perimeter is even inscribed within slotted *proscenium* screens as if to dramatize the theatrical connotation.

Forming the central vortex are the famous spiral ramps

< Nature confronts culture. Photo by Berthold Lubetkin, 1933.

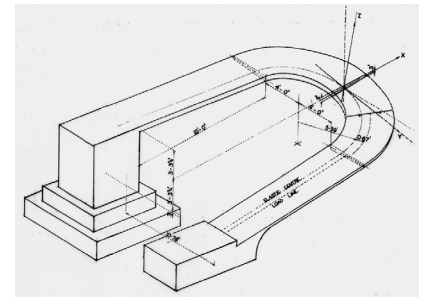


The geometrical proposition.
Drawing by John Allan.

< Bridge of Dreams. Photo by John Allan, 1987.



< An aquatic sculpture enclosed within
proscenium screens.
Photo by John Havinden, 1934.



The structural reality. Drawing by John Allan.

purporting to provide the flightless birds with a purposeful promenade, whilst in fact ceremoniously leading them back to the same bank from which they embarked—an architectural conceit exaggerating their endearingly comic aspect on land in contrast to their dazzling speed and grace in water. However, nobody should imagine this playful *capriccio* was not the result of fiendish ingenuity.

Conjured in reinforced concrete of only 10 cm thickness the surrounding screen walls were a masterpiece of shuttering carpentry and geometrical precision. But the ramps are still more inventive in their exploitation of a double cantilever—their longitudinal outreach extending over 14 m in length, their cross section tapering from 15 cm across to 8 cm to optimise the impression of delicacy by

disguising their inner thickness with a thinner outer edge.

Yet there is still the mystery of how the ramps are supported. What could account for their structural capacity to carry the equivalent weight of 24 adults lining each ramp without collapsing into the water? The answer is right in front of you—artfully concealed. At the top and bottom of each ramp is a massive concrete abutment anchoring and counterbalancing the enormous leverage of the ramp itself. But each of these four enormous abutments is either buried or camouflaged. Those at the ramp feet are hidden below the water line and assimilated into the pool frame. Those at the ramp summit are disguised as something else—one forming the landing of the flight of shallow radial steps that rise around the north-west quad-

rant, the other absorbed into the volume of a keeper's store that sits below the diving tank in the centre of the southern walkway. An illustration of the structural reality, with these concealments removed, reveals just how crucial to the architectural concept is this ingenious deception.

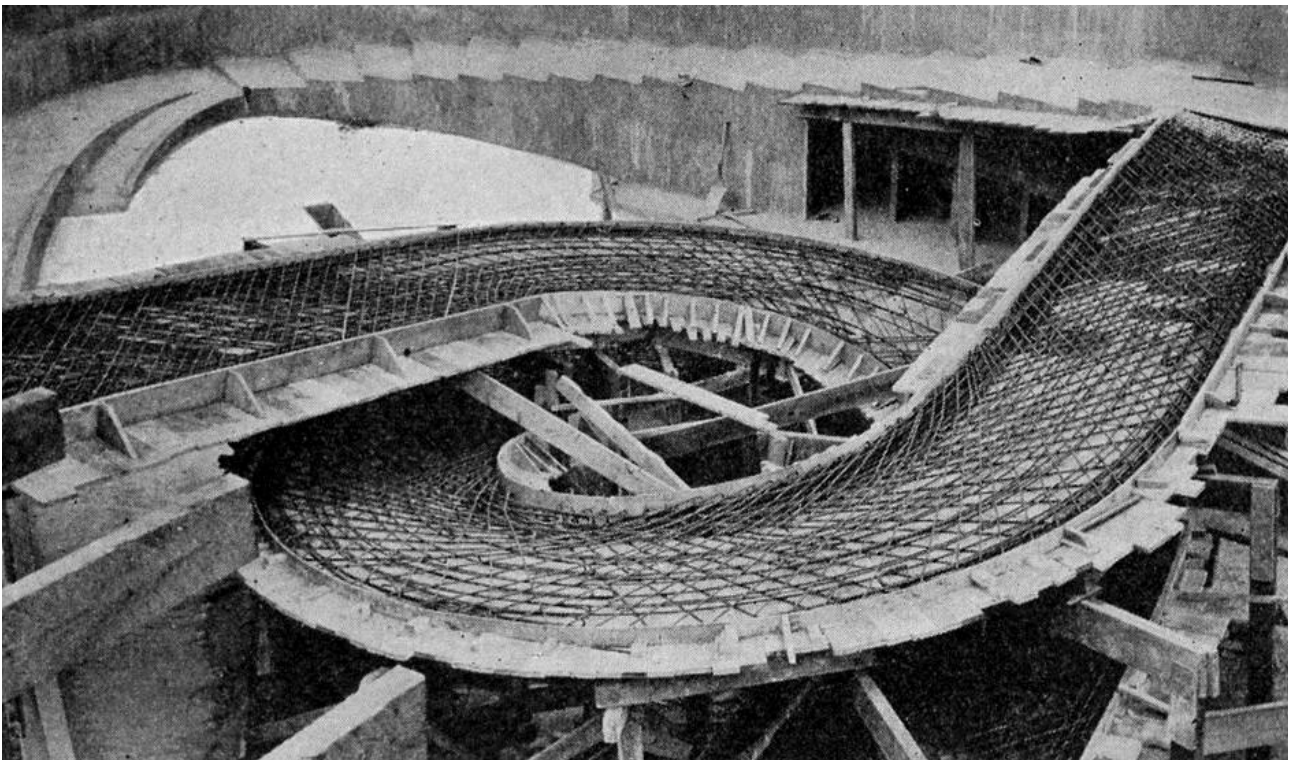
In this subtlety lies the key to Lubetkin's sophisticated approach to structure. Defying the contemporary platitudes of 'Functionalism' with its simplistic conflation of honesty and beauty, Lubetkin's rare vision lay in perceiving that structure should be expressed where it was significant but suppressed where it was not. In this solution he was assisted by the Danish engineer Ove Arup, who supported Tecton in the structural realisation of all its key works—though in this instance, according to participants, the calculations were undertaken by his younger recruit Felix Samuely, who reportedly resolved the Penguin Pool's daunting mathematical complexities over a single weekend. These were summarised as comprising 6 lines statically indeterminate, each section being subject to bending moments in vertical and horizontal planes, a torsion moment, an axial force and two shearing forces.

Beyond the structural gymnastics there are many other details to admire, for example, the semblance of centrifugal motion created by the series of overlapping slipways which chase each other round the perimeter promenade, or the alternating materials and colours—grey slate paving and red rubber compound—that further enhance the

pool's 'diameter' by alternating across the four walkway quadrants.

With its unique fusion of geometric energy, structural brilliance and theatrical bravura the Penguin Pool has invoked many associations. The Constructivists' preoccupation with the spiral and its symbolic Marxist connotations of 'progress' is perhaps the most direct, and would certainly have resonated with Lubetkin as a recent émigré from revolutionary Russia, where he had witnessed the double helix of Vladimir Tatlin's fabled Monument to the Third International. The theatrical stage sets of Meyerhold and Lissitsky with their implied suggestion of 'a world within a world' have also been cited as a possible source of inspiration.

Yet at the heart of his conception Lubetkin had a more philosophical proposition in mind—a particular vision of man's place in nature—as informed by his Marxian reading of science and evolution, and the distinction to be drawn between the kingdom of nature and the kingdom of culture. The Penguin Pool and his many other zoological works were to stand as normative statements of man's intelligent place in nature. Lubetkin's distinctive approach in the design and setting of his architecture lies in rejecting both camouflage and conquest as metaphors of intervention. Rather man's instrumentality was to be both explicit and benign, proclaiming, in his favoured description, a vision of 'nature tamed—not with a fist, but with a smile'.



A masterpiece of carpentry. J.L Kier & Co, 1934.



Symmetry on a diagonal axis. Photo by Ray Charter, 1987.

Such a stunning piece of architectural showmanship, it was inevitable that the Penguin Pool would become a mascot for the early Modern Movement in Britain, whilst providing Lubetkin himself with an international 'calling card' through its widespread publication and critical reception. 'It was that unique monument' the Penguin Pool by Lubetkin and Tecton, which first dramatically attracted the attention of the world to developments in England', wrote the American commentator Henry Russell Hitchcock in 1937.

Its zoological advantages were also acclaimed, at least initially. The first occupants apparently thrived and bred successfully, with the enclosure's clean lines and easy maintenance providing a healthy environment resistant to infection and the incidence of avian malaria more often experienced in simulated 'natural' exhibits. With ensuing developments in animal husbandry however this early success would later be challenged. Different (South African) birds were substituted for the original Antarctic species, their less gregarious nesting behaviour being unsuited to the closely spaced accommodation of the original design. To accommodate this changed pattern of use a series of incongruous wooden hutches were arranged around the perimeter walkways quite contradicting the abstract quality of the original conception.

In the mid-1980s, when the building had reached a state of considerable dereliction, I was privileged to undertake a major restoration of the Penguin Pool, working with Lubetkin himself, then in his 80's. This substantially secured the fabric of the structure, renewed the hydraulic services and reinstated the original colours whilst also incorporating judicious improvements to the nesting accommodation and diving tank. In 1987 Lubetkin together with Ove Arup, also by now an octogenarian, attended the re-opening ceremony and the pool enjoyed a new period of popular and critical acclaim. But more recently its fortunes have altered again and currently the birds have been removed altogether, leaving the exhibit empty and without its sense of humour.

These reversals represent a particular conundrum. While the changing culture of captive animal display reflects an increasing ambivalence over the ethical acceptability of zoos as such, there has been a parallel and growing appreciation of the outstanding architecture they have sometimes produced. Virtually all of Lubetkin's zoological works—some seventeen surviving structures including further pavilions at Whipsnade and Dudley Zoos—are now protected architectural monuments, introducing a dual conservation challenge—conservation of the build-



Cry for an unrealised world. Photo by John Allan, 1987.

ings and conservation of endangered species, now regarded as the principal justification for survival of the zoo itself—a reconciliation not always easily achieved. Zoological controversies aside, however, the architectural acclaim of the Penguin Pool remains undiminished, with it being statutorily protected at Grade I—the highest level of designation available in England.

And what of Lubetkin's dreams? There is no doubt that

the Penguin Pool remains an icon of early Modern architecture—radiant with innocent optimism. But half a century later Lubetkin would reflect otherwise. 'The philosophical aims and orderly character of those designs are diametrically opposed to the intellectual climate in which we live... My personal interpretation is that these buildings cry out for a world which has never come into being'.

The question for our age is whether that cry is still heard.

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John Allan

Director of Avanti Architects for nearly 30 years. First Chairman of **docomomo**-UK 1989–91. Biographer of Berthold Lubetkin, John Allan has led all Avanti's Modern Movement conservation projects, including the restoration of Lubetkin's Penguin Pool, Highpoint Flats and Finsbury Health Centre.

Concrete's Furthest North

Early 20th Century Heritage
of Modern Civil Engineering
in Iceland

86



IN 1935–36, the English writer and design critic Philip Morton Shand (1888–1960), proponent of Modernism, translator of Walter Gropius and founder of MARS group (Modern Architectural Research Group) published two articles in the magazine “The Concrete Way”. The first one was entitled “Concrete’s furthest north”, highlighting the advanced and wide-ranging use of concrete construction in Iceland.¹ With the second article were photographs of newly built public buildings by architect Sigurdur Gudmundsson (1885–1958) as well as bridges designed in the 1920s and 1930s by the engineers of the Icelandic State Highways Department.² Shand was impressed by the work of the “gifted and thoroughly modern minded architect such as any country might be proud of” as well as the work of “first rate-engineers” of this “geographically remote island which at that time had only 100,000 inhabitants and 2,000 motorcars. He also points at the photos “as evidence of the wonderful clearness of the air which is characteristic of Iceland’s brief Arctic summers.”

By Pétur H. Ármannsson

TODAY, the concrete buildings and engineering constructions praised for their modern spirit by the well-known English critic have become a part of Icelandic history. Some examples have vanished, others are still standing as ruins or have been modified beyond recognition, some are being restored and a few have even acquired a status as heritage landmarks.

For centuries, Iceland was without roads and bridges. Transportation on land was restricted to narrow horse-paths during the summer and ice and snow during winter. Countless lives were lost while passing the many dangerous rivers that dissected the island and which in many cases determined its division into regions. One can really say that the wheel was not “discovered” as a means of transportation in Iceland until the late 19th century. Around that same time was the beginning of the modern era of bridge buildings. In 1891, the first large steel suspension bridge over the Ölfusa River, South-Iceland, was inaugurated. It was 115 m long, produced in Newcastle, England. Four years later, the other large glacial river in South-Iceland, Thjorsa, was bridged with a similar type of suspension bridge. Several large rivers were bridged with steel suspension bridges in and around 1900. Of those early steel bridges, only one has survived, that of Ornfósdalsá, West-Iceland, built in 1899. An extensive restoration of that bridge, sponsored by the Icelandic Road Administration (ICERA), is just about complete.

The introduction of concrete construction around 1900 was a turning point in Icelandic architecture and engineering. For the first time, an economical method was found to make long-lasting construction out of lo-

cal materials. Early on, concrete was used for technically advanced structures. About the time that concrete made its appearance, the first professional engineers and architects came to practice in Iceland. The country was at that time one of Europe’s least advanced in terms of economy and technology. All basic infrastructure was missing: roads, bridges, harbours, water and sewage. Public buildings were needed: schools, churches, hospitals and last but not least, new dwellings and farmhouses. The art of making buildings was very much seen as part of a general technical reform.³

Cement was first used in building construction in Iceland as part of the renovation and extension of Reykjavík Cathedral in 1845, a stone building from the late 18th century.⁴ The first complete concrete building in the country, a farmhouse at Sveinatunga, West-Iceland, was built in 1895. In 1897, the first concrete lighthouse was built at the tip of Gardskagi peninsula, West-Iceland. It was a rectilinear tower standing on a stone pier, designed by the Royal Danish Lighthouse Authority.⁵ This historic lighthouse is still standing and well maintained. During the first half of the 20th century, a series of lighthouses were built along the entire coast of Iceland, most of them in reinforced concrete.

One of the first civil engineers to practice in Iceland was Jón Thorláksson (1877–1935). During his studies at the Polytechnic School in Copenhagen from 1897–1903, the new concrete technology was still not part of the curriculum.⁶ After graduation, Thorláksson conducted a research on suitable building materials for the construction of permanent buildings in Iceland. His conclusion was that concrete was by far the best choice, given the scarcity of wood, clay (for brickmaking) and suitable building stone.

In 1905, Thorláksson became State engineer in charge of road and bridge construction. Two years later,

< Two-span arched concrete bridge over the Hvítá River, West Iceland (1928). Photo courtesy of ICERA Road Museum.



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Figure 1. Restored bridge over the Fnjóská River, North-Iceland (1908). The longest span of a reinforced concrete arch in Scandinavia at the time of construction (55 m). Photo by Pétur H. Ármannsson

Figure 2. Restored steel-truss bridge over Skálfandafliót, North-Iceland (1930). Photo by Pétur H. Ármannsson.

Figure 3. Restored bridge over the Bláskeggssá River, West-Iceland (1907). Earliest use of concrete in bridge construction. Photo courtesy of ICERA Road Museum.

Figure 4. Abandoned reinforced concrete arch bridge over the Hamarsá River, East-Iceland (1915). Photo by Pétur H. Ármannsson.

Figure 5. Abandoned reinforced concrete arch bridge over the Midfjardará River, East-Iceland (1914). Photo by Pétur H. Ármannsson.

Figure 6. Inauguration of concrete bridge over glacial River Markarfljót, South-Iceland, July 1934. The bridge is abandoned but survived without damage the flood caused by the eruption of Eyjafjallajökull in 2010. It served as a temporary bridge while damages to the current road were fixed. Photo courtesy of ICERA Road Museum.

Figure 7. Recently restored bridge over the Örnólfsdalsá River, West-Iceland (1899). The oldest suspension bridge and only surviving 19th century bridge. Photo courtesy of ICERA (Icelandic Road Administration) Road Museum.

Figure 8. Restored concrete bridge at the west mouth of the Héradsvötn River, North-Iceland (1926). Photo courtesy of ICERA Road Museum.



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he designed a small concrete arch bridge at Bláskeggsá W.-Iceland, the first one of its kind in Iceland. His calculations showed that concrete construction for bridges was considerably less expensive than steel, since sand and gravel was easily available at most sites and the only imported material that needed to be transported to the site was cement.⁷ In Thorláksson's estimates, maintenance cost was lower with concrete than in bridges of steel.

In 1908, concrete with steel reinforcement was used for the first time in an arch bridge over the Fnjóská River in North-Iceland, designed by the Danish engineers Christiansi and Nielsen. It was a very advanced structure for its time. The concrete arch, measuring 54.8 meters, was considered the longest of its kind in the Nordic countries. The completed bridge was praised for its beauty and appeared in international advertisements for the engineering firm.⁷ It was used for automobile traffic until 1968. In 1993, it was restored to its original appearance by the Icelandic Road Administration (ICERA).

During the subsequent years after 1908, concrete was used for the construction of several arch bridges. Some of these arches are still standing as ruins in the landscape, like the ones at Hamarsá, Southeast-Iceland from 1914 and Midfjardará in Bakkafjörður, Northeast-Iceland from 1915. Other types of concrete bridges were also tried out. Most common were flat-arch bridges of several spans, with piers having cut-waters on the side facing the stream. The bridges of Héradsvötn, Skagafjörður, North-Iceland from 1926 and over Markarfljót, South-Iceland, are good examples of the flat-arch type. Both of them are still standing and the former was restored as a historic landmark in 1995.

In 1925, engineer Árni Pálsson (1897–1967) started working for the national road administration. For many years he was in charge of bridge construction and design. Today, he may be considered to be one of the greatest architects of bridges in Iceland in the 20th century. One of his greatest achievements was the two-arched concrete bridge over the Hvítá River at Ferjukot, Borgarfjörður, West-Iceland, completed in 1928. In an article of 1934, Philip Morton Shand praised the design of the Hvítá bridge in the following manner:

This lovely little, two-span arched concrete bridge is a paragon of Modern design. Without aspiring to do anything more than cross a river in the simplest and cheapest way consistent with solidity it triumphantly achieves architecture with a capital "A". An English engineer might object that it is almost as hump-backed in the middle as a medieval masonry pack-bridge. In Iceland, however, speed matters little for the commonest means of transport is the sure-footed, shaggy-haired native ponies that are accustomed to climb almost precipitous mountain slopes. So the designer could not plead the same practical justification for incurring the additional expense involved by flattening out its gradient as engineers of countries whose roads carry heavy motor traffic. There is another reason why this design is interesting: two-spanned bridges are comparatively rare. The writer of an article which recently appeared in a Paris newspaper, who claimed there were not half a dozen in the whole of France, would probably agree that one might search the world without finding a modern example that fits into its surroundings more perfectly and naturally than this one.⁸

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Graduated in Architecture at the University of Toronto, Canada in 1986 and postgraduated at Cornell University, Ithaca, New York in 1988–1990. He worked in the studio of Dagný Helgadóttir and Guðni Pálsson in Reykjavík and between 1993 and 2005 he was the Curator of Architecture at the Reykjavík Art Museum. Since 2006 he is part of the Gláma-Kim Architects team and is the author of several publications and articles on 20th century architecture in Iceland.

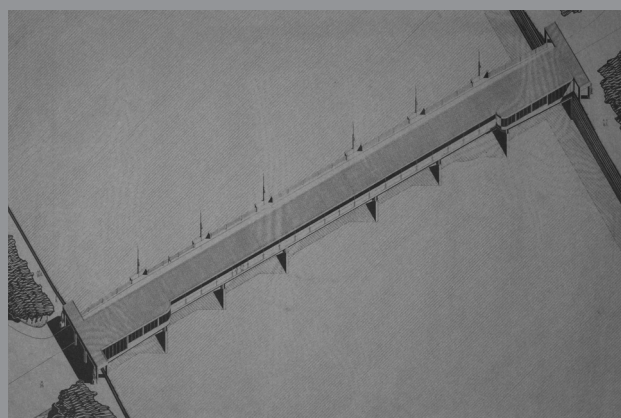
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An Intriguing Work of Engineering and Architecture: The Colonnade Bridge in Piešťany



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THE period around the year 1930 could be termed the culminating point with respect to the Modern architectural avant-garde in Slovakia. It was then that the concepts emerged from the most important works, the first Slovak architectural journals began to be published, the School of Applied Arts opened, as a Slovak variant of the German Bauhaus, and an entire range of other artistic and social initiatives indicated that Slovakia's cultural environment could not only absorb avant-garde impulses, but develop them in a unique way. It was precisely at this moment that the history of one of the most famed bridges in Slovakia, the Colonnade Bridge in Piešťany, began to be written.

By Henrieta Moravčíková

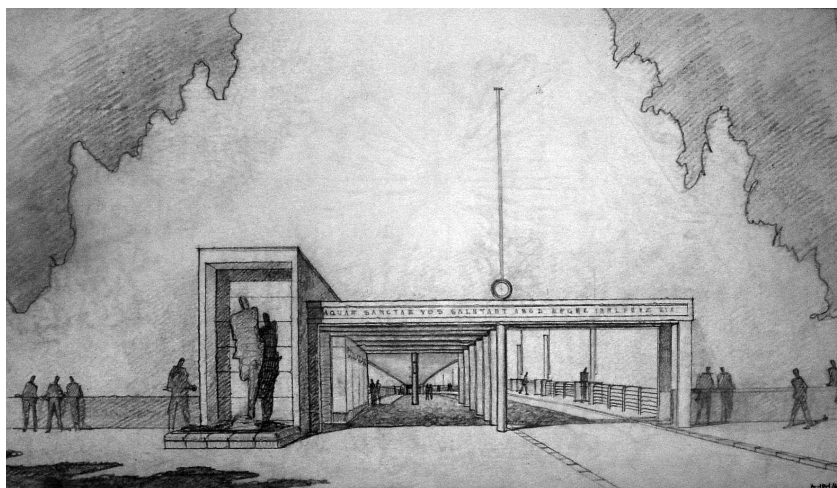
THE construction of the bridge was initiated by the director of the Piešťany spa, Lajos Winter (1870–1968), whose balneological efforts greatly contributed to the overall development of the town. He himself not only brought Modern ideas of treatment to the spa, but also stimulated the sharp increase in construction that continued in the town until the outbreak of the Second World War. Thanks to Winter, and often at his personal invitation, Piešťany played host to construction by the renowned Budapest architects Ármin Hegedűs and Henrik Böhm, the Bratislava architects Franz Wimmer, Andreas Szőnyi, Artur Szalatnai or Friedrich Weinwurm, and eventually the key protagonist of an emerging authentic Modern Slovak architecture, Emil Belluš. Part of the modernization plans of Lajos Winter included the construction of a direct link between the town centre and the spa-baths, situated on the island in the river known as *Kúpeľný ostrov* (Spa Island). Yet the new bridge was not only to be a transport link, but a “protected covered bridge with retail spaces”.¹ In addition, it was also to be “used for drinking-water cures, and thus needed to have the right artistic stylization”.²

When Lajos Winter in 1930 contacted Emil Belluš (1899–1979) to provide the artistic form to the emerging structural design of the new bridge across the river Váh, Belluš was already a relatively well-known architect. He had already completed several buildings, among them the newly finished building of the postal and telegraph office in Piešťany (1928–1931). At that time, Belluš was also working on the design for the building of the Slovak Rowers' Club in Bratislava, which was completed in 1931. It was with this iconic work of Modernism that for the first time an entire range of current construction methods were used, from the reinforced-concrete frame through the open floor plan up to the architectural details based on

the aesthetics of the modern ocean liner. Belluš also had experience with bridge design; in fact, the bridge in his native town of Banská Bystrica was his very first completed work. This reinforced-concrete bridge across the river Hron (1922–25) was designed when Belluš was still a student at the Technical University in Prague. However, the structure of the bridge was prepared by the Czechoslovak Construction Corporation, with Belluš only influencing its architectonic form. The traditional composition of a simple, indeed classical shape recalls the works of Belluš' teachers, and in no way prefigures the Modernity of his later realization in Piešťany. The pair of channeled columns with lanterns at the top, located on both sides of the bridge, even recall the work of Jože Plečnik, whom Belluš came to know during his Prague studies. Likewise, Matúš Dulla in his monograph on the work of Belluš draws attention between the parallel between Plečnik's bridge for Ljubljana and Belluš's bridge in Banská Bystrica, though noting that Belluš, unlike Plečnik, never succeeded in imprinting his own vision upon his native town.³ And yet, what Belluš failed to do in Banská Bystrica succeeded over 100% in Piešťany, where the Colonnade Bridge not only brought fame to its architect but became the town's symbol and its most famous architectural work.

The relatively demanding and in many respects innovative construction of the bridge was realized by the Trnava branch of the well-known construction firm of Pittel & Brausewetter. The plan for the structure was prepared by the Swiss engineer Alexander Schwarz, then an employee of the firm. The 148 metre-long reinforced-concrete construction of the bridge is divided into seven bridging fields, supported by six pillars, with the two central ones placed on reinforced-concrete blocks. The other four pillars in the riverbed, and the two on the riverbank are situated atop massive clumps of reinforced-concrete pilings. The structure of the bridge-frame is formed from joined ferroconcrete girders. However, the central field is placed on the brackets of the adjoining fields using joints. The gigantic reinforced-concrete pilings of octagonal

< The Colonnade Bridge by **Emil Belluš**. Axonometric view by the architect and view from the town centre. Drawing from USTARCH SAV. Photo from the Archive of the Slovak National Gallery.



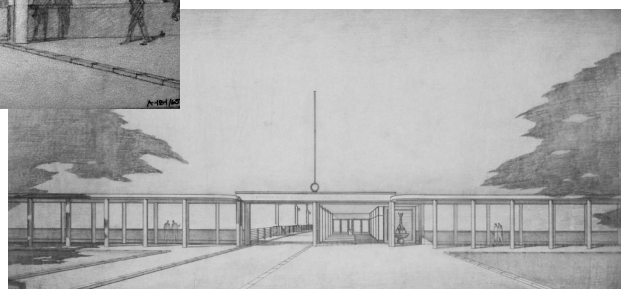
The main portal from the town in **Belluš'** drawing. Image from the Archive of the Slovak National Gallery.

shape, with a diameter of nearly half a meter, length of 10–12 m and weight of 4,000–5,000 kg were one of the main technological specifications of construction. The pilings, resembling enormous pencils, were forced into the river-bottom to a depth of 8–10 m, to reach firm bedrock and prevent damage to the structure in the flooding event. However, the bedrock in the riverbed is of varying depths, meaning that the depth of sinking and the precise length of the individual pilings could not be determined in advance. Nor could the pilings be made beforehand, as was the case in other such buildings, meaning that the cement would not have enough time for the correct hardening. As a result, the pilings were made using an innovation from the Slovak cement works in Ladce, the quick-drying cement Bauximent. This material allowed for quick hardening while retaining the needed firmness. As a result, pilings of only 48 hours of age could be used for the bridge. The exacting demands for load-bearing and structural solidity required exceptionally massive reinforcement. Through the use of another innovation of the time, Isteg steel, which could bear up to 40% greater loads than traditional circular rods, it was possible to reduce the dimensions of the reinforcements and thus the structure as a whole. Precisely this material can be thanked for the bridge's slender elongated lines.⁴

This structurally ingenious fundament formed the basis that was further handled aesthetically by Emil Belluš. The upper part of the bridge was divided into two parallel strips, for motor and foot traffic. The pedestrian section had a roofing system similar to that of railway platforms. At the centre were supports placed at regular lengths apart, holding up the long roof surface with T-shaped girders. Unlike the open platform, however, the spaces between the supports were enclosed with a glass wall,



General view. Photo from the Archive of the Department of Architecture USTARCH SAV.



The not realised spa colonnade in Belluš' drawing. Image from the Archive of the Slovak National Gallery.

serving as protection from the strong west winds that would otherwise make walking on the bridge less pleasant. On both sides of the bridge, Belluš installed, within the first bridge-fields, small shops, and in the covered pedestrian section benches. Thanks to the forward-looking architectural design, the bridge became a living part of the town, similar to the Renaissance bridges in Florence or Venice. Adding to the Modern appearance of the bridge was its slender steel railing with flag-mounts and large glass panes, at the centre of the bridge decorated with etching by the Slovak painter Martin Benka. Another unique feature of the bridge was its nocturnal illumination, in the form of long lines of lights integrated into the structure so as to emphasize its basic form. Similarly to Le Corbusier placing in front of the pavilion of the journal *L'Esprit Nouveau* at the Paris Exposition of 1927 a Purist sculpture by Amédée Ozenfant, Emil Belluš too created a space for a statue in front of the bridge. Though the realistic figure *Barlolámač* (Crutch-Breaker) by Rudolf Kühmayer is not a masterwork of Modern sculpture, it has become a symbol of the town and today even forms part of the town seal. Both of the entrance portals to the bridge were ornamented, at the builder's request, with inscriptions. On the side facing the town is the title from the Latin poem by Adam Trajan from 1642 *Saluberrimae Piestiniensis Thermae* (Song of Praise for the Piešťany Baths). The portal on the side of the spa island, in turn, addresses the patients with its Biblical injunction *Surce et ambula* (Arise and Walk). On the side of the island, the bridge was

originally to have connected to the spa colonnade. Though this was never realized, the plan gave the bridge its name 'Colonnade Bridge'. Construction lasted for just under 11 months in 1931 and 1932, yet work was only carried out in autumn and winter, so as not to disturb the spa patients.

The bridge was ceremonially opened in the spring of 1933, with the Czechoslovak foreign minister, Edvard Beneš, present. At this time, Belluš was only 34 years of age; later, he recalled the time of his work on the bridge as the most beautiful time of his life. Even at this early point, the bridge assumed its place in history as an important symbol of Slovakia's entry into Modernity. Yet despite all the social and political connotations that drew attention to the bridge at its opening, its fame is still largely derived from its being an excellent work of architecture. It joins together the two key principles of Modern architecture: technical complexity and artistic simplicity. Precisely these two qualities enchanted the Austrian architectural historian Friedrich Achleitner, who termed the Colonnade Bridge a work of genius in the balancing of the Constructivist aesthetics of ferroconcrete with the riverside landscape.⁵ Most architectural historians rank the Colonnade Bridge as the crowning moment of Belluš's Functionalist period. Even in the most recent monograph about the architect, the bridge is the key work in the chapter entitled 'Functionalism', though the author does recall that in Belluš's oeuvre function was always paramount,

and that in the Colonnade Bridge there was a fortunate meeting of functional requirements and Modern formal vocabulary, with the artist's classic sense of rhythm and visual counterpoint.⁶

At the end of the Second World War, the bridge was damaged by the retreating German army, with significant damage to the central part of the bridge structure. Almost by miracle though, the glass plates were saved, since one of the spa employees removed them in time. During rebuilding of the bridge, the decisive question was simply to renew as quickly as possible the link between the town and the spa island. Yet, though, the bridge was not then viewed as an architectural landmark, the work was carried out following the original plans from the 1930s. Bearing in mind the relatively brief interval between construction and repairs, there was not even a radical difference of construction technologies or materials, such that the rebuilt section can hardly be told apart from the original. The bridge was opened again in 1956. Though the present bridge is, to an extent, simply a replica, it can still be regarded as a consistent and authentic landmark of the Modern era. It was under such words that it was registered in the National Landmark Register, as of April 10, 1987 as entry number 2347/0. The Colonnade Bridge in Piešťany was also among the first works that the Slovak working group entered in 1994 into the Slovak Top Register of **docomomo**.⁷

Notes

1. These are the words used in the memoirs of Lajos Winter. Winter, L., *Spomienky na Piešťany*, Balneologické Museum, 2001, 75.
2. Such phrases were used about the bridge even during its construction. Weisz, E., *Pistyan's Aufstieg*, Forum, vol. 1, n° 6-7, 1931, 196.
3. Dulla, M., *Architekt Emil Belluš*, Bratislava, Slovart, 2010, 39.
4. Schwarz, A., *Bau einer gedeckten Eisenbetonbrücke in Pistyan*, Forum, vol. 1, 1931, 376-377.
5. Achleitner, F., *Mitteleuropa-auch kein architektonisches Thema?* WAS-Zeitschrift für Kultur und Politik, Dezember 78, 1994, 5-25.
6. Dulla, M., *Architekt Emil Belluš*, Bratislava, Slovart, 2010, 94.
7. Fiche for the Colonnade Bridge was elaborated by Klára Kubičková, first chair of the Slovak working chapter. Top register-Slovakia, Ed. K. Kubičková, Bratislava, SAS, 1994.

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Henrieta Moravčíková

Dr. Ing. Arch., senior researcher and head of the Department of Architecture at the Institute of Construction and Architecture, Slovak Academy of Sciences in Bratislava. Editor and member of the editorial board of the scientific journal *Architektúra & Urbanizmus*. Chair of **docomomo** Slovakia since 2000, she has published several monographs, studies and critiques on architecture of the 20th century. Together with Matúš Dulla she published *20th Century Architecture in Slovakia* (Slovart, 2002) and edited the first synoptic monograph on Slovak architecture *Architecture in Slovakia: concise history* (Slovart, 2005).

Lincoln Park Passerelle: Rainbow Bridge

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AS seen by approaching motorists on Chicago's Lake Shore Drive, the "Rainbow Bridge" appears as if it's crossing the 6-lane roadway with a graceful leap worthy of a ballet dancer. To people crossing the bridge, its gentle rise provides comfortable access to a popular beach and recreational parkland at edge of Lake Michigan.

By Tim Samuelson

SINCE its completion in 1940, the pedestrian bridge popularly known as the "Rainbow Bridge" has become a familiar feature of Chicago's cityscape. But in its early years, it also gained recognition as a structure of innovation and beauty. Within four years, it was selected by New York City's Museum of Modern Art as one of the best structures in the United States—putting it in the same company with the Golden Gate Bridge, and other major public works projects of the late 1930s era. Other expressions of appreciation soon followed.

It was heady recognition for a bridge of relatively modest size and origins. Its creators were a team of relatively unknown engineers working as employees of the governmental agency in charge of Chicago's park system, and the bridge itself was relatively small—a structure designed to carry beach-bound citizens traveling by foot, bicycle and stroller.

But its unexpected notoriety was consistent with Chicago's reputation for making pragmatic solutions to urban challenges that achieved beauty in their unpretentious directness. It was a tradition that could be seen in the late 19th century when the city's architects and engineers solved a lack of downtown commercial space by using the local availability of steel and cleverly adapting existing technologies to evolve the modern skyscraper. The resulting buildings were not only tall, but their honesty of expression also gave them presence—and often beauty.

Chicago's creative ingenuity was certainly evident in solving multiple challenges presented by the Rainbow Bridge project. For pedestrians, it needed to provide comfortable access across the highway to the beach, keeping in mind that many users would be toting chairs, picnics and children. For the unimpeded flow of traffic on the highway below, it needed to cross the highway without intermediate supports. And its prominent location—rooted in popular park, and set on the lakefront between the urban skyline and nearby exclusive homes—required visual compatibility with these features.

Modernism driven by technology offered a logical solution, drawing on the creative *momentum* established Chicago's popular 1933–34 "A Century of Progress" world fair.

A low rigid metal frame arch spans the entire roadway, with slightly stylized concrete abutments at each end incorporating pedestrian access by stairs and gently inclined ramps. Users above on foot, bicycle or in child strollers are given a picturesque and comfortable journey as cars maneuver freely below. And the span's gentle low-rise curve and delicate stairs and ramps of buff-colored concrete merge comfortably with the natural landscape of surrounding parkland and Lake Michigan vistas. As a whole, it creates an expressive gateway to those approaching the city skyline, and a transitional passage for those leaving.

From initial concept to finish, the project was under the direction of the Chicago Park District, the municipal agency responsible for the city's parks. Early citations credit the department's Chief Engineer, Ralph H. Burke for designing the project, but his role was most likely administrative. A surviving sketch in Chicago Park District archives suggests architect Maurice J. Glicken as the originator of the design concept, and other materials indicate Lyman C. Riggle as structural designer, and C. Thomas Kelly as structural engineer.

Fabrication of the metal superstructure was contracted to the American Bridge Company, located in the nearby steel manufacturing city of Gary Indiana. Actual construction was done under the supervision of the Chicago Park District staff, with some of the funding coming from the Works Progress Administration job incentive program established by the United States government during the 1930s depression era.

A contemporary description of the span provided by Chicago Park District described it as "a three hinged, tubular arch built-up of angle irons and flush steel plates." The structural arch spanned 187 feet across the roadway, with a height of approximately 25 feet. To address concerns about using such a relatively new technology for such a wide span, staff engineers subjected the frame to an extensive barrage of structural tests over a period of several months and seasonal climate changes. Among these, a test load of 185 T was placed a mid-span along the crown, far exceeding loads anticipated for actual usage.

The bridge attracted considerable public attention and curiosity by the time of its completion in late 1940.

< View of bridge. Photo from the Chicago History Museum.



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But it soon received another level of appreciation beyond local beachgoers, motorists and area residents. Its inclusion in the Museum of Modern Art's 1944 "Built in the USA" exhibit and catalogue was followed by its publication in *Architectural Forum* magazine in the same year. Critical recognition from MOMA came again in 1949 with its inclusion in a book devoted to modern bridge design. It was documented as part of the *Historic American Engineering Record* in 2001.

The bridge became a popular favorite in Chicago as well, and regarded as a distinctive component of the city's urban fabric. The bridge continued to be monitored for structural stability, requiring minor structural adjustments over the years, the most significant being the addition of diagonal bracing after a 1990 engineering study recommended additional strengthening to accommodate people crowding the bridge to watch nearby lakefront airshows and festivals.

A competition was held to create a replacement

bridge in 2005, the entries including one proposal to replicate the existing bridge with only minor modifications. An entirely different contemporary design was ultimately selected. The proposal to demolish the existing bridge raised considerable outcry in the Chicago preservation community. Lack of funds halted the proposed replacement of the historic 1940 bridge, but its long-term survival remains uncertain.

Notes

1. Chicago Park District: Ralph H. Burke, chief engineer; Maurice J. Glicken, architect; Lyman C. Riggle, structural designer; C. Thomas Kelly, structural engineer. Erected, 1939-40.

Tim Samuelson

Cultural historian for the City of Chicago, has been instrumental in celebrating and protecting Chicago's past for more than 25 years. He is highly regarded for his stewardship of the cultural and architectural history of the city at the Commission on Chicago Landmarks and the Chicago Historical Society. He obtained an English degree from Roosevelt University and a fellowship at Harvard's Graduate School of Design and worked on architect John Vinci's restoration projects.

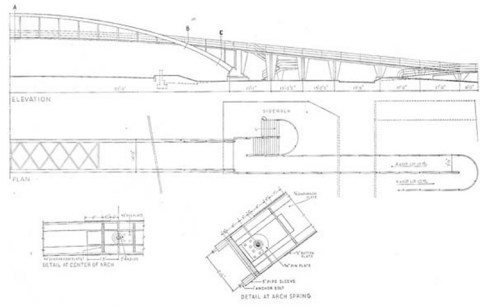
Figure 1. View of arched span. Photo by Hedrich Blessing studio from Chicago History Museum.

Figure 2. Detail of footbridge.

Figure 3. Footbridge detail. Photo by Hedrich Blessing studio from Chicago History Museum.

Figure 4. Frontal view of footbridge. Photographer unknown.

Figure 5. Lincoln Park Passarelle at present.
Photo from HistoricBridges.org by Nathan Holth.



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Mizen Head Footbridge or 'Building a Bridge, to a Build Bridge'



MIZEN Head Footbridge in County Cork is a reinforced concrete through-arch structure spanning 50 m. The original structure was demolished and rebuilt 2009-2011, 100 years after its completion. This article describes the construction challenges of safely reconstructing a bridge in a difficult site location.

The bridge provides access to a lighthouse on the tiny island of Cloghán, at the tip of Mizen Head in Southwest Cork. It is the result of a design competition held in the early 1900's. The winning entry was by Mr. Noel Ridley of Westminster, London. It had the form of a pair of parabolic arch ribs spanning 50 m supporting a pedestrian deck, suspended by vertical hangers from the ribs in the central section.¹

By Kieran D. Ruane

ON October 18, 1907, sanction was given for the erection of a reinforced concrete bridge to give access to the island. Construction commenced in 1908 and was completed in 1909. The Contractor was Alfred Thorne and Sons of Westminster, London, at the cost of £1,272.

The original bridge comprised both precast and *in situ* reinforced concrete elements. The arch ribs were constructed in stages both onshore and *in situ*.^{2,3} The initial rib cross section was an open precast concrete trough to allow launching of the ribs. The section allowed precast concrete trestles and deck edge beams to be added before the ribs were completed with in-situ concrete. The bridge deck and the hangers were cast in-situ. The reinforcement in the structure was in the form of round bars, rectangular bars and sheets of steel folded in a corrugated manner. It was a construction of an era of proprietary reinforced concrete, following the Ridley-Cammell system.⁴

The Site

It is difficult to get access to the bridge site, a sea gorge between the mainland at Mizen Head and the tiny island of Cloghán. The soffit of the bridge is some 45 m above the bottom of the gorge. By vehicle it is possible to access to within 300 m of the mainland abutment. Thereafter, access becomes a narrow and steeply inclined footpath.

Origins

From the start maintenance activities on the bridge have been carried out by the Commissioners of Irish Lights. A maintenance contract was undertaken in 2000 for repainting the bridge and carrying out concrete repairs. An inspection at this time revealed areas of spalled concrete

and severe reinforcement corrosion, particularly at a joint between a deck hanger and the northern edge beam. In 2002, structural engineers RPS (then M.C. O'Sullivan and Company Ltd.) were appointed to conduct an inspection and assessment of the footbridge. Specific information was collected by material tests, observations and geometrical surveys. This information helped to establish the condition of the structure and provide material and geometric parameters for analytical models and for maintenance, repair or strengthening scheme development. The defects noted during the inspection were summarized as rust staining, areas of hollow sounding concrete, cracking and localized areas of missing concrete. All the defects noted were related to corroding reinforcement. No defects caused by structural actions were observed. In general, the visual inspection of the bridge found it to be in good condition given its age and its location in an exposed site.⁵ This was due to the quality of the original construction and to the regular maintenance of the bridge.

Material tests were used to determine the integrity and strength of the concrete and to investigate reinforcement corrosion mechanisms. Both non-destructive and destructive tests were used ranging in complexity from hammer tap surveys to petrographic examination. BA 35/90⁶ presents information on these and other tests with useful references.

Two 105 mm diameter cores were taken from the deck of the bridge. One of these cores was compression tested and found to have an equivalent cube strength of 27.5N/mm². Three cores removed from the arch ribs in 1990⁷ were compression tested and found to have equivalent cube strengths of 70.3, 46.4 and 72.9N/mm².

Petrographic examination was carried out on two core samples taken from the structure. The coarse aggregate used in the deck construction was dominated by crushed greywacke and sandstone particles having a nominal maximum size of 14 mm. The aggregate in the coarse fraction was probably locally derived.

< Mizen Head Footbridge by Mr. Noel Ridley, in 2004.



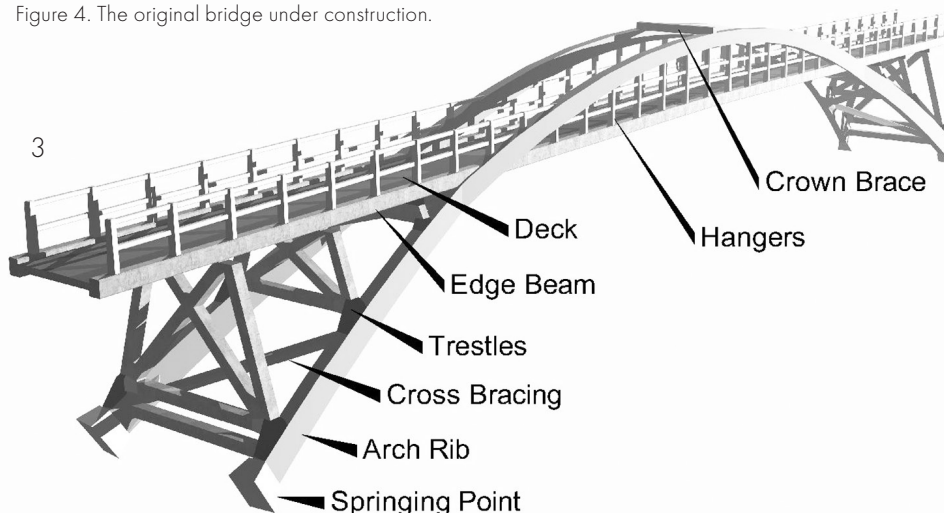
Figure 1. Temporary access scaffold supported directly from the arch ribs erected in June 2005.



Figure 2. Petrographic analysis of the original bridge concrete showing presence of sea shells.

Figure 3. The structural elements of the bridge.

Figure 4. The original bridge under construction.



No evidence of damage due to alkali-aggregate action was found in the petrographic examination, although traces of gel were present in voids in the paste. Examination of a thin section taken from a portion of the core sample showed fine cracks running through aggregate particles into the cement paste. These were found to contain alkali silicate gel and indicated that an expansive reaction had taken place between the greywacke aggregate and alkalis in the paste, causing very localized damage to the concrete in the area where the core had been taken. This is considered to be the only reported example of alkali-aggregate reaction in Ireland to date.

In summary, chloride content levels were very high throughout the structure. This did not affect the integrity of concrete directly but it provided a mechanism for reinforcement corrosion to occur. Evidence of damage to concrete caused by the expansive product of reinforcement corrosion was clear in the inspection. Defects ranged from areas of hollow concrete where corrosion had caused delamination of the cover zone to areas of spalled concrete. Carbonation levels were very low. Based on the petrographic examination, low levels of alkali-aggregate reaction, low carbonation levels, high chloride levels, and strength estimates from cores and Schmidt hammer tests, it was concluded that the concrete, excluding the concrete in the cover zone, was of a sound nature.

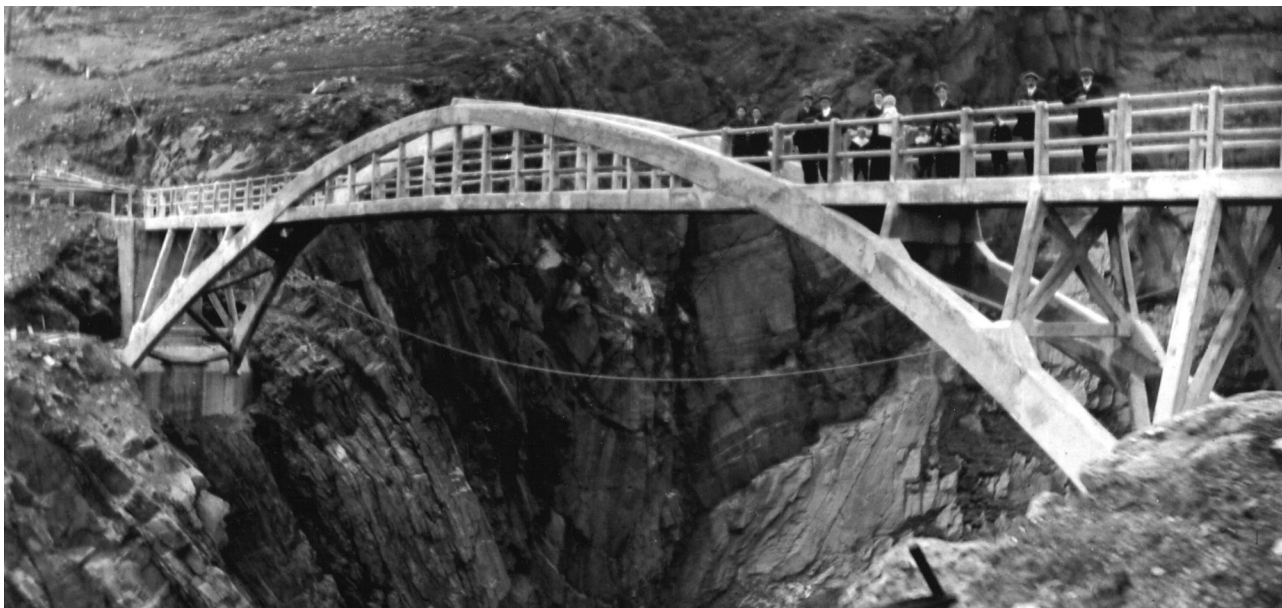
Based on the original construction drawings and the information gathered during the principal inspection, a finite element assessment of the structure was performed by RPS. The results indicated that the structure was adequate for continued use due to good reserves of structural resistance to applied dead and live loading effects.

However, given that the central suspended span of the deck was relying on reinforced concrete hangers in direct tension and given the high chloride induced steel corrosion throughout the structure, it was recommended that the hangers be strengthened and that measures be taken to halt the corrosion of reinforcement in the structure. A monitoring regime was placed on the structure to allow regular inspections at six-monthly intervals.

In 2004, a Preliminary Report for Strengthening and Repair of the Mizen Head Footbridge was produced. It was recommended that the hangers be reinforced with Near Surface Mounted Fibre Reinforced Polymer (NSM FRP) bars, that concrete repairs be undertaken to repair defects on the structure and that a cathodic protection system be installed on the structure to stall the rate of reinforcement corrosion. However, it was noted that the suitability of the structure to receive a cathodic protection system would need to be confirmed by specialist testing before a definite recommendation could be made.

In February 2005, electrical continuity testing of reinforcement in the structure was undertaken to assess the feasibility of providing a cathodic protection system for the structure. The specialist testers concluded that there was a limited amount of reinforcement continuity within the arch ribs and within some hangers but that there was no general continuity of reinforcement steel within the structure, either between structural elements or within individual elements.

Following the issue of the electrical continuity testing of the Preliminary Report, the Mizen Footbridge was closed to pedestrian traffic. In June 2005, an access scaffold for the bridge was procured. The scaffold was sup-



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ported directly from the arch ribs only and provided an independent bridge deck for the structure. The scaffold allowed access to be maintained at Mizen Head until a permanent solution was developed. It was expected that the scaffold would have a lifespan in the region of three to five years.

Detailed Scheme Development

A revised Preliminary Report was presented to the Commissioners of Irish Lights in September 2005. It considered the following solutions:

Option 1: A strengthening and repair scheme which involved an initial strengthening and repair of the arch ribs and rib braces followed by a sequential removal and replacement of the remaining elements of the deck superstructure. The mass concrete foundations at the arch springing points and deck ends would be retained.

Option 2: A scheme which initially involved the construction of new arch ribs (parallel to and outside the existing ribs) using the existing ribs (strengthened if required) as falsework, followed by the sequential demolition of the existing bridge, followed by the construction of trestles edge beams, hangers, and the deck slab. This scheme produced a replica of the existing bridge though the deck would be 700 mm wider. The mass concrete foundations at the arch springing points and deck ends would be retained.

Option 3: A scheme which involved replacing lost steel throughout the structure with small diameter FRP (Fibre Reinforced Polymer) bars using the NSM (Near Surface Mounted) method followed by a large concrete repair scheme.

Various factors fed in to the selection of the preferred option. These included heritage considerations, cost, environmental issues, ease of construction, health and safety, and durability.

Option 2 was recommended as the preferred option

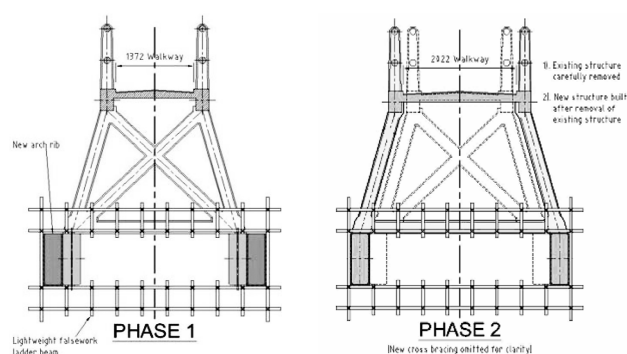


Figure 5. Sectional elevations through the bridge indicating the solution to use the existing ribs as falsework for the construction of new ribs. The new ribs would then be used to support demolition works on the old bridge.

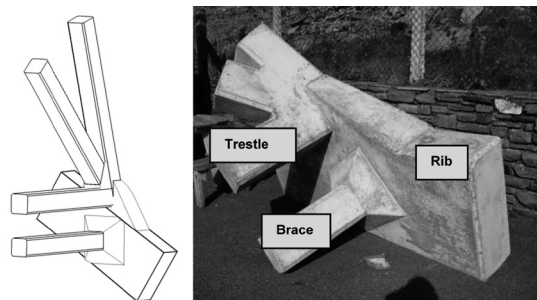


Figure 6. Trial panel comprising braced arch rib section at trestle support.

as it maintained the current appearance and form of the bridge, it gave the best long term solution and provided an economic solution which could be built safely with minimal impact on the environment.

The replacement structure was designed as a two-pinned arch. Analysis was undertaken using the LUSAS finite element system and design was undertaken to British Standard BS5400. The live loading consisted of 5kN/m² nominal pedestrian loading and a maintenance vehicle load case.

Construction

A tendering process took place in 2009. Funding for the project was provided by Fáilte Ireland (the Irish Tourism Authority), Cork County Council and the Commissioners of Irish Lights. Under an agreement between Cork County Council and the Commissioners of Irish Lights, Cork County Council undertook the role of Employer and entered in to agreement with Irishenco in September 2009 for the demolition and reconstruction of the bridge. Works commenced in October 2009 with measures to improve access to the bridge. There was limited scope to widen the lower reaches of the footway to the mainland abutment. However, the upper reaches of the footway were locally widened to allow limited access for delivery vehicles and construction plant.

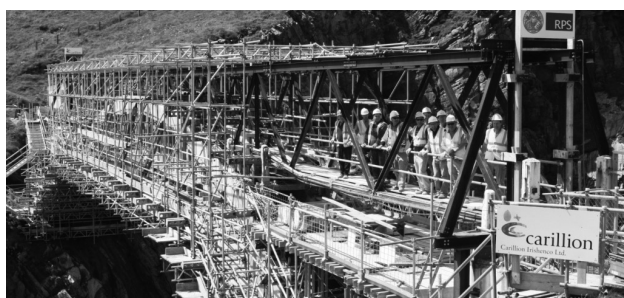


Figure 7. Erection of the temporary truss. All of the members were delivered and erected by hand.

Construction of the trial panel was an early activity in the construction program. It allowed the engineers, carpenters and reinforcement fixers to develop their detailed construction plans before undertaking the permanent works. The geometry of the bridge was difficult to form. The ribs vary in depth and they are flared out in the back-spans. Where members such as braces and trestles intersect the ribs, the member ends are locally widened with tapering faces. Each of these details was faithfully reproduced from the original bridge and detailed in to the new works. The carpenters likened the formwork required to construct the new bridge to cabinet-making such was the complexity involved.

At tender stage, Irishenco proposed the concept of 'Building a Bridge, to Build a Bridge' i.e. to construct a temporary bridge prior to the commencement of full-scale construction and demolition works. The purpose of this temporary bridge was primarily to act as a fail-safe for the duration of the works. This concept was advanced after the contract was awarded and it fed in to the detailed development of Irishenco's temporary works design.

The temporary works design included:

- Use of the existing arch ribs to support the construction of the new ribs, an access scaffold in the back-spans and a temporary deck system.
- Use of a 52-metre-long steel truss to span across, and above, the existing bridge deck to act as a fail-safe for the works, to provide support to the main access scaffold and to provide support to an overhead winch and gantry capable of lifting and transporting a safe working load of 1,500 kg.
- Use of a large scale scaffold to allow full access to all parts of the central portion of the bridge.
- Use of the new arch ribs to support the demolition of the old arch ribs and the construction of other permanent works structural elements.

Key stages of the integrated demolition and reconstruction sequence are detailed below.

Demolition of Suspended Deck and Hangers and Construction of New Deck and Hangers

The existing deck was propped off the temporary deck and the hangers were removed using circular saws. The existing deck was wire-cut in to pieces lowered on to the temporary works deck and removed with the overhead winch. Formwork was installed for the new deck and edge beams, reinforcement was fixed and the new elements were poured. New hangers were subsequently fixed and poured.

Demolition and Reconstruction of Back Spans—Trestles, Edge Beams and Deck

The original deck and edge beams in the back-spans were demolished and removed from the bridge. A temporary deck was installed prior to demolition works. This was supported from the original arch ribs and it allowed the demolition of the deck and edge beams in the back-spans to be undertaken in the same manner as the suspended deck in the centre of the bridge. Trestles, edge beams and deck section were constructed.

Transfer of Loading to the New Ribs—Demolition of the Original Ribs and Braces

Prior to the demolition of the original ribs, all of the temporary works which were relying on the original ribs for



Images of the New Mizen Bridge completed in 2010.

support were transferred to the new ribs. As both sets of ribs were located at the same level, the exercise involved a careful inspection of the myriad of support details to ensure that all loads would be transferred smoothly. It was essential that no temporary works element could snag on other elements on removal of the original ribs. Such a situation could give rise to a suddenly applied load and a crush injury hazard. Supports were also adjusted so that the original ribs would be supported from the new ribs. The new ribs were also braced off each other for stability. Hinges were cut in to the original ribs at the springing points. Finally hinges were cut in to the crown of the original ribs. These were gradually reduced and eliminated so that the original ribs were directly supported by the new ribs. Demolition of the ribs now proceeded through the use of concrete circular saws, coring and mechanical expansion jaws.

Construction of Braces and Composite Deck Sections, Grouting of Mesnager Hinges

The final structural elements to be constructed were the braces between the ribs in the back-spans and the section of deck composite with the arch ribs at the quarter-span points. Following this, the main temporary works were sequentially dismantled and removed from the site. The Mesnager hinges were grouted and the remains of the original arch ribs were finished in concrete to provide a legacy of the original structure.

Conclusion

The New Mizen Bridge was completed in December 2010 and opened to the public on March 17, 2011. The project was delivered safely to program and within

the scheme budget. It was a project marked by a very successful collaboration between client, contractor, and engineer. The new structure is a fitting testimony to the original concept and contractor and to the Commissioners of Irish Lights who looked after the original structure for hundred years. The new structure also preserves a landmark feature on the coast of Ireland for future generations to enjoy.

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Bridging the Gap

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ON July 30, 1870, a visitor to the Niagara Falls noted glumly in his diary that “the impression of the waterfall was gripping, but not what I had expected”. Having travelled from Northern Europe to reach this scenic spot, the traveller—a railway engineer—was frankly disappointed. The landscape was flat and dreary, and only seen from very particular angles did the falls live up to their sublime reputation. What consoled the disillusioned tourist, however, were the many beautiful bridges built to accommodate traffic, commerce, and sightseeing around the falls: “The proud Clifton suspension bridge with its 1269’ span, 300’ above the river, was light and beautiful. The picturesque bridges across to Goat Island and “Three sisters”—all in pleasant harmony—give to the place a decidedly attractive character” he enthused.¹ Regardless of its reputation as the most spectacular natural scenery in the world, to our railway engineer, Niagara was saved only by the sublime spectacle of the bridges.

By Mari Hvattum

THE disappointed engineer was not alone in his fascination for bridges. Although the 19th century witnessed an ever-increasing interest in the natural landscape, the man-made environment held an even greater attraction, especially once it got big enough, fast enough, or complex enough to take on some of the sublimity of nature. The American historian David Nye has coined it the ‘technological sublime’, seeing the obsession with railways, roads, bridges and dams as a particular characteristic of Modern aesthetic sensibility.² Bridges play a key role in this new sensibility, both as objects in their own right and as tokens of an entirely new landscape, created and shaped by infrastructure. Mediating between the natural and the man-made, symbolising man’s mastery over nature, the bridge was, to 18th and 19th century eyes, a super-symbol of Modernity. And yet, the bridge in itself is ancient, and has been a key motif in architecture, painting and garden design for millennia. The 20th century fascination for bridges draws on both these strands, making their cultural history a fascinating and somewhat paradoxical story.

Bridges and the Modern Transportation Landscape

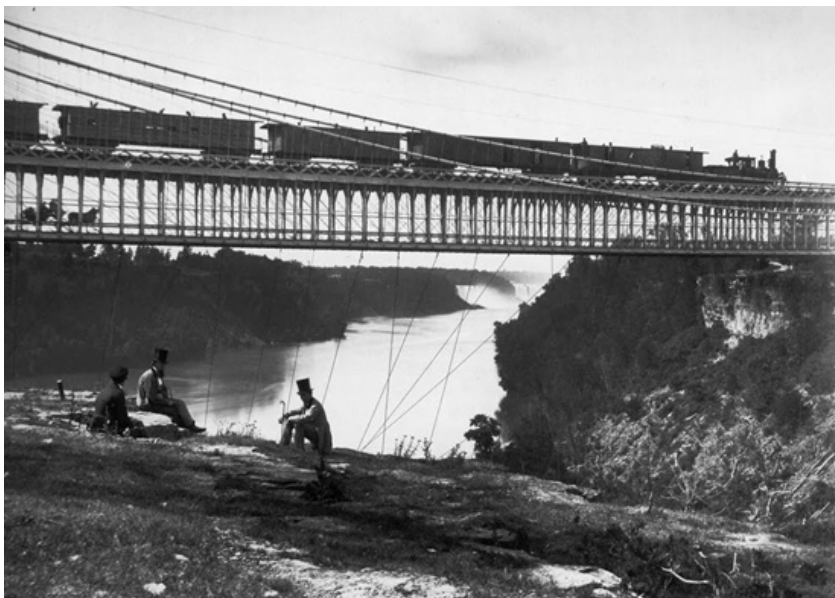
Modernity is mobility, articulated not least by means of Modern infrastructure. From the ambitious road-building projects of the *École des Ponts et Chaussées* in 18th century France, through North-American canal building, English railway development, Nazi *Autobahns*, and American Parkways, infrastructure has been considered both a harbinger of global Modernity and an articulation of the native landscape. The German historian Thomas Zeller, for instance, shows how the Nazi *Autobahn* was

conceived as much as an aesthetic orchestration of the German landscape as an economically efficient transport network.³ Wolfgang Schivelbusch’s study of the early railway landscape, J.B. Jackson’s analysis of the North American car-landscape, or Alison Smithson’s reading of the English motorway come to similar conclusions, pointing to the close links between infrastructure and landscape perception.⁴ Bridges play a particular role in this perception. Built precisely where the terrain resists passage—where rivers, lakes, canyons or ravines make smooth passage impossible—bridges epitomize the dramatic transformation to which the landscape is subjected by Modern engineering. Early Modern bridge design reflected this drama. As the brief for a 1791 bridge building competition at the *École des Ponts et Chaussées* put it:

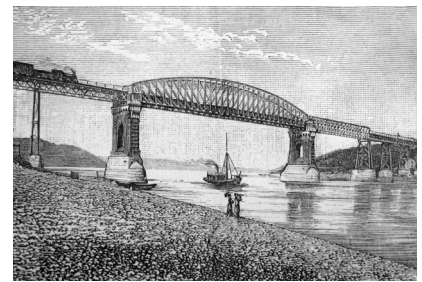
Before projecting, it is essential that one examine carefully the sites and proportion of the bridge to the objects which surrounds it: in a wealthy and beautiful town, one builds a light bridge, enhanced by the beauties and agreements of architecture to which this kind of structure is susceptible; in the countryside or in a small town, a light and simple bridge; amidst the mountains, a heavy and bold bridge. If one seeks to build a bridge next to a substantial rock, it is essential that its construction combine a stability recognized and demonstrated by calculation, a boldness and a form as astonishing and remarkable as the mass which is adjacent to it.⁵

The quote above is taken from the French historian of technology Antoine Picon, who has studied the particular aesthetics at work in 18th century bridge building. While the enlightenment engineer subjected nature to dramatic transformation, he did not conceive it as violation, Picon argues. Rather, to join up the countryside was understood as an act of completion: fulfilling a potential that nature had left unfinished.⁶ The bridge, then, became not only a practical device but a powerful cultural symbol with its own particular aesthetic codes. Not merely part of an

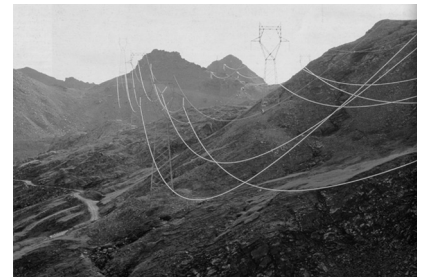
< M1 motorway junction bridge in Buckinghamshire by Sir Owen Williams & Partners. The Motor Magazine 4, November 1959.



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abstract network, bridges were conceived in relation to their local context and their particular construction process. The latter was particularly important, as the often dangerous process of constructing bridges added to their sublime character; “Since the bridge was born of the suffering of the engineer and his workmen, and since it courted danger in braving the abyss and the impetuosity of the river, it was regarded as sublime” writes Picon, pinpointing the processual aesthetics invested in bridge building in Modern Europe.⁷

If the sublime became a key aesthetic category for describing bridges—used to coin everything from Fowler and Baker’s Forth Bridge to Calatrava’s Alamillo—sublimity is not the only aesthetic quality ascribed to bridges in the Modern period. In the 18th century garden, bridges were used as picturesque elements in the landscape, giving character and beauty to particular places and views along the garden path. Bridges enhance the view, giving depth and definition to the scenery, wrote the garden theorist Thomas Whately in 1770.⁸ This picturesque practice survives in the way bridges are described and experienced in 19th and 20th century travel literature. In his 1874 guide book to Norway, for instance, Christian Tønsberg described the “splendid bridges” as the highlight of the railway journey, giving visual variety to an often tedious landscape.⁹ Brimming with enthusiasm, these guide book authors describe the bridges not only as technological or infrastructural marvels but as beautiful and interesting objects, adding to the character and beauty of the natural landscape. In an interesting anticipation of the 20th century aestheticization of technology voiced by Modernists such as Sigfried Giedion and Le Corbusier, 19th century

guidebooks celebrated the bridge as the quintessential expression of the Modern age.

Given their profound symbolic and aesthetic significance, it is no wonder that bridge design became such an iconic task in the 20th century. Yet it was a fraught task, a balancing act between many conflicting demands. When the engineer Owen Williams—responsible for the English M1 motorway from 1951 until 1959—launched his design for the M1 motorway bridges, for instance, critics attacked his chunky structures for being out of sync with the *Zeitgeist*.¹⁰ As the architectural historian Nikolaus Pevsner observed: “Sir Owen evidently wanted to impress permanence on us, and permanence is a doubtful quality in devices connected with vehicles and means of transport. Elegance, lightness, and resilience might have been preferable”.¹¹ Caught in the crossfire between ‘firmitas’, ‘utilitas’ and a very time-specific understanding of ‘venustas’, Sir Owen’s bridges were deemed deficient, responding neither to the mobility of the route nor to the qualities of any particular place.

Bridges play a significant if paradoxical role in Modern imagination. Joining the landscape into a navigable network, the bridge is part of a placeless system of infrastructure. As a constructed object, however, the bridge is part of a particular context, contributing to creating, recreating and interpreting places. As Heidegger reminds us: the river banks are not banks until the bridge links them. And although bridge construction and bridge design has changed greatly during the last centuries, this dual challenge remains. The bridge is a route as well as a place, and its particular position in the cultural imagination rests on this duality.



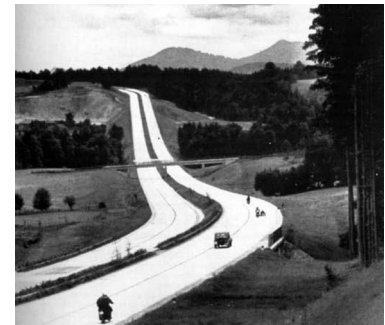
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Figure 1. Niagara Suspension Bridge, 1859. Photo by William England.

Figure 2. Railway bridge at Minne, Norway. Xylography. In Christian Tønsberg, *Norge, Illustreret Reisehaandbog*, 1874.

Figures 3 and 4. Utility poles crossing landscape published in *Rassegna 63, Electricity*, 1995. Archivio Storico Enel.

Figure 5. Highway junction at old 101 Pacific Coast Highway, San Diego, 1947. Photo by Howard Rozelle.

Figure 6. Poster of the Reichsbahn headquarters for the German Reiseverkehr. Design by **Robert Zinner**, Berlin, 1936. © DHM, Berlin.

Figure 7. Autobahn near Irschenberg, today A8 Highway, published in *Die Strasse*, 1936.

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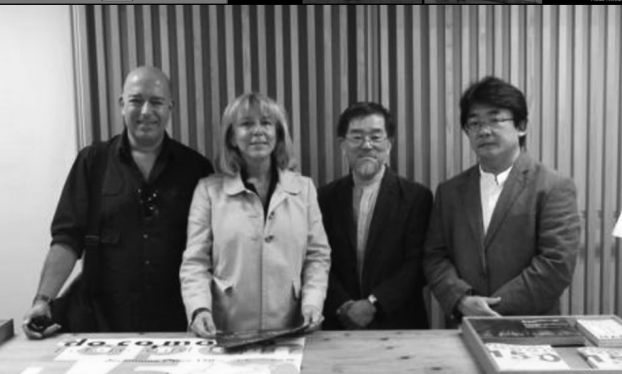
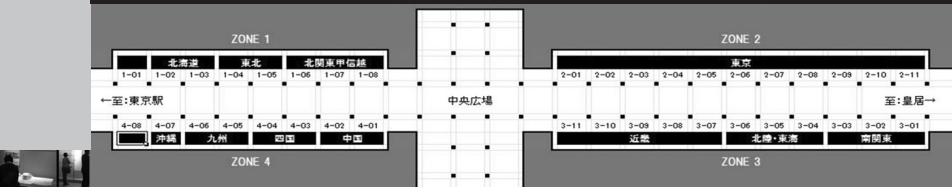
Mari Hvattum

Architect from the Norwegian University of Science and Technology in Trondheim (1993), with studies in philosophy and aesthetics at the University of Bergen and a PhD from the University of Cambridge, U.K (1999). Professor of architectural history and theory, teaching Modern architectural history and theory on all levels in the school, she has also taught at The Architectural Association, London, Mackintosh School of Architecture, Glasgow, University of Edinburgh, University of Strathclyde, and Central European University, Prague. She publishes internationally on 19th and 20th architectural discourse and practice, and is vice president of the European Architectural History Network EAHN.

The **docomomo** Japan 150 Selections —Future and Legacy—

By Koichiro Kanematsu.

docomomo Japan, Director. Exhibition Curator



Ana Tostões, Chair **docomomo** International

João Belo Rodeia, Chair **docomomo** Iberia

Koichiro Kanematsu, Director **docomomo** Japan, Exhibition Curator

Yoshiyuki Yamana, **docomomo** Japan

DOCOMOMO Japan 150

Future and Legacy
未来への遺産展



2011年9月23日-10月3日
行幸地下ギャラリー

docomomo Japan became an official national chapter of **docomomo** International in 2000. In keeping with the other principal international chapter members, **docomomo** Japan registered the first list of 20 significant buildings and sites in Japan. Then, in 2003, the list expanded to 100, and subsequently in 2011, the list increased further to present the **docomomo** Japan 150 Selections.

This year our prevalent routine life was disrupted as we all were devastated in Japan by the massive M9.0 class 3.11 Northeastern Japan Great Earthquake and Tsunami as well as being faced with a chain of serious threats caused by the damages at the Fukushima Dai-ichi Nuclear Power Plant. Yet it also happened to be the year the UIA session of the World Congress of Architecture, scheduled to be held in Tokyo at the Tokyo International Forum from September 25 to October 1. Thus despite and/or because of the disaster, we, **docomomo** Japan, considered it also provided a seemingly opportunity to reconfirm our *kizuna* or solidarity, therefore, we had decided to take the occasion to present concurrently with the UIA session an exhibition of the **docomomo** Japan 150 Selections.

The exhibits were comprised of photographs, drawings, sketches, models and associated furniture. The exhibition was shown from September 23 through October 3 at the Gyoko Basement Gallery, in the form of exhibits in double rows of very long continual showcase windows that were opened to public in the underground passageway between the Tokyo Station and the Imperial Palace, located within a short walking distance from the Tokyo International Forum, the venue of the UIA session. It was prepared as an associated event to the UIA session by the working group set up within the **docomomo** Japan and volunteer students and supporters. The executive committee for the exhibition was chaired by the president of **docomomo** Japan Hiroyuki Suzuki and its members included such illustrious Japanese architects as Shoji Hayashi (unfortunately died on November 30, 2011), Seizo Sakata, Fumihiko Maki, Arata Isozaki, Tadao Ando and Taro Ashihara.

In conjunction with the exhibition, we hosted a thematic symposium titled *The Fudo (Regional Contexts) and the Modern Movement: the agenda for maintenance and preservation* at the Astudio Hall of Aoyama Gakuin University on September 25 with Professor Kazi Khalid Ashraf of the University of Hawaii and Ana Tostões, **docomomo** International Chair, as visiting participants. The symposium generated lively discussions.

In citing candidates for significant architecture compellingly representative of the Modern Movement in Japan, it became prerequisite to define

the issue of what would constitute the notion of Modernism or Modern Movement in Japan. In addition to the framework of the **docomomo** International charter, to what extent if any, Japan, as a nation belonging geo-culturally to a non-Western sphere, should reflect on this subject.

The 150 Selections of buildings and sites are exhibited with the subtitle *'Future and Legacy'* in 11 regional groups according to geographic locations. Consequently interesting relationships between the specific regional context of each site and the architectural ideas based on the notions of the Modern Movement began to emerge. **docomomo Japan 150 Selections**, is directed toward not only Japanese audience but also architects visiting from abroad. The display has thus adopted a regional exhibit style to assist the viewer's appreciation of added contextual background to comprehend the various ideas of architecture based on the premises of the Modern Movement in Japan.

Exhibition statement that relates closely to some of the underlying activities of **docomomo** Japan

Retrospective Presentations of Architecture of the Modern Movement

In the two previous exhibitions, the sequential style reflected the relation of architecture in a chronological flow of time. In the exhibit of the *20 Selections*, we began the listing of works with architecture focused toward a new era that maintained vestiges of stylistic architecture such as the Sumitomo Building (1926). The selection of characteristic wooden structures of the Modern Movement distinctive to Japan such as the Hizuchi Elementary School (1958) in Ehime Prefecture and the Miyukino-ma at Hassho-kan (1950) in Nagoya expressed our desire to convey the receptivity of Japanese architecture of the Modern Movement to the rest of the world.

Regional Presentations of Architecture of the Modern Movement

When the Japanese archipelago is considered in the context of time, age and region, from the northern region of Hokkaido to the southern region of Okinawa, the word *'fudo'* or regional contexts and local culture, emerges within the elements of the lives of its inhabitants and the diverse natural and man-made environment.

There may be those who sense a lack of correspondence between the architectural works of

Modern Movement and their respective regional contexts. It may be that the image of the surge of architecture created upon the waves of post-war economic high-growth after the 1950s is stubbornly ingrained in our subconscious collective memory. There may also be those who feel that historical distinction and specificity of place are ignored in those works. Could this be so? Careful examination of each work reveals that the creation of architecture is a connection and bond among people, and that it is the flow of the age and soil that would ultimately receive architect and building.

Through the passage of time, these works of architecture create primordial scenery in people's minds; and that scenery is in agreement with the regional context.

Legacies for the Future

In consideration of the circumstances of each **docomomo** chapter, the fundamental guideline used as an indicator for selecting works as stipulated by **docomomo** International is that the architecture is seen as innovative from a technical, social and aesthetic point of view. In response to that guideline, the range of registering architectural works in Japan was established within the time frame of the 1920s up till 1970; in 2006, that was extended to include the decade of the '70s as well. Around 1960, events such as the collapse of CIAM (*Congrès International d'Architecture Moderne*) prompted a reexamination of the Modern Movement.

As the selected works face the threat of demolition due to the extreme ubiquity of Modern Movement architecture, rendering them to appear as ordinary structures, we titled the first two exhibits 'Modernism Architecture as Cultural Heritage,' in order to convey the various appearances and value of those works. On the occasion of the **docomomo Japan 20 Selections** exhibition, President of **docomomo** Japan and architectural historian Hiroyuki Suzuki, who also serves as chair of the executive committee for this exhibition, stated: "please keep in mind that this exhibit is not a compilation that shows the result of historical investigation, but is a starting point connecting history and the future."

For this exhibit, I transpose his words to say "it is a starting point connecting history and the future to consider the regional context (i.e., *'fudo'*) and architecture of the Modern Movement," and ask you to view these works of architecture as part and parcel of their respective localities. I also hope that these works will encourage the response that their maintenance, preservation and utilization as 'Legacies for the Future' is a matter of significant importance.

English Translation & Editing by Shin Ichiro OHNISHI

Архитектура авангарда Москвы 1920–1930-х.

Справочник–путеводитель.

КРАСНАЯ КНИГА. Moscow avant-garde architecture 1920–1930 guide-book. RED BOOK.

By Nikolay Vassilev, Marian Estratova, Elena Ovsyannikov and Oleg Panin

Publisher: С. Э. Гордеев

(S. E. Gordeev)

ISBN: 978-5-91566-021-6

Language: Russian

Year: 2011



This reference guide includes around 500 architecture works. The materials collected in it show Moscow as a dynamic city, a huge construction site at the end of the 20s both in the centre and in the outskirts of the city. Impressive mass residential areas located outside the Garden Ring, with very interesting layouts and well-preserved buildings which in some cases are mentioned for the first time. In addition to the general information, the book includes a schematic map showing their location in the city.

As the authors say, the Moscow mass building legacy of the 1920s-early 30s has not been very much studied and has not been included in guidebooks, although they have formed an important urban environment which is still preserved in the city. The authors have set the task to avoid sampling the story of the masterpieces of avant-garde and instead to show the typical architectural forms throughout Europe which are also common in Moscow.

The book will be useful not only for specialists and local historians but also for the general public interested in preserving the historic appearance of Moscow.

Ivan Blasi

Secretary General docomomo International

Berthold Lubetkin: Architecture and the Tradition of Progress

By John Allan

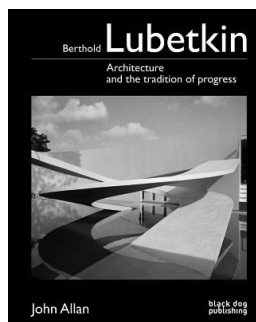
Publisher: Black Dog Publishing

Limited London

ISBN: 978-1-9073-1714-9

Language: English

Year: 2012



This updated and comprehensive study is an essential book which was originally published in 1992 by RIBA Publications. Following a 20-year friendship, author and architect John Allan documents unpublished drawings, photographs, and extracts of writing in this richly illustrated study.

Allan sets Lubetkin's work in the wider historical, social and political environment of the time.

From his early work, in Paris in the 1920s, when he was acquainted with renowned architects such as August Perret and Le Corbusier through to the work of his practice Tecton, the book provides a comprehensive account of his landmark buildings.

His post-war work, including the troubled project to build Peterlee New Town, is also fully covered. In addition to his outstanding architectural achievement, Lubetkin's life provides much speculation. This book reveals the man behind the architecture: a survivor of the Russian Revolution, European traveler, social commentator and intellectual in Europe during the 1920s associating with leading figures of the avant-garde and a committed social activist in Britain throughout the 20th century.

From the Publisher

El Patrimonio del Movimiento Moderno: Experiencias, Presente, Desafíos

By Stella Maris Casal et al.

Publisher: Ediciones FADU

ISBN 978-9-5029-1307-0 (online)

ISBN 978-9-5029-1306-3 (DVD)

Language: Spanish

Year: 2011



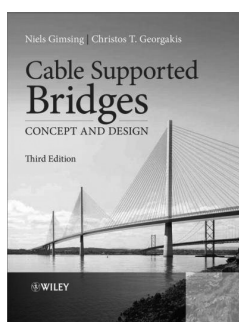
This publication can be downloaded for free as a pdf file from the web site of the School of Architecture at the University of Buenos Aires at www.fadu.uba.ar/publicaciones/lib.html.

As the first volume published in 2008, *El Patrimonio del Movimiento Moderno: Pensamientos, Reflexiones, Aprendizajes*, it compiles a series of essays, part of which are edited transcriptions from meetings with outstanding practitioners and scholars who kindly shared their knowledge and experiences on the theme with the young team of researchers coordinated by Stella Maris Casal. The publication does not pretend to have any strict editorial line and is composed by a general introduction and two chapters. In the first, the guest authors were invited to "talk about what they knew and what they liked" concerning their approach to Modern Movement in architecture. Thus, all the texts are first hand ideas, visions, reviews, memories of people for whom the modern ideas and practices are worth enhancing. Allen Cunningham and Jorge O. Gazaneo are well known referents for our docomomo community, and their contributions enlighten two edges of the same issue: the first approach to Modernity and its challenge facing the future. Raúl Rivarola is an outstanding practitioner whose work is included in the international register; his contribution allows us to understand how Modern Movement ideas were successfully applied and adapted to the local context. Max Page and Lucas van Zuijlen introduce the critical approach to the international experience which makes it possible to compare and establish links with the Argentine experience. In the second part, a selection of contributions produced by the work-

ing team, based on their personal lines of research, aims at making their effort known. The decision to have this first online edition was easy: no funds but much enthusiasm and the will that those valuable testimonies were available for anyone interested in the theme, and particularly for students.

Cable Supported Bridges: Concept and Design

By Niels J. Gimsing and Christos T. Georgakis
 Publisher: Wiley (3rd edition)
 ISBN: 978-0-4706-6628-9
 Language: English
 Year: 2012



Fourteen years on from its last edition, Cable Supported Bridges: Concept and Design, third Edition, has been significantly updated with new material and brand new imagery throughout. Since the appearance of the second edition, the focus on the dynamic response of cable supported bridges has increased, and this development is recognized with two new chapters, covering bridge aerodynamics and other dynamic topics such as pedestrian-induced vibrations and bridge monitoring.

This book concentrates on the synthesis of cable supported bridges, suspension as well as cable stayed, covering both design and construction aspects. The emphasis is on the conceptual design phase where the main features of the bridge will be determined. Based on comparative analyses with relatively simple mathematical expressions, the different structural forms are quantified and preliminary optimization demonstrated.

This provides a first estimate on dimensions of the main load carrying elements to give an initial input for mathematical computer models used in the detailed design phase.

From the Publisher

Le Corbusier. Le Cabanon

(*Le Cabanon par Le Corbusier*)

By Rax Rinnekangas

Text by Fernando Marzá

Architectural advisor: Juhani Pallasmaa

DVD production company: Bad Taste Ltd Finland

Publisher of book: Arquia documental22

Code: 8437009411223

Language: Finish.

Subtitles in English / Spanish

Year: 2010 / 2011



The series of five independent documentary films (ca. 60 minutes) about outstanding private houses on different continents designed by the world's leading architects in the 20th century, appeared between 2007 and 2010 in DVD format produced by Bad Taste Ltd. The five films explained the Melnikov House by Konstantin Melnikov in Moscow built between 1927 and 1929; Villa Mairea by Alvar Aalto in Noormarkku in 1938; the Casa Estudio of Luis Barragán in Mexico City built in 1948; Le Cabanon par Le Corbusier in Roquebrune Cap Martin in 1952 and the Koshino House by Tadao Ando in Ashiya, Hyogo, built between 1979 and 1984. The recently published book written by Fernando Marzá which includes the film by Rax Rinnekangas is the last missing documentary of this series of the Arquia collection. The collection includes fantastic texts by different authors and reproduces original images and drawings with a very high quality. Le Corbusier (1887-1965) sketched Le Cabanon in 45 minutes as a birthday present for his wife Yvonne Gallis in December 1951. The wooden cabin of 16 m²-situated in the hillside of Roquebrune, Cap Martin-was to serve as a model for minimal living. The film tells the amazing story of Le Cabanon-from the architect's first arriving at Côte d'Azur via Eileen Gray's E-1027-house to the final building connected with the *Étoile de Mer* restaurant-and the fate of the architect in his paradise home.

Ivan Blasi

Secretary General docomomo International

Landscape and Structures: A Personal Inventory of Jürg Conzett

By Jürg Conzett and Martin Linsi

Publisher: Scheidegger and Spiess

ISBN: 978-3-8588-1321-3

Language: German and English

Year: 2011



A magnificent compilation of civil engineering structures throughout Switzerland made by Jürg Conzett and the photographer Martin Linsi, divided geographically and chronologically, exemplifying successful aesthetic structures. Conzett represented Switzerland at the 12th International Architecture Exhibition at the Venice Biennale with the exhibition Under the title "Landscape and Civil Engineering".

Routes, Roads and Landscapes

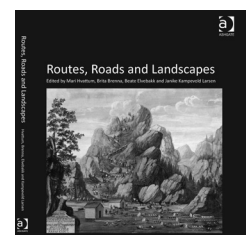
By Mari Hvattum, Brita Brenna, Beate Elvebakk and Janike Kampeveld Larsen

Publisher: Ashgate

ISBN: 978-1-4094-0820-8

Language: English

Year: 2011



Bringing together outstanding scholars from cultural history, geography, philosophy, and a host of other disciplines, this collection examines the complex entanglement between routes and landscapes. A particular focus is on the Modern transportation landscape as it came into being with the canal, the railway, and the automobile. These modes of transport have had a profound impact on the perception and conceptualization of the Modern landscape.