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Footbridges

Structure Design History

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Construction Design History

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With photographs by Wilfried Dechau

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About this Book

In his introduction to the 1984 reprint of Georg Mehrtens' classic, *Der Deutsche Brückenbau im XIX. Jahrhundert*, which was first published in 1900, Ernst Werner commented succinctly: "It is the fate of bridges that serve only the pedestrian simply to be overlooked in the chronology of bridgebuilding." It was not until the new millennium that this began to change somewhat – not least because a remarkably large number of cities saw the beginning of a new era as an occasion to polish up their image with a "millennium bridge". A bibliographic search on the subject of bridges carried out in the German National Library at the beginning of 2007 returned a total of around 2,500 publications. When the search term was restricted to footbridges, the catalogue produced 31 titles, of which a considerable number were bibliographic lists of essays and articles. The huge discrepancy in the results is partly explained by the fact that bridges have a great metaphorical and symbolic value, and thus appear in countless titles relating to politics and society. The literature on footbridges is sparse at an international level too. Apart from the published proceedings of two conferences and the *fib guidelines* of 2005, no attempt has yet been made to focus exclusively on this small and impressively varied type of structure. With this book, we hope to have made a modest start.

The idea of writing a book about bridges that are for the sole use of people on foot – or at most on bicycles – excited us greatly. We hope that engineers, architects, landscape architects and town planners will find it stimulating, and that the lay reader will find it just as appealing.

We wanted to give as broad a view as possible of footbridge construction in Europe without being tied to any current ideology or doctrine. Bridges that strive for perfection as structures alone have as much of a place in our selection as those designed to delight the eye with ornament. But more about this later.

Approach

This book presents around 90 footbridges in a latent chronology. By "latent", we mean that we have not blindly followed their exact dates, preferring to explain their variety in terms of more complex relationships that can best be grasped thematically. After all, some types of structure are the result of technological or scientific developments linked to particular periods, while other approaches to design belong to ages with a particular way of expressing form. At one time the engineers are spurred on to achieve ever lighter structures; at another the architects realise the bridge's effectiveness as a quasi-homoeopathic means of repairing the damaged townscape, and at yet another the bridge as a technical artefact is sublimated to the aesthetic of an Arcadian landscape. The history of footbridge construction is therefore a prime example of how the histories of technology, art and the world in general overlap, and we wanted to take into account the complex interplay between them.

The specialist knowledge of the structural engineer comes to the fore in essays that explain the technical aspects in straightforward and understandable language, so that anybody can understand the aesthetic potential that is inherent in a particular structural design. Finally there is a compendium, listed by location, of a further 120 footbridges that we had no space to discuss in detail. We hope it will provide a starting point for readers who want to discover more for themselves after this first glimpse of a fascinating area of bridgebuilding.

Selection

Which bridges should we discuss in greater detail – and for what reasons? One thorny question followed another. We had no intention of hiding the fact that one of this book's authors works for Schlaich Bergermann and Partners, a practice which to date has built more than 50 footbridges, but as a quick glance at the book will confirm, there was no question of using it as a showcase for their work. So it was back to the difficult decisions. We selected bridges of relevance to one or another aspect of the relatively short history of the footbridge; bridges that appealed to us both (or to one of us, at least); bridges that are unequalled in some way; bridges that could certainly be improved; bridges that demonstrate courage in construction, astuteness in design, or an infallible sense of form. We made a point of seeing all of the bridges ourselves (with a few exceptions), as did our photographer, who enjoyed our complete confidence.

Our selection is necessarily incomplete, subjective and open to argument – completeness was never our aim. We admit that our view, naturally, is one from the German-speaking countries. We were kept busy enough just by having to work together as an engineer and an architectural critic: a rare combination, in which agreement is certainly not reached without argument first, but ultimately we succeeded because we both had the will to make it work.

Acknowledgements

To venture upon the first ever study, however limited, of the construction, design and history of any type of structure is a daring, not to say crazy, undertaking, and we would never have begun it if we had not been able to count on assistance from many quarters. For their advice and information we would like to thank Jan Biliszczuk, Berthold Burkhardt, Keith Brownlie, Dirk Bühler, Jürg Conzett, Cornel Doswald, Sergej Fedorov, Andreas Kahlow, Andreas Keil, Martin Knight, Jörg Reymendt, Jörg Schlaich, Klaus Stiglat, René Walther and Wilhelm Zellner. Without the energetic and support and encouragement of Auyon Roy, Simone Hübener and Andrea Wiegelmann, this book would never have appeared in 2007 – and might not even have made it in 2008. We would also like to thank our knowledgeable translators, Chris Rieser and Richard Toovey.

In addition, our special thanks go to Wilfried Dechau, who discovered many bridges, especially older ones, during his constant travels as our photographer; he would set off on account of one bridge and come back with seven. During the last few years he has taken new photographs of almost all of the bridges in this book – a labour whose documentary value to the study of the history of footbridges cannot be overestimated.

Ursula Baus, Mike Schlaich, July 2007

Kronsforde, bridge over the Elbe-Trave Canal, 1959

Bridges and Pictures

At the age of 15, with the first single-lens reflex camera of my very own, I naturally took shots of the area around my parent's house. That included the bridge across the Elbe-Trave Canal. I crossed this bridge every day on the way to school and I could see it from my room. Of course, it would be going too far to say that this was the origin of my affinity for bridges. My enthusiasm for looking at bridges through the medium of photography was (re-)awakened 30 years later on, when I photographed the Max Eyth Lake footbridge by Jörg Schlaich. In 1989, this was a welcome and relaxing diversion for me from the routine of conventional architecture photography. I recently revisited the bridge to photograph it again for this book (see p. 92).

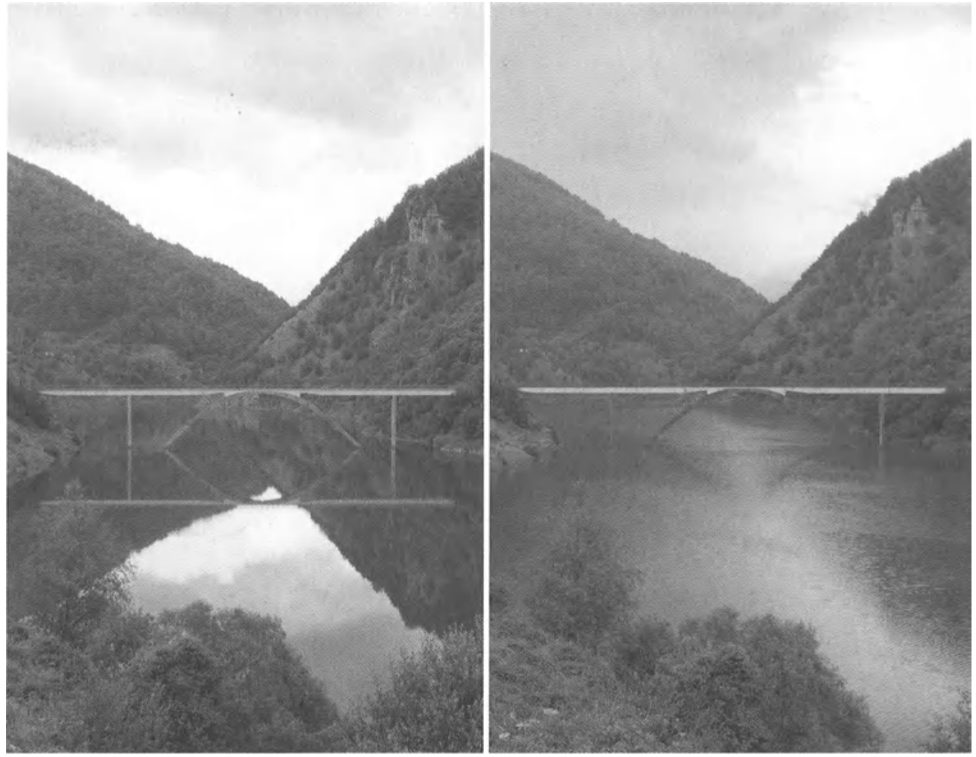
In spite of that refreshing intermezzo, bridges remained an exception in my work. This changed with the building of the Storebaelt (Great Belt) bridge in Denmark: I visited the site many times between 1996 and 1998 to record the exciting process of building what was, for a brief period, the suspension bridge with the longest free span in the world. I managed to get a lot of interesting shots, some of which were shown in the *brückenschlag* exhibition in 2000, and in a photo calendar. They were followed, in 2004, by a project on the Traversiner footbridge. This gave me a unique opportunity to photograph work on site in the Grisons Alps every day for a period of several months. Its immediate results were a book and exhibition about the Traversiner footbridge. At the same time, plans for this book by its two authors were gaining substance, and I gradually came to the decision that my camera and I should take an active part here too. This meant taking up-to-date photographs of as many of the bridges featured in it as possible. The illustrations that the authors had managed to collect up to that point were very disparate, so it was going to be difficult to produce a book that would be pleasant to look at. The idea of starting again from scratch and giving the book a consistent photographic identity therefore eliminated a lot of problems at one stroke.

It was clear that this could only be done to a certain degree. Trips to Coimbra and London, for example, turned out to be unnecessary, since outstanding photos of these bridges had already been taken by Christian Richters, Nick Wood and James Morris. It also seemed out of proportion to make a long trip through Norway for a few bridges far apart, when plenty of photos of them already existed. Not to mention the problem of time travel: some bridges no longer existed, because they had been built for special events, and in these cases we were fortunate in being able to use photos taken previously by Leo van der Kleij and Florian Holzherr. That still left plenty to do, however. All the same, we were not really aware that we had let ourselves in for an almost endless task. I came back from every journey with at least twice as many bridges as I had been expecting to find on the basis of the source material. On my travels, almost everyone I talked to about the objects of my interest had a suggestion to make. And so the itinerary became ever longer and, at the same time, more fruitful. My thanks are due above all to Martin Knight and Cornel Doswald, from whose expertise I benefited in England and Switzerland. The most adventurous discovery for me personally was, by the way, thanks to Bill and Alison Landale, my bed-and-breakfast hosts in Ellemford, Berwickshire, without whom I would never, ever, have found the uncommonly delicate and apparently fragile – yet astonishingly practical – suspension bridges across the River Esk (see p. 198).

It can, on the other hand, be quite frustrating to have to ask for information in order to find a certain bridge. It then becomes clear how much people's perceptions of one and the same bridge can differ. In Maidstone, for example, neither the name "Millennium Bridge", nor words like "suspension cable", "concrete" or "new" were of much help in finding out which way to go. Not to mention the name of the bridge's engineer, Jiri Strasky. Everyone who we asked directed us to a cable-stayed bridge, which, although it was also called the Millennium Bridge, had nothing in common with the one that I was looking for, except that it, too, crossed the River Medway – at the other end of the town.

Internet route planners are also of limited use, since their purpose is to give directions to drivers – who have, of course, no need of footbridges. The most reliable sources of information are topographic maps, but they are not always to hand – or, at least, not all of those that are

Vagli di Sotto, bridge by Riccardo Morandi. 5 June 2007, 12.20 and 13.27



needed. And even then, they are only of use if they are up-to-date. One example of this was the footbridge over the Bregenzer Ach river near Langen and Buch. These two villages lie five kilometres apart, as the crow flies. The footpath winds along the valley for stretches, petering out in meadows among herds of cows. The older people in the village still remember a bridge that was there when they were children. A spring flood washed it away one night. But a little bit further upstream, they tell me, there is another one like it, near Fischbach and Doren – and that one is still standing. Off I go again. My navigation system knows many Fischbachs, but none of them near Bregenz. The faint hope that I might find signposts to this, the only bridge in the vicinity, proves, as it so often has, to be naive. Signposts tell you about places to get to, not ways of getting there. In other words: the next village, and not a bridge on one of the ways to it. The exception does prove the rule, of course, and once, looking for a suspension bridge across the Subersach near Egg, I did find a signpost that said *Wire bridge – Lingenau*.

This at least confirmed that the bridge still existed and was passable, so the walk there carrying a heavy camera was not going to be completely in vain – although you never know whether it is going to be worth the effort until you actually get to the bridge. Only then do you see, if it is an old bridge, how much of it has survived and in what condition – and how much it still has in common with the original design. Warning signs advising pedestrians to cross one at a time can be an indication that the bridge is in its original state, but this is not necessarily so. All that is certain, in that case, is that it has not been spoiled by insensitive reinforcement or renovation. The Kettensteg in Nuremberg, for example, may appear to hang from its chains, but it is now supported in a different way. The faint-of-heart would nevertheless be well advised not to tread heavily when they cross this particular bridge. That could set it swaying and oscillating badly – not dangerously so any more, but not every stomach can cope with it. After a taking a first look around, I check out the bridge. Go on it; look down. Walk across. Get down off it at the other side, if possible. See what is supporting it and how – then where and how the loads are distributed and ultimately transferred to the abutments. First I look, then I take the photos. The weather and the light are important factors, without a doubt. Only once, in Maidstone, did I have to stifle the pangs of conscience and settle for photographs taken in bad weather. There was no sign of an improvement and I had a plane to catch at Heathrow airport. Even in rain, the bridge itself makes a good impression, as can be seen on page 76.

Whatever one photographs, it can only be "shown in the best light" if the weather cooperates. This is clear to see in two exposures, taken only one hour apart, of Riccardo Morandi's bridge in Vagli di Sotto, which is set exquisitely in the landscape. The first, which I took shortly before a storm, shows shimmering green water that is as smooth as a mirror, whereas in the second, taken as it began, the surface has become matte, criss-crossed by fine ripples.

One of the last journeys that I made for this book took me to Bilbao in June 2007. Upon entering my hotel room, I hardly believe my eyes. Above the bed hung a drawing of an old, asymmetrical footbridge: one that I had never seen before, although I had travelled to over 200 bridges in the previous three years. Did it perhaps cross the Nervión river? In Bilbao? When? Where? I could see, as it were, the writing on the wall: obviously, even if several photographers were to spend a further three years on this quest, they would still encounter unknown structures. The next surprise came hard on its heels, when I tracked down the place in Bilbao where, according to the hotel staff, the bridge had once stood. What I found was an arched concrete bridge (which up to then had been completely unknown to us) that connected to two different levels on the higher bank of the river in an exceptionally clever way (see p. 55). Of course, we had met a bridge of this type before: it seems likely that the Bilbao bridge was known to Marc Mimram, to whom we owe the Pont de Solferino in Paris.

Wilfried Dechau, 2007

Você quis saltar? Did you want to jump? *Pascal Mercier, Night Train to Lisbon*

Looking at the history of bridgebuilding as part of architectural history, we see that today's comparatively distinct and unquestioned differentiation between footbridges and other types of bridge came about slowly at first, and by no means constantly. The history of footbridges is linked to that of bridgebuilding in general – sometimes more so, sometimes less – and this is one of the aspects that make it so interesting to study the footbridge on its own, as a type of bridge in its own right. In order to define the characteristics of the footbridge, which of course has a longer history than the road bridge, we need to look at when its typology began to differ from that of large-scale bridges. This occurred towards the end of the 18th century, when Enlightenment thought, science, early industrialization and the increasing importance of the economy stimulated rapid technological and social change, together with a growth in mobility and traffic. In the 19th century, advances in transport technology began to exert a fundamental influence on bridgebuilding, with ever-higher standards required for road and rail. These new, high-performance modes of transport made fresh demands on bridge construction, in response to which a specially qualified expert in bridgebuilding appeared on the scene – the structural engineer – whose profession quickly acquired a coherent profile.

Footbridges were only indirectly affected by these technological changes and from this point onwards their development took a course of its own. After all, trains today may reach speeds of 400 km/h or more and the volume of road traffic may require six, eight, or even ten lanes (with all of the consequences that this involves for large-scale bridge construction), but a human being, whether standing, walking or jumping, remains a constant factor in the equation. To this extent, the interplay of technical progress, imagination and functional variety in the case of footbridges is open to other influences, which bring forth an inexhaustible variety of distinctive designs. It is a brief that again and again allows more to be done than providing a mere footbridge – the degree to which credit for this is due to architects, or structural engineers, or both, becomes clear only upon examination of individual cases.

What happens on a footbridge, anyway? Not feeling firm ground underfoot usually indicates a precarious situation. At the same time, a swaying surface, or a narrow pathway, can also produce a shiver of excitement when we have to let ourselves in for more or less perceptible oscillations, or glimpses into a yawning abyss. Bridgebuilders have to live with the awkward fact that people react to oscillations and heights in very different ways: some may become dizzy with euphoria, while others may find their knees turning to jelly.

Footbridges are generally built to satisfy a tendency to laziness, a love of convenience, or a joy in contemplation; whether they cross rivers, streets or valleys, their main purpose is still to shorten the route from one place to another. Only in very rare cases is it the thrill of danger, or the temptation to be free of the ground, that motivates people to build them.

Tarr Steps, Exmoor, earlier than 1000 BC

Making these shortcuts not only safe enough even for sleepwalkers, but also pleasant to walk across, is an important part of the brief when designing a footbridge. Of course, the basic principle applies: a bridge should be structurally sound, easy to maintain and cheap. All the same, a lot more can be achieved by paying attention to criteria such as an appropriate route, attractive views, a comfortable environment and a memorable appearance. A footbridge's balustrades, parapets, hand rails, surfacing, niches and balconies should take into account that people will not only walk across it, but would also like to stop for a moment, lean against it, rest on it, sit down and look around, or just be alone -- and that whatever they do, they will touch it. Thus, a footbridge does not remain just a bridge, but matures into a jogging track, a boulevard, a promenade, a place for a rendezvous and, finally, a landmark. Last but not least, lighting design has a prominent part to play, as pedestrians experience nighttime illumination in a completely different way from a car driver concentrating on the road. With such a variety of tasks, standard solutions seldom prove satisfactory. The basic types of structure as such are in no way adequate to meet all of the different requirements. In order to achieve a design that is more than just the shortest way of connecting two points, it is best to vary them, combine them and develop them experimentally. This naturally stimulates the design ambitions of the structural engineer, but the architect and the landscape designer also feel called upon to take over engineering's choicest task. In matters relating to atmosphere, significant forms and the sensory effects of material properties, most structural engineers find themselves out of their depth, inasmuch as they have received far too little exposure to design-related topics of this sort during their studies. Merely calling upon the repeatedly quoted Vitruvian terms utilitas, firmitas and venustas is not of the slightest help in enriching the world of contemporary building. Anyone who seriously demands that a structure be useful and stable and beautiful makes themselves as laughable as a politician who, quoting Goethe, says that Man is noble, helpful and good. Even when they do not appear banal, Vitruvius' terms no longer have a definite substance to offer. The architects' situation mirrors that of the engineers: they are given a basic understanding of structural theory as students, but rarely develop it into an ability to design structures. Of all things, then, it is the modest footbridge, a class of structure comparable in status to the semi-detached house, which on account of its complex characteristics puts the much-vaunted cooperation between architects and engineers to the test. One of the professions is defending a source of income; the other is hungry for new ones.

For us (an architecture critic and a structural engineer) the most important thing is the result; we examine each case to see where credit is due and we can recommend, both from our own experience and in general, aiming for amity and lively debate. The fact that the footbridge, such an unpretentious structure, is still capable of experimental and imaginative development, in spite of all of the standards and regulations, makes up much of its charm. This applies throughout Europe, where a jungle of rules and red tape makes building a complicated and expensive business.

A simple suspension bridge (c. 1890) near Ardez in Switzerland. It can be crossed by only one person at a time.

Parameters and Structural Design

Users experience footbridges much more directly than road or railway bridges. As we cross a footbridge, we can touch the structure and study the details, thereby allowing us to grasp the structure fully in every sense of the word. These are bridges to be touched. The design freedom for the structural engineer is much more pronounced than for road or rail bridges in spite of some parameters particular to footbridge structures. This design freedom is a welcome and exhilarating challenge. In this section, the issues unique to footbridge design will be summarized briefly. Additional information can be found in the *technical overviews* and the references, which provide an introduction to the technical literature.

The Third Dimension

Pedestrian bridges allow the design to break free of the linearity of high-speed traffic, whose bridge decks generally attempt to join two points separated by an obstacle as directly as possible. The geometry of the bridge deck in the horizontal plane can be chosen freely and may be quite curved. A spatial experience may be achieved by the suspension of the bridge deck, by a moveable bridge, or by the intersection of multiple pathways.

The geometry of the gradient of the bridge deck may also be relatively freely chosen, which also opens up new possibilities for emphasizing the spatial geometry of the structure. Walkable arches and stress ribbon bridges are therefore possible design alternatives for footbridges, although it should be noted that deck gradients greater than 6 percent present problems for wheelchair users. It is not simply the maximum slope that presents a problem, but the potential energy required to overcome the slope. This may be expressed as the inverse of the product of the length and slope. Alternative pathways must be offered for wheelchair users where there are steep deck gradients or stairways.

Dimensions

Most pedestrian bridges are narrow, with decks between of 3 and 4 m. As a rule of thumb, 30 pedestrians per minute for every metre of deck width can cross the bridge without impeding one another. Even with the largest crowds, this figure rarely reaches 100 pedestrians per minute. Most European codes call for a minimum deck width of 2 m for bridges open to pedestrian and cycle traffic.

Given these pedestrian densities, it is surprising that the pedestrian live load of 5 kN/m^2 called for in most European codes is roughly equal to the loading of the main lane of a roadway bridge. In many countries, this load may be reduced for longer bridges. Statistics show that such crowding (5 kN/m^2 is equivalent to 6 people per square metre) is very improbable on a long bridge deck. As pedestrians are much less sensitive to deflections than road or railway traffic, footbridges may be much more slender and lightweight than road or railway bridges. Because of this, footbridges are often lively, and dynamic analysis of the structure should be carried out in the early phases of the design.

Load testing – where numerical calculations cannot replace the intuition and experience of the engineer, here on site for the construction of the footbridge in Sassnitz

Materials and structure

In addition to asphalt and concrete, many other materials can be used as deck surfacing. For timber surfacing, the danger of slipping should be considered, especially if the wood planks follow the longitudinal direction of the structure. The moisture expansion of the wood must also be taken into account. Grating surfaces are cheap, allow light to pass through the deck and do not require drainage. They are, however, difficult surfaces to cross for pedestrians who are barefoot or wearing high heels. Laminated glass surfaces must have a high level of opacity to prevent people below from viewing through the deck. Glass surfacing is primarily found in interior spaces or for covered footbridges.

Railings require particular attention and must be at least 1.2 m for bridges open to cyclists. The railing should be designed to withstand a transverse load of 1 kN/m applied at the height of the handrail. Because of the height of the guard-rails, they are often incorporated into the global structural system of the bridge. The design of the handrail has an important impact on the visual impression of the bridge. The railing may appear either opaque or transparent from afar and must give the user a sense of safety. It often seems appropriate to integrate the lighting system into the handrails or railing posts, just as the shadows cast from the railing effect the visual impression of the deck during the day. New materials and innovative structural systems are often more readily approved by the owners and local administrations than large bridges where the total risk and costs are much higher.

Freedom of design

Bridge design has long been regarded as the most rigorous in the challenging field of civil engineering. With the smaller scale of footbridges, bridge designers can finally let their hair down and truly indulge their creative side. Self-critical engineers often seek advice from architects, industrial designers, and landscape architects for design issues such as the integration of the structure into the surrounding environment, the light, colour, and feel of the structure. In cases where the engineers and architects in the design have a good history of cooperation between one another, the traditional roles of architect and engineer become blurred to the benefit of the overall project.

It is often said of large bridges that "a bridge

St Gallen-Haggen, Bridge over the Sitter, Rudolf Dick, 1937[1]

is no destination". This is however not at all true for the design of footbridges. The pedestrian should remember his or her experience crossing the structure as being particularly pleasant. The footbridge designs of the last few years have shown just how much is possible in bridge design. The increasingly large number of design competitions has shown how seriously the design of these structures is taken. The challenge of structural innovation, the audacity of competition, and the owner's desire to create a landmark structure often overshoot the goal. Bridges that are designed to impress often break with rational technical design tenets. We have to admit that these technically unreasonable structures may become quite impressive given the right lighting and spatial perspectives but must not be taken as design ideal.

The design team should not overlook the role of the structural system as a catalyst for the diversity of footbridge design. Moreover, the development of the appropriate structure, given the surrounding environment, functional requirements, or the additional requirements of the owner, must be seen as the central challenge of the project.

1 Dick, Rudolf, Von der Sitterbrücke Haggen-Stein bei St. Gallen, in: Schweizerische Bauzeitung, 118, 1941, pp 122-123

Truly, opposing what is customary is a thankless task. *Heinrich Heine*

Any general history of bridge construction inevitably begins with footbridges. The search for the origins of bridgebuilding has so far taken us back to early civilizations in China, Mesopotamia and South America. There is archaeological evidence of simple suspension bridges for those with a steady head for heights, small timber beam bridges and stone slab walkways for people and animals, like those at Tarr, Exmoor, or in Postbridge on Dartmoor, and Lavertezzo in Switzerland (see p. 20). It may well be that globally accessible Internet data banks, such as Structurae, Bridgemeister and Brückenweb, are creating a new basis for writing a more reliable history of early bridgebuilding. That is neither within the capacity of this book, nor is it our intention.

Our interest begins explicitly with the time in which traffic-related requirements resulted in quantum leaps in bridgebuilding and also in the birth of structural engineering as a definable profession -- one that has dominated the construction of footbridges, too, to this day. It soon becomes clear that the qualifications and professional ethos of the structural engineer were determined to a great degree by each new means of transport: first the railway train, with bridges and vast station sheds, then the car, with gigantic motorway bridges. Cost-effectiveness, too, played an increasingly important part, which limited the structural engineer's freedom to play with forms in order to achieve a particular, contemporary design. Looking back over the development of the footbridge in comparison, we see that the relationship between construction, material, form and cost-effectiveness allowed much greater room for manoeuvre. Because people experience the built environment much more slowly and with greater immediacy on foot than they do in cars or trains, this freedom was used, then as now, in a cultural, time-dependent sense: intuition and experience, experimentation and science; displays of magnificence; gracefulness and bareness these are the themes that, in retrospect, are of specific relevance to the history of footbridges. They do not replace each other in sequence, but rather add to a growing wealth of design and structural concepts, which the present age can draw upon and continue to work with.

The mediaeval stone bridge at Lavertezzo in the Verzasca valley, Switzerland

Bigger, faster, further – traffic, architect and engineer

Ever since traffic and its technical requirements began to drive innovation in large-scale bridge construction, the footbridge has developed along a recognizably separate path. The small-scale structure for human beings and animals gradually became something special. Building it remained nonetheless the responsibility of structural engineers. Their professional identity changed repeatedly from the mid-18th century onwards, as experience was arranged in a systematic framework, theoretical knowledge grew exponentially and economics put pressure on the construction industry. This becomes evident if we outline how things stood towards the end of the 18th century.

Economy in bridgebuilding

On 14 February 1747, Jean-Rodolphe Perronet was appointed head of the newly founded École Nationale des Ponts et Chaussées (National School of Bridges and Roads) in Paris. He was not merely an engineer, but also an extraordinarily talented organizer and an important contributor to an ambitiously planned compendium of knowledge: the encyclopaedia edited by d'Alembert und Diderot. Perronet took the art of building (which even now we keep wanting to see as an inviolate whole) and split it with an axe that has continued in use to this day: economics. Admittedly, he did so on orders from above: Jean-Baptiste Colbert, the finance minister of the Sun King, Louis XIV, had decided to wrest control of road, canal and bridgebuilding from the hands of the aristocracy, tradesmen's associations and religious orders. His aim was to make it better and, above all, efficient, as part of a policy of centralization under the absolute monarchy. Once again, politics was driving developments in the construction industry. The process had begun in 1716 with the establishment of an engineering corps, from which the École Nationale des Ponts et Chaussées was later created. Many parts of the country became more accessible: at the beginning of the 18th century, the stone bridges in France had numbered around 600, but by 1790, 400 more had been built, while the number of wooden bridges doubled during the same period.[1] The military had already started crucial initiatives to advance knowledge of roadbuilding and fortress construction in the 17th century; these resulted in the founding of a military engineering school in Mézières in 1736.[2] Colbert then drew a fateful conclusion: he postulated that economy is essential for an infrastructure to be built up efficiently – and Perronet, of all people, raised economy of material to the status of an aesthetic principle. Towards the end of his working life, he prided himself on having been the first to give works of art a form "qui tire de l'économie de matière un moyen de décoration".[3] The efficient use of material itself became an aesthetic criterion, the first step on a path that was to have immeasurable consequences for (engineering) bridge construction and later for architecture as a whole.

1 Barrey, Bernard: Les Ponts Modernes, 18e 19e siècles, Paris, 1990, p. 25f.; Grélon, Stück, 1994, p. 84
2 Kurrer, 2003, p. 39; Straub, 1992, p. 163f.
3 Picon, Antoine: Perronet, in: L'art de l'ingénieur, Paris 1997, p. 364; Marrey, 1990, pp. 39 and 60f.

Tarr Steps, Exmoor, 1000 BC

Clapper Bridge, Postbridge, Dartmoor

Thus the *Querelle des Anciens et des Modernes*, a peculiar disagreement over reverence for Antiquity and the modern spirit of innovation that had broken out in literary circles half a century earlier, was joined by another issue. No sooner had engineers liberated themselves from the dogma of classicism, than design became pervaded by the concept of economy. This did not change with the degradation of the ENPC to a practice-oriented school and the re-establishment of the École Polytechnique for more academic studies. On the contrary: the theoretical and practical branches of the new profession, the engineer, drifted ever further apart.[4]

Truth of Construction

Thriftiness was a concern not just of the French, but of the English too.[5] It is also worth remembering that a Jesuit significantly influenced the formation of opinion in the architectural debates that began in the mid-18th century. In 1753, Marc Antoine Laugier, who was living in Paris as court chaplain, published his *Essai sur l'architecture*, one of the most important texts on architectural theory of its time. In it, Laugier fulminates against pomp and display and, taking as an example a touchingly primitive hut consisting of four tree trunks, a pitched roof and a bit of wattle-and-daub, expounds on *truth of construction*. This marks the first appearance of a term that has remained hotly disputed in the assessment of architecture in general (and of bridges in particular) up to this day. There is, after all, no agreement about what a *true construction* might be and whether, if it were taken to mean something like a *right construction*, it would always also be *beautiful*.

The aesthetics of economy and the truth of construction were ultimately joined at around the same time by a further aspect, that of esteem for the functional. This was the work of an Italian Franciscan monk, Carlo Lodoli (1690-1761), who promoted the opinion that architecture (which when referred to then always included what we now think of separately as engineering construction) should be functional. In his writings, Lodoli relates function less to the arrangement of spaces than to the material display of purposes.[6] These topics belonging to architectural theory penetrated far into areas in which the image of the nascent structural engineering profession (in a narrow sense) was becoming more sharply focused: intuition and experience; science and economy.

It should not be forgotten that, for bridgebuilding especially, crucial impulses came from the military sphere. Matters relating in any way to visual appearance had no part to play there, functionality and efficiency being the sole criteria for a way of building that eventually developed a long and inventive tradition.[7]

4 Grélon, Stück, 1994, p. 17f.
5 ibid., p. 85
6 Laugier, Marc Antoine, Essai sur l'architecture, 1753/86; Memmo, Andrea (ed.); Andrea Lodoli
7 Schütte, Ulrich, Baumeister in Krieg und Frieden, Wolfenbüttel, 1984

Cambridge, reconstruction of the bridge of 1749

Old Walton Bridge, oil painting by Canaletto, 1754

Intuition and Experience

In England and, above all, France, the technical and scientific aspects of construction played an ever greater part in defining the profile of the engineer, who in principle was also thinking economically. In England, where there was no institution comparable to the École Nationale des Ponts et Chaussées, an attempt to educate students specifically in construction was made by John Soane (1753-1837), the best-known architect in the country, who became a professor at the Royal Academy in London in 1806. He was already greatly interested in bridgebuilding when he set off on the Grand Tour for the first time in 1778. On the way to Rome, he stopped off in Paris to visit Perronet and see his brand new stone bridge, the Pont de Neuilly, built in 1768-74.[1] It was wooden bridges, however, that Soane encountered on his return through Switzerland. The history of wooden bridge construction has many celebrated structures: Julius Caesar's rather vaguely described bridge across the Rhine, built during his successful advance northwards through Europe;[2] the Danube bridges that are carved on Trajan's column in Rome and the bridges described by Alberti[3] and Palladio[4] respectively – the latter inspiring countless footbridges throughout Europe.

Wooden bridge construction in England might best be represented by a small footbridge designed by William Etheridge (1707-1776) and built by James Essex in Cambridge in 1749. Known as the "mathematical bridge", it also served as a model for Garret Hostel Bridge in Trinity College (1769) and the bridge at Iffley Lock in Oxford (1924).

1 Maggi, Navone, 2003, p. 11
2 Gaius Julius Caesar, De bello gallico
3 Alberti, Leon Battista, Zehn Bücher über die Baukunst, ed. Max Theuer, Darmstadt 1975, p. 202ff.
4 Palladio, Andrea, Die vier Bücher zur Architektur, eds. Andreas Beyer and Ulrich Schütte, Zurich/Munich 1984(2), p. 219ff.

Hittisau, Kummabridge, 1720

Wettingen, 1795

Schaffhausen, 1795

Etheridge followed it soon afterwards with a larger wooden bridge: Old Walton Bridge, which survives only in the well-known painting of it by Canaletto from 1754. It was a larger version of the "mathematical bridge" in Cambridge, which was reconstructed in 1866 and 1905. The design did not give the wooden elements sufficient protection for a bridge of this sort to survive.

The Grubenmanns' Wooden Bridges

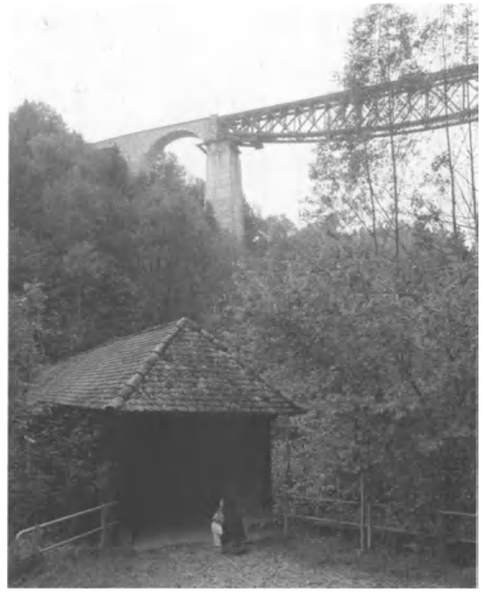
What Soane saw in Switzerland amazed him: up in the Alps, wooden bridge construction had matured to a surprising degree in the hands of the Grubenmann brothers, without the benefit of any academic infrastructure of the sort existing in London and Paris. Their lack of theoretical knowledge was more than compensated for by their love of experimentation and their store of experience. This caused a sensation. William Coxe, another Englishman, in his *sketches of the Natural, Political and Civil State of Switzerland (sic)*, writes of the bridge in Schaffhausen: "If one considers the size of the plan and the boldness of the structure, one is astounded that the builder was a common carpenter without any science, without the slightest knowledge of mechanics and wholly unversed in the theory of mechanics. This extraordinary man is named Ulrich Grubenmann, a common countryman from Tüffen, a small village in the canton of Appenzell, who is very fond of his drink. He has uncommonly great natural skilfulness and an astonishing aptitude for the practical part of mechanics; he has progressed so exceptionally far in his art by himself that he is justly counted among the innovative master builders of the century."[5]

Soane and his assistants painstakingly drew the covered wooden bridges in Schaffhausen (1757), Wettingen (1760) and many others that, in spite of spans of over 50 m, fitted into the landscape well. Because most of the Grubenmanns' wooden bridges were destroyed by 1800, these drawings would have been of great value, but in Basel, John Soane lost almost all of them along with his drawing equipment.[6] As well as their refined construction, Soane praised the picturesque quality of the Swiss wooden bridges and logically, in his lectures, examined the interplay between the structure and appearance of a bridge and the landscape.[7] He considered Perronet, who was of Swiss origin, to be a good engineer, but a bad architect, saying that the Pont de Neuilly bridge, in particular, lacked the "beauty of elegance".[8]

Indeed, the Alpine region was home to an outstanding, continually growing tradition of wooden bridge construction, which reached a peak of experimental daring and accumulated experience in the work of Hans Ulrich Grubenmann (1709-1783) and Johannes Grubenmann (1707-1771).[9] Even before the Grubenmann brothers, the art of building wooden bridges was certainly advanced. The first hanging truss bridge had been built in 1468 over the Goldach near St Gallen, with a span of 30 m. This type of bridge spread rapidly in the 16th century, with spans ranging mostly from 20 to 30 m; the longest, at 38 m, was the bridge over the Limmat at the Landvogteischloss in Baden, Switzerland, built in 1572.[10]

5 quoted by Killer, Josef: Die Werke der Baumeister Grubenmann, 1985, p. 35
6 For the varied transfer of drawings of bridges from Switzerland to England, see Navone, Nicola: The eighteenth-century European reputation of the Grubenmann brothers, in: John Soane, 2003, p. 31f.
7 Burns, Howard: From Julius Caesar to the Grubenmann brothers: Soane and the history of wooden bridges, in: John Soane, 2003, p. 19
8 Burns, p. 20
9 Stadelmann, Werner: Holzbrücken der Schweiz – ein Inventar, Chur 1990; Killer, Josef: Die Werke der Baumeister Grubenmann, 1985; Steinmann, Eugen: Hans Ulrich Grubenmann, 1984;
10 Killer, 1984, p.23

 Urnäsch, Kubel, 1780



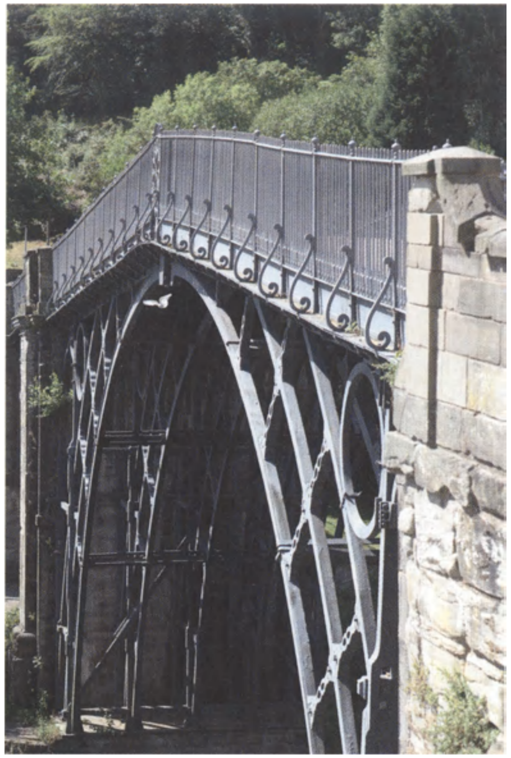
Also worthy of note are the Kumma bridge of 1720 in Hittisau and the Rosanna bridge of 1765 in Strengen. Hans Ulrich Grubenmann, in particular, became astonishingly ambitious in spanning great distances with timber structures, because bridges with foundations in the water were repeatedly washed away by floods. Only two of his bridges have survived in the Appenzell canton: the Urnäsch bridge of 1778, between Hundwil and Herisau, and the Urnäsch bridge of 1780, between Herisau and Stein im Kubel. Both of them are narrow, covered bridges with a span of around 30 m and are designed to carry horse-drawn traffic as well.[1] The structure of both consists of a hanging truss with struts arranged in a five-sided polygon and four pairs of suspension posts. Above all, though, it was the aforementioned bridges in Wettingen and Schaffhausen that aroused fame and admiration. Two points should be considered here. The first is that although these were vehicular bridges, they might well not be perceived as such today, in view of the remarks made by William Coxe when he visited Switzerland again after ten years: "The bridge stretches and gives, as though it were hanging on enormously thick elastic ropes; it trembles and quakes under the tread of any pedestrian, and under the laden carts that drive over it, the swaying becomes so great that the inexperienced fear the collapse of the same."[2] Grubenmann first wanted the Schaffhausen bridge to span the full 119 m from bank to bank, but his clients insisted that the middle pier of the previous bridge be used as a support. Grubenmann's impressive models (among them one of the Schaffhausen bridge) can be found today in the Grubenmann Collection in Teufen.[3] The line between footbridge and road bridge is drawn differently nowadays, of course, and swaying is not tolerated. Although timber construction in Switzerland was also refined by Josef Ritter (1745-1809) and Blasius Baldischwiler (1752-1832), the baton for large-scale wooden bridges passed to the American bridgebuilders.[4]

The second point concerns the aesthetic effect of the bridges. A look at them reveals nothing about their construction: they are mostly clad, making them appear like long timber houses, and, as the contemporary view of the Wettingen bridge shows, they were even painted with architectural forms. The visual integration of this bridge as a long building into its village context and the way in which the pitched roofs over the long arches of the bridge in Schaffhausen fit into the surrounding roofscape both confirm that the contemporary understanding of beauty is to be measured in terms of the picturesque treatment of the bridges and not of their structure, which could only be seen from within – and then only with difficulty in the dim light. To this day, it is precisely as footbridges that covered wooden bridges continue to be built in the unique styles of their respective periods (page 148 onwards).

1 Stadelmann, 1990, IV 8 and 9
2 Coxe 1786, quoted in Killer, 1984, p. 36
3 The original model of the Schaffhausen Bridge is in the Allerheiligenmuseum, in Schaffhausen, and there is a reproduction in the Grubenmann Collection, in Teufen.
4 After c. 1800, large-span timber bridges are developed above all in the USA by Theodore Burr, as truss structures, Kurrer, 2003, p. 47

View inside the Urnäsch bridge in Kubel; structural model (below)

Coalbrookdale Bridge, 1779



Science, Economy, Experimentation

The effect on the 18th century of improvements in ironworking, early calculating methods and the approaching Industrial Revolution cannot be underestimated. Until the end of the 17th century, the blast furnaces in which pig iron was smelted were fired with wood. They reached a maximum temperature of 1200 °C, producing iron of a quality and malleability that did not permit large components to be formed. Then, in 1709, Abraham Darby (1678-1717) had the idea of firing the furnaces with low-sulphur coke, which allowed temperatures of up to 1500 °C to be obtained. This produced runny, malleable iron for casting – a milestone for bridgebuilding, too, although the iron thus manufactured early on was brittle and could only be subjected to loads in compression.

In 1779, a design by architect Thomas Farnol Pritchard (1723-1777) for a wooden bridge spanning 30 m was built using cast-iron components as an experiment. This became the celebrated iron bridge of Coalbrookdale, erected by John Wilkinson (1728-1808) and an iron foundry owner, Abraham Darby III (1750-1789). It was the first of a line of cast-iron arched bridges, which ended, however, as early as 1819 with the construction of Southwark Bridge in London, by John Rennie the elder. At 73.20 m, it still has the longest spans of any cast-iron bridge in the world.[1]

The types of steel manufactured nowadays form strong joints when welded and are available as tubes, rolled sections, sheet and cast parts. Such components can be welded together to create bridges with huge spans, which thanks to the high strength of steel can be made significantly more slender than concrete bridges.

Cast Iron and Wrought Iron

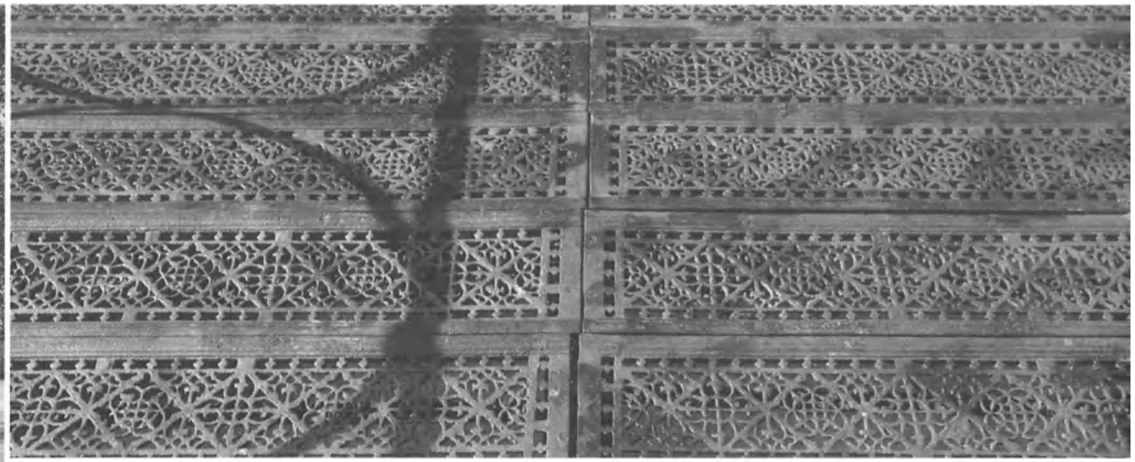
The first cast-iron bridge to be built in France, however, was a footbridge. It crossed the River Seine with an overall length of 166.5 m. Louis Alexandre de Cessart, Inspector General of the École des Ponts et Chaussées, and Jacques Dillon built the Pont des Arts in 1802-04 with nine arches, each spanning 18.5 m. In 1984, it was replaced with a reconstruction in steel, which had seven arches instead of nine.[2] The Pont des Arts is nevertheless still much loved by Parisians on account of its function as a footbridge; it is also a place to meet, or spend an evening (or even the whole day), rather like a public square. Sited between two stone bridges, Pont Neuf and Pont du Carrousel, the delicate structure appears to skip gracefully and easily over the Seine. Along with the Passerelle Debilly and the new footbridges near Solférino (see p. 142) and Bercy (see p. 144) the Pont des Arts displays the historical dimension of the Seine's relationship to the city.

It was another project for a pedestrian bridge that gave Antoine Rémy Polonceau an opportunity to explore the limits of feasibility in 1829: his bridge across the Seine near rue de Bellechasse uses cast iron and wrought iron in a combination of arches and suspension bridge, with a free span of 100 m.[3]

The development of iron production was definitely motivated by a desire for technological progress, coupled with the economic prospects dependent upon it. Perhaps surprisingly, these interests played along with the architectural expectations of absolutist rulers up to the end of the 18th century and, in some cases, into the age of European Restoration. This placed the main emphasis on the picturesque quality of buildings and other structures, as their settings in English and German landscape gardens demonstrate perfectly. Before the efficiency of iron (and later on, steel) was consistently and methodically improved, every known type of bridge had been incorporated into the range of available designs for footbridges and tastefully installed in the parks and gardens of Europe.

1 Pelke, Eberhard, 2005, p. 24
2 Lemoine, Bertrand, Pont des Arts, in: Les Ponts de Paris, Paris 2000, p. 211
3 Paris, Archives nationales, Cartes et plans; ilustration in: Deswarte, Lemoine, 1997, p. 93; the Polonceau truss system was invented by his son, Barthélemy Camille Polonceau.

Pont des Arts, built 1802-04 with nine arches; reconstructed in 1984 with seven arches, each spanning 22 m



Avington Park, around 5 km northeast of Winchester – iron bridge, built c. 1845, repaired in 1996

Bridges as Design Features for Parks

Stone and wood continued to dominate bridgebuilding into the early 19th century. The maximum free spans that could be achieved with structures of these materials gradually became clear. Cast iron offered only a moderately improved performance in respect of span lengths and stability. All the same, bridges such as the Coalbrookdale Bridge were of such importance as models of technical innovation that they were incorporated as standard design features in parks and landscaped gardens. In this context, footbridges played an astonishing role, being used as models to illustrate everything of importance in bridgebuilding in general. They demonstrate in miniature what distinguishes mere bridgebuilding from the art of bridge design; there is a focus on aesthetic issues, which were unfortunately to become neglected in large-scale bridgebuilding. Today it is still – or rather, once again – possible to see one of the best examples of this fashion for footbridges: the Gartenreich area between Dessau and Wörlitz, the first landscaped park to be laid out in a German state.[1] This model agricultural area and the landscaped garden at its heart were laid out on a grand scale by Leopold III Friedrich Franz von Anhalt-Dessau, who came of age in 1758, and his architect Friedrich Wilhelm von Erdmannsdorff, beginning in 1764. Prior to that, they had travelled in England, among other countries, familiarizing themselves with the latest ideas in places such as West Wycombe Park, belonging to Sir Francis Dashwood[2], Kew Gardens by William Chambers, and Henry Hoare's estate at Stourhead, in Wiltshire.[3] Wörlitz, however, stands out for the sheer number of bridges and variety of bridges in its design programme. Almost 50 bridges were built in the *Gartenreich* area as a whole, 19 of which stood in Wörlitz Park. The picturesque, scenic treatment of the bridges and, above all, of their settings may well have been influenced by William Chambers. Chambers had travelled to China, where he had become acquainted with the Chinese approach to designing buildings and gardens; in 1749 he had begun studying under Jacques François Blondel at the École des Arts in Paris, later visiting Rome to see its Classical and Renaissance architecture. Back in England, Chambers began planning Kew Gardens in 1755. Nothing is left to chance in these picturesque and carefully composed gardens: visitors are led along a "beauty line" from one enchanting view to another – and small bridges are an integral part of these scenic compositions. The bridge programme at Wörlitz also includes an educational element with its roots in Enlightenment thinking. Types of bridge from different eras and cultures with different methods of construction appear like stage sets as one walks among its many waterways. The topography of the former flood plain has been artificially varied in the park to create different landscapes in miniature, for which matching footbridges have been chosen – or vice versa: the chain bridge needs a rocky chasm; the miniature version of the iron bridge of Coalbrookdale is given a gradually rising embankment; an overgrown

1 Bechtholdt, Frank-Andreas, and Thomas Weiss (eds): Weltbild Wörlitz. Entwurf einer Kulturlandschaft, Stuttgart 1996; Sperlich, Martin, in: Daidalos 57, 1997, p. 74f.; Unendlich schön. Das Gartenreich Dessau-Wörlitz, Berlin 2005

2 Trauzettel, Ludwig: Brückenbaukunst, in: Unendlich schön, 2005, n.p.

3 Sperlich, 1997, p. 76

4 Burkhardt, Bertold: Das Brückenprogramm in Wörlitz, in: Weltbild Wörlitz, 1996, pp. 207-218

Wörlitz – Coalbrookdale Bridge in miniature, 1791

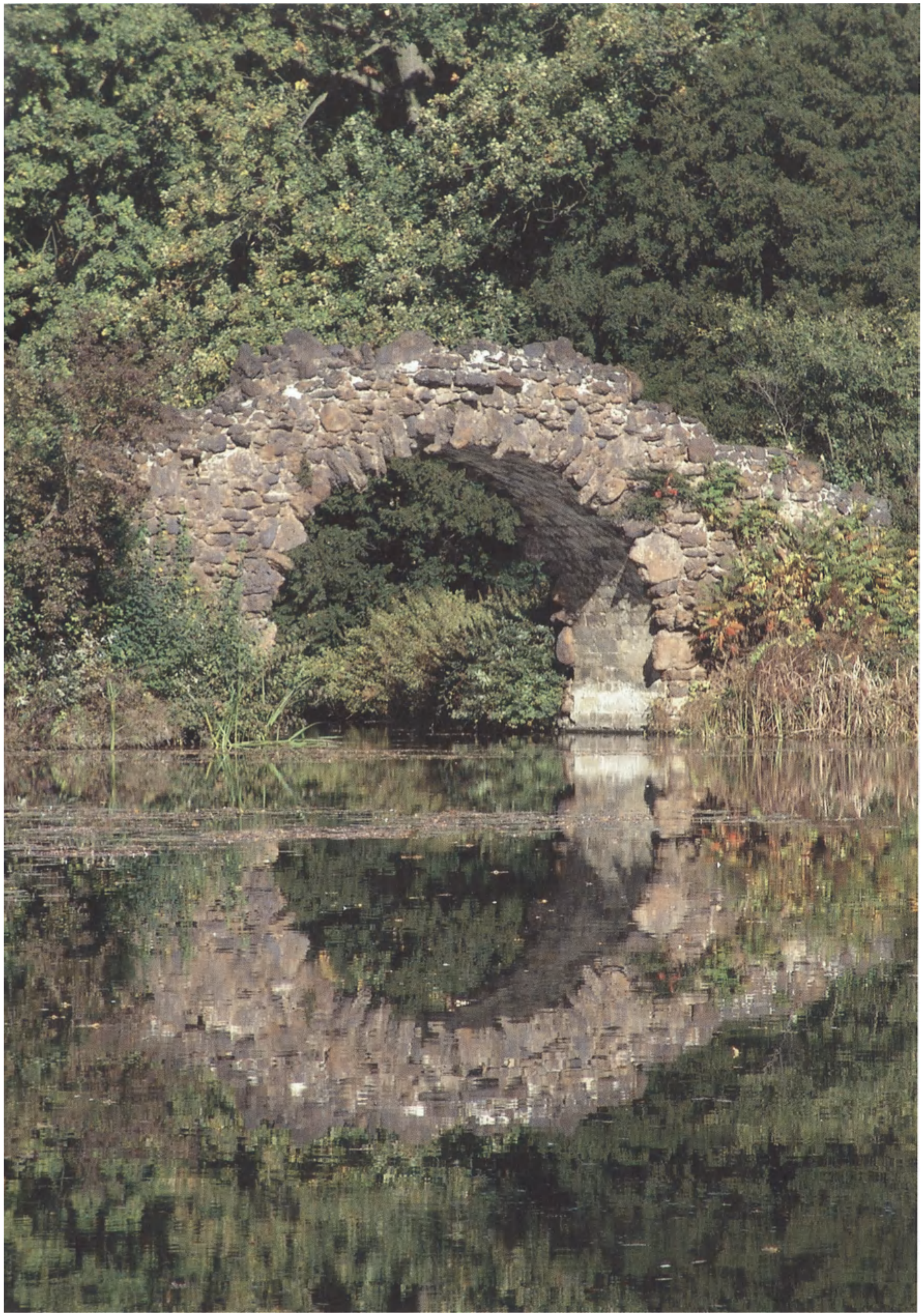
Chain bridge, suspended between two artificial cliffs

path leads to the swing bridge and so on. This rich and varied design programme has been described in detail by Berthold Burckhardt, who was in charge of the recent repair and reconstruction of the Wörlitz bridges.[4]

Landscaped gardens like this one could well be thought of as a prefiguring some of the ideas in Disneyland. On the other hand, it is also clear that the small-scale bridge was gaining a degree of autonomy, albeit primarily in the sense of ornament and education and less because of its potential for structural experimentation.

Regrettably, not all of the park's moveable bridges have survived, although the Agnes Bridge, a Dutch swing bridge, may still perhaps be reconstructed. It is also remarkable that although, besides Chinoiserie, it was Swiss scenes that were considered to be particularly picturesque, wooden bridges of the Swiss type and even Alpine-style, covered, wooden bridges are missing in Wörlitz.

The High Bridge



White Bridge, 1773

The bridges and the landscape typology in Wörlitz complement each other to create a consistently atmospheric and often magnificent whole. Here, once again, there is an invocation of something that is already implicit in the idea itself, less utopian than unworldly: the harmonious unity of nature and technology; the accord in the souls of the artist and the technician; the simultaneity of the ideal of beauty and fulfilment of function. What footbridges can achieve with almost magical ease becomes proportionately more difficult for bridges at the larger scales demanded by modern traffic flows. A single generation later, criticism was voiced of the picturesque approach taken at Wörlitz, of which footbridges were an essential part. The philosopher Georg Friedrich Wilhelm Hegel (1770-1831) wrote, "Whereas a huge park, especially if rigged out with Chinese pagodas, Turkish mosques, Swiss chalets, bridges, hermitages, and goodness knows what other curiosities, claims our attention on its own account; it pretends to be and to mean something in itself. But our allurement vanishes as soon as it is satisfied, and we can hardly look at this sort of thing twice, because these trimmings offer to the eye nothing infinite, no indwelling soul, and besides they are only wearisome and burdensome when we want recreation and a stroll in conversation with a friend."[1] From a historical point of view, this criticism ignores the holistic significance of late 18th-century landscaped parks, in which bridges also demonstrated structural knowledge.

1 Hegel, Georg Wilhelm Friedrich, I, trans. T.M. Knox, Oxford, 1998, vol. 2, pp. 699-70

Drawbridge at the swan pool

Sun Bridge, 1796, spanning 8 m; the rolled iron of the springings came from England

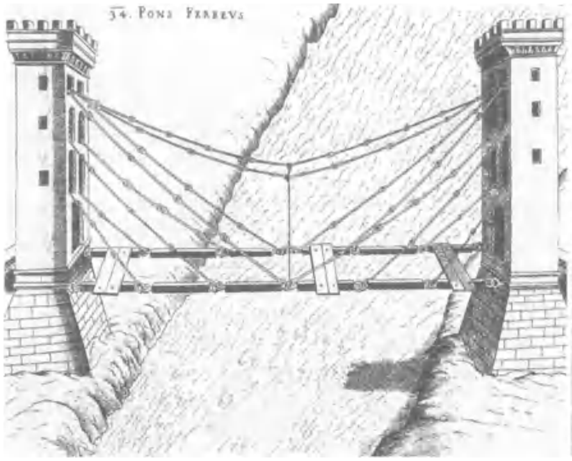
Bridge in the park of Charlottenburg Palace, Berlin, 1801

Interest in scenic landscapes, which should not be without bridges, revived periodically. In the 19th century, Friedrich Ludwig von Sckell (1750-1823), Peter Joseph Lenné (1789-1866) and Herrmann von Pückler-Muskau (1785-1871) designed gardens that delight in eclecticism to an astonishing degree, with a tendency to give the "natural" its due. Although footbridges no longer played the role that they had in Dessau-Wörlitz, they were not neglected as a design feature in parks, as is illustrated here by Ferdinand von Triest's 12 m span, cast-iron bridge of 1801 in Charlottenburg Park, Berlin, and the Devil's Bridge of 1852 in Kassel, to name but two. In England, the home of the landscaped park, there are countless examples of bridges being used as the centrepieces of scenic compositions.

The national garden festivals held at regular intervals in different places, have their roots in a different tradition: that of the 18th-century botanical collection. They too sometimes provide opportunities to build high-quality footbridges as part of urban improvement schemes, as is shown on page 196.

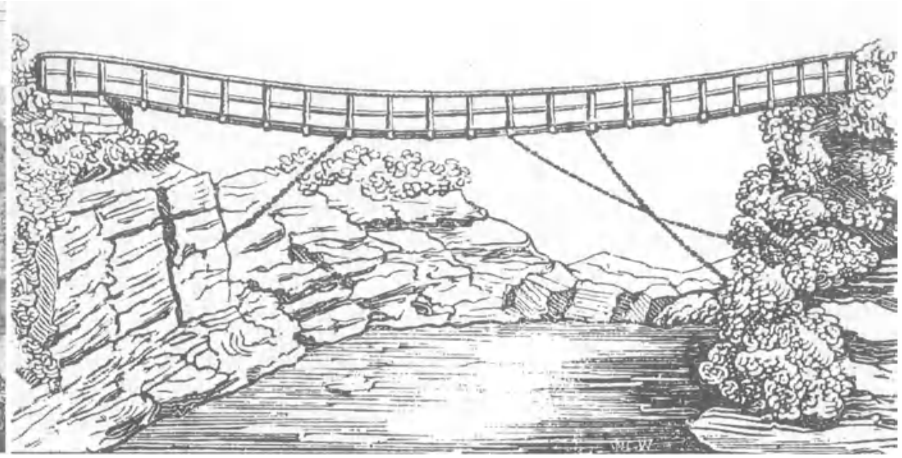
The Devil's Bridge, Wilhelmshöhe Park, Kassel, 1792-93, by Heinrich Christoph Jussow

Faustus Verantius, 1615



Fischer von Erlach, bridge in Sina, 1721

Winch Bridge – second version of the bridge first built in 1741, sketch by Cumming, 1824, from Peters



Suspension Bridges – Experiments in Iron and Steel

As we mentioned earlier, from the late 18th century onwards, engineers found themselves confronted with new tasks as a result of developments in iron technology and the onset of industrialization. At first, cast iron had been used structurally in the same way as timber; the iron was brittle and could not be subjected to any tensile load. Improving the tensile strength of this material went hand in hand with the development of chain, wire rope and wire cable suspension bridges. It quickly became clear that the limits of what was possible had not yet been reached, by any means.[1] In connection with the earliest chain, wire rope and wire cable suspension bridges, the footbridge acquired a role that earned it increasing attention: that of the experimental prototype, serving in trial runs of new structures based on theory or research.

To a considerable degree, stimuli came from other cultures. It is particularly interesting, for example, how Johann Bernhard Fischer von Erlach, writing in 1721, treats bridges in the first-ever outline of architectural history as such. In his second book, which concerns the art of building in Roman times, he mentions Augustus' bridge across the Tiber (a monumental stone bridge with dimensions suitable for a herd of elephants) and Hadrian's bridge to the Castel Sant'Angelo, which is somewhat more modest. Fischer von Erlach is much more deeply impressed, however, by bridges made in other ways and by other cultures, which he considers in his third book. This is dedicated to the architecture of the Arabs and Turks, the Persians, the Chinese and Japanese. One type of bridge moves Fischer von Erlach to express sheer astonishment, when he reports on one of "the wonderful chain bridges in China, built from the peak of one mountain to another with boards on twenty iron chains near the town of Kingtung."[2] The stories told by European travellers of rope and chain bridges in far-off China certainly express admiration. Fischer von Erlach's source of information for the Chinese chain bridge was a work published in 1667 by a Jesuit, Athanasius Kircher, *China Monumentis Illustrata* – the depictions are similar in every respect.

The development of the suspension bridge did not really begin to take off in Europe until the 19th century, when it became technologically and economically attractive to produce iron and steel for the manufacture of chains, cable and wire rope. The most important bridges were built in areas of rapid industrialization, where the spirits of commerce and invention came together. In the following sections, we will take a look at the early chain suspension bridges, then the wire cable and wire rope suspension bridges. In England and Germany, it was mostly chain suspension bridges that were built, whereas wire rope was experimented with in other countries.

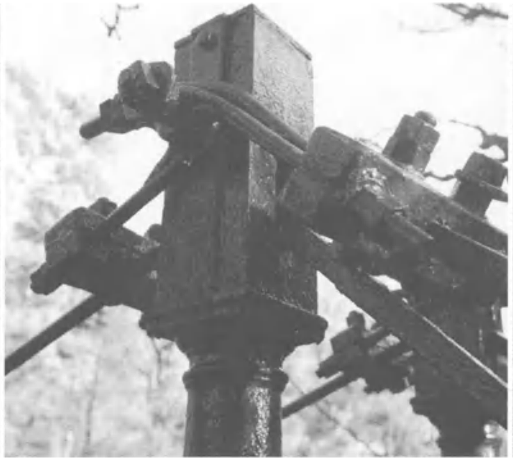
Chain bridges

The Schöllenen ravine on the St Gotthard pass in Switzerland was supposedly the site of a chain bridge built as early as the 13th century. Better known, because they are the oldest surviving illustrations in this

1 Werner, 1973; Wagner, Egermann, 1987; Peters, 1987

2 Fischer von Erlach, 1721, Zweites Buch

Winch bridge in Middleton, 1830, repaired 1974

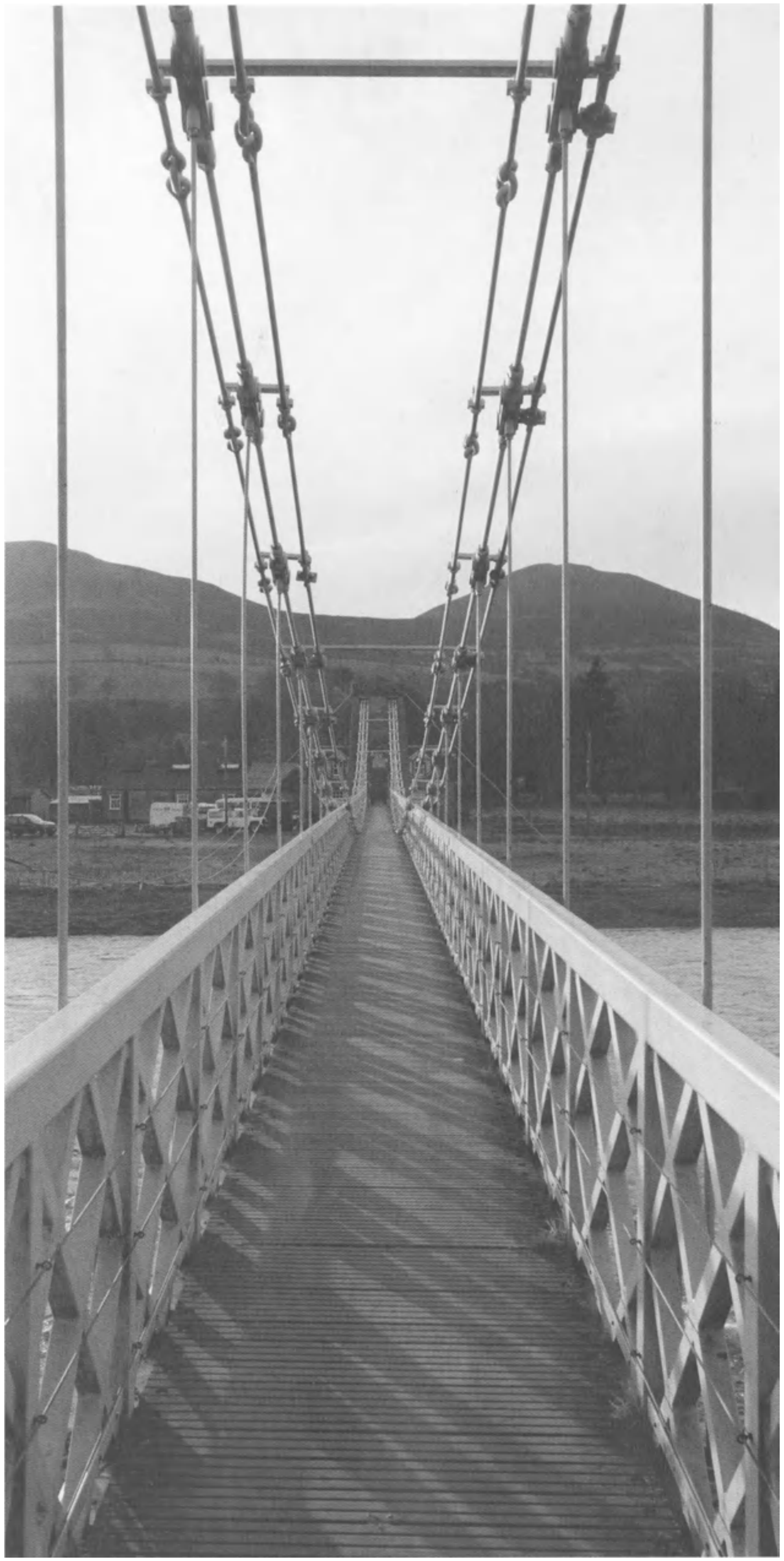



field, are three suspension bridge designs described in a book on mechanics by Faustus Verantius in 1615-17. His chain bridge is more like an eye-bar bridge, hanging from massive towers, and in parts it anticipates the chain-stayed bridge. Verantius' *Machinae Novae* was soon translated into many languages, which was consistent in view of Verantius' (1551-1617) persona as a multilingual polymath and author of dictionaries. Incidentally, the word that he used for cast iron translates as "bell food".[3]

The next oldest bridge became surprisingly well known. It was the legendary pedestrian chain suspension bridge that spanned 21 m across the River Tees near Middleton, in Cumbria. It was built in 1741 to shorten the journey for workers going to Middleton from Holwick, on the other side of the river.[4] The walkway, which consisted of timber boards lying on chains, was apparently given a modicum of stability by four tensile chains anchored down in the valley; only on one side was there a handrail for safety. The bridge attracted visitors from far and wide, many of whom were greatly alarmed by the degree to which it swayed. A poet from Newcastle described it as a "dancing bridge".[5] In 1802, the chains parted under the weight of nine people and although it was subsequently repaired, it was replaced in 1830 by a new bridge sited a little farther upstream, which again required a span of 21 m. This second bridge was completely restored in 1974. The span that could be achieved with chains had been demonstrated by the Chinese much earlier, in 1706, with the hanging Tatu bridge in Lutingchao; still standing today, it has nine eyebar chains and it spans around 100 m.[6]

3 Mehrtens, 1900, p. 3f.
4 Peters, 1987, p. 27
5 Marrey, 1990, p. 116
6 Ewert, 2003, p. 57

Melrose, 1828; below: collapse of the bridge in Brighton



The fascination of suspension bridges and the opportunities they offered for improving transport gave a new impetus to bridgebuilding, initially in the United States of America: patents were secured and records broken. James Finley (1756-1828) built the first chain bridge with a rigid deck over St Jacob's Creek in 1801; it had a span of 21 m.[1] He had this design of bridge patented immediately – unfortunately, none of Finley's bridges have survived. The stiffening of the deck was decisive in gaining acceptance of this type of bridge in Europe and the USA – however fond people may otherwise have been of "dancing bridges".

In the *UK*, the chain suspension bridge spread very quickly and again, the footbridge took on an experimental function. In 1817, a chain bridge was built across the River Tweed near Dryburgh by the brothers John and William Smith; while in the same year Redpath & Brown built Kings Meadow Bridge, which spanned 33.5 m, also over the River Tweed near Peebles.[2] The chain bridge at Dryburgh collapsed after a short time in 1818; the current bridge (a cable suspension bridge) dates from 1872. Thomas Telford (1757-1834) and Isambard Kingdom Brunel (1806-59) dared straight away to build, on a much larger scale, bridges that were no longer exclusively for pedestrians: the Menai Strait Bridge (1826); the chain bridge at Conway Castle (1822-26), and the Clifton Suspension Bridge (1864).[3] A span longer than the 100 m had already been achieved in 1820 by Sir Samuel Brown's Union Bridge near Berwick, also across the Tweed. Brown had been experimenting with chain bridges since 1808, braving repeated setbacks such as the severe damage caused by high winds to his chain bridge for Brighton pier in 1836.[4]

Although bridge portals were still frequently built of stone, as at Melrose in 1828 and Glasgow in 1855, they were increasingly being constructed as steel trusses (especially for cable suspension bridges), as at Dumfries in 1875 and Peebles in 1905 – the latter richly ornamented (see illustrations on p. 46). Portland Street Bridge in Glasgow, designed by architect Alexander Kirkland and engineer George Martin with a respectable span of 126 m, is a good example of how stone portals help to integrate bridges into the urban context of the city and prevent them appearing as an all too self-contained technical construct. The stone portals seem to be part of the urban fabric, whereas the steel frame portals, such as those of the bridge in Peebles, belong completely to the bridge as a unit.
The Glasgow bridge, parts of which had to be renewed in 1871, is highly regarded nowadays and is illuminated as a city landmark. The bridge in Melrose was restored in 1991, before which it had been limited to carrying no more than eight people at a time.

1 Ewert, 2003, p. 58
3 Peters, 1987, p. 37
3 Building work on the Clifton Bridge was interrupted for political reasons from 1842-60. Pugsley, Sir Alfred (ed.), The Works of Isambard Kingdom Brunel, an Engineering Appreciation, Bristol, 1976
4 Peters, 1987, p. 95

The fates of these early cases make it quite clear that the main structural problem for suspension bridges was oscillation. Practitioners well versed in chain bridges, such as James Dredge (1794-1863) and Roland Mason Audish certainly built countless chain bridges, but most of them collapsed after a fairly short time.

Chain bridge, "Kettensteg", Nuremberg, 1824

In 1900, Georg Mehrtens (1843-1917), professor of engineering at the Technische Hochschule in Dresden, reflected soberly that "Wholly in contrast to arched bridgebuilding, the building of suspension bridges has at no time really got going in Germany."[1] In Mehrtens' opinion, only a few early chain bridges were of importance. As far as is known today, the oldest surviving chain suspension bridge in *Germany* is the "Kettensteg", a footbridge built across the Pegnitz in Nuremberg by Johann Georg Kuppler in 1824-25, which spans a respectable 80 m. According to a Prussian publication of 1822, the idea of suspending bridges was first proposed by Carl Immanuel Löscher in 1784; piers and trestles could be dispensed with if the bridge deck were to be suspended, for which Löscher recommended bars or chains.[2] Of the chain bridge in Nuremberg, the four main suspension chains, hangers and railings remain. The suspension chains consist of tension rods with hooked ends and eyelets. Its original oak pylons were replaced in 1909 by steel truss masts – a change that caused problems with dynamic loads: pin joints and rivets worked loose, not least because it had become a popular amusement to set the deck oscillating. In 1931, both sections of the bridge were stabilized with two timber trestles each, fixed to foundations in the riverbed. Since then, private groups have repeatedly attempted to have the Kettensteg restored to its original state.[3] Also built in 1824 was Christian Gottfried Heinrich Bandhauer's (1790-1837) pedestrian bridge across the river Saale in Nienburg: a chain-stayed bridge on timber pylons, which tragically collapsed in the following year under the load of a large number of townsfolk at a public celebration.[4]

In spite of the occasional bad experience, German engineers were soon constructing chain bridges of larger dimensions that could also carry carts and coaches: a chain suspension bridge spanning 31 m that was built in Malapane (a centre of iron production) in Upper Silesia in 1825 had 75 cattle herded onto it as a test of its loadbearing capacity – hardly something that would be done for a mere footbridge.[5] In 1828, another chain suspension bridge designed for larger loads was built in Bamberg, with towers designed by Leo von Klenze. Fourteen years later, a traffic restriction was introduced for reasons of safety and in 1891 this bridge was demolished. One of the bridges that has survived, however, is the early, small footbridge in the Ilm park in Weimar, dating from 1833, which is suspended from three parallel chains on each side and spans a mere 14.8 m.

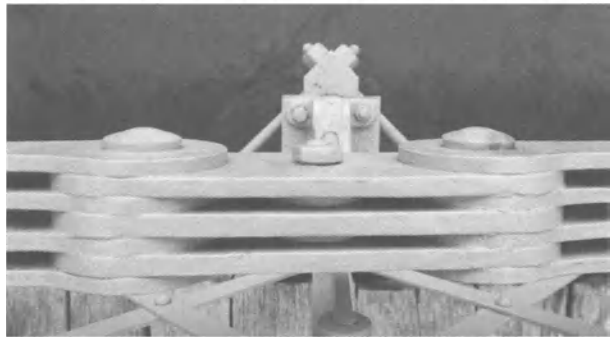
The tale of the small pedestrian bridge spanning 28.1 m across the upper Ruhr in the park of Laer manor in Meschede is an interesting one. It was rediscovered towards the end of the 1990s. In 1998, a researcher studying the archives of the manor's owner found a manuscript by Johann August Röbling, containing a detailed description and calculations for a 75 m suspension bridge across the Ruhr near Freienohl.[6] Röbling had placed great emphasis on stiffening his bridge adequately, in addition to which he had proposed an alternative design with lengths of wire cable instead of chains. The manuscript, from 1828, gives the young Röbling's position as "Conducteur", roughly equivalent to a construction manager. His solution was later adopted by a colleague, A. Bruns, when designing the much smaller chain suspension bridge at Laer manor, completed in 1839. It stood unnoticed on the privately owned property for many years until its significance was realized in 1998, when it was given listed monument status.[7] This did not prevent a tree from falling on one of its pylons during a storm in 2007. Although temporary measures were immediately

1 Mehrtens, 1900, p. 75
2 Verhandlungen des Vereins zur Beförderung des Gewerbefleißes in Preussen, Berlin, 1822, p. 127
3 Petri, Kreutz, Stahlbau, 5, 2004, pp. 308-311
4 Pelke, p. 33

5 Bauausführungen des Preussischen Staates, vol. 1, Berlin, 1842, p. 67 (note by Andreas Kahlow)
6 Schmitz, Christoph, Die Ruhrbrücken, Münster, 2004, p. 126
7 Grunsky, Eberhard, Von den Anfängen des Hängebrückenbaus in Westfalen, in: Zeitschrift Westfalen, vol. 76, Munich, 1998, pp. 100-159; Schmitz, 2004, p. 163f.

Laer, 1838-39

Altenbergsteg, Berne, 1857



taken to stabilize it and prevent it from collapsing, the bridge was a pitiful sight. Half of a pylon had to be replaced with a temporary structure of steel beams, while freight tie-down straps took the place of broken or endangered hangers.

The oldest suspension bridge in *Belgium* is thought to be a small footbridge in the park of Wissekerke manor, which was built in 1824, the same year as Nuremberg's Kettensteg. Spanning 23 m, it was designed in the English chain bridge tradition by Jean-Baptiste Vifquain, an engineer from Brussels who had travelled around England.[8] The same year saw the foundation of the *Gesellschaft für Kettenbrückenbau* (chain bridge construction company) in Vienna by Ignaz von Mitis, which built the city's first chain suspension bridge four years later – this was the first bridge to have chains made of steel, but unfortunately it was dismantled in 1880 to make way for a larger bridge.[9]

The oldest surviving chain suspension bridge in *Switzerland* is probably the Altenbergsteg in Berne, built in 1857 by a native of that city, chief engineer Gustav Gränicher (1820-1879). With a width of 2.1 m and a length of 57 m, this footbridge, now a listed monument, connects the old city centre (after making the steep descent to the river Aare) with the Altenberg quarter. It is stiffened by lattice girders that simultaneously function as its parapets; the superstructure has cross-bracing to prevent lateral deformation. The flat chains are made up of members 3 m long, each of which consists of four parallel ribs measuring 9 cm wide and 1.7 cm thick. These chains run over rocking piers and are anchored in the river embankment at the southern end and in the ground at the northern end.

8 de Bouw, M., I. Wouters, Investigation of the restoration of the iron suspension bridge at the castle of Wissekerke, in: WIT Transactions on the Built Environment, vol. 83, 2005

9 Mehrtens, 1900, p. 6

Paris, Buttes-Chaumont, 1867

St Petersburg, Post Office Bridge across the Moyka, 1824, span 35 m

In *France*, the focus of interest was more on cable and wire bridges, but of course chain bridges were built as well. The country's first chain bridge was the Drac river bridge near Grenoble, built by Crozet and Jourdan in 1827.[1] In 1839, Berdoly and Dupouy built a chain bridge across the Agen with a span of 174 m, but tests showed that it would be unable to carry the planned loads, so it had to be reinforced, finally being reopened in 1841. Even so, it failed to last long, and in 1882 the chains were replaced by four steel cables on each side. At first, no more than 60 people were permitted on the bridge at any one time, but in 1906 this was reduced to 25; then in 1936 the main suspension cables had to be replaced. In the early 1950s, high water levels in the Garonne damaged the bridge, which had been in need of repair in any case, leading to increasing doubts about its long-term stability. In 2001-2002, the complete bridge was reconstructed.[2] The challenge of bridgebuilding naturally appealed to one particular engineer with an aptitude for business: Gustave Eiffel (1832-1923). In 1867, he built a 63.86 m span chain suspension bridge in the park of Buttes-Chaumont. However, he never favoured this type of bridge, preferring to exploit the possibilities offered by steel truss structures. The chains of this bridge have, in the meantime, been replaced by wire cables.[3]

The first two decades of the 19th century were remarkable for an unprecedentedly rapid transfer of knowledge and technology across national and language barriers, as far as *Russia*. When it came to solving tricky technical problems, the court in St Petersburg readily called on the services of French or German experts. Notable names in the field of bridge building include a Spaniard, Augustin Bétancourt (1758-1824), a Frenchman, Pierre-Dominique Bazaine (1786-1836), and two Germans, Wilhelm von Traitteur (1788-1859) and Carl Friedrich von Wiebeking (1762-1842) – the latter working from Munich. Traitteur had little success as an engineer in his native Baden, but in 1813 he was introduced to the Tsar of Russia, who was married to a princess of Baden. In the following year, he began work in St Petersburg under the Spaniard Bétancourt, taking over as superintendent of bridges in 1821.[4] Pierre-Dominique Bazaine, who had come to St Petersburg before Traitteur, experimented with cable suspension bridges as early as 1823. The bridge built in the park of Catherine Palace in the same year was, however, a chain suspension bridge, because the production of wire was not as far advanced in Russia as it was in France.[5] Although it was probably the first of its type to be built in Russia, chain suspension bridges had not been unknown there before that: Nikolaus Fuss from Switzerland (Euler's successor at the St Petersburg Academy of Sciences) had designed a suspension bridge spanning 300 m across the river Neva many years earlier. Traitteur worked on chain bridges on a large and a small scale simultaneously. His three pedestrian bridges have survived: the Post Office Bridge of 1824 across the

1 Peters, 1987, p. 68
2 La Passerelle d'Agen. Le sauvetage d'un ouvrage historique, in: Freyssinet Magazine, Jan-April 2003; Lecinq, Benoît, and Sébastian Petit, Renovation of the footbridge over the Garonne in Agen, in: footbridge 2002, proceedings, pp. 120-121
3 Lefresne, Y., La réconstruction de la passerelle suspendue des Buttes Chaumont, in: Travaux, 482, May 1975, p. 50
4 Fedorov, 2000, p. 80
5 ibid., p. 184
6 ibid., p. 197

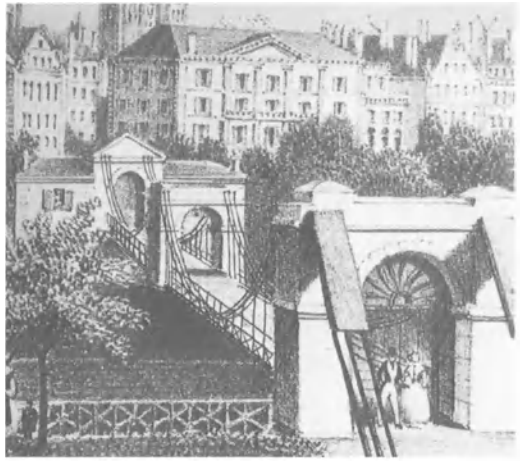
Lion Bridge, 1825-26, span 23.5 m

Bank Bridge, 1825-26, span 21.5 m

Moyka river and the Lion and Bank bridges of 1825-26 over Catherine (now Griboyedov) Canal. For the bridge across the Moyka, the Swiss engineer Henri Guillaume Dufour had sent plans to St Petersburg – these can no longer be found, but it should be noted that a model of his St Antoine bridge did exist in the teaching collection in St Petersburg.
In 1823, Traitteur began designing this small bridge, spanning 35 m; in order to reduce oscillations, the main suspension chains were to be fixed to the deck in the middle of the bridge (sag-to-span ratio 1:16). Two chains consisting of 19 eyebars each support the bridge via 36 hangers, they run over 2.5 m high cast-iron obelisks and curved, spoked frames down to cast-iron ground plates. For the two other bridges, Traitteur abandoned the obelisks in favour of animal figures, namely lions and gryphons – the latter being an heraldic beast on the coat of arms of Alexander von Württemberg, who ran the Russian highways authority in St Petersburg. This design innovation gives these bridges their special charm – animal figures as anchorages for chains or wire ropes do appear again at a later date on the Lion Bridge in Berlin (see p. 48), but apart from this they did not enjoy success in engineering circles. Traitteur returned to Germany in 1830, after which he built little. All three footbridges were listed as protected monuments in 1935, since when they have all been renovated, generally overhauled or reconstructed.[6]

Footbridge construction certainly served as a field of experimentation in this early phase of the new construction typology, albeit one in which there were initially many failures. While the engineers did not hesitate to attempt large, high-maintenance chain bridges, some of which are still in use today, the chain suspension bridge was not destined for a glorious future. The fatal collapse of a chain bridge in Angers in 1850, designed by the highly experienced engineers Joseph Chaley and Théodore Bordillon, was a serious setback. Better prospects were offered by the development of wire cable and wire rope bridges, in which advances were made by the Séguin brothers and Henri Guillaume Dufour in France and Switzerland, and by Brix and (later) Röbling in Germany – although the latter emigrated to the USA in 1831.

The challenges faced by the engineers of the early wire cable and wire rope bridges are described briefly on the following pages.



Pont St Antoine, Geneva, 1823

Suspension bridge over the Cance in Annonay, 1822

Cable and Wire Rope Bridges

Chains proved to be too susceptible to failure – if a link in the chain were to snap, this would immediately have dire consequences for the stability of the whole structure. It was therefore important to develop an alternative, in the form of flexible and durable rope of wrought iron wires. This was of particular interest to the mining industry, which needed a more efficient means of extraction at the pithead. The problem was addressed by Wilhelm August Julius Albert, director of mines in Clausthal in Germany, who invented what is supposed to have been the first ever wire rope in 1834. It had a diameter of 18 mm and consisted of three strands of four wires each.[1] In the construction industry, the aerial spinning process patented by Roebling, who had emigrated in 1831 to the USA, met with success where long (and thus heavy) cables were needed, because it allowed lightweight single wires to be "spun in place without support" into a thick cable of parallel wires.[2] By the second half of the 19th century, the most important types of cable or wire rope were already known and subsequent progress was limited to making improvements in the materials, the cross-sectional geometry of the wires, and their arrangement in the strands and rope. [3]

In the USA, Josiah Hazard and Erskine White, manufacturers of wire cable, began with (yet again) a footbridge: the first-ever cable suspension bridge, built in 1816 over the Schuylkill Falls in Philadelphia. Its impressive span of 124 m would not be exceeded for decades, although it did collapse shortly after being built, under the weight of a snowfall.

In Europe, it was French engineers who pioneered the development of cable suspension bridges, with the help of theoreticians whose calculation methods opened up new perspectives for what had, until then, been a risky type of construction. Bruno Plagniol and Claude Henri Navier, both of whom were bridge and road engineers, became interested in the idea of suspension bridges in general, and worked out a theoretical basis for building with wire ropes. [4]

Encouragement also came from an unexpected quarter: the banker and industrialist Benjamin Delessert, who was appointed president of the Banque de France in 1802 at the age of 29. Shortly before that, he had set up a sugar factory in Passy; it was there that he later decided to build a link between his house and the factory premises. In 1824, work went ahead: Delessert pragmatically chose a combination of chains and wire cable bundles for the 1.2 m wide footbridge, which spanned 52 m. The main suspension elements were four bundles of 100 wires each, alongside two chains made up of iron bars 4 m long and 2 cm thick. They ran over the top of two wooden towers, behind which they were anchored in massive masonry blocks. The hangers were attached to them at intervals of 1 m.[5]

Delessert, however, did not want to become a bridge builder and he counselled anyone with an interest in suspension bridges to seek advice from Navier, Seguin, Dufour, Dupin and Cordier – with good reason: after reading an article about cable suspension bridges published in the official gazette *Le Moniteur* in 1821, the brothers Marc (1786-1875) and Jules Seguin (1796-1868) had embarked on an audacious project to build a cable

1 Verreet, Roland, Ein kurze Geschichte des Drahtseils, 2002
2 Peters, 1987, p. 171
3 Gabriel, Knut, Hochfeste Zugglieder, Manuskript, University of Stuttgart, 1991-92; Wagner, Egermann, 1985

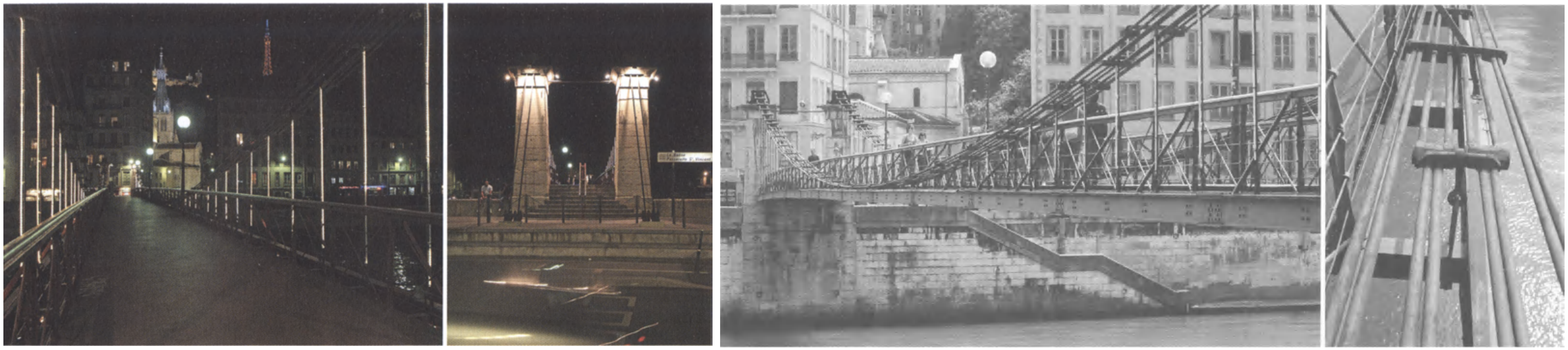
4 Navier, Claude Henri, Rapport et Mémoire sur les Ponts Suspendus, 1823; Ewert, 2003, p. 58
5 Marrey, 1990, p. 121; Peters, 1987, p. 68
6 Casciato, Maristella: Le Pont de Tournon, in: L'art des ingénieurs, p. 510
7 Marrey, 1990, p. 121; Peters, 1987, p. 68 f.
8 Peters, 1987, p. 124 f.
9 Marrey, 1990, p. 122

suspension bridge across the River Rhône between Tain and Tournon.[6] Once again, the new type of construction was first tried out on a footbridge: in 1822, Seguin and Navier built a small bridge across the Cance, near Vernosc les Annonay, on a property belonging to Marc Seguin off what is now the D270 road. Over a metre wide, the bridge managed a span of 18 m.[7] It was carried by six cable bundles of eight wires each, with the deck resting on four of them and the other two serving additionally as handrails. In the middle, it was guyed down to large rocks in the river to prevent it from swaying badly. Today the bridge, which was later strengthened with twisted wire ropes, is a sorry sight: it is falling apart, as are the buildings of the former paper factory. It is, however, still possible to make out the rudiments of the wire assembly. Further experience for the Tain-Tournon bridge was gained with the construction of a narrow footbridge spanning 30 m across the Galaure at St Vallier, which stood until 1844,[8] and a bridge across the Eyrieux between St Fortunat and St Laurent, the stone portals of which still exist.

Another footbridge with an experimental character was built roughly at the same time by Bruno Plagniol. His son François later wrote that it had been 18 m long and 90 cm wide and had crossed the River Payre near Chomérac. He omitted to mention that his father's bridge had been destroyed by a high wind soon after construction.[9]

Doubts were indeed voiced about the safety of this type of bridge. Seguin, who was a technician through and through, as well as a mechanical engineer and transport organiser, did not lack practical proofs, which he

Passerelle Saint Vincent, 1832, 75 m span



published in 1824 in *Des ponts en fil de fer* [On iron wire bridges]. That summer, work began on the Pont de Tournon across the River Rhône, for which the Seguins bore the full costs and risk. To stiffen the deck, they used the railings, designing them as trussed girders. Completed in 1825, the bridge was unfortunately demolished in 1965.

The first cable suspension bridge for public use, however, was built in Switzerland, by Seguin in cooperation with Henri Dufour. Seguin's ideas and experiences inspired and encouraged Guillaume-Henri Dufour (1787-1875) sufficiently to awaken his interest in the wire cable bridge.[1] On 1 August 1823, the world's first public bridge to be supported only by wire cables, the Pont St Antoine, was inaugurated by Dufour and Seguin in Geneva. With a width of 2 m and a length of 84 m, this footbridge was suspended from six wire cables across two bays of approximately 40 m each; it was calculated for a load of approximately 160 people and was guyed in several places to counteract deformation.

There were risks involved in building larger bridges for greater loads, because no tradition had yet been built up: no body of knowledge based on accumulated experience. For this reason, it is impossible to underestimate the importance of the publications, above all those by Claude Henri Navier (1780-1836), that cemented confidence in the new types of structure.[2] Articles about this type of bridge are few and far between, but to this day it is still producing beautiful footbridges in ever-new variations.[3] Joseph Chaley, a pupil of the Seguins, achieved a span of 273 m at an early date with his bridge across the Saane in Fribourg. He owed much to Louis Joseph Vicat's idea of weaving the suspension members from single wires in their final position on site, with the load distributed equally to each of this bridge's 1,056 wires. The importance of Vicat's contribution to the quality of wire cable production is undisputed.

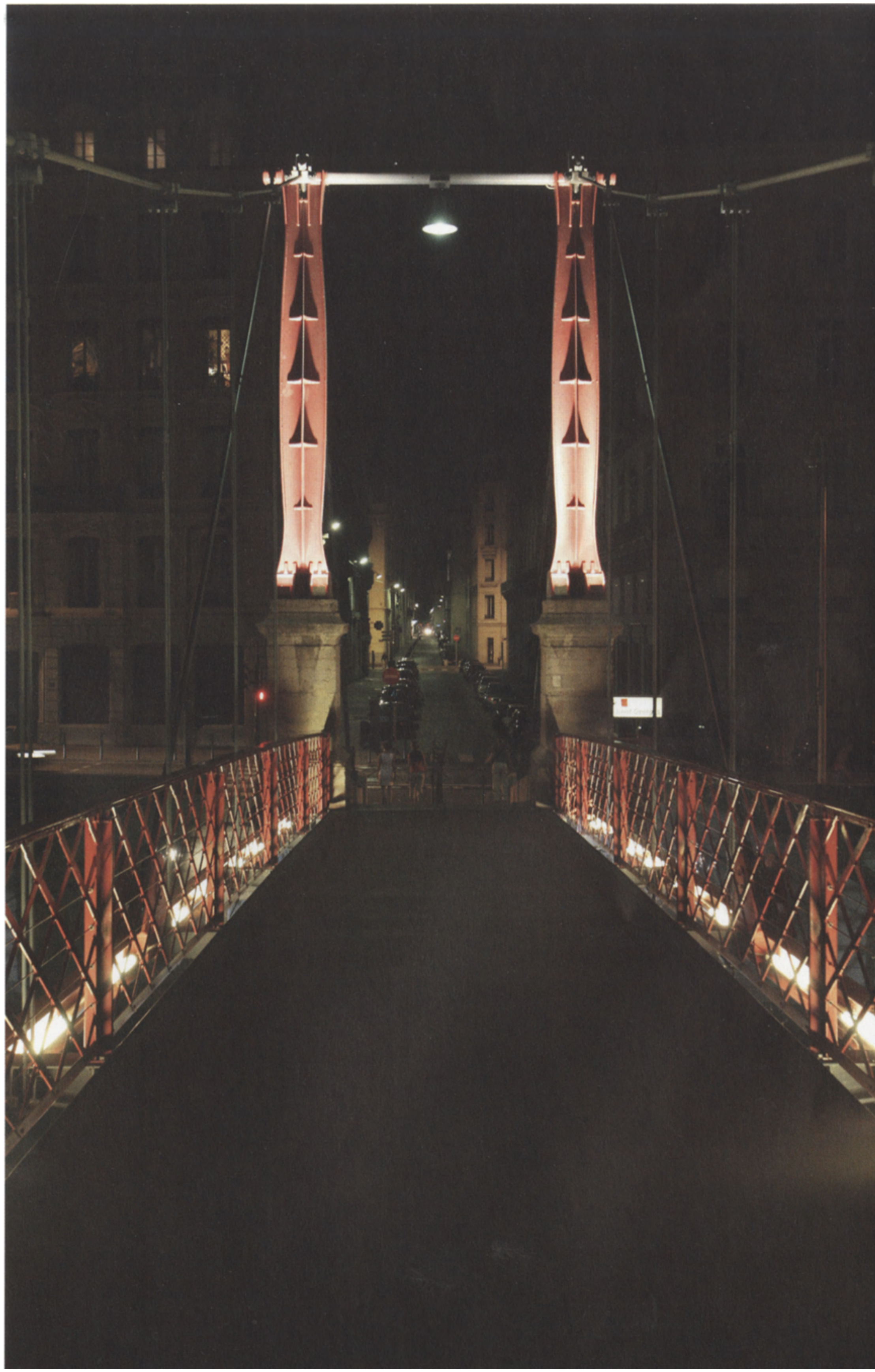
Throughout Europe, suspension bridges spread very quickly in the second half of the century. Giving examples here can only convey a small part of the history of bridgebuilding as we sketch it out country by country. To start with, we focus on Lyon, because the city at the confluence of the Rhône and Saône rivers was endowed with several historically significant footbridges over a short period. They include the Passerelle Saint Vincent of 1832, the Passerelle du Collège of 1844, and the Passerelle Saint Georges of 1852. The latter two suspension bridges were blown up by German troops on 1 and 2 September 1944, but they were reconstructed under the direction of André Mogaray after the war.[4]

The 2.8 m wide Passerelle Saint Vincent has connected the old part of Lyon with today's city centre across the River Saône since 25 October 1832, and it may be accepted as being the original structure. To the south of it are the Passerelle du Palais de Justice, a cable-stayed bridge from 1983-84, and further south the Passerelle Saint Georges, which delights the visitor with its beautiful proportions and its walled steps leading up to the columns on which the steel pylons stand. The Passerelle du Collège, which is suspended from two stone pylons that stand in the river bed, crosses the Rhône in the east of the inner city. Renovated in 1996, it has benefited greatly from vehicle ban on the banks of the Rhône, which have been landscaped as a pedestrian zone.

Lyon hosts a world-famous festival of light an so, as part of the revitalisation programme, light artists were commissioned to beautify the entire central district. Among other things, they designed dramatic night-time lighting schemes for the three aforementioned bridges, keeping in harmony with their familiar appearance by day. They have also managed brilliantly to avoid dazzling passers-by, or forcing them to inch their way forward in the dark, or otherwise disorienting them in the slightest.

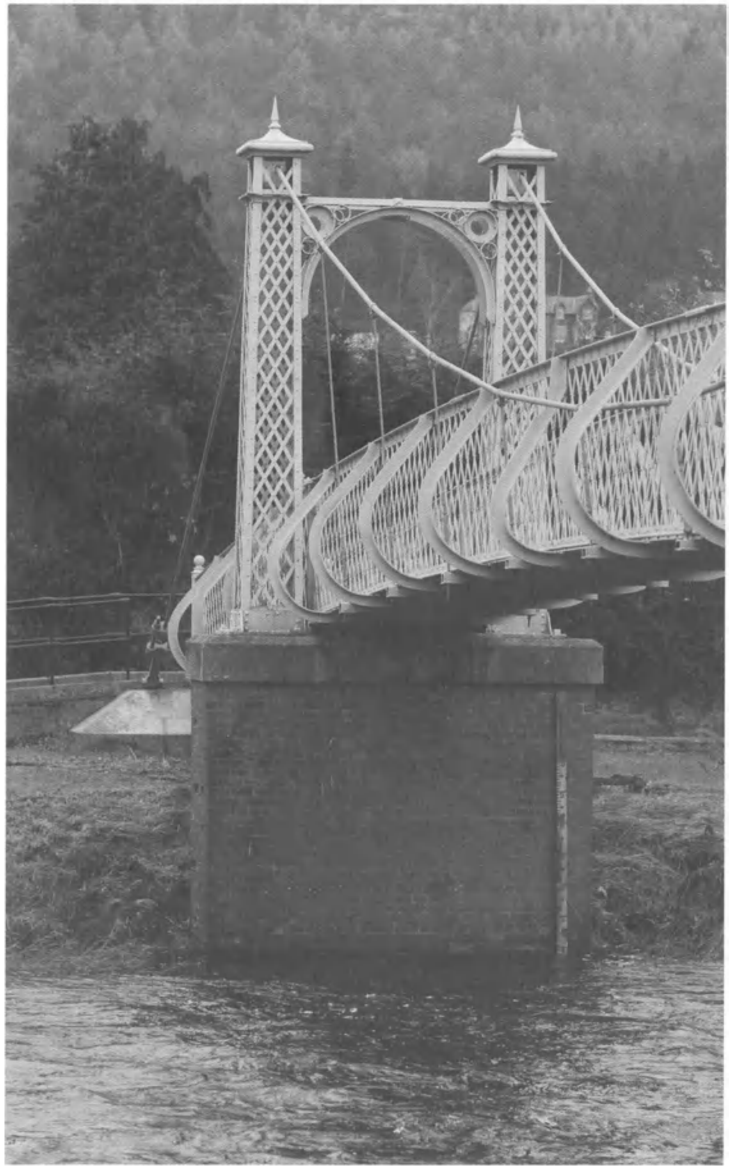
1 Marrey, 1990, p. 122; Peters, 1987, p. 70 f.
2 L'Art de l'ingénieur, p. 328; Pelke, 1987, p. 69
3 For a compilation of the first articles since 1807, see Peters, 1987, p. 69
4 Pelletier, Jean, Ponts et Quais de Lyon, Lyon, 2002, p. 21 f.

Passerelle Saint Georges, 1852, 87.5 m free span



Passerelle du Collège, 1844, main span 109 m, total 198 m

Peebles, 1905



Ilkley, 1934

The reasons why so many of the first cable bridges collapsed were (besides the as yet imperfect methods of static and dynamic analysis) that the iron wire produced at the time developed fatigue under alternating stress and was susceptible to brittle fractures, as well as being difficult to anchor. Furthermore, the comparatively flexible and lightweight superstructures were susceptible to vibrations. These problems were brought under control once tough and fatigue-resistant steels became available and the superstructures were sufficiently braced by truss frames, heavy deck girders, or additional guy cables. For the first half of the 19th century, however, the scepticism shown towards the new type of structure was not unjustified.

The leading country in the early years of cable bridge construction, after 1822, is considered to be France: estimates of the number built there vary from 300 to 500. In *England*, industry certainly developed to meet a wide range of applications, even though engineering received nothing like as much support there as it did in France.[1] The approach taken by British engineers can be described as practical and pragmatic; for building bridges, they placed their trust in chain systems rather than in novel wire cable. Charles Stuart Drewry (1805-1881) maintained that wire was impractical for anything that exceeded the scale of a footbridge.[2]

Of the early cable bridges known in Britain, most were in *Scotland*, where Richard Lee built an experimental wire cable bridge with a span of 34 m across the River Gala in 1816. This was followed by bridges across

1 Amouroux, Lemoine, 1981, p. 63; Peters, 1987, p. 144
2 Drewry, Charles Stuart, 1832, cited in Peters, 1987. p. 146; Kemp, Emory L., Samuel Brown: Britain's Pioneer Suspension Bridge Builder, 1977, cited in Peters, 1987, p. 37
3 Hume, John R., Scottish Suspension Bridges, Edinburgh 1977, cited in Peters, 1987, p. 38
4 Mehrtens, 1900, p. 75

Dumfries, 1875

Invercauld, 1924

the River Etterick and, in 1817, Kingsmeadows Bridge, which spanned 33.5 m across the Tweed near Peebles, as well as the first Dryburgh Abbey Bridge, by John and William Smith. At this point, the development of wire cable bridge construction ceased abruptly, only resuming after 1880.[3] However, the architectural vocabulary of the simple chain or cable-supported bridge then underwent a number of utterly incongruous variations. England and Scotland lacked a strongly rooted academic tradition in engineering – in contrast to the situation in France, where the engineering profession had the self-confidence to develop an aesthetic approach of its own. The archetypal suspension bridge with a stiffened deck girder was given an individual character by pylons with a historical touch, such as the columns and architraves added to the bridge of 1875 across the River Nith in Dumfries, neo-Gothic filigree work at Peebles in 1905 and Ilkley in 1934 (David Rowell Engineers), and castellated towers on the bridge over the River Dee at Invercauld in 1924 (James Abernethy Engineers). Here, it becomes evident that the approach to designing bridges was very much an architectural one.

The relationship between (engineering) structure and (architectural) details was a controversial subject that led to violent disputes internationally, as it still does. The design of portals was subject to some very odd flights of fancy indeed, which, in the case of larger bridges especially, attracted derisive comments from far and wide.[4]

The Lion Bridge in Berlin's Tiergarten, 1838, 17.3 m span

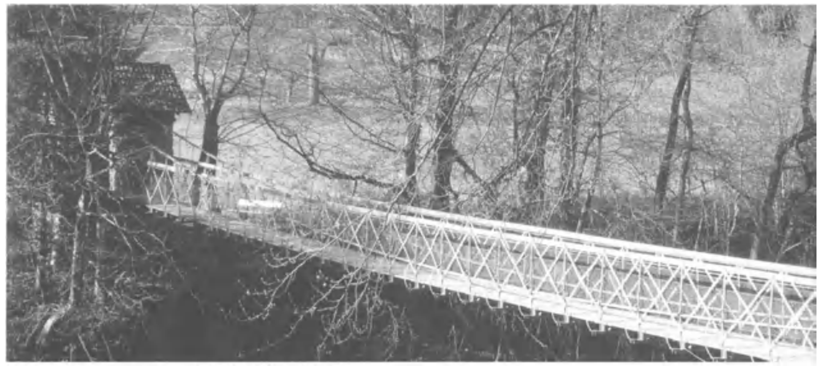
Suspension bridge construction in Germany progressed haltingly, as we mentioned earlier in connection with chain bridges. The sceptical attitude taken there towards suspension bridges was described clearly in 1900 by Mehrtens, who wrote that they were not able to carry the heavy railway trains of modern times safely, as the cable-supported bridge over the Niagara had shown.[1] All the same, the potential of iron wire, for example, was certainly recognized. Adolph Ferdinand Wenzeslaus Brix (1780-1870) was officially commissioned to carry out experiments using iron wire, the result of which was a small footbridge in Berlin's Tiergarten, the Lion Bridge (Löwenbrücke) of 1838.[2] Designed by Ludwig Ferdinand Hesse (1795-1876) and manufactured by the Borsig-Werke, it was a 2 m wide suspension bridge with a wooden deck, spanning 17.3 m. In 1958, it was restored and given protected monument status. Whether it was based on the Lion Bridge (Lavov most) in St Petersburg is not known for certain.

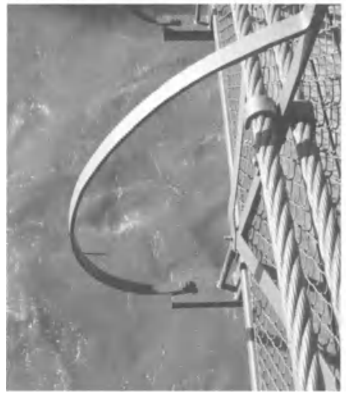
It was not until the end of the 19th century that the suspension bridge played a significant part in large-scale bridge construction in Germany. The designs entered for competitions increasingly featured suspension bridges and finally it was acknowledged that for distances of 200 to 300 m, suspension bridges could successfully compete with girder or arched bridges, "namely, when the site being considered is one at which (...) the beautiful appearance of the bridge is the main consideration."[3] In 1898, Kübler and Leibbrand built a cable bridge 6.2 m wide, spanning

1 Mehrtens, 1900, p. 31
2 ibid., p.5
3 ibid., p. 76

Wetter, 1893, 38 m span

Achberg, 1885, 48.6 m span





72 m, at Langenargen on Lake Constance. This shore-anchored suspension bridge was restricted to carrying pedestrian traffic in 1982-83. One of the people who originally worked on it was Othmar Hermann Ammann, then a trainee: the man to whom we owe the George Washington Bridge across the Hudson River.[4] Earlier, in 1885, a cable footbridge with a span of 48.6 m had been built across the River Argen in Achberg.

In many places, the value of old footbridges was not recognized - especially when they stood on private property, where gaining access was difficult or impossible. One of the earliest pedestrian suspension bridges, for example, which crossed the River Ruhr in its middle reaches, was built in 1875 on land belonging to a screw manufacturer near Hengstey. It was demolished between 1926 and 1928, when the property was sold to the regional water utility company.[5]

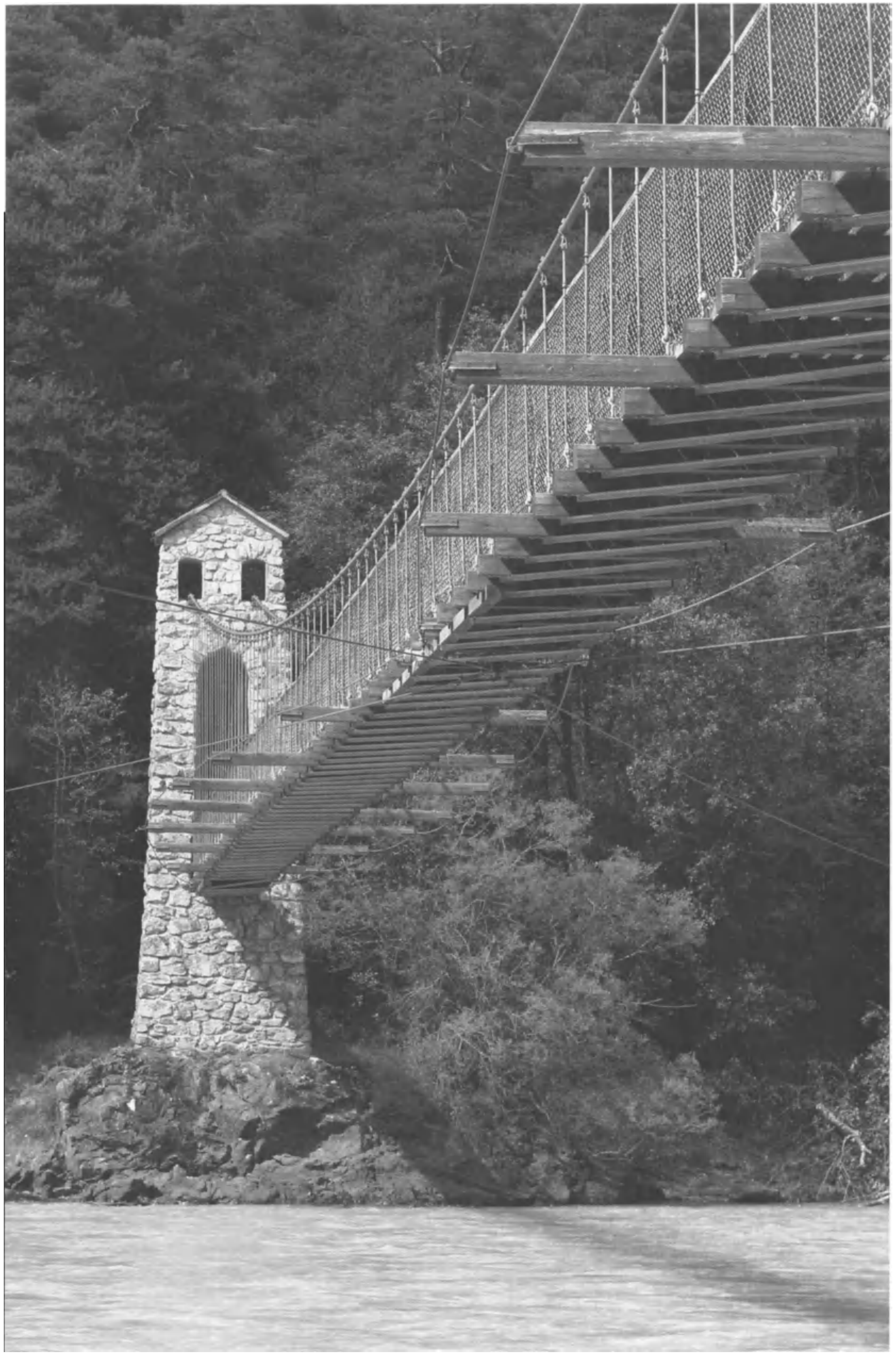
Another example is Am Kaltenborn footbridge in Wetter, North Rhine-Westphalia: a cable-supported bridge built in 1893 across the Ruhr with a span of 38 m.[6] The deck truss is suspended via hangers at intervals of 1.5 m from two wire ropes. The two pylons are truss frames 6 m in height, standing on rectangular masonry abutments. Although the bridge has been a protected monument since October 1985, it has not been looked after, and since 1990 it has been closed. In any case, this beautiful structure stands in a water catchment area, which it has been forbidden to enter since 1957. It seems that whenever somebody studies a waterway systematically, they come across pedestrian bridges that have languished in oblivion for reasons never to be known.

Our earlier comment about the difficulties faced by chain bridges also applies to wire cable and wire rope bridges: this type of structure made little headway in Germany, where bridgebuilding was dominated by arched or girder bridges made of iron and concrete.

It was not until the second half of the 20th century that Fritz Leonhardt, Frei Otto and Jörg Schlaich made outstanding advances in lightweight construction, including the use of cables. Jörg Schlaich, in particular, succeeded in building pedestrian bridges of a unique lightness that have been recognized as masterpieces throughout the world.

4 Mehrtens, 1900, p. 78; Schlaich, Schüller, 1999, p. 114
5 Schmitz, 2004, p. 313
6 Schmitz, 2004, p. 337 f.; Grunsky, E., Ein Denkmal der Ingenieurkunst Der Schulwegsteig in Hamm und die Entwicklung der Hängebrücken im frühen 20. Jahrhundert in Deutschland, in: Bauingenieur, 1995, pp. 507-514

Stams, 1935, spanning 93.7 m across the Inn



Lingenau, 1876, 37.20 m span

Whereas in England, France and Germany, the motivation for using iron and, later, steel to maximum effect in bridge building was provided by industrialization, the *Alpine region* was dominated by a certain pragmatism. Valleys and ravines had to be bridged for rural society to function, so efforts were concentrated on perfecting wooden bridge construction. Things changed in the latter half of the 19th century, when many fascinating small suspension bridges were built. A journey up remote valleys in search of footbridges will usually produce results – it is no accident that Switzerland views its landscape and cultural identity partly in terms of road and bridge building.

Regrettably, only a few of the many pedestrian bridges still in existence can be shown here. Many of them lie off the beaten track, where they are certainly shown off to advantage by their beautiful surroundings, with breathtaking panoramas and dramatic chasms. Moreover, a virtue was often made of the need to build simply, resulting in ingeniously conceived structures such as Kanzler-Dollfuss Footbridge in the Austrian village of Stams. At one time, it was threatened with demolition to make way for a motorway, but the local community successfully prevented this.[1] The bridge, which spans 93.7 m and is only 1.1 m wide, is suspended from two wire ropes; its wooden cross beams project from the deck to a varying extent, their tips following a curve on plan from the bearings to the centre of the bridge. Into their ends are screwed U-shaped iron profiles, through which a tension cable is threaded, cleverly stabilizing the structure.

Only one person at a time was originally permitted to cross the 82 cm wide catwalk across the Subersach in Bregenzerwald near Egg and Lingenau. Initially suspended from four wire ropes, with bracing in each

1 Lang, Maria-Rose, Geschichte der Brückenbautechnik, dargestellt am Beispiel von Hängebrücken aus Vorarlberg und Tirol, in: Industriearchäologie, Innsbruck, 1992, pp. 161-171
2 ibid., p.163
3 ibid., p.165


Doren, 1914, 76 m span


Hittisau, after 1885, 30.6 m span

bay between the hangers, it did not exactly perform well in a loading test that was carried out in 1908 with 30 sheep and, after that, up to nine people. Since then, the main suspension ropes have been replaced, and in 1988 the bridge was renovated in an exemplary manner.[2]

Another small footbridge dating roughly from the second half of the 19th century crosses the River Bolgenach between the village of that name and Hittisau. With a span of 30.6 m and a width of 86 cm, it can be classed as an archaically simple structure, as the detail of the vertical suspender bar shows all too clearly. This simplicity was carefully retained when the parish of Hittisau had the bridge repaired in 1985 – nowadays it is constantly in use, as it lies on a trekking route.[3]

The bridges are maintained by the regional governments of Vorarlberg and Tyrol. The appreciation of bridge culture in lower-lying regions is demonstrated by other examples, such as the Doren-Alberschwende wire rope footbridge of 1914 and the Langen-Buch wire rope footbridge of 1905 – both across the Bregenzerach. Some of the details are stunningly simple, although it would be highly inadvisable to imitate them and not all of them would satisfy current regulations. They deserve high praise nonetheless – and not just on account of their historical value. Local indigenous building prefigured many inventions that supposedly date from more recent times. In an astonishing number of classic footbridges, one is impressed by the use of chain-link railings, which improve the transparency and the damping of a bridge, lightweight translucent gratings for flooring, and the consistently minimized use of material in lightweight construction. The engineers of today, equipped with powerful computers and the best analysis methods, can only take their hats off to their forerunners in admiration.

Ardez, bridge over the Hinterrhein, c. 1890

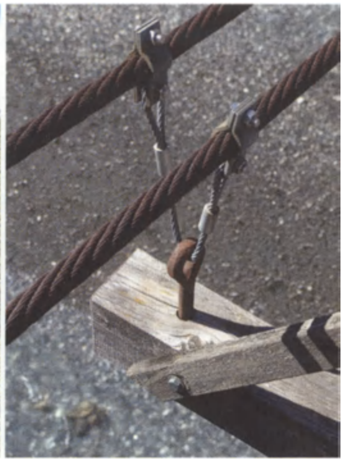
Simplicity is also to be found in *Swiss* suspension bridges. Charming small bridges along today's hiking routes may not be an undiluted pleasure for those without a head for heights, but of course they are all completely safe. One of Switzerland's first wire rope bridges was the Gwaggelibrugg in Neuenhof, near Wettingen Abbey, completed in 1863. Its suggestive name (Wobbly Bridge) was no coincidence, and when it was restored in 1981 clearly recognizable measures were taken to strengthen it.[1]

Engineering students in Zurich benefited from the presence of Karl Culmann (1821-81), the founder of graphic statics, and his successor Karl Wilhelm Ritter (1847-1906), also a brilliant teacher. Graphic statics, which made it possible to visualize basic structural behaviour, thus formed the basis of structural design in Switzerland, producing bridges that were unequalled anywhere in the world.[2] This fortunate academic constellation seems to have borne fruit almost everywhere in practice, especially because engineering work (for example, on the Gotthard and Rhaetian railways) was generally recognized as being important for Swiss identity and was ultimately in line with the aims of the Swiss heritage movement.

Beside the very simple walkways, like the one in Ardez across the River Inn, and the refined ones, like that across the Hinterrhein at Thusis, there were suspension bridges built to a relatively high standard, as at Corcapolo, Frasco and many other places. The Sils footbridge, near Thusis, was built by Richard Coray (1869-1946), who was not an engineer at all, but an experienced carpenter. He constructed and even designed falsework for the many of the most important bridges, such as the

1 Inventar Historischer Verkehrswege der Schweiz, AG 158.0.1, ed. Cornel Doswald
2 Lehmann, Christine, and Bertram Maurer, Karl Culmann und die graphische Statik – Zeichnen, die Sprache des Ingenieurs, Berlin, 2006

Thusis, 1925, suspension bridge over the Hinterrhein



Corcapolo, bridge over the Melezzo in Switzerland

Salginatobel Bridge. The structure of the bridge near Thusis, from 1925, was designed in such a way that individual components could be replaced without much difficulty over the years – an idea that was picked up by Jürg Conzett when designing his first Traversiner bridge (see p. 122).

Two new projects prove that the range of possibilities open to designers of suspension bridges has by no means been exhausted, even in Switzerland. One of them is Jürg Conzett's Traversiner bridge II near Rongellen (see p. 212) and the other is Walter Bieler's long-span suspension bridge in the Grisons, which has, however, yet to be built.


Chazelet, St. Benoit, 1875

Offenbach, Dreieichpark bridge, 1879


Düsseldorf, exhibition bridge, 1880, 12 m


Toulouse, Passerelle des soupirs, 1902, 42 m



Bremen, bridge by G. Wayss, 1890, 40 m


Saintes, Charente-Maritime, Poitou, 1926-27

Concrete

Although the early chain and cable-supported bridges coped equally well with long spans and high loads, dedicated amateurs (yet again) were busying themselves with the possibilities offered by another material. The search for mortars that would set underwater had intensified as early as the mid-18th century, owing largely to John Smeaton, who was building the Eddystone lighthouse off Plymouth. After 1810, explanations of how and why different binders work as they do were found roughly at the same time by a German chemist, J.F. John, and a French engineer, Louis Joseph Vicat, working independently of one another. In 1818, Vicat published the practical knowledge of this subject that he had gained while building a bridge across the Dordogne in Souillac.[1] Patents for new binders were taken out very quickly: by John Aspdin for Portland cement in 1824; by Joseph Louis Lambot for ferrocement in 1848 and by François Coignet for *béton aggloméré* (a compact concrete) in 1847. The great drawback was that this promising construction material possessed negligible tensile strength. Lambot tried embedding iron mesh in concrete early on, but when he showed the results at the 1855 World's Fair in Paris, they attracted little attention.[2] Of greater consequence were the experiments carried out by Joseph Monier (1823-1906), a gardener, who was granted his first patent in 1867 for plant pots made of concrete with iron wires laid inside it. This was extended in 1873 to cover bridges, walkways and vaulting. In 1875, Monier built the world's first reinforced concrete bridge on the estate of the Marquis de Tilière at Chazelet. Spanning 16.5 m across the castle moat with a 4 m width, it was supported by narrow concrete beams reinforced with thin, round iron rods.[3] Strictly speaking, it was not merely a footbridge.

The potential of combining iron and concrete was soon recognized, and in the decade from 1880 to 1890, patents followed one another in quick succession. Bridgebuilding played an experimental and – in view of the fact that development was coupled with commercial success – a new, demonstrative role. In 1879, an arched footbridge with a 16 m span was built in Offenbach's Dreieichpark by a local Portland cement factory, Feege & Gotthardt. This had been conceived as a temporary structure for advertising purposes, but it was left standing anyway. In the 1970s, its foundations and prestressed bands were repaired, and in 2007 it underwent a complete renovation. Fortunately, it has been restored to its original state, without railings, so the elegance of the small arch is once more evident.[4] One year after the Offenbach bridge, Dyckerhoff & Widmann built a small, stepped bridge at the 1880 trade and art fair in Düsseldorf. Spanning 12 m with a rise of 2.25 m, its arch was lavishly decorated in a historicist style, with a baldachin-like structure at the centre.[5] Another temporary, experimental structure was built for the Swiss National Exhibition of 1883 in Zurich: the Devil's Bridge, which spanned just 6 m and was only 10 cm thick at the crown.[6] It was followed in 1890 by a prototype bridge in Bremen with a 40 m span and a crown thickness of 25 cm.[7]

Mathias Koenen's (1849-1924) brochure on Monier's system, published by Gustav Adolf Wayss (1851-1917) in 1886, provided a theoretical

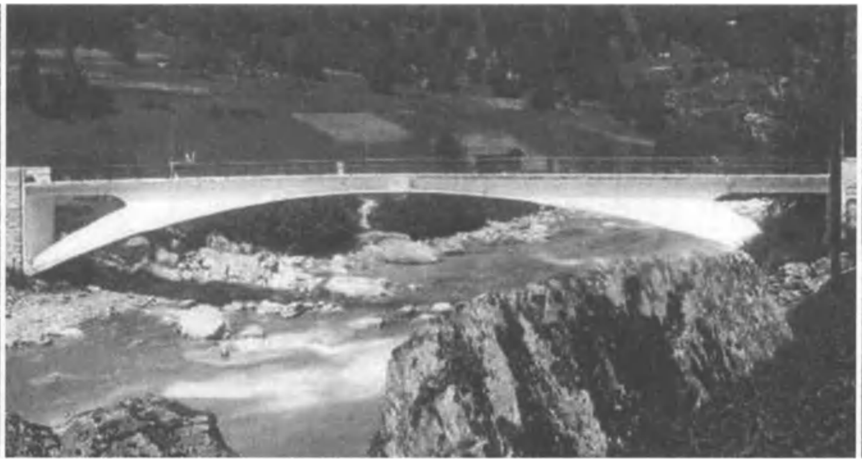
1 Stiglat, 2005, p. 57
2 Marrey, 1995, p. 28
3 Stiglat, 2005, p. 58;
4 Küffner, Georg, in: FAZ, 6.2.2007
5 Stiglat, 1995, p. 26
6 Schindler-Yui, 1995, p. 182
7 Troyano, 2003, p. 318f.; Straub, 1992, p. 259f.

basis for using reinforced concrete, but this was still far from a breakthrough in construction practice. "Le béton restait un matériau suspect" (Concrete remained a suspect material) was the sobering conclusion noted down about a small concrete bridge, 3.5 m wide with a span of 39 m and a crown thickness of just 23 cm, that was built in the grounds of the Wildegg cement factory in 1890.[8] In 1893, François Hennebique (1843-1921) was granted the first patent for his T-beam system, which Gustave Quintin used in 1902 to build the Passerelle des soupirs (span 42 m) across the Canal du Midi in Toulouse.[9] The new construction material needed continued promotion and research, which led Hennebique to found *Le Béton armé* in 1898. The journal contributed to the international dissemination of ideas and knowledge about concrete. In Germany, the main focus of interest was on methods of calculation. One milestone was the calculation method published in 1902 by Emil Mörsch. A small footbridge was built for the 1905 world fair in Liège, followed by the Schwarzenberg bridge in Leipzig in 1913. Saintes (Charente-Maritime, Poitou) in France acquired a new concrete footbridge in 1926, while in 1929 Cholet (Maine-et-Loire) was given a concrete footbridge in the form of a Vierendeel girder spanning 16.4 x 30.7 x 30.7 x 19.2 m.[10]

Also worth mentioning is an arched concrete bridge from 1939 in Bilbao, one of the first where the arch itself is used as a footway to access a second, lower level at the bearing of the bridge.

8 Marrey, 1995, p. 31; Brühwiler/Menn, 2003, p. 8; Troyano, 2003, p. 318
9 Marrey, 1995, p. 34
10 Marrey, 1995, p. 94


Nessental, 1931




Tösssteg in Wülflingen near Winterthur, 1934

Robert Maillart

Nowhere were form and structure combined with such unique elegance as in the bridges of Robert Maillart (1872-1940) in Switzerland. Maillart's teacher at the Eidgenössische Polytechnische Schule in Zurich, Wilhelm Ritter, awakened his students' interest not only in function, structural stability and economy, but also in form.[1] After receiving his diploma in 1894, Maillart worked in other practices for eight years, before setting up his own business in 1902 in order to specialize in reinforced concrete construction. He closed the business in 1919, but found other outstanding construction companies, with which he worked well. Maillart became the father of a particular bridgebuilding tradition and, thanks to the Salginatobel bridge, he enjoyed worldwide acclaim as an engineer. The underlying reason why this relatively modest project produced such an influential result was the logical way in which Maillart's design took into account all of the bridge's components. This approach was evident beforehand in a small, unassuming beam footbridge, the Triftwassersteg of 1931 in Nessental near Gadmen: a simple T-beam of reinforced concrete, 1.5 m wide, with a span of 21 m.[2]

With the Tösssteg of 1934 near Wülflingen, Maillart succeeded, together with W. Pfeiffer, in creating a monolithic concrete structure that was, moreover, without "abutments that frame the loadbearing structure and separate it from the terrain. Leaving them out seemed just as revolutionary as building a house without a plinth."[3] Instead, they built a slender polygonal arch bridge (rise-to-span ratio = 1:10.84) with a stiff deck girder that also formed a base for the iron railings. The elegance of the 38 m arch impressed Max Bill, who wrote: "The structure is of a lightness of appearance and an appealing naturalness, as though it had grown here by itself and had sought a way across the river."[4] The arch slab and the cross walls are each 14 cm thick and the stiffening girder is 54 cm thick. Thanks to a slight reverse curvature at both ends, the transition to the shore is especially elegant. In comparison to the footbridge of 1931 in Ladholz,[5] which sadly has been destroyed, the Tösssteg seems like a quantum leap: the sculptural energy that was so important to Maillart is strikingly evident. In 2004, the bridge was renovated, unfortunately using an opaque paint that conceals the material nature of the concrete arch, while barriers were inserted at both ends, making a mockery of Maillart's efforts to achieve a smooth transition between the bridge and firm ground. At one end, which leads to a busy road, the need for some sort of safety measure is understandable, but at the other end it is not; in any case, it is clear that more attractive designs for barriers need to be found.

Maillart's small pedestrian bridges are excellent early examples of his contribution to finding forms for concrete (reinforced with iron or steel) that are appropriate to the material. One decisive step towards improving structural performance was yet to come: prestressing. Towards the end of the 1920s, Eugène Freyssinet received his first patent for this principle, which he made known in the 1935 lecture *Une révolution dans les techniques du béton*.[6] The possibilities that prestressing opened up for constructing large bridges were exploited in earnest after the Second World War by Ulrich Finsterwalder and Fritz Leonhardt. The next section of this book, which focuses on individual projects, begins at this point in time.

Although this review of the history of the footbridge has been a brief one, a large part of the structural, formal and functional variety of this type of structure is already evident. Above all, the fact that engineers and architects have repeatedly used this brief as an opportunity to experiment explains the sheer range of examples – one that extends yet further after the mid-20th century, as is illustrated by footbridges from all over Europe.

1 Menn, Christian, Preface Billington, 1990, p. IX
2 Bill, Max, 1955, pp. 76-77
3 Maillart, Robert, Einige neue Eisenbetonbrücken, in: Schweizerische Bauzeitung, 11. April 1936, p. 157f.
5 Bill, 1955, pp. 72-73
6 Brühwiler, Menn, 2003, p. 24

Tösssteg, photos from 2006

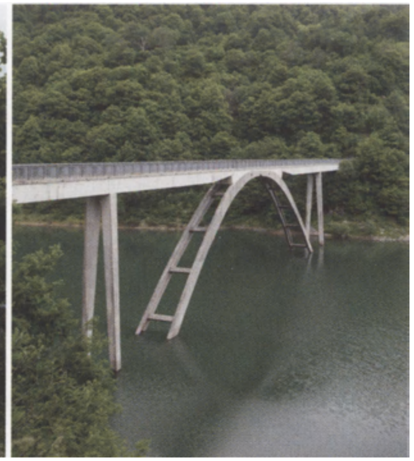
Construction as an Ethical Maxim

Enough of Action. We want promises. *Eduardo Galeano, In Praise of Courage*

The two world wars certainly created a caesura in architectural history, but the theory that things began entirely from scratch in Germany after the Second World War has long been discredited among architectural historians. In structural engineering, the question seems hardly to have been addressed. While the architects – not just in Germany – were debating political entanglements and the architectural expression of totalitarianism, the structural engineers maintained a steadfast silence. After the war, many German engineers carried on working in much the same way as they had beforehand. Franz Dischinger (1897-1953) died comparatively young, but others, such as Ulrich Finsterwalder (1897-1988), Hubert Rüsch (1903-1979), Gotthard Franz (1904-1991), Hellmut Homberg (1909-1990) and Willi Baur (1913-1978) unquestionably provided continuity in the world of structural engineering as it became increasingly internationalized. For Anton Tedesko (1903-1994), who worked for many years in the USA, Ove Arup (1895-1988) and Fritz Leonhardt (1909-1999), it became a matter of course to build in other countries.

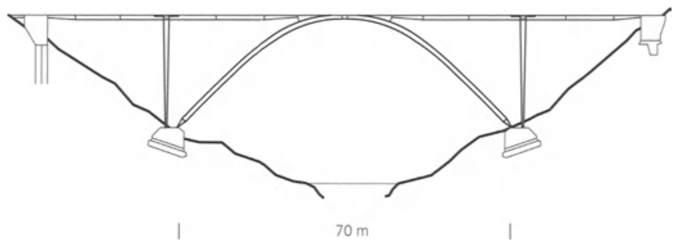
However, form and expression, functional structural criticism and the political aspects of engineering construction were seldom debated in the 1950s and 1960s. These were the years of Germany's economic miracle, in which large bridges, especially, embodied technical progress and the triumph of mobility as a consequence of freedom and affluence, which, for the time being, was not called into question. The argument that engineers had a responsibility to society was put forward at length by Fritz Leonhardt, in particular, who like Fritz Todt had already seen cooperation with architects (Tamms, Bonatz) as self-evident in earlier times, under the National Socialists. Leonhardt liked using terms such as "beauty" and "elegance" and with these two categories (which were never precisely defined) he combined a general ethical approach that had a rationally argued commitment to the wellbeing of the community. Individualism did not have a dominant role. A masterful sureness of touch in choosing the right construction was supposed to result in a good, attractive form, as if of its own accord.

Formal restraint was considered to be a virtue; monumentality (which Paul Bonatz still thought right on occasion) was avoided as far as possible, while formal quality was expected to result from working closely with the architect. Designing loadbearing structures according to the logic of statics and construction seemed to be an ethical requirement. Their aesthetic evaluation was not considered systematically for quite some time. A panel discussion about the Olympic buildings in Montreal, which concluded a congress of the IASS in July 1976 and is documented in Civil Engineering-ASCE 12/1976, mentioned a fatal development, namely, that insecurity was leading engineers to slip ever more frequently into the role of mere constructors, serving architects who designed however they liked. The relationship between architects and engineers still remains controversial. As far as footbridges are concerned, however, all was still more or less well in the engineer's world, as the following pages show.



Bridge in Vagli di Sotto near Lucca, Italy, 1954

During a discussion of Maillart, Nervi and Morandi, Philip Johnson remarked that Nervi certainly created the most beautiful roofing structures in the world, but Riccardo Morandi deserved the greater respect as he applied more care to the fundamentals of design and had thereby created wonderful bridges with the most beautiful structures. Riccardo Morandi (1902-1989) founded his own office at the age of 29 and began to work closely with construction companies. Morandi strove to learn the practical aspects of construction and technology of concreting as efficiently as possible. These issues were at the heart of design at that time. It is these two primary interests that truly come together in the pedestrian bridge in Vagli di Sotto. Both halves of the bridge were constructed with-out supporting scaffolding but were constructed vertically and rotated into place. The arch haves are joined together at keystone of the arch with a pinned connection. The elegant bridge is 40 m high and spans a narrow section of a reservoir. The arch span is 70 m. The keystone joint is almost capriciously staged; the deck girders become thinner and thinner as they approach the bearing and lie like pick-up sticks on point supports. This, along with the already extremely slender structure, creates an almost fragile visual impact. At almost the same time and with the same spectacular erection procedure, Riccardo Morandi built a stiffened polygonal arch bridge with a 100 m span over the Storms River in South Africa. The high Vagli di Sotto footbridge has a fantastic setting in the Tuscan landscape, and its reflection in the still waters of the reservoir is fascinating.



Boaga, Giogrio, Riccardo Morandi, Bologna 1984, Troyano, 2003, p. 290; Strutture di calcestruzzo armato e di calcestruzzo precompresso, 1954

Enzsteg in Vaihingen, Germany, 1962

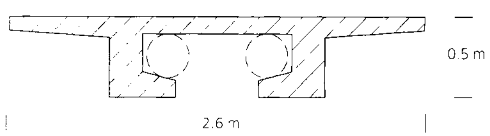
The narrow, 2.6 m wide concrete arch footbridge spans 46.2 m and was originally designed as a pipe bridge. To link utility with beauty, the city administration decided to cover the waterpipes with a deck for pedestrian and bicycle traffic. Fritz Leonhardt, one of the most experienced experts in reinforced concrete, was commissioned to design it, in cooperation with the architect Paul Bonatz, and later Gerd Lohmer; they produced a reasonable structural design while respecting the aesthetic demands of the bridge.

Enthralled by Eugène Freyssinet's article "Une révolution de l'art de bâtir", Leonhardt visited him in 1943 and quickly recognized the potential of the composite material, which had not yet been exploited. While the scientific and technical work with reinforced and prestressed concrete was being carried out in France and Switzerland, Leonhardt's book *Spannbeton für die Praxis* became a work of "towering importance" (Christian Menn).

During the construction of the Enzsteg, Leonhardt's ambitions lie in designing a slender arch bridge – a small structure of impressive elegance. The cross section is a plate girder with two webs and flanges for the pipes. The slab is only 50 cm thick at the keystone. With the deck cantilevering 75 cm to the side, the first visual impression is of the 12 cm thick cornice as a wafer-thin arch over the Enz. At the left abutment, three prestressed anchors transfer the arch thrust to the underlying rock, 6 m below the terrain. The opposite abutment is a "back pack bearing" founded directly on the rock and providing a walking surface.

The bridge has remained completely undamaged. The steel railings – which were originally red – have occasionally been painted, and an abrasive coating was recently added to the walking surface. Leonhardt had originally smoothed the concrete walking surface and refused the additional surfacing. Apart from this, the footbridge is unchanged to this day and bears witness to Fritz Leonhardt's original design intentions: to create technically appropriate construction as elegantly as possible. Leonhardt's small footbridge is the incarnation of his understanding of his career, with the realization of the ethical responsibilities of the design engineer.

In the meantime, trees and vegetation have grown along both riverbanks, so that the lengths of the abutments are hidden. This leaves the visual impression that the footbridge is floating in the surrounding environment. This change remains in harmony with the design.


0.5 m
2.6 m

Schiersteiner Footbridge, Wiesbaden, Germany, 1961

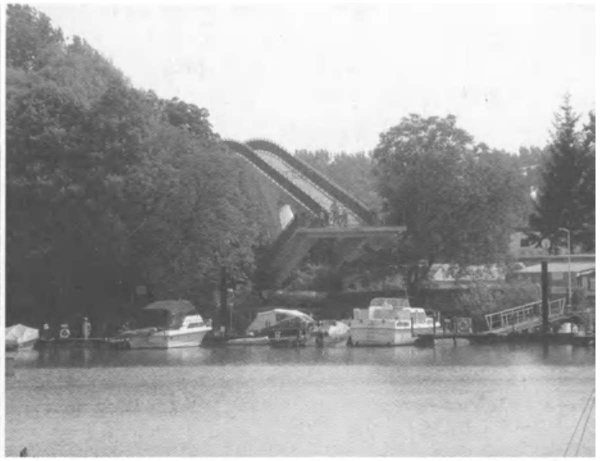
In 1964, as Dyckerhoff Cement Works celebrated their 100th anniversary in Wiesbaden-Amöneburg, the company offered to construct a pedestrian bridge over the entrance to the port of Wiesbaden-Schierstein as a gift to the city of Wiesbaden. The bridge was conceived to complete a pathway that had been interrupted for decades and leave the Rhine riverbanks even more scenic than ever: the bridge should become a landmark. The Schiersteiner Footbridge may be considered a pioneering accomplishment from a structural standpoint, which began an era of bridge design history in the mid 1960s. The footbridge is a product of industrial development during Germany's economic boom years, when technical advances were necessary to keep ahead of the competition. Although the technical advances of the structure were not classified, they were not freely advertised. The only informative publication on the structure appeared in a 1967 internal Dywidag report.

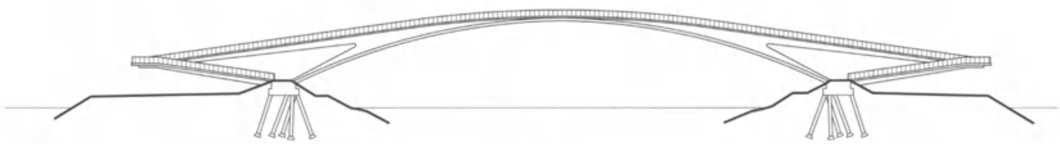
The first designs for the bridge were conceived in the Wiesbaden branch of the company in 1964. In the Munich office of Dyckerhoff & Widmann, Ulrich Finsterwalder – one of the leading engineers of the time along with Fritz Leonhardt – learned of the ambitious plans and the marketing importance of the project. As it was intended be something extraordinary and formally challenging, Finsterwalder sought the counsel of his friend, the Cologne architect Gerd Lohmer, as he often had before. Meanwhile, the challenges had multiplied. The cement works hoped to demonstrate the advantages of lightweight concrete in bridge construction – a development that was already further advanced in the USA. Finsterwalder (1897-1988) led the construction office of Dyckerhoff & Widmann in Munich, a position he took over from Franz Dischinger in 1932. He would use the opportunity to develop free cantilevering construction in lightweight concrete, so as not to disrupt ship traffic during construction. Finsterwalder enjoyed worldwide recognition for his bridges in Balduinstein and Worms, constructed in the 1950s using the free cantilever method. Lohmer had studied architecture in Stuttgart and worked from 1936 to 1942 with Paul Bonatz; he concentrated on the emblematic, attractive form and probably designed the layout of the pathways and cantilevering ramps and spiral landings.

For the first time, white, high strength lightweight concrete LB 300 would be used for prestressing concrete in free cantilever construction. Normal-weight concrete was chosen for the ramps and lower arches. The arch itself did not need to be prestressed, but the cantilevering ramps and podiums required prestressing. They sit piggyback on the arch as triangular trusses. The upper ramp acts as a tension member, while the ramp pair below acts as compression struts. The deck slab is around 3 m wide and rises to a height of 16 m above the waterline. The arch rise is 12 m

Experiment in cantilevering construction

Spiral landings become viewing platforms





with a span of 96.4 m. The wind forces are transferred to the abutments by a 50 cm thick lower flange, with a width of 1.5 m at the midspan and 3.0 m at the supports.

Lightweight concrete seemed a logical solution, as its weight was only a third of that of normal concrete. The tonnage of prestressing steel was 20 percent lower than for normal concrete. The LB 300 concrete quickly reached sufficient strength to allow two segments to be concreted per week. Special attention was paid to the anchorages of the prestressing steel and the creep and shrinkage properties of lightweight concrete. Experiments showed that these properties differed little from normal concrete. But the Young's modulus of the concretes varied greatly, with 17,000 N/mm^2 for LB 300 and 30,000 N/mm^2 for normal concrete. This resulted in differing deformations of the material. The dynamic behaviour of the structure during construction was also studied; in service, the three pin-jointed arch structure is very stable.

In 1967, the Schiersteiner Footbridge, with a span of 100 m and a 64 m long segment in lightweight concrete, was the longest lightweight concrete bridge in the world. Competition pushed rivals to further technical developments – market shakeout as it is called today – but they were unable to find a more economic system. The Schiersteiner Bridge provided the first experience with new materials from which the Dyckerhoff Cement Works and the construction office of Dyckerhoff & Widmann in Munich benefited. Larger spans in lightweight concrete were first possible in the 1970s, with the pedestrian bridge over Lake Fühling in Cologne, followed by the second Deutzer Bridge over the Rhine in 1979, a prestressed lightweight concrete roadbridge with a span of 184 m.

Alsen, Klaus, Die Dyckerhoff Brücke in Wiesbaden-Schierstein, in: Dywidag Berichte, 5, 1967, pp. 1-6
Wittfoht, 1984, pp. 262-264
Baus, Ursula, Der zweite Blick: Schiersteiner Steg in Wiesbaden, in: DAB, 12, 2005, pp. 22-23

Kingsgate Bridge over the Wear in Durham, UK, 1966

After deciding to change field of study from philosophy to civil engineering, Ove Nyquist Arup (1895-1988) chose reinforced concrete design as his specialization at the Polytekniske Lereanstalt in Copenhagen. Reinforced concrete, the preferred material for the classical modern, is also used in this footbridge, the Kingsgate Bridge over the Wear. The bridge would be the last structure that Ove Arup would design himself. Arup founded his own office in 1946 and developed his multifaceted talent to become the most successful engineer of his generation. Arup was born in 1895 and was not much younger than Dischinger or Finsterwalder. Arup benefited greatly from his sophistication, comprehensive skills, and his early realization of the fruitfulness of cooperation with architects.

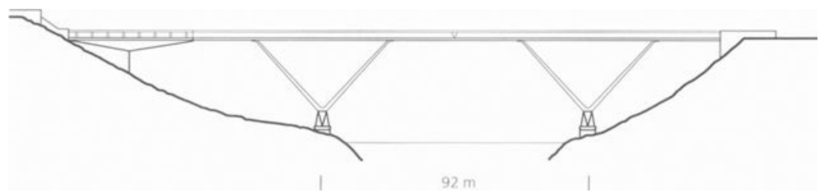
Ove Arup considered this bridge to be one of his favourite structures, as he later managed of the daily work of his office and was seldom able to design himself. His talent lay in his ability to lead his team as he recognized that good architecture is only possible when the owner's, engineer's, architect's and contractor's interests are coordinated. His work was – typically or almost stereotypically for his generation – given an ethical connation: design should be "logical", true and honest, natural, economical and efficient. Ove Arup, like Fritz Leonhardt, did not attempt to explain the motto "Truth and honesty in design", but his well thought-out designs were appropriate to the materials and forces, and seemed to suffice as explanation.

The 31 m long bridge is impressive not for its span, but for its courageous form that makes us appreciate the role of truth, goodness and beauty in design. The double V-formed supports cantilever high above the riverbed to reduce the span of the bridge effectively. The capricious detail of the joint between the supports and the deck girder almost resembles a butler's hand carrying a tray. The path layout is particularly interesting; a pedestrian approaching from the city is offered a view of the underside of the structure. This would be impossible for the straight approach, so that it was necessary to create a kink in the path. In addition, a light descent at the bridgehead theatrically exaggerates the pathway.

The erection procedure was unique and differed from Riccardo Morandi's construction methods for Vagli di Sotto footbridge in that the two bridge halves were fabricated on land parallel to the riverbank and then lifted onto the supports.

Ove Arup and Partners 1946-1986, London, 1986, pp. 158-161
Troyano, 2003, p. 379 and p. 472

The path leading to the campus is 37 m above the river

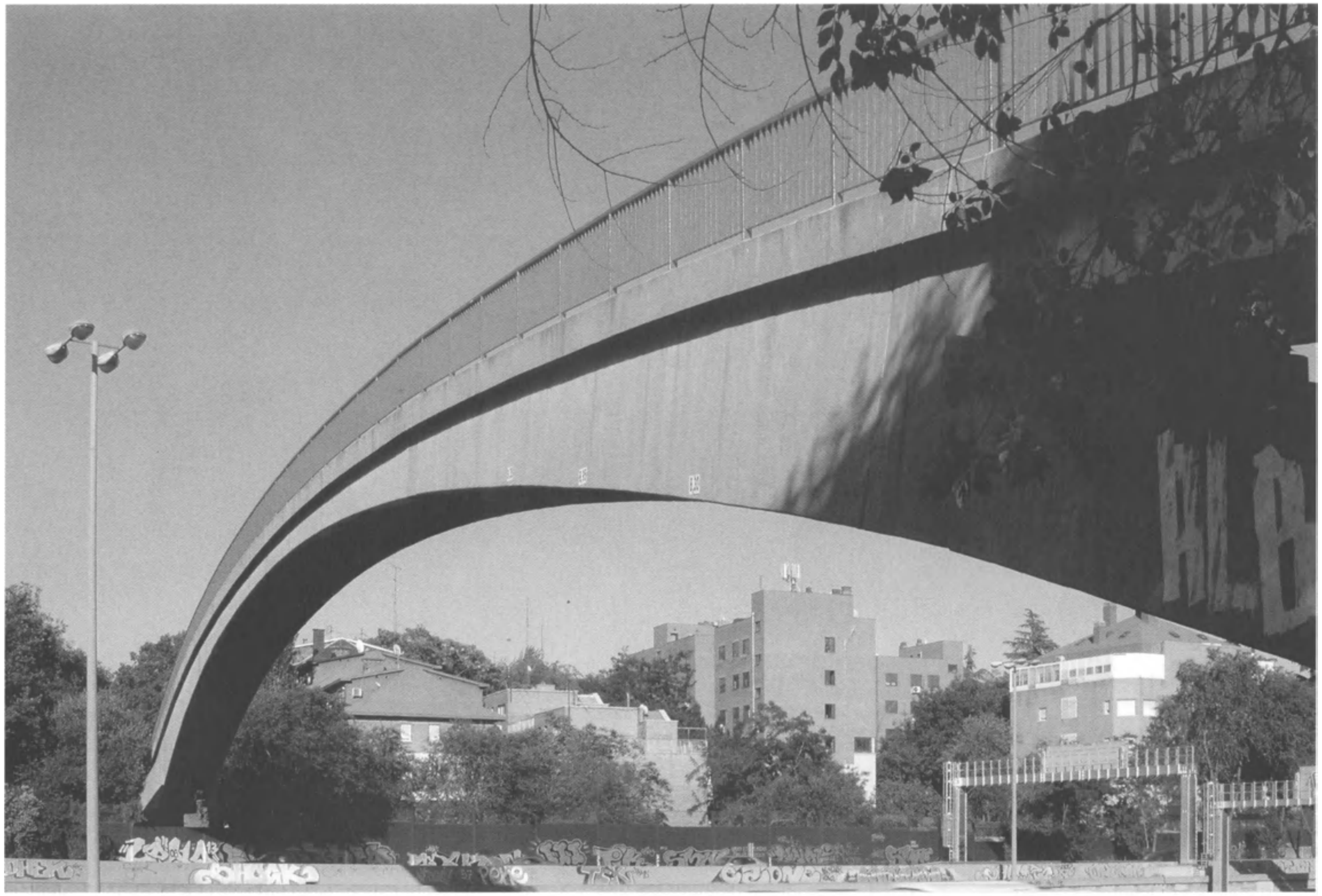


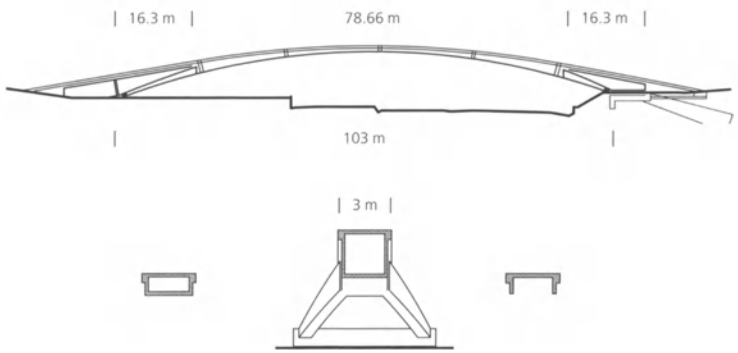
Arch bridge over the M30 motorway in Madrid, Spain, 1979

Most European cities expanded at an incredible rate during the post-war economic boom in Europe. The resulting increase traffic has led to highways in urban areas that can be called unfriendly at best for pedestrians. On example of this is the M30 motorway in Madrid, which has cut a gash in the urban texture to the west of the city centre. Only after completion of the motorway was it decided to build two pedestrian bridges over it. The footbridges were to span 80 m without intermediate support in order to join the neighbouring residential areas. The bridges were to be built quickly while minimizing the disruption to motorway traffic, but had great aesthetic requirements, as the city wanted to create a good impression from the motorway. José Antonio Torroja, son and successor to Eduardo Torroja, analysed a cable-stayed bridge with a span of 86 m as well as a low arch with a span of 103 m and two pinned joints. He wrote at the time that he decided on the arch solution for aesthetic reasons. An iterative computer-driven form-finding procedure minimized the depth of the structure. The result is a structure with a form defined by optimization, and impressive in its slenderness and elegance. With its reinforcement in the quarter points of the span, the structure recalls the works of Robert Maillart.

Steel trestles provided support for the structure during erection. Prefabricated prestressed concrete segments with a length of 19 m and a weight of 80 t were placed upon the temporary supports. The 40 cm wide joints between segments were concreted in situ. A sliding support was provided at one side of the bridge to allow the installation of jacks. The jacks were used to press the structure together and initiate the arch behaviour. The pressure from the 700 t jacks lifted the bridge from its formwork with a superelevation to compensate for the anticipated deformation due to creep and shrinkage of the concrete.

Torroja, J. Antonio, "Dos pasarelos sobre la Avenida de la Paz", in: ATEP, Hormigón y Acero, 3rd trimester, 1979




16.3 m
78.66 m
16.3 m
103 m
3 m

It was as though he had nothingness in his hands. *Alessandro Baricco, Silk*

After the heady economic upturn of the post-war decades, the oil crisis of 1973 brought the Western world back to reality in a series of almost unreal experiences: houses lit only by candlelight in some countries; car-free Sundays in others, the tarmac empty of all but curious pedestrians and gleeful cyclists. The limits of growth and the finite nature of resources were forcefully brought home to people; throughout the world, economy and efficiency took over as the main production criteria. In architecture and, to an even greater degree, in engineering construction, slenderness was a signal that the ethics-based criteria of so-called honest construction and truthfulness to materials could be developed further. Lightweight construction, which exploited loadbearing capacity to the full, suited an age in which behaving responsibly towards the environment became popular as a political goal.

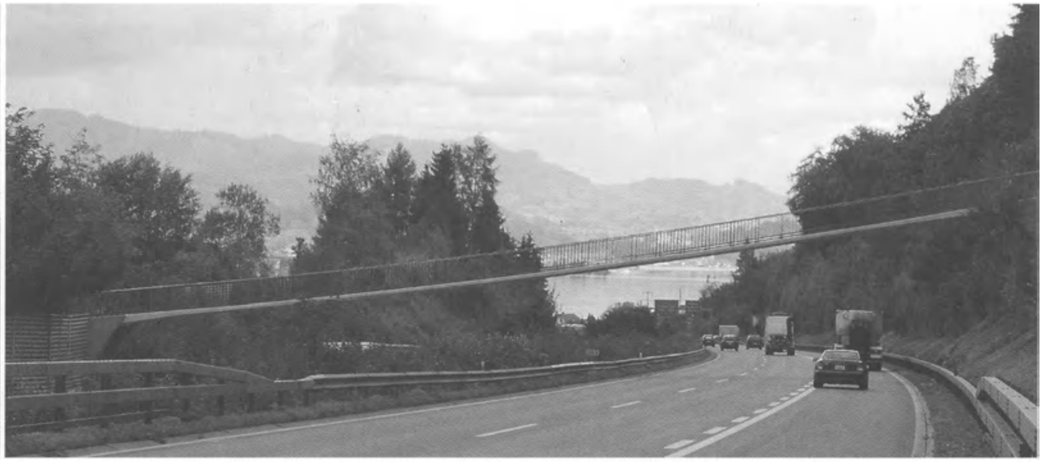
With the construction of the pavilion in Montreal and the roof above the Olympic buildings in Munich, lightweight construction methods in the tradition of Buckminster Fuller and other pioneers showed that they could give architecture new momentum. In bridgebuilding, the desire to conserve resources and the increased pressure to reduce costs compelled engineers to take lightness to the limit. Structural systems such as stress ribbon bridges and cable-supported bridges were refined and calculation methods were adapted to optimize the use of material. The design vocabulary, unfortunately, was reduced to slenderness, which acquired an almost unquestioned status as a quality of design.

After all, it is not really enough to equate *lightness* with *slenderness* with *beauty* as the justification of an aesthetic judgement.

Cable-supported bridges, which can be built in a great variety of forms and with considerable elegance, have undisputed potential. The implicit reliability of wire rope can be illustrated by thinking of tightrope artistes: our fear is not that the cable could snap, but that the performers (or, in a metaphorical sense, the designers) might lose their footing. In this sense, the lightweight, gracefully curving pedestrian bridges designed by Jörg Schlaich's practice can be seen as outstanding performances. They achieve their effect less by powerful massing than by a confident, almost poetic, sense of line.

Stress ribbon bridges gain individual design quality whenever the structural principle is thought out and tested in different materials. Both types of bridge require uncompromising attention to detail – and not just structural detail. They also both bring with them one unwelcome problem: many pedestrians are unwilling to accept walkways that sway even slightly, even though the structures concerned (often flexible ones) have by no means reached the limits of their loadbearing capacity. Vibrations and oscillations start to make pedestrians feel uncomfortable long before they jeopardize the stability of the bridge. Bracing and stiffening therefore become less of a structural problem than a matter of design, because stabilizing components of any sort tend to obscure the simplicity of line that gives such delicate structures their poetic air.

The first of its kind: with its gradient of about 15 percent, the stress ribbon bridge over the N3 at Pfäffikon, 2006



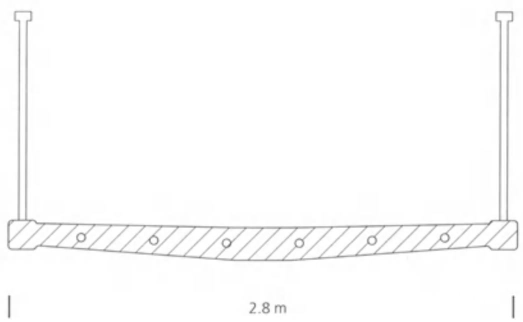
Stress Ribbon Bridge in Bircherweid, Switzerland, 1965

The first concrete stress ribbon bridge for pedestrians was built in Bircherweid, Switzerland, in the mid-1960s. René Walther and Hans Mory had founded their own office in Basel just two years before, and this structure confronted them with an aesthetic problem, which they were able to solve with a technical approach. The photos show that the traffic lanes of the N3 motorway have very different elevations. Intermediate piers were not permitted. René Walther first designed a skewed truss structure but the aesthetics of the structure did not suit the surrounding landscape, which has a view descending to the lake below. René Walther remembered Ulrich Finsterwalder's repeated recommendations for stress ribbon structures for bridges, and decided to propose a slender stress ribbon bridge to the Swiss authorities. If the authorities had the courage, the first-ever pedestrian stress ribbon bridge would be built in Bircherweid. An architect was not consulted on the project.

The engineers would exploit the strength of the material. The deck slab is merely 12 cm deep at the edges and 18 cm deep in the middle of the deck. The sag of the ribbon is merely 40 cm for a span of 48 m. The high anchorage forces are redirected over a saddle at the abutment and anchored into the underlying soil. Five rock anchors were used at the upper abutment (V = 800 t), and six at the lower (V = 810 t). Six steel tendons are encased in the thin deck slab. The bridge has been in service for decades, even though the structure is considered very lively. René Walther's friend and colleague Christian Menn referred to the structure irreverently as a "trampoline". But such vibrations do little to disturb the "robust mountain men" of the area. As the recent Swiss code has required that 20 percent of the anchors be able to be inspected and replaced, the bridge was refitted. Electric monitoring devices were installed and continually measure the tension forces in the steel tendons.

René Walther has continued to propose stress ribbon structures, notably in a competition with a multi-span stress ribbon pedestrian bridge over the Rhône, unfortunately without success. Project cost is becoming more and more the deciding factor in competitions – stress ribbon structures are not the cheapest option due to the large foundation anchorages they require for the tension forces in the structure.

The Bircherweid footbridge in a photo from 1965



Stress Ribbon Bridge in Geneva, Lignon-Loex, Switzerland, 1971

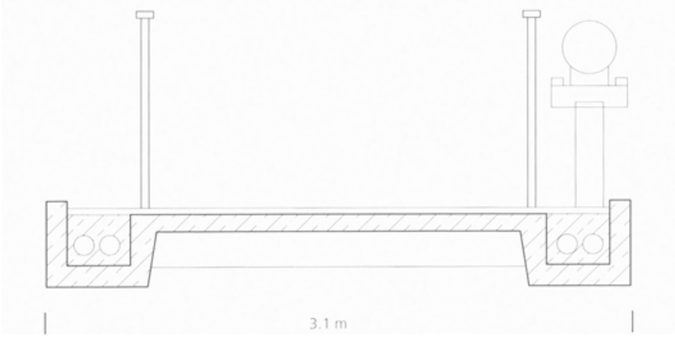
As part of a pipeline from Marseilles via Lyons and Grenoble to Geneva, a structure was needed to cross the Rhône between Lignon and Loex near Geneva. The Rhône divides the very different worlds: multi-storey buildings dominate to the north, while the southern side is an idyllic country landscape. In 1962, the city of Geneva decided to build a new suburb with three-storey buildings to house approximately ten thousand inhabitants in Lignon; it was finished in 1971. It was therefore obvious to link the construction of the pipeline structure with a footbridge to join Lignon with the recreational area of Loex to the south.

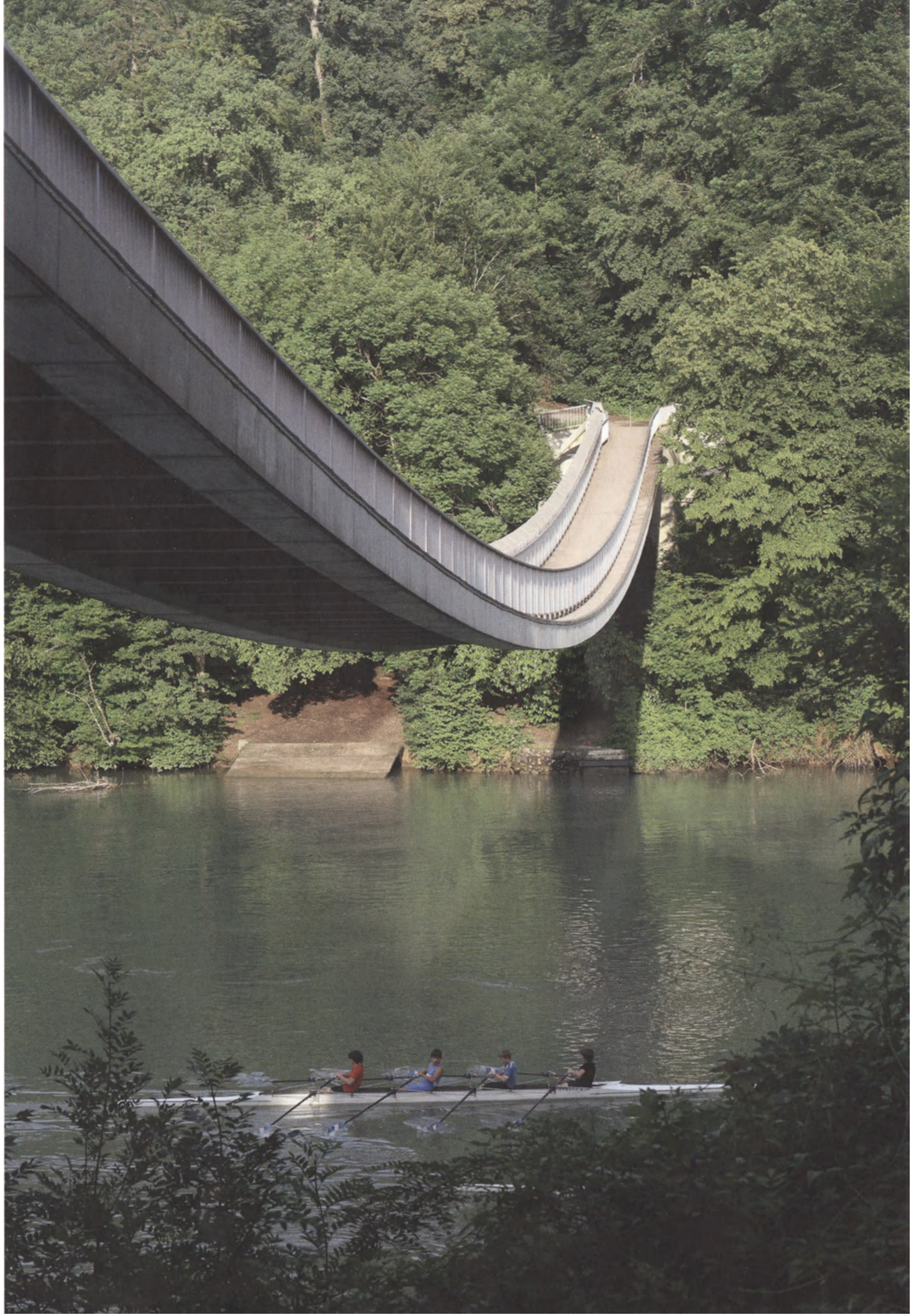
For the free-spanning structure, the engineers of H. Weisz from Geneva and Otto Wenaweser + Rudolf Wolfensberger from Zurich designed a stress ribbon structure, supported by four prestressed cables (d = 92 mm). With a cable sag of 5.3 m, the maximum slope of the deck is around 16 percent. Slopes of the bridge deck in contemporary stress ribbons are limited to 6 percent, producing much greater tension forces. The deck is made from 74 prefabricated slab segments, each 3.1 m wide, which were laid on the supporting cables. This process took 5 days, after which the joints between the segments were concreted in situ to create a continuous slab. After the concrete had hardened, the supporting cables were again stressed. Altogether, the bridge creates a very robust impression; it is not easily excited to dynamic oscillations. Children are thrilled to descend the steep gradient of the deck on their bicycles.

The pipeline runs alongside the western railing. For maintenance reasons, placing the pipeline below the deck – as in Fritz Leonhardt's Mühlacker Bridge – was not considered. It is unfortunate that the pipeline blocks the view over the western railing. It is placed so high as wind tunnel testing showed that the opening between the pipeline and the deck would need to be roughly 1.5 times the diameter of the pipeline to avoid dynamic oscillations. The two abutments are broken down into compression and tension members. The footings are anchored with 25 m long rock anchors due to the inferior quality of the overlying soils. Wolfensberger considered the abutments and anchors to be the critical elements of the construction. As the anchorage forces are inversely proportional to the sag of the stress ribbon, Wolfensberger chose the maximum possible sag and decided to construct stress ribbon bridges in areas with good-quality soils.

After 30 years, the bridge's formal reserve continues to be convincing. The undisturbed riverbank is a protected area, where local rowers do not disturb the beavers – The Rhône valley has remained almost completely undisturbed.

The maximum gradient is 16 percent.



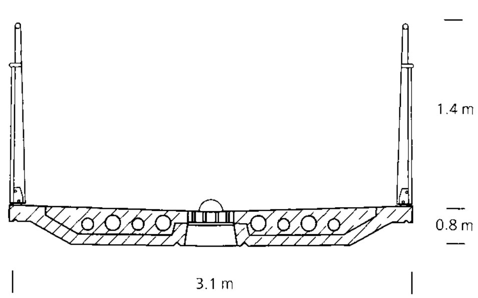


The flamboyant central stair at the change of direction

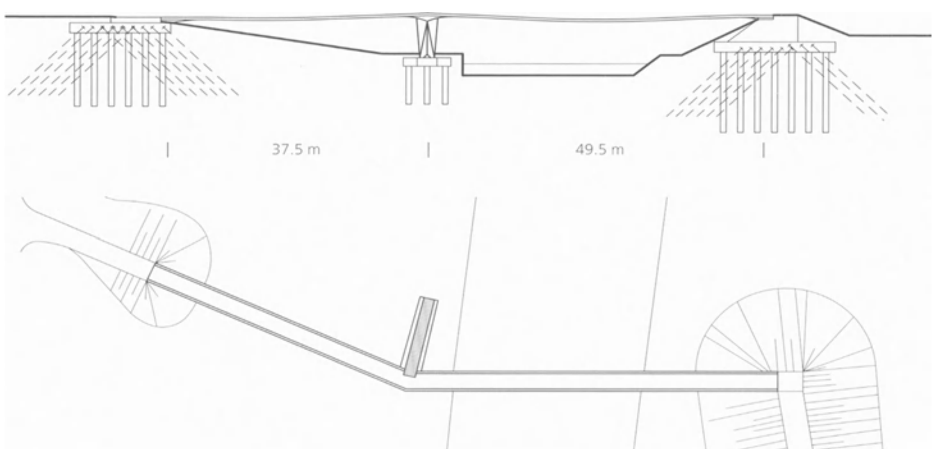
Stress Ribbon Bridge in Maidstone, UK, 2001

The extraordinary aspect of the structure designed by Strasky Husty and Partners together with the architects from Studio Bednarski in Maidstone, south east of London jumps out at the viewer: a stress ribbon bridge with a change of direction at midspan. The Kent Messenger Millennium Bridge and expanded park connects the area between the railway and river, which had been difficult to access. A natural environment can be found here not far from the city centre. The design idea was to free up the pedestrians' view from the bridge deck completely, so that structural systems using pylons, mast and cables were out of the question. A thin stress ribbon bridge where the hanging deck acts as the main structure was the obvious choice. The total length of the construction is 101.5 m is divided into two halves, one 49.5 m and the other 37.5 m, by a kink creating a 25° change of direction in plan. The problem of the great horizontal forces resulting from the directional change is elegantly solved. These horizontal forces are supported by compression forces in a solid concrete stairway. In order to prevent the deck from lifting upward due to the incline of the stairway, a slender steel column is added. The superstructure consists of 3 m long prefabricated segments hung on steel cables. The joints between the segments were concreted in situ and pretensioned with addition prestressing tendons. This stress ribbon design is typical of Jiri Strasky. The advantage of the stiff deck is its relatively small dynamic response. The trade-off is that the high stiffness of the deck produces great local bending moments near the abutments. The decks are therefore haunched near the abutments and at the intermediate pier. The stainless steel railing with stainless cablenet infilling aid contribute to the light appearance of the structure, despite England's typically rainy weather. Drainage is provided by steel grating, which allows water and sunlight to pass directly through the deck. Jiri Strasky is one of the great experts on stress ribbon bridges: in 1985 near Prague, Strasky built a multi-span stress ribbon with spans of 85.5 m – 96 m – 67.5 m. In the Maidstone Footbridge, the technical challenge is the directional change of the deck.

Bednarski, Cezary M., Kent messenger Millenium Bridge, Maidstone, UK, in: Footbridge, 2002, pp. 110-111



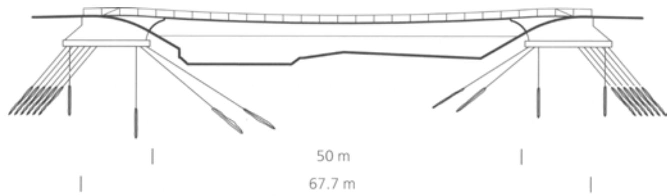
Unusual for a stress ribbon bridge – the opposite bridgehead is not in sight

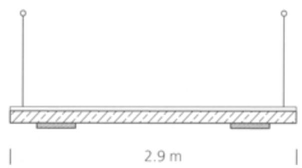


With a free span of 52 m, the bridge sags by only 80 cm

Footbridge in Enzauen Park, Pforzheim, Germany, 1991

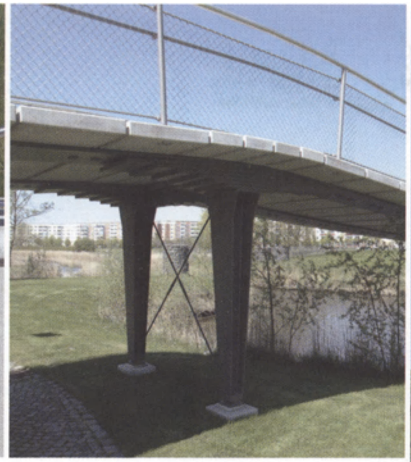
Once again, a provincial garden show was an occasion to do something for the pedestrians in a city defiled by traffic. As the landscape along the Enz riverbank was to be newly groomed, it was easy to blend the robust abutments of the stress ribbon bridge into the riverside embankments. Greater simplicity in a structure is hard to imagine; a hallmark of Schlaich Bergermann and Partner's work. Two thin metal plates (480/40 mm, St 52-3) are hung between the abutments. Lightweight concrete plates are then bolted onto the ribbons (d = 17 mm). The bridge has a sag of merely 80 cm in order to respect the maximum slope of 6 percent for wheelchair users. Each plate ribbon was transported to the site in three segments, which were then welded together on site. The railings, consisting of steel tubes with a chain link filling, contribute the dynamic damping of the structure. The transparent railing makes little visual impact. As the curvature of the deck increases near the abutments, the concrete plates become shorter. The critical area of a stress ribbon bridge is near the abutment. Live loads create bending moments in the tension members if they are rigidly connected to the abutment, causing fatigue to become an issue. To avoid this, the ribbons are supported by a saddle with a large enough radius to limit the cyclical loading to below the fatigue limit. In total, four new pedestrian bridges that reanimate the attractive riverbanks were built for the garden show.





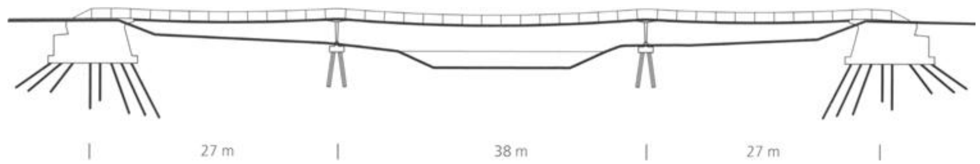
Leicht, weit, 2003, pp. 256-257

Concrete slabs are bolted to steel ribbons

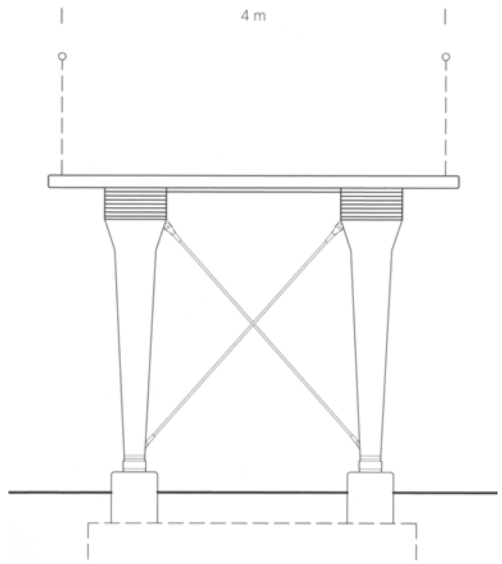


North Bridge in Rostock, Germany, 2003

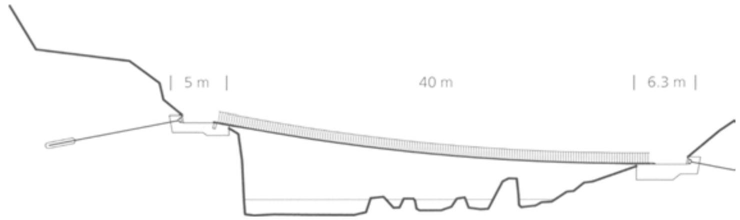
To harmonise natural landscapes – or to put it more modestly, landscaped countryside – with curious and active people makes the garden shows potent occasions for uniting beauty and utility. In general, the brief garden shows leave an extended recreational areas and create more of an impact than the phrases "extraordinary gardening" or "the Olympics of gardening" would have us believe. It was at such an occasion, the 2003 International Garden Show in Rostock, Germany, that several footbridges were built over the waterways that traverse the site. Schlaich Bergermann and Partner designed a multi-span stress ribbon structure for the North Bridge over a tributary of the Unterwarnow near Schmarl. Each of the three spans has a length of 27 m. Two plate ribbons are hung between the abutments and over two intermediate bridge piers. These intermediate piers consist of articulated columns with a carriage spring elastic saddle. Concrete slabs, 12 cm thick, are bolted to the ribbons. The effects of span continuity must be taken into account for such a stress ribbon: as one span is loaded, tension increases in the adjacent spans to resist the deformation. Schlaich Bergermann and Partner again proved themselves experienced masters of stress ribbon structures.



Schlaich, Mike, Die Fußgängerbrücken auf der internationalen Gartenschau IGA 2003 in Rostock, in: Bauingenieur, 10, 2003
Russel, H., Five modest bridges make economic sense for garden show, in: Bridge Design and Engineering, 4, 2003



Western abutment



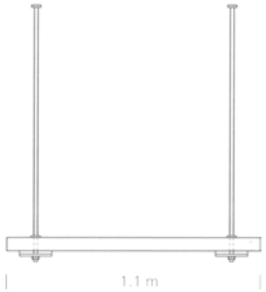
Pùnt da Suransuns, Viamala, Switzerland, 1999

The exceptionally beautiful hiking path in Viamala is accompanied by several bridges from the office of Conzett Bronzini Gartman in Chur. One of these structures can be found north of the crossing of the A13 road and the Hinter Rhine in a deep valley with a wandering river. The 40 m span of the pedestrian bridge is long, but its position is well chosen: it is easy to access and not directly under the roadway. Given the site, a stress ribbon structure had several advantages; the abutments are at different elevations – as in René Walther's Bircherweid Bridges ; and to the steeper abutment, the slope is 20 percent. Another reason is that the hiking route was to be a stone path to match the surrounding landscape. Jürg Conzett suggested a stress ribbon structure with a granite deck, remembering Heinz Hossdorf's design of a prestressed granite bridge for the reconstruction of the Devil's Bridge in the 1950s. Jürg Conzett employed gneiss from the neighbouring town of Andeer for the deck, and V4A chrome-nickel steel or duplex stainless steel for all steel components. These steels resist the corrosive effects of the salt spray from the adjacent highway. The joints between the granite slabs are filled with 3 mm thick aluminium bands.

Erection procedure: first, the abutments were precisely concreted, and the flat pegs to which the steel bands would anchor were concreted directly into the abutments. The granite slabs were successively laid on the steel plates beginning from the lowest point. The trick is that the

Structure as Space, 2006, pp. 224-229
Conzett, Jürg, Punt da Suransuns Pedestrian Bridge, in: Structural Engineering International, May, 2000, 2, 10
Schweizer Architekt und Ingenieur, 1, 2000

The steel bands' attachment to the vertical members of the railing can be clearly seen from below



granite slabs were attached to the ribbons using the vertical members of the railing. The bands wedge against one another during tensioning and the vertical railing attachments are tightened and the handrails is precisely installed.

The dynamic behaviour of the 40 m long bridge could not be predicted, for vertical oscillations in particular. Hikers however enjoy the raw attractions of the rocky landscape and are not fearful when the bridge vibrates, although it does so much less that the slender silhouette would lead one to expect. Near the abutments, carriage spring saddles soften the transition to the anchorage. The horizontal oscillations of the structure, which can be excited by a single hiker, are naturally larger than the lateral vibrations of Foster and Arup's Millennium Bridge in London. This small bridge unites the finest aesthetic elements: the raw rocks in the Hinter Rhine, the flat, glittering gneiss slabs, and the shining chrome steel suit each other. The overall visual impression of the bridge leads one to believe that the structure has bypassed all limits of slenderness – even though its surface is of stone. Altogether, the stress ribbon bridge is a masterpiece of minimal art.

Bridge in Vent (A)

Bridge made of grass in Himalaya

Stress Ribbon Bridges

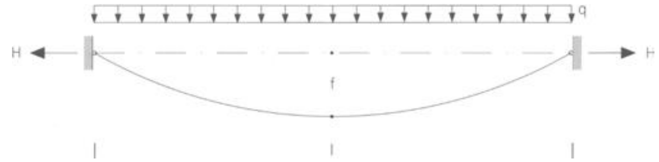
The stress ribbon structure is one of the oldest bridge archetypes. Primitive bridge builders attempted to span distances wider than the length of an existing tree trunk by throwing a line across a ravine and tying it on both sides to a large rock or tree. In this simple and natural structural system, cables are stressed between the two abutments and serve as the walkway. It is difficult to imagine a simpler structural system: walkway surface and supporting cable, often from natural fibres, are one. The cables of modern European stress ribbon footbridges consist in prestressing tendons or a system of at least two adjacent steel bands or cables laid out at the edges of the deck. The walkway is then provided by either a concrete deck slab encasing the prestressing tendons, or by individual concrete or stone planks fixed atop the steel ribbons or cables. Such stress ribbon structures have become possible only by the invention of high-strength steel. The advantages of the high yield strength of this steel are being exploited in contemporary structures (see beginning of this chapter: Ulrich Finsterwalder 1970, and in Switzerland René Walther, 1967 and Otto Wenaweser, 1971).

Some stress ribbon bridges have been designed as roadway bridges, the most famous example of which is the conceptual design of a bridge over the Bosphorus by the engineer Ulrich Finsterwalder. However, most are footbridges, as pedestrian traffic is better suited to counteract the oscillations of these lively structures or overcome the slope of stress ribbon structures near the abutments than road or railway traffic. Bridges for which the deck is suspended from the handrails acting as the main supporting tension element may also be considered stress ribbon bridges.

High-strength materials find their ideal application in stress ribbon structures. In most structures, the strength of construction materials cannot be fully exploited, as problems of stability or deflection through elastic strain control the design. Stability, however, is not an issue for a pure tension stress ribbon structure. With respect to deflections of the stress ribbon, the effects of elastic strain are much less influential than geometric or second-order effects. In addition, by exploiting its material strength, the depth of the tension member can be greatly reduced. This in turn decreases local

Positions of the stress ribbon

Stress ribbon bridge with l, q, f, and H



bending stresses at the abutments and saddles, which significantly affect the design.

Analysis, Forces

Stress ribbons are quite simple to calculate if we exclude local effects near the abutments. The tension force (S) in the stress ribbon is dependent on the length of the span (l), the loading (here a distributed load, q), and the sag (f) of the ribbon and is calculated as follows:

$$S = H = q \cdot l^2/8 \cdot f$$

The horizontal component (H) of the stress ribbon remains constant along its length, while the tension force (S) increases with the slope of the ribbon towards the abutments. Wee can see that the horizontal component (H) of the tension force is equal to the maximum bending moment of a simply supported beam under distributed load ($q \cdot l^2/8$) divided by the maximum sag f. We can also see that the ribbon cannot be stressed flat: the horizontal component H approaches infinity as the sag, f, approaches zero. Ribbon sag is therefore necessary, even if this causes unwanted slopes at the abutments. The designer must therefore find a balance between cost and pedestrian comfort, between the foundation costs of anchoring high-tension forces and the pedestrian's difficulty in overcoming the slope of the bridge. For footbridges, a common ratio of the structure's sag under self-weight to span is 1/50. This limits the slope of the deck to 8 percent at its steepest, assuming an approximate parabolic form for the gradient of the deck, rather than the exact hyperbolic form.

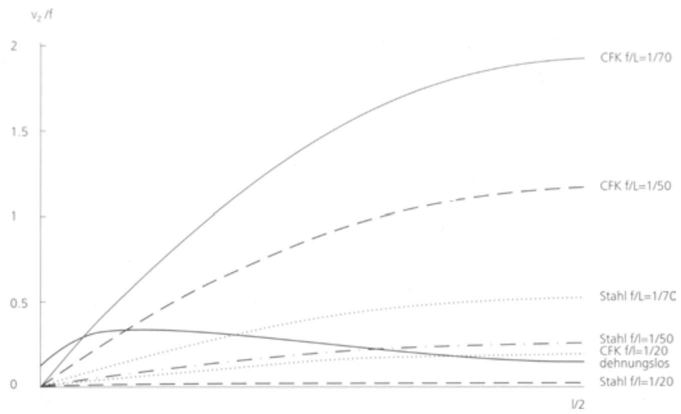
The apparent simplicity of the stress ribbon relies on the great tension forces in the deck, which require complex anchorages. The abutments and the transmission of the horizontal anchorage forces to the underlying soil are the greatest challenge in the design and construction of these bridges. Apart from the abutments and foundations, erection of stress ribbons structures is quite simple. The cables of stress ribbon structures arrive on site at their final length on spools. For structures using stiff plates, the plates are transported to the site in segments that must be welded to form the final ribbon. Before final anchoring, the ribbon or cable is shorter than in its final state. The tension members must therefore be stretched or stressed before anchoring at the abutments. The deck surface is then either placed upon the tension members or concreted around them. For bridges with individual slab segments placed upon steel bands, the band should be thinner near a saddle or abutment than over the free span. Precision is required in determining the ribbon length as even minute errors in the length of the cable produces great differences in the ribbon sag. During erection, the anchorage should be made to allow for adjustments, should an error in length occur.

For long, multi-span stress ribbons structures, the tension force of the deck continues over the intermediate piers and need only be anchored at the abutments. Arches are often used as intermediate supports for multi-span stress ribbons. If the right geometry is chosen, the horizontal thrust of the arch can cancel the anchorage force of the stress ribbon.

Multispan stress ribbon bridge

Arch with stress ribbon

Elastic and geometric deflection



Deflection, strain

The funicular form of a cable under constant self-weight is the hyperbolic sine while the funicular form for a constant distributed load is the parabola. The difference between these two functions is minimal for small sag to span ratios of around 1/50. As an approximation, the cable form can be taken as a simple parabola in such cases. Equilibrium occurs as the stress ribbon takes the funicular form for the respective loading condition. For an increase in a constant distributed load over the span, the tension force will increase, producing an increase in sag and strain in the ribbon. The parabolic form will however remain. Should the loading have a different distribution, the deck will seek equilibrium by taking the funicular form for this load case. For such deflections, where there is no strain at the midspan but rather a change in the form of the deck, the strain is roughly equal to that of the distributed load. As the elastic strain of the stress ribbons plays little role in the deflections, thin and flexible ribbons of high strength materials may be used.

Bending and redirection

Particular attention must be paid to the zones of abrupt redirection of ribbon geometry such as the near the anchorages or above the intermediate piers of multi-span stress ribbon structures. The tension member cannot have a rigidly fixed connection in these regions, as the combination of high bending stresses from cyclic live loads and high tension stress would lead to fatigue failure. The tension member in these zones must be reinforced to minimize the bending stresses. For stress ribbons made of steel bands, the bending stress may be reduced by using a round saddle that allows controlled deflection of the bands in these zones. This allows the band to deflect to find its optimum form with respect to the variable loading. The saddle radius can be chosen to ensure that the variation in ribbon stress stays below the fatigue limits, or that the stresses remain below the yield strength.

Above the saddle, the pure tension stress σ_S (as is found at the midspan) is combined with bending stress σ_M due to the redirection of the ribbon. The total stress σ of a stress ribbon with the width b and depth h at the saddle is therefore

$$\sigma = \sigma_S + \sigma_M$$

with

$$\sigma_H = S/A \approx H/b \cdot h = q \cdot l^2/8 \cdot f \cdot b \cdot h \text{ and } \sigma_M = M/W$$

The bending stress σ_M is due to the bending moment that results from the curvature of the ribbon at the saddle. The curvature is indirectly proportional to the saddle radius. The curvature of the ribbon may be expressed

$\kappa = M/E \cdot I = 1/R$

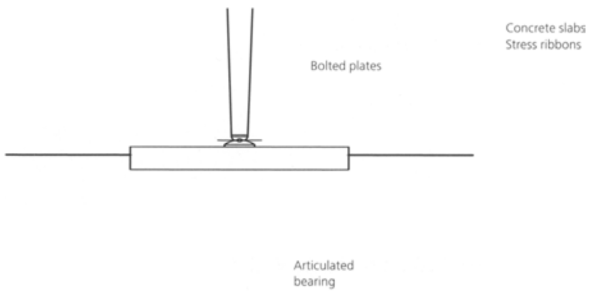
The bending stress is therefore

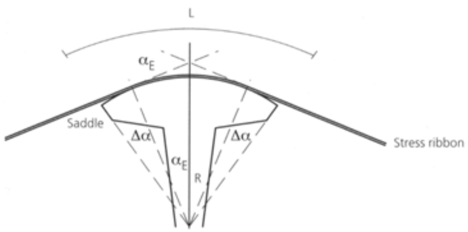
$$\sigma_M = M/W = \frac{M \cdot h/2}{I} = E \cdot h/2 \cdot R$$

where

A Cross-sectional area
E Young's modulus for the ribbon
I Inertia of the cross section

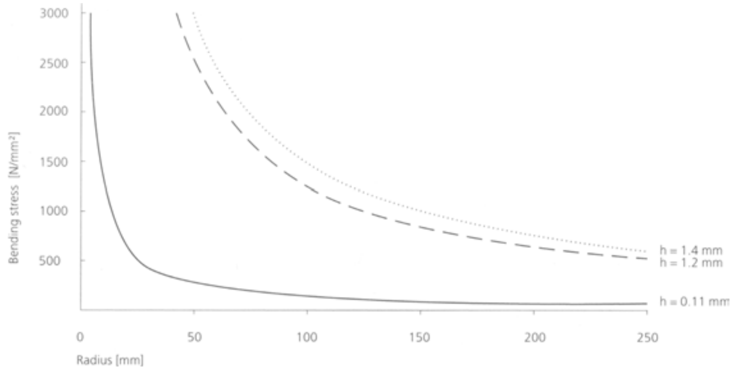
Saddle of the multi-span stress ribbon bridge in Rostock with carriage springs





Saddle size

Bending stress as a function of saddle radius



W Elastic modulus of the section (= 2·I/h)

R Radius of the saddle

As shown in the equation above, the bending stress is indirectly proportional to the saddle radius and directly proportional to the ribbon depth. In order to reduce the bending stress, the saddle radius should be as great as possible with the thinnest possible ribbon depth. The required saddle radius can be determined for a material with a yield strength of f_{yd}, depending on the sag, ribbon depth and width, loading and span as follows:

$$R = 4 \cdot E \cdot h^2 \cdot f \cdot (b/8 \cdot f_{yd} \cdot f \cdot b \cdot h - q \cdot l^2)$$

The advantage of high-strength materials is evident in the equation above. Not only can bands of high-strength materials withstand higher stresses, they are also thinner. This leads to a reduction of bending stresses and saddle size. The image below left shows the required saddle size with respect to type of band and magnitude of the bending stress.

The saddle length must be chosen so that the band never reaches the edge of the saddle under variable loading to avoid folding. The required length for a saddle above an intermediate pier is given as follows:

$$L = 2\,\pi\,R\,\alpha/360$$

where

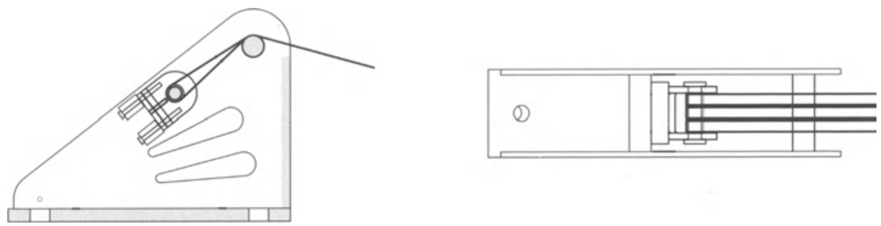
$\alpha = \alpha_{deadload} + 2\Delta\alpha = \arctan(4f/l) + 2\Delta\alpha$

$2\Delta\alpha$ = The change in angle of the ribbon at the saddle due to live loading and erection tolerances.

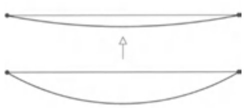
Lateral bracing

All stress ribbons are susceptible to dynamic excitation due to their light weight. The ribbons themselves exhibit very low material damping characteristics, which can result in the structure oscillating widely. The bridge's dynamic behaviour can be improved by creating a prestressed concrete ribbon that is rigid in bending, or by adding mass to the structure. For this reason, heavy concrete slabs are used for the bridge deck in the

Anchoring of the ribbons



Cable Stiffening

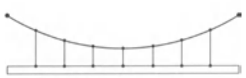


Reduction of sag

Additional mass

Bending stiffness

Additional cables



Stiffening girder

Pforzheim and Rostock bridges to add mass and decrease the deflections of the structure under variable loading. Fortunately, the natural damping characteristics of non-structural members may be exploited to add damping. Chain link guardrails have been proven effective by dissipating the dynamic energy of the structure into heat energy through friction in the guardrail filling. The Glacis Bridge has shown that a chain link guardrail can double the damping of the structure [fib guidelines 2005] The images to the left show the five most important methods for reducing the deflections of suspended ribbons. By adding additional structural elements that are not part of the suspended ribbon, bridges with cable girders and stiffening trusses can be considered separate structural typologies.

Carbon fibre ribbons

The advantages of high-strength materials mentioned above would incline a designer to choose the highest-strength material currently available, carbon fibre. Carbon fibre is currently used in the aviation industry and racing cars due to its high strength – 10 times higher than normal structural steel – and its low weight – one fifth of that for steel. In structural engineering, carbon fibre has strangely enough found little application or application as reinforcement of existing reinforced concrete structures.

A test bridge project using carbon fibre ribbons was therefore carried out at the Technical University Berlin. The structure was designed according to the current codes and standards. The structure demonstrates that a ribbon thickness of only 1 mm is sufficient to support a span of 15 m.

In order to reduce the dynamic oscillations of this extremely lightweight bridge, additional mass is added to the bridge in the form of 10 cm deep concrete slabs. This is the starting point for further research at the TU Berlin, on "intelligent" damping systems that would allow very lightly decked, and therefore lively structures, to be efficiently "quieted" – without the additional mass. Carbon fibre materials could then be used optimally in the structural design.

Test bridge at the Technical University Berlin

Eibl, Josef and Klemens Pelle, Zur Berechnung von Spannbandbrücken, Flache Hängebänder, Düsseldorf, 1973

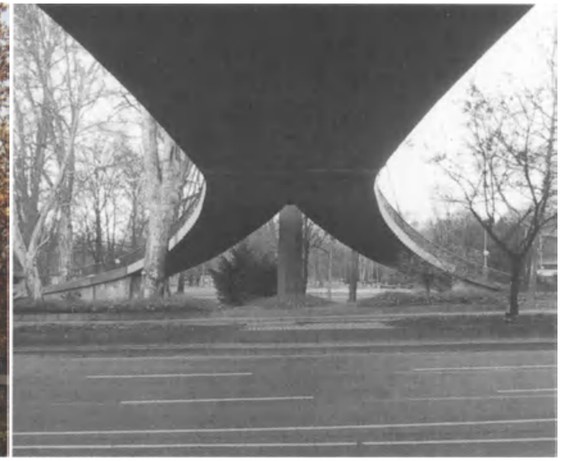
Oster, Hans, Fußgängerbrücken von Jörg Schlaich und Rudolf Bergermann, Exhibition catalogue, 1992

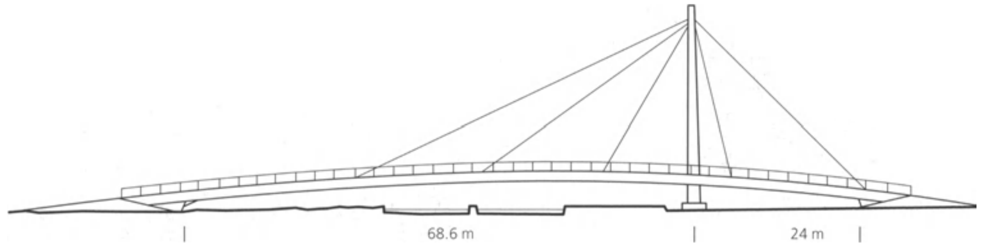
Schlaich, Jörg and Stephan Engelsmann, Stress Ribbon Concrete Bridges, Structural Engineering International, 4, November 1996

Schlaich, Mike et al., Guidelines for the design of footbridges, fib, fédération internationale du béton, bulletin 32, Lausanne, November 2005

Strasky, Jiri, Stress ribbon and cable-supported pedestrian bridges, Thomas Telford, London, 2005

The footbridge connects two very different parks over a highway

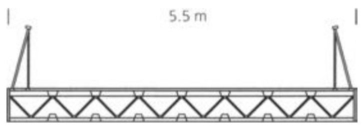




Schiller Footbridge in Stuttgart, Germany, 1961

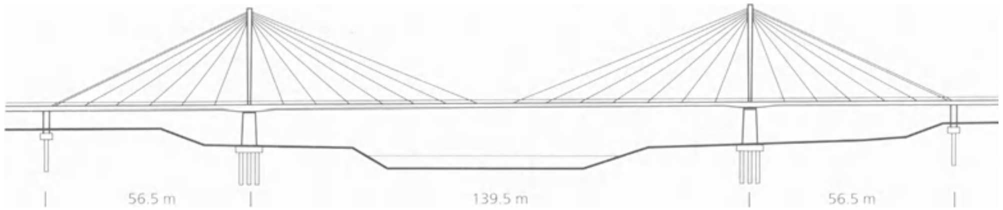
After the Second World War, Fritz Leonhardt's attempts to create light and slender structures quickly set a high standard for structural design. The relevance of the ideals of *lightness* and slenderness to German culture were explicitly laid out, but these ideals the opposite the National Socialist monumental aesthetic. Steel, and later prestressed concrete, enabled the engineers to embody the lightweight ideal in structural design. The Enz Footbridge is a wonderful example of this (see p. 62). The engineers in the office of Leonhardt & Andrä would not rest until they had reduced the depth of the deck slab from 52 to 50 cm. The structural system of the cable-stayed bridge is well suited to this desire: by decreasing the distance between cable supports, the deck can be made more slender as the bending moments are reduced. Fritz Leonhardt's greatest goal was to make the deck as slender as possible, although he never explicitly discussed the aesthetic rationale of the ideal of slenderness in design. The angular contours of the cable-stayed structure did not, however, guarantee respect for Leonhardt's second design maxim: elegance.

There are two types of cable-stayed bridges. In the "harp" arrangement, the stay cables are parallel to one another. Fritz Leonhardt built the first cable-stayed bridge with a harp arrangement in 1952 in the Düsseldorf family of bridges. The architect Friedrich Tamms insisted on this cable arrangement, which continues to shape the skyline of Düsseldorf, in particular the Oberkasseler, the Theodor-Heuss, and the Rheinknie Bridges. Fritz Leonhardt referred to the fan arrangement as the most "natural and technically effective" cable arrangement, as can be seen in the footbridges in Stuttgart and Mannheim.



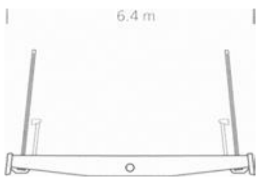
Leonhardt, Fritz and Wolfhart Andrä, Fußgängersteg über die Schillerstraße in Stuttgart, in: Bautechnik, 1962
Schlaich, Schüller, 1999, pp. 173-174

Typical 1970s blocks of flats required pedestrian access to the city centre. The deck widens around the pylons.

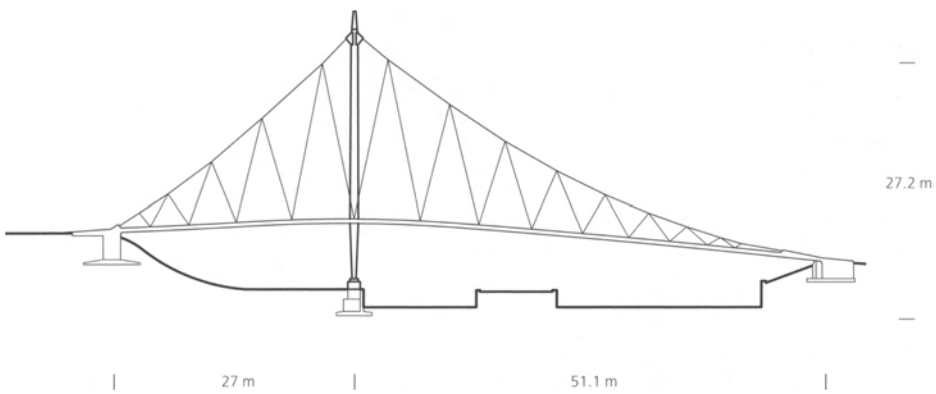


Neckar Footbridge at the Collini Centre in Mannheim, Germany, 1973

The structure consists of a flat deck girder suspended from two stay cable planes to each edge. The stay cables (parallel wire strand) are individually anchored at the top of the steel pylons. The longitudinal distance of 9 to 10 m between stays, enables the deck girder con consist of a trapezoidal section only 60 cm deep in reinforced concrete. The stiffening girder is haunched in the longitudinal and transverse directions. The girder has a depth of 1.2 m at the pylons. An expansion joint is provided at the midspan, and the bearings at the base of the pylons are fixed in translation by free to rotate. The joint in the midspan allows the bridge deck to expand but nevertheless transfers shear forces and torsional moments. The cross section of the steel pylon is merely 1x1 m at the base. The depth of the pylon cross section increases in longitudinal direction to 1.4 m at the head of the pylon to make room for the cable anchorages. The wide flood plane of the Neckar and main span of 139.6 m may have contributed to Leonhardt's choice of a fan arrangement for the stay cables, but the brittle, linear appearance of the bridge does not bring elegance to mind. The Neckar footbridge does not have a modelled appearance, despite the widening of the deck at the base of the pylon. The visual impression remains linear, comparable to a line drawing.



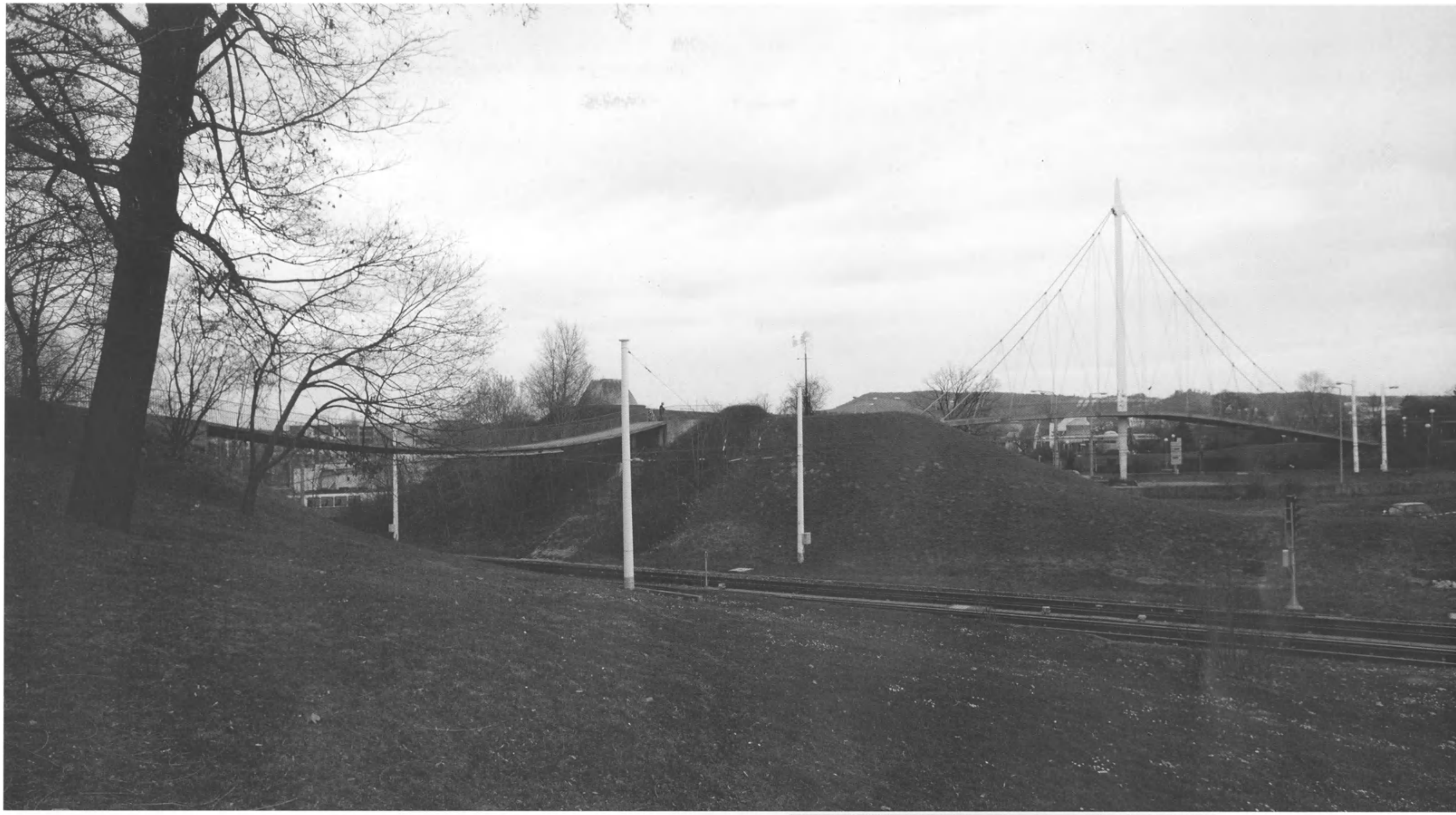
Dornecker, Artur, Eberhard Völkel and Wilhelm Zellner, Die Schrägkabelbrücke für Fußgänger über den Neckar in Mannheim, in: Beton- und Stahlbau, 2 and 3, 1977, pp. 29-35 and 59-64
Keller, Giorgio, Ponte pedonale strallato sul Neckar a Mannheim, in: L'industria Italiana del Cemento, 11, 1982, pp. 817-825

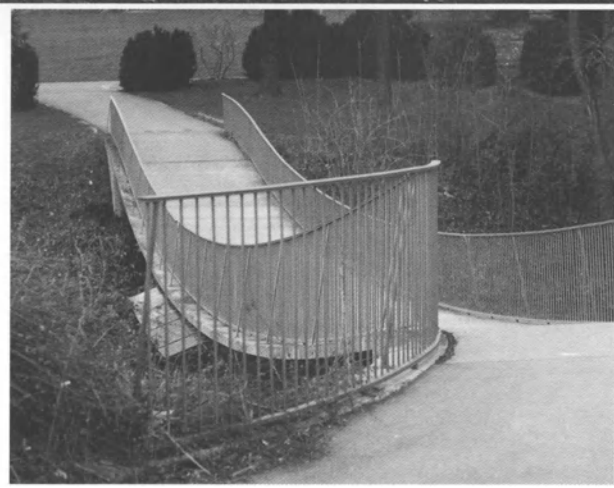


Footbridge in Rosenstein Park, Stuttgart, Germany, 1977

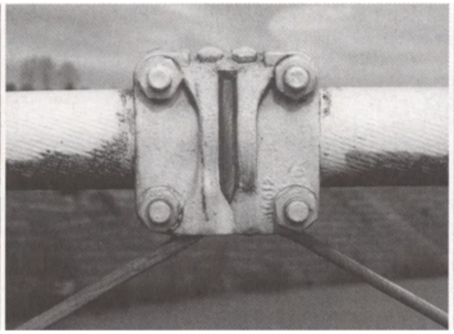
Jörg Schlaich worked as a young engineer in the office of Leonhardt and Andrä, the birthplace of lightweight construction. In the early 1970s, the office was working on the construction of a tent roof for the Olympic sports halls in Munich. Jörg Schlaich – a partner in the office since 1970 – developed into a structural engineer with exceptional curiosity, fantasy and disrespect for the conventional wisdom. As part of a provincial garden show, a redevelopment of a city zone, left barren by traffic planning, was ordered. Pedestrians were to be able to cross over a multi-lane motorway and tramline from a park to the popular spa. This led to the creation of the first contemporary self-anchored suspension bridge. The deck girder, a concrete slab, is fixed at one abutment but free in horizontal translation at the opposite abutment. A lifting of the deck is blocked at this abutment. The main cables (fully locked coil strand d = 75 mm) are anchored at each of the deck's corner points. A continuous saddle is provided at the head of the pylon without clamping. The anchorages of the cables are merged into the deck, making inspection and maintenance difficult. The mast is a simple square cross section of four welded plates to avoid high costs. This footbridge was built as a cable truss bridge, with the surface slabs laid directly on the structural cables.

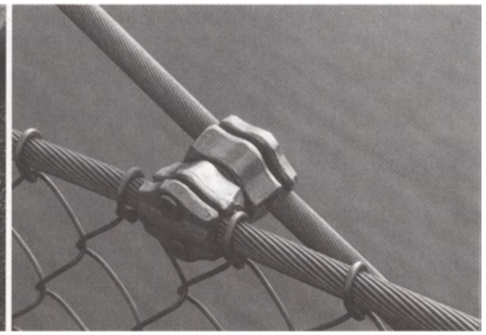
Schlaich, Jörg and H. Beiche, Fußgängerbrücken über die Bundesgartenschau 1977 in Stuttgart, in: Beton- und Stahlbetonbau, 1, 1979, pp. 11-16



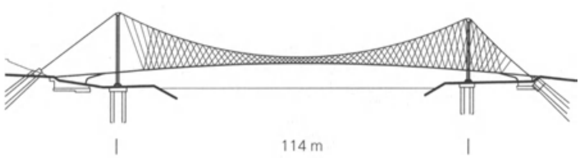


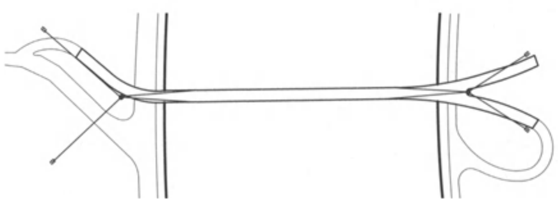






Bridge at Max Eyth Lake near Stuttgart, Germany, 1989





The construction of the cable suspension bridge marked the parting of Fritz Leonhardt and Jörg Schlaich, who founded an office with Rudolf Bergermann in 1980. The bridge crosses high above the Neckar and connects a residential zone near the river with the Max Eyth Lake recreational area. At one bank, a narrow path continues up a steep hillside vineyard. The wide floodplains of the Neckar extend to the other bank. Jörg Schlaich designed a suspension bridge with 20 to 25 m high masts (round hollow steel, d= 711 mm, t = 40-50 mm) the deck passes in front of the mast and joins the vineyard path. To the other side, the deck splits just before the mast. To the left the approach spirals down to a path parallel to the riverbank, to the right directly to the lake. Leonhardt felt that the mast should stand to the side of the deck. The light curvature of the bridge can easily be viewed from atop the deck and engrains the visual appearance of the structure. With a span of 114 m, the deck is merely 30 cm deep. The mast to the side of the flood plain supports half of the bridge as well as the approach; to the vineyard side, the mast only supports one half of the bridge and it passes directly to an abutment. The mast to the vineyard side is back-stayed with two cables anchored to the hillside. The hangers are inclined along the length of the deck, which helps to stiffen the deck girder. The railing consists of a wire net simply clamped to cables running parallel to the edge of the deck, one of which serves as the handrail. The main cables and backstays are fully locked coil strand (d = 106 mm) and the hangers are thin stainless helical strand (d = 16 mm). Prefabricated deck elements were suspended from the main cables starting at the midspan during erection. These segments were in the form of a U. After the rebar of the individual segments was welded together, the remainder of the deck was concreted in situ to create a continuous slab. This procedure made it possible to erect the structure without the use of formwork but required a very high level of geometric and technical precision.

Schlaich, Jörg and E. Schurr, Fußgängerbrücke bei Stuttgart, in: Beton- und Stahlbetonbau, 8, 1990, pp. 193-198

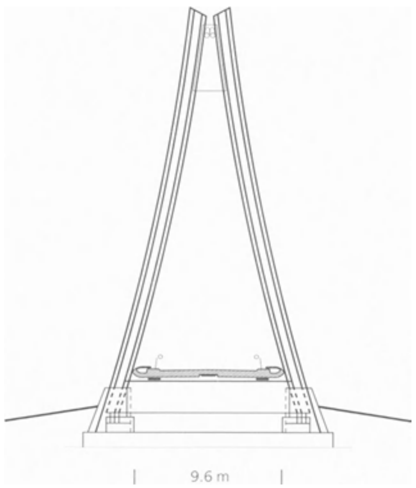
A main span of 252 m – one of the longest suspension footbridges in Europe

Suspension Bridge in Vranov, Czech Republic, 1993

The reservoir in Vranov, near the 1930 border between Austria and the Czech Republic, is a popular vacation area in the summer. The bridge replaces a ferry and supports water and gas lines between the town centre with its hotels and restaurants and the beach the other side of the river. The deck is a slender slab with a 252 m main span and two 30 m approach spans.

Jiri Strasky is an extremely experienced pedestrian bridge designer. His first stress ribbons appeared in the 1970s in the former Czechoslovakia, made of prefabricated concrete segments and prestressed tendons as the tension element. Seven of these DS-L Bridges were built between 1979 and 1985. His suspension bridge over the Vranov Reservoir in southern Moravia is potent evidence that suspension bridges are relevant structures for spans less than 1000 m. With a main span of 252 m, this footbridge slender footbridge is one of the longest in the world. The deck of the structure is 3.4 m wide and only 40 cm deep. The technical curiosity of this bridge: part of the horizontal component of the suspension cable is anchored in the deck, thereby reducing the costs of the abutment anchorage.

Strasky, 2005


9.6 m

Steel cables combined with a reinforced plastic deck

Halgavor Bridge in Bodmin, Cornwall, UK, 2001

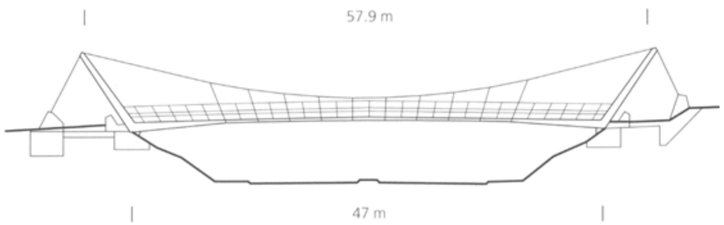
The Halgavor Bridge south of Bodmin in Cornwall is one of the first bridges made from fibre-reinforced plastics in the UK. The bridge was required to cross a heavily used highway and was to cause minimal disruption to the traffic below and need minimal maintenance. In addition, the bridge would be used as a bridleway, the waste from which creates a highly corrosive environment. These requirements led the engineers of Flint & Neill from London, known for their experimentation, to suggest a carbon fibre-reinforced plastic as the material for the superstructure due to its lightweight, corrosion resistance and durability.

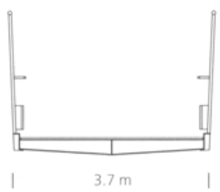
The suspension cables and mast of the structure with its 47 m span are in steel. The hanger cables have a radial arrangement. They and the 1.8 m high wire net railings are in stainless steel. The railings are so high due to the bridleway. At the bottom of the railing, wooden blinders are provided. The 3.5 m wide fibre-reinforced deck consists of two channel-shaped, 50 cm deep edge beams and a 37 mm deep composite sandwich plate. The plate is supported by secondary transverse and longitudinal girders. The stiffness of the deck is determined by the lower Young's modulus of the handmade edge beams ($E = 12{,}800\ N/mm^2$). The machine produced sandwich panels have higher stiffness ($E = 22{,}000\ N/mm^2$). The deck is flexible enough to be monolithically connected to the side abutments without creating high stress from constraining forces under temperature loading.

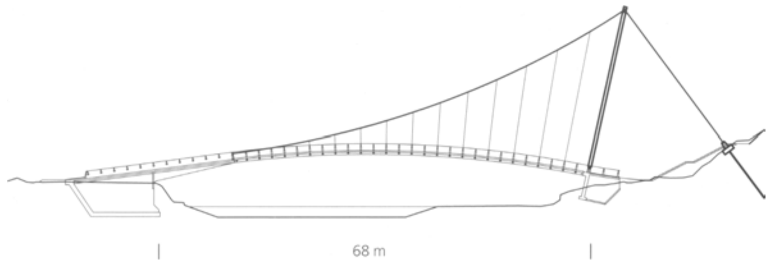
There are no codes and very few guidelines for the design of fibre-reinforced plastics, so testing was required to verify the structural integrity. The bearing strength of the bolted anchorage of the hanger into the deck was confirmed by testing. The dynamic response of the structure was closely monitored before its inauguration. The damping effects of the wooden blinders, the flexible surfacing of recycled tyres, and the chain link railing were sufficient to hamper dynamic oscillations.

The erection of the deck was carried out in one night with the 31 m long midsection of the bridge was hung from the suspension cables. The bridge was opened to the public in July 2001. Should these plastic bridges truly have lower maintenance costs and erection time, we will surely see more of them in the future.

Firth I., Cooper D., New Materials for New bridges Halgavor Bride UK, in: Structural Engineering International, May 2002, SEI 12:2


57.9 m
47 m

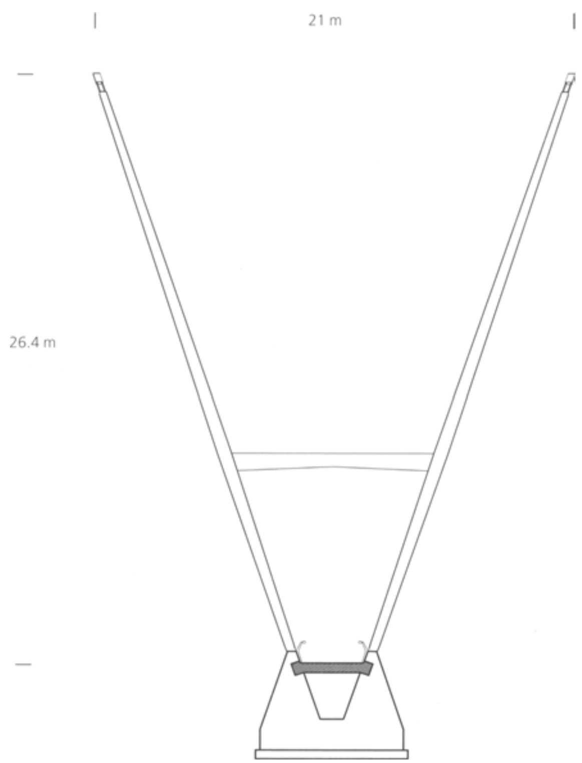

3.7 m



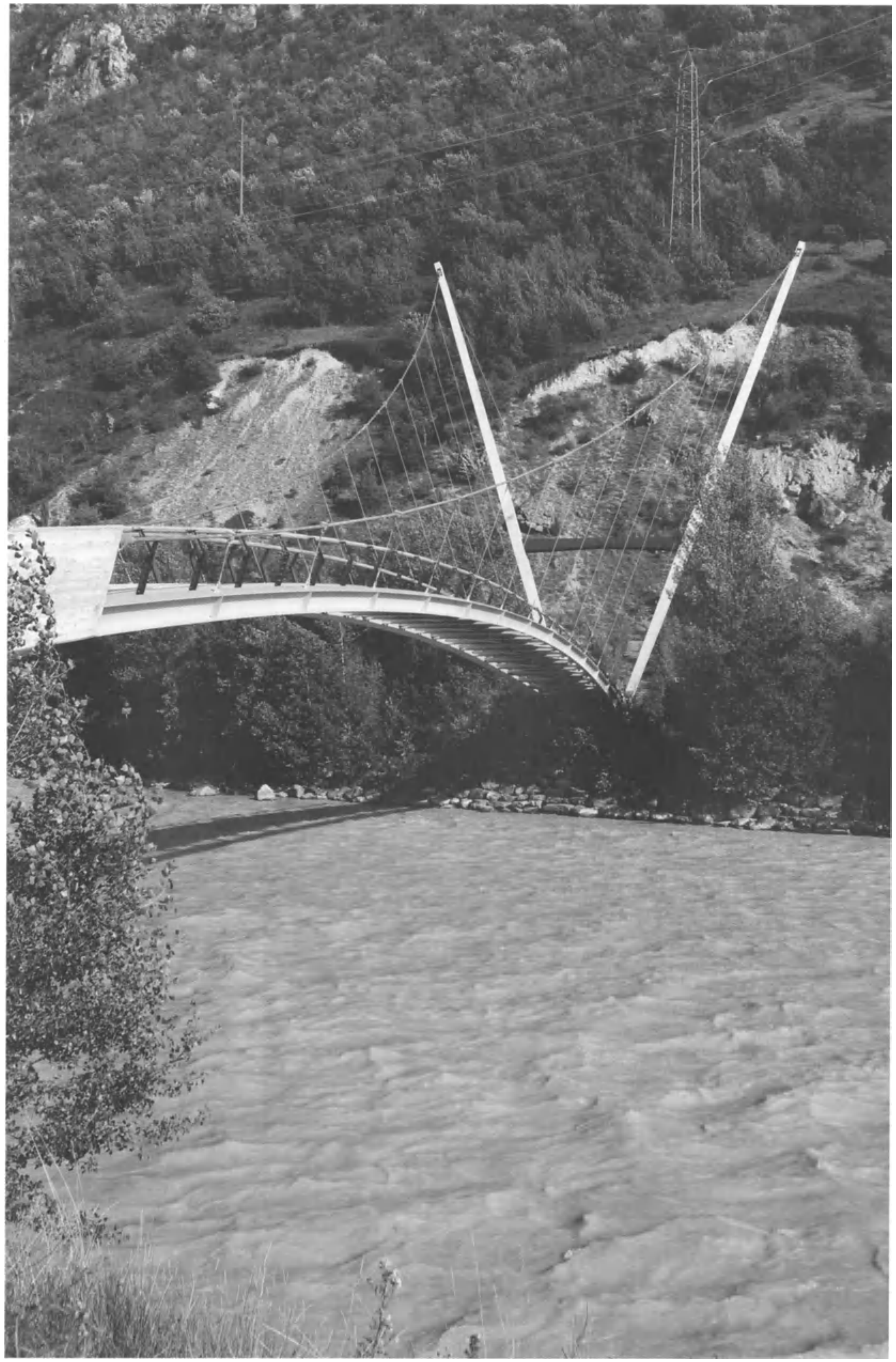
Bridge over the Rhône in Sierre, Iles Falcon, Switzerland, 1998

In the Rhône valley, the conversion of the industrial society is just as difficult as it is anywhere else, in spite of a more versatile economy. Abandoned industrial zones must be rehabilitated and converted to counteract their deterioration. In Sierre, the Iles Falcon are just such an industrial zone that is being reverted piece by piece to a more natural environment, with a hiking trail that crosses the Rhône and joins a steep hillside. An asymmetrically suspended, 3.6 m wide bridge entices hikers to cross. The inclined, 26.36 m high pylons make a powerful architectural gesture. Over the next few years, the hiking path will be completed up the hillside – until then the bridge seems unmotivated and without a role. It is striking that the engineers of Dauner, Joliat & associés use the northern abutment as central design constraint and integrate it into the hiking trail. The sole problem of the anchorages' potentially overpowering visual impact is elegantly solved. Well-conceived details for the railing and the change in deck surfacing at the bridgehead along with the precise execution produce a coherent structure with a span of 68 m and a total length of 88.45 m. The tensioning of the suspension cable creates light arching of the deck. Due to changes in temperature, the bridge is stiffer in winter and more flexible in summer – but always sufficiently stable. One unique feature is the black beam that joins and stabilizes the two masts. Hopefully the hiking trail will soon be completed and the bridge will soon carry pedestrians after nine years as a ghost bridge.

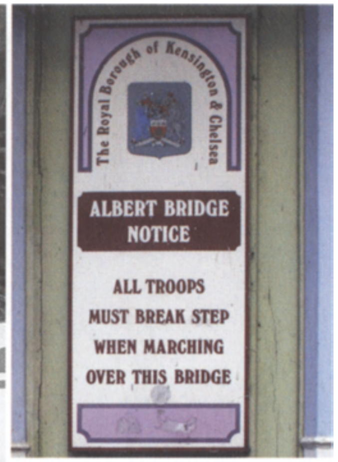
From an industrial area to natural environment



The bridge currently ends in no man's land, a hiking trail will be added shortly



Load testing of the footbridge in Sassnitz



Dynamics, vibrations

In the German language, the term for structural engineers is *Statiker*, and the structural analysis and calculations of a project are referred to as the *Statik*. These expressions refer to the field of static mechanics, the dominant field of mechanics that structural engineers handle. In the analysis of most structures, the loading that acts on the structure is considered to be stationary, which means that the structure is considered to deform only slightly, and not to vibrate. Increasingly lightweight and slender structures are being built as high-strength materials become more readily available. This often produces more aesthetic designs while conserving resources. Lightweight structures, however, are lively structures that exhibit larger deflections than heavy structures, and are generally susceptible to dynamic excitation.

While statics are largely sufficient for analysing a heavy stone arch, the dynamic behaviour of a lightweight footbridge must be considered carefully. Not all phenomena in the dynamics of structures are completely understood. Recently, several landmark pedestrian bridges have exhibited spirited dynamic oscillations, resulting in much press coverage and the subsequent installation of damping devices. It is no surprise that the dynamic behaviour of pedestrian bridges has become the main topic of many bridge conferences. A chapter of this book is therefore devoted to the dynamics of pedestrian bridges.

Generally speaking, it is the loading of the pedestrian themselves, and more rarely wind loading, that excites bridge structures to large oscillations, or sometimes to collapse. Two spectacular bridge collapses in England (Broughton Bridge near Manchester, 1831) and France (Angers, 1850) due to synchronized marching of soldiers have led to the common practice of soldiers to break step while crossing a bridge. This can be seen on the notice on the Albert Bridge in London ("All troops must break step when marching over this bridge"), and in the current German road traffic regulations.

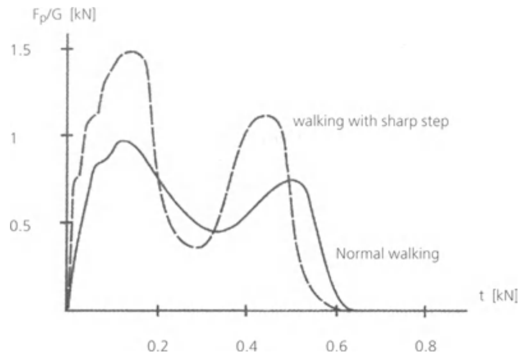
Frequencies

The design of the structure depends on the resonance (from the Latin, *resonare*: to echo) of the structure. A good example of this is a swing.

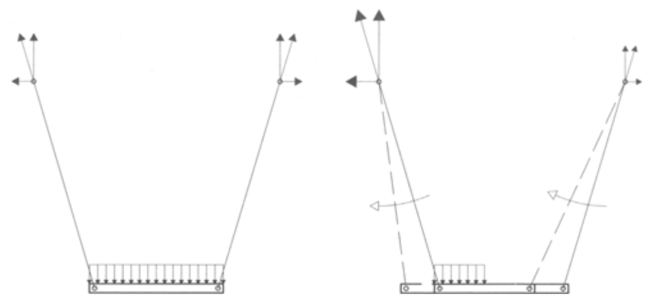
Step frequencies of pedestrians

	fs [Hz]	vs [m/s]	ls [m]
slow pace	1.7	1.0	0.60
normal pace	2.0	1.5	0.75
fast pace	2.3	2.3	1.00
normal running	2.5	3.1	1.25
sprinting	> 3.2	5.5	1.75

Loading behaviour



Deck with inclined hangers



Like a pendulum, the swing has one natural frequency that is dependent on the length of the swing but independent of the mass. Regardless of the initial force that acts to push the swing, it always oscillates at the same frequency, measured in oscillations per second with the unit Hertz (Hz). If the swing is pushed regularly at the right moment, i.e. with the same frequency as the swing, the amplitude of the swing displacement can be greatly increased with little force. The swing is now resonating with the frequency of excitation exactly equal to the natural frequency of the structure. Unlike the swing, each pedestrian bridge has many natural frequencies, and if one of them lies near the step frequency of pedestrians, resonance can occur.

The step frequency depends on the speed of the pedestrian. It should be noted that by hopping or jumping, the pedestrian can bring the bridge to great oscillations more quickly than by walking. This is because the excitation force of someone hopping is several times the weight of the individual. This can be illustrated with the help of a plastic 1 l bottle filled with water and a scale. First, the bottle is released suddenly at the top of the weighing surface, and then from 50 cm above the scale. The bottle of water weights 1 kg, but will show 2 kg if suddenly released at the weight surface. The scale will show 30 kg when the bottle is released 50 cm above the scale.

The pedestrian does not simply introduce vertical loads into the structure. During the transfer of force from one foot to the other, horizontal forces are transferred to the deck that can produce horizontal oscillations of the structure. Pedestrians are extremely sensitive to horizontal vibrations as they easily disturb our balance. Unconsciously, the pedestrian increases the horizontal oscillation by automatically walking with a "sailor's roll". This implies synchronizing the step frequency with the horizontal frequency of the structure to walk more safely along the deck. This effect is often referred to in technical literature as the *lock-in effect*. Even large bridges are susceptible to the phenomenon if sufficient pedestrians are present. It is reported that the Brooklyn Bridge was brought to oscillate noticeably during the August 2003 New York City blackout, as thousands of commuters were forced to cross the structure by foot. At its inauguration, the Millennium Bridge in London vibrated under a heavy pedestrian density with such amplitude that it was closed shortly thereafter. The Millennium Bridge was reopened after the installation of a complicated damping system. The inclined hangers of the deck also led to the additional horizontal forces exciting the bridge oscillation.

Footbridges with vertical natural frequencies between 1.3 and 2.3 Hz, or with horizontal frequencies between 0.5 Hz and 1.2 Hz, must be considered as being susceptible to dynamic excitation. It is precisely in these frequency ranges that many lightweight bridges have natural frequencies.

Damping

Damping helps to limit the dynamic response of the structure. The energy of motion of the structure is dissipated as thermal energy through friction in the material or between structural components. The damping of the structure is often large enough to prohibit unacceptable

Comfort Level	Degree of comfort	Vertical acceleration	Horizontal acceleration
CL 1	maximum	< 0.5 m/s²	< 0.1 m/s²
CL 2	mean	0.5 - 1 m/s²	0.1 - 0.3 m/s²
CL 3	minimum	1 - 2.5 m/s²	0.3 - 0.8 m/s²
CL 4	unacceptable	> 2.5 m/s²	> 0.8 m/s²

Acceleration limits (Synpex)

Chain link guardrails in Pforzheim

levels of vibration. In addition, the pedestrian often expects lightweight structures to vibrate and therefore does not perceive the vibration as uncomfortable.

The acceleration of the structure is commonly used to measure the comfort of a pedestrian. Roughly 10 percent of gravitational acceleration or 1 m/s² is considered as being easily perceived by the pedestrian. Accelerations greater than 2.5 m/s² are considered unacceptable. In order to determine whether a structure is susceptible to pedestrian-induced oscillation, the natural frequencies must be determined. This is easy using current software. It should be noted that for very lightweight structures, the weight of the pedestrians may have a significant effect on the system mass and the structure's natural frequencies.

Should the natural frequencies of the structure lie in a critical band of frequencies, the bridge designer and owner must determine an appropriate level of comfort. This translates into the establishment of appropriate acceleration limits. A narrow footbridge on a hiking trail may have very different comfort criteria from a footbridge with high pedestrian density, such as at a convention centre or an urban pedestrian overpass. In these cases, dynamic calculations are required to verify that

– the expected vertical acceleration under normal service conditions lie below the acceleration limits,

– there is no *lock-in effect* or horizontal oscillation,

– intentional excitation such as jumping or hopping do not cause the bridge to collapse. The comfort criteria are naturally not considered for this type of loading.

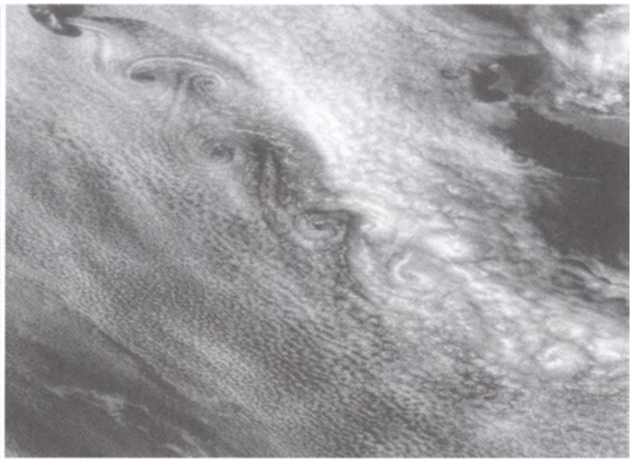
The results of the calculations must be taken with a grain of salt, as the damping of the structure can only be roughly estimated. The true dynamic behaviour of the bridge can only be determined by testing after erection. These results too only provide a momentary insight into the dynamic behaviour of the structure, as the material properties are often time-dependent. Experience and caution should guide the calculation, and it should be noted that the damping depends on the material and structural typology. In addition, the complexity of the details, the particular natural frequency studied, the number of pedestrians, the deck surfacing and furnishings, and even the type of railing affect the damping of the structure. The chain link guardrails of the Pforzheim Bridge were shown to have doubled the damping of the stress ribbon structure.

If calculations show that the dynamic limits may be exceeded, provisions for the possible installation of dampers should be taken into account in the structural design. This allows for the subsequent installation of a damping system should unacceptable accelerations be observed on the finished structure. Viscoelastic dampers require relatively large deflections to be effective. Tuned mass dampers are effective for some frequencies only and require a rather large mass, typically 1 percent to 5 percent of the total bridge mass.

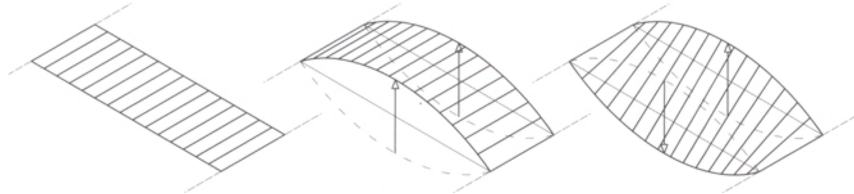
Wind loading should also be considered in the dynamic analysis of the structure, as wind may also excite a dynamic response from a lightweight structure. At low wind speeds, the wind flow can be assumed to be laminar, breaking off at the leeward edge of the deck. This can cause a periodic detachment of vortices at the leeward edge, often referred to as vortex shedding. These vortices

Viscoelastic dampers

Karman vortex shedding



Model of natural and torsional frequencies



cause a periodic excitation of the structure and may lead to the dynamic excitation of the structure. These oscillations will generally not cause the structure to collapse, but may be uncomfortable for pedestrians. As structural engineers say, this is a serviceability problem.

It is only at high wind speeds and turbulent air flows that a structure may be pushed to collapse. The most famous example of this is the Tacoma Narrows Bridge. This was an 850 m long suspension road bridge. Four months after its inauguration, the bridge collapsed due to an aerodynamic instability that was unknown at the time. This instability was such that the energy of excitation from the wind was always greater than the energy dissipated by the damping, thereby leading to collapse. In order to avoid flutter, bridge decks are designed to be thin, aerodynamic cross sections for which the torsional natural frequency is very far from the natural frequency in bending. The critical wind speeds above which flutter occurs can be determined by wind tunnel testing. It must be shown that the critical wind speed lies above the highest wind speed expected at the site.

Cables from cable-stayed and suspension bridges may also oscillate due to rain. This phenomenon occurs only for large bridges, as the long, heavy cables necessary for large bridges exhibit low natural frequencies and low damping. Cable oscillations have not yet been observed in footbridge structures.

European Comission, Research Programme of the Research Fund for Coal and Steel RTD, Technical Group 8, RFS-CR-03019 (2006), Advanced load models for synchronous pedestrian excitation and optimised design guidelines for steel foot bridges (Synpex), Final report, August 2006

Setra, Footbridges, Assessment of vobrational behaviour for footbridges under pedestrian loading. Setra - Reference 0644A, Paris http://www.setra.equipement.gouv.fr, Oktober 2006

Equilibrium is most beautiful shortly before it collapses. *Peter Fischli, David Weiss*

In the second half of the 20th century, bridgebuilders chased one record after another. Free spans of 2 km and more were easily bridged with classic suspension bridges in Storebelt and Japan. Few designers diverged from the standard solutions as owners feared that the unusual structures would incur higher construction and maintenance costs. The innovative spirit of engineers and architects – thankfully – could not be silenced, as smaller, more manageable footbridges began to be the focus of their creative energy. For example, did bridges have to be straight? Could the newly developed plastics improve bridge construction? Could different structural systems be rationally paired with other materials? The geometry of the designs becomes more playful as one might expect for a structure on a human scale. The great possibilities opened by computer-aided design and calculation are truly being exploited by the designer. But it has been shown that only experienced, ambitious architects and engineers who have learned the fundamentals of construction and design can carry out such computer-aided innovations. The computer must never become more than a tool in such design experiments.

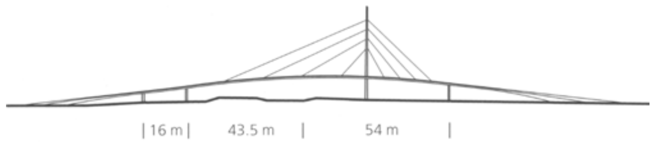
We have found successful examples of each of the above-mentioned themes. We emphasize curved bridges and the combination or deconstruction of different structural systems. The development of new materials also belongs to the domain of construction experiments. The creative impulse in structural design knows no bounds.

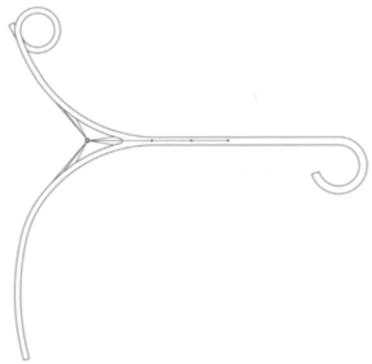
Las Glorias Bridge in Barcelona, Catalonia, Spain 1974

The bridge built at the Plaza Glorias Catalana in 1974 by Leonardo Fernandez Troyano is another example of the adaptability of footbridges in difficult terrain and complicated traffic relations. Two curved ramps are suspended to one edge and meet at the steel mast of a cable-stayed footbridge. They then merge into one slender box girder with a span of 68 m over a highway.

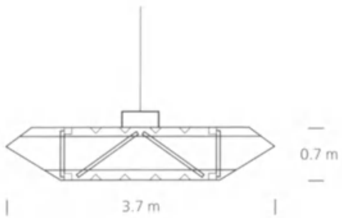
The bridge was originally red and had to make way for the 1992 Olympic games in Barcelona. The structure is just north of the Forum, a newly conceived cultural centre for the city. As the cables could not be dismantled, the entire bridge was lifted by jacks so that the cables could be cut. For the reconstruction, the steel box girder was placed on temporary trestles as it had been in 1974. The cables were then installed and stressed. Cable-stayed structures are normally installed by free cantilevering. This method could not be used due to the unilateral suspension and curved ramps. Leonardo Fernandez Troyano designed symmetrical ramps in reinforced concrete for the transition to the straight bridge segment and the new site.

A visit to the bridge shows that the structure, although perfectly maintained and painted, is hardly used due to its position in the urban environment and difficult relations with the surrounding pathways.
In spite of this and its age, we can only hope that this elegant bridge will soon entertain a greater number of users.





Troyano, Leonardo Fernández, Tierra sobre el agua, in: Collegio de Ingenerios de caminos, canales y puertos, Madrid, 1999


0.7 m
3.7 m

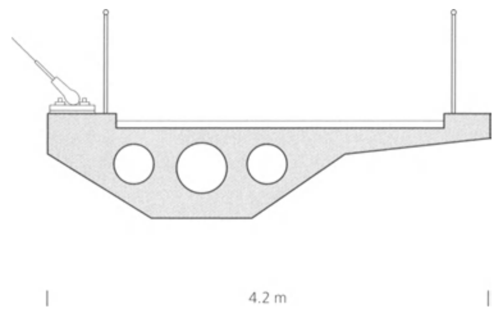
Bridge in Kehlheim, Germany, 1987

The pedestrian bridge in Kehlheim can rightly be called an experimental construction. This is the first structure based on the realization that a ring girder could be unilaterally suspended along its entire length without torsional moments.

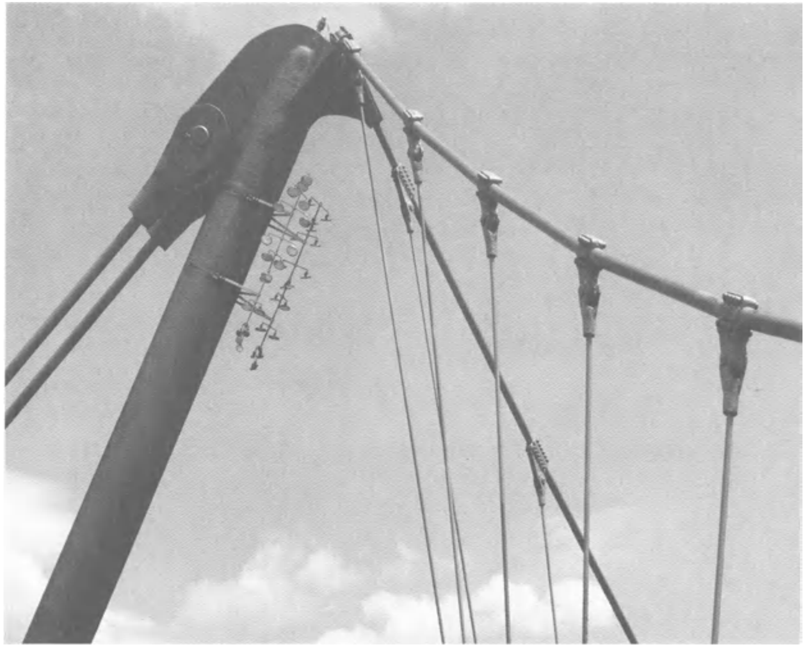
The idyllic river landscape suffered as the Altmühl River was extended and became part of the Main-Danube Canal. Shipping lanes required it. Kehlheim is an historic place with a well-preserved city centre and, high on a hill overlooking the city, the *Befreiungshalle* that King Ludwig I of Bavaria had Leo von Klenze build (1842-63) to commemorate the war of independence from Napoleon.

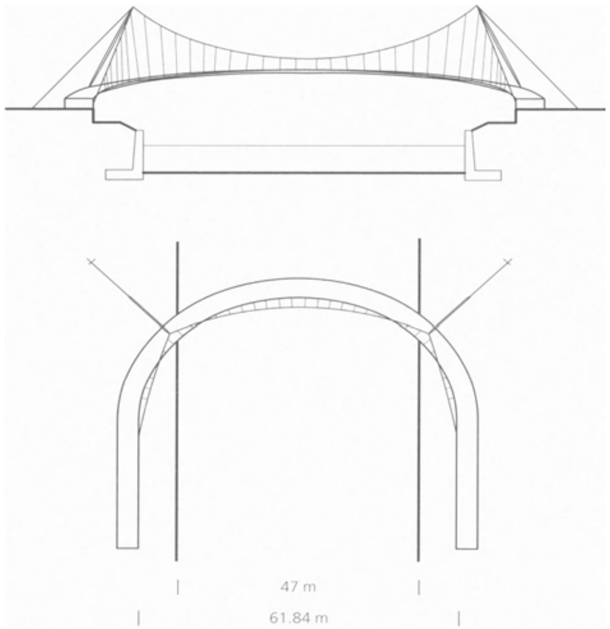
Schlaich Bergermann and Partner, with the architect Kurt Ackermann, designed a suspension bridge in the historically and environmentally important area near the Torhausplatz. The structural system is a suspension bridge anchored partly in the deck and partly in the abutments with the plan of the deck in an arc and long approach ramps. The structure spans a distance of 60 m and the deck is longer because of its curvature. The ring girder proved itself as an efficient structural system. A mast at each riverbank supports the main suspension cable and the hangers run along the inner edge of the deck. The masts were required to be lower than the tower of an historic building in Kehlheim. The result is a somewhat compact pylon anchorage, but the curvature of the suspended deck high over the water leaves a lasting visual impression.

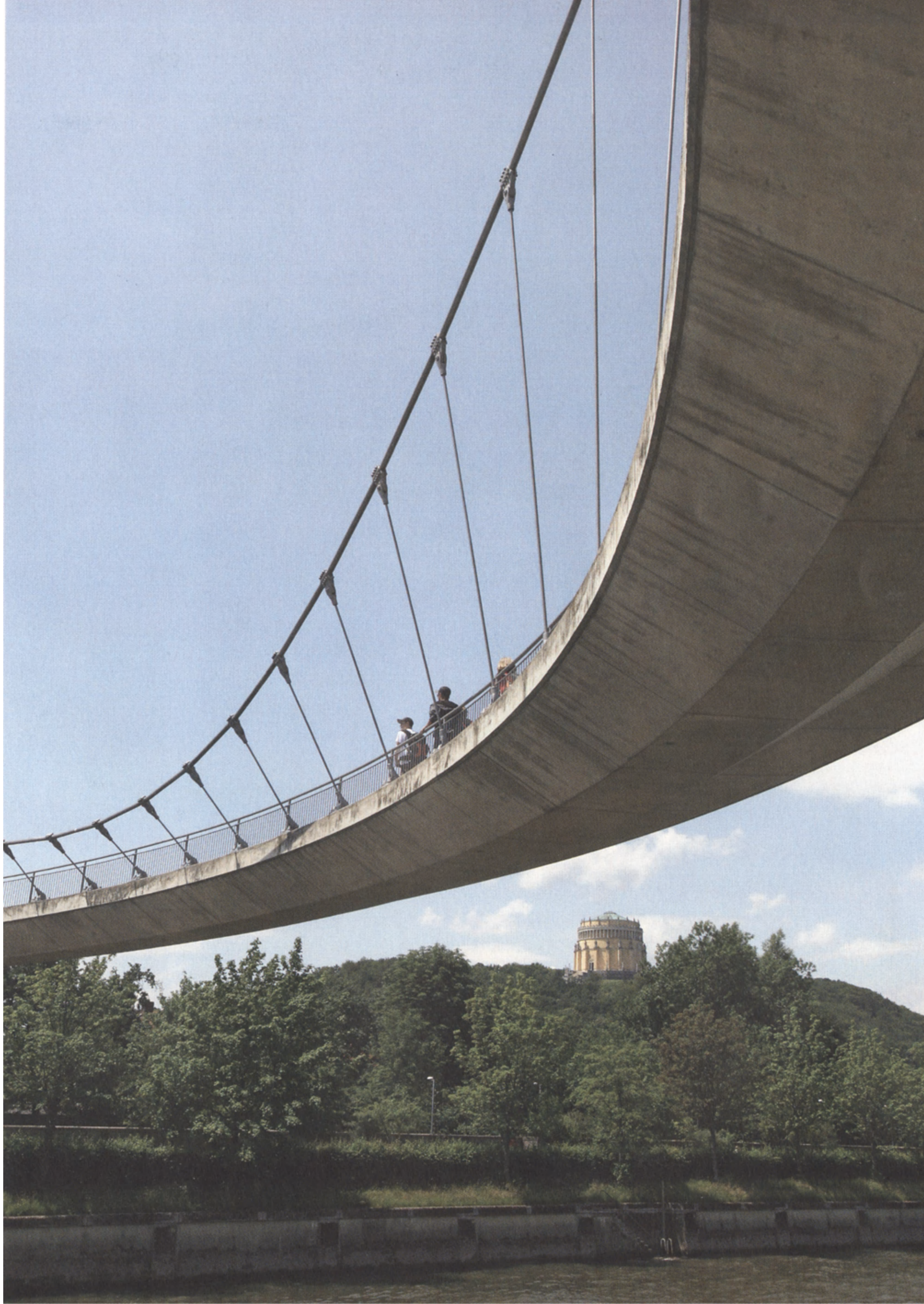
Leicht, weit, 2004, p. 246
Oster, 1992, pp. 38-39

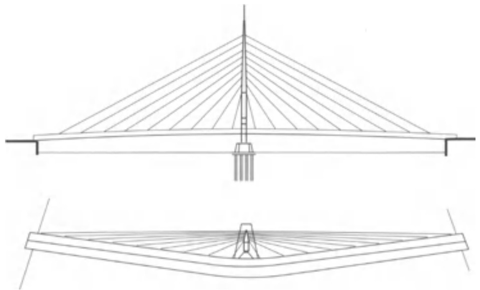


Pylon with main cable and anchorage

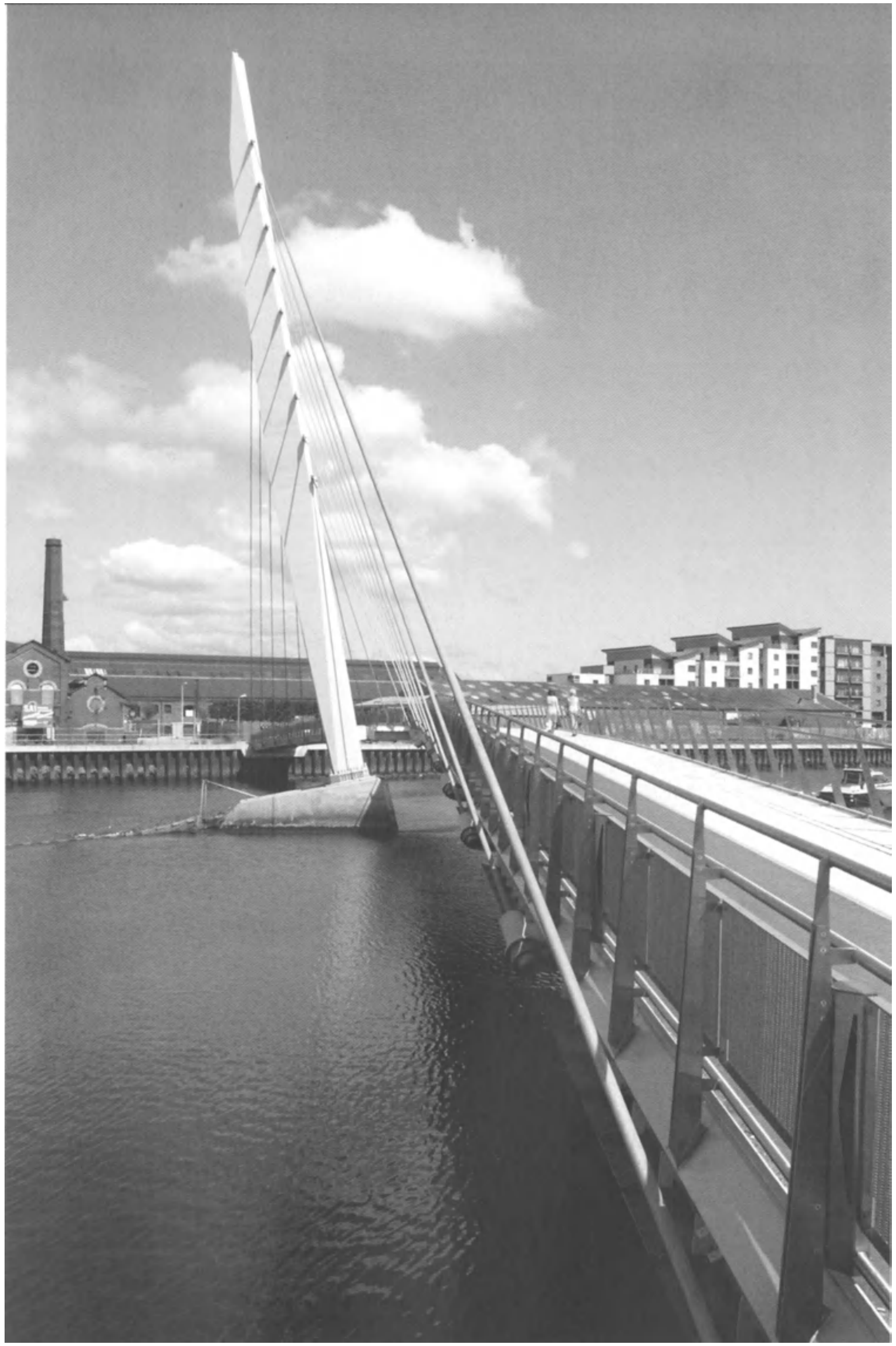








Bridge in Swansea, Wales, UK, 2003

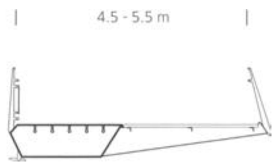


Wilkinson Eyre worked on this structure in cooperation with the engineers Flint & Neill. The architectural intention was to create a mast that reflected the surrounding masts of the sailing boats while still creating an impressive visual landmark. The footbridge is a unilaterally supported cable-stayed bridge with a kink in the deck, and joins the port area with a newer city zone.

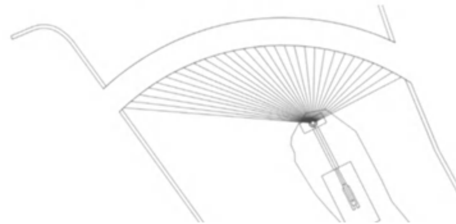
The 140 m long superstructure has a kink in the horizontal plane at the mast. Each portion of the deck is unilaterally supported, leading to high torsional moments. The structural advantages of a ring girder were not exploited.

Instead, the deck girder is fixed in torsion at the abutments and the mast. At the mast, a bearing and an eccentrically positioned cable can support an eccentric pair of forces, i.e. a torsional moment. The steel box section is surfaced with a cantilevering aluminium walkway to minimize weight and the torsional moment acting on the deck. The mast is fixed at the base and inclined to minimized bending.

Sanders, P., Firth, I., Design and Construction of the Sail Bridge, Swansea, UK, Bridge Engineering 158, Issue BE4, 2005

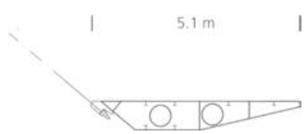


This unusual structure is illuminated to great effect



Pasarela del Malecon in Murcia, Spain, 1996

Javier Manterola from the office of Carlos Fernandez Casado is currently the most experienced bridge engineer in Spain. His 1983 Barrios de Luna Bridge, a motorway bridge over a reservoir, was the longest cable-stayed bridge in the world at the time of its construction. Manterola plays with the spaces created by the fanning cables of the bridge. After the famous Sancho El Mayor Bridge over the Ebro de Castejón in 1978 and the Lerez Bridge in Pontevedra in 1995, he created another example here in 1995. The Pasarela de Malecon is a 59 m span cable-stayed bridge with a curved deck and an eccentric mast. This creates a very beautiful fan form but leads to the necessity of back-stayed cables to bring the horizontal component of the deck cables into equilibrium at the head of the pylon. These forces must be transferred to the foundations and further to the soils below. In order to minimize the anchorage forces, the deck was conceived as a lightweight steel box girder. During erection, three prefabricated segments of the deck girder were supported on temporary trestles founded in the riverbed, and welded together. The unilaterally supported ring beam can support the overturning moment by offset compression and tension forces in the girder completely without torsion (see p. 116).

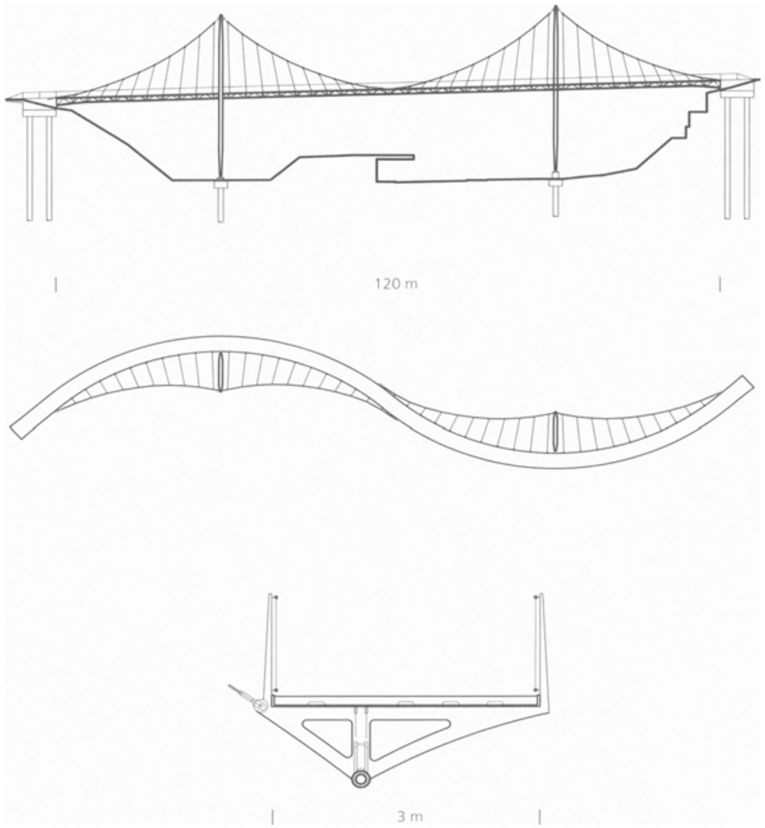


West Park Bridge in Bochum, Germany, 2003

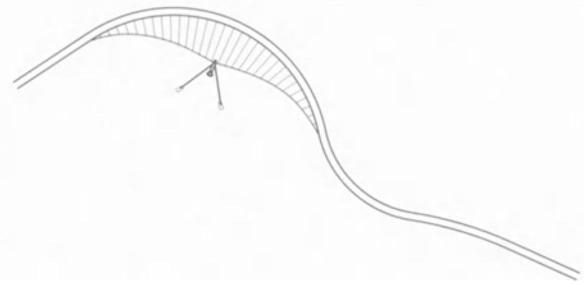
For a century, the Ruhr was considered the flourishing economic centre of the German coal and steel industries. The environment suffered and the international competition for steel and for other energy sources grew. The transition of the Ruhr to a centre of the service industry began with the IBA Emscher Park, and will continue for decades. Bochum is in the middle of this transition, the remnants of industry are being converted, renovated and given new life. Good connections between residential and recreational areas are necessary. To create one such connection, the engineers of Schlaich Bergermann and Partner designed a double-curved bridge in a very difficult environment. The S-formed 3 m wide pedestrian and cycle bridge consists of two 66 m long arc segments above the Gahlensche Straße and the railway below.

The deck is suspended from two masts. The bridge deck of each segment is suspended from a suspension cable at the inside of the arc. The cross section of the superstructure varies with the direction of the hanger cables. Unlike a straight girder, which must be fixed by two bearing axes, the ring girder need only be supported along one axis, simplifying the reinforcement of the section. While the ring girder of the Kehlheim Bridge is a monolithic prestressed concrete girder (see p. 108), later ring girders are broken down into compression and tension forces, in cables and tubes. The masts of the Bochum structure do not require back stays or fixed footings. As the footings of the masts are lower than the anchorages of the suspension cables, the cables stabilize the mast. However, the deflection of the structure changes with each load case, so an articulated connection is required at the footing to avoid bending in the pylon. The form of the bridge provides not only an efficient connection to the neighbouring pathways, but creates a symbol of the urban renewal.

Göppert, Klaus, A. Kratz and P. Pfoser, Entwurf und Konstruktion einer S-förmigen Fußgängerbrücke in Bochum, in: Stahlbau, 2, 2005, pp. 126-133


120 m
3 m

An unusually transparent railing expresses the bridge's function as a balcony



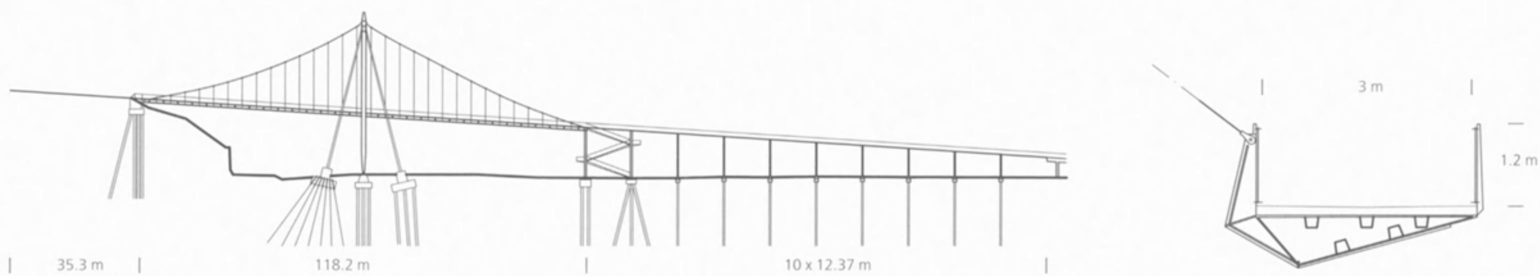
Bridge overlooking the Baltic Sea in Sassnitz, Germany, 2007

From Sassnitz, at the northernmost end of Rügen Island, great ships once passed on their way east and west. The quay is now the home of a glazed railway station, a beautiful historic hall, and portions of the city that overlook the Baltic from a high hillside. The island of Rügen has become a popular vacation destination. A pedestrian and cycle bridge was built in 2006 to make Sassnitz more accessible to these visitors and link the city centre with the port. The bridge would have to overcome a difference of 25 m in elevation and respect the protected railway building and the various streets at the site. With the curvature of the bridge deck, all of these requirements were met, and the increase in bridge length permits the deck to bridge the change in elevation with a more manageable slope. Nevertheless, much longer ramps would be necessary to maintain a tolerable slope, had the structure not been able to land above the port. A 7 m high portion of ramp projects from the railway station, as a bridge for transit traffic was demolished after German reunification. Connecting with the transit station was not only a gesture of forgiveness, but also allowed the bridge to exploit the existing railway station ramps and, with a length of "only" 240 m, limit the gradient to 7 percent.

The 3 m wide deck sweeps across the port in a long arc to create a balcony over the sea, opening up new perspectives and views. These views are unimpeded as the unilateral suspension lies at the interior of the arc. The balcony is a 130 m long suspension bridge that transitions into a continuous beam on multiple supports as the curvature and slope of the terrain decrease.

The structure's distinctive feature is that the hanger cables are attached to cantilevers projecting from the inside edge of the bridge deck. The height of the cantilevers was chosen so that the resulting force of the hangers passes through the centre of gravity of the deck. With this principle, there are no overturning moments in the structure due to deck load and uniformly distributed load on the deck. This reduces the stresses in the deck girder (see Technical Overview Curved Bridges). Normally, it would have been possible to leave the 40 m high mast without backstays, as in the West Park Bridge in Bochum (see p. 112). In order to minimize the deflections of the deck under live loads, four backstays were installed. The backstays are the same cable as the suspension cable, a Galfan-coated fully locked coil with a diameter of 95 mm. For pedestrians in a hurry, a stairway was built at the end of the suspension bridge that also serves as an abutment for the horizontal forces from the deck.

Dechau, Wilfried, Seebrücke. Fotografisches Tagebuch, Berlin/Tübingen, 2007


35.3 m
118.2 m
10 x 12.37 m
3 m
1.2 m

Footbridge in Sassnitz, 2007

Bridge in Deutsches Museum, Munich

Curved Bridges

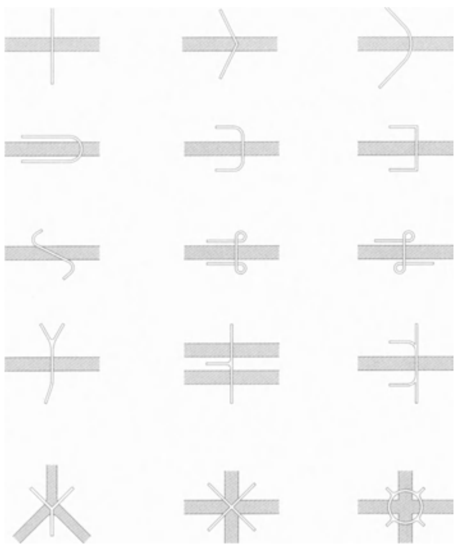
In contrast to road and rail bridges subject to high-speed traffic, the footbridge designer is literally allowed to design some pretty crooked structures. The low speed of the user opens up a spatial dimension and a multiplicity of forms. The deck can elegantly flow into the existing pathways and closely follow the adjacent elevations. The structure may also contain multiple approaches or decks in order to connect a network of pathways. If approach ramps are parallel to the central obstacle being bridged, a curved deck with a seamless transition from one approach to the other seems a natural solution. In some instances, the curvature of the deck and the resulting increase in length may be exploited to minimize the steepness of the bridge gradient, similarly to a spiral staircase. This opens a completely new level of design freedom, as the deck is not simply curved, but pylons become inclined, arches become tilted, and suspension cables create spatial silhouettes. The complex structural behaviour of these three dimensional structures is discussed here.

Circular ring girders

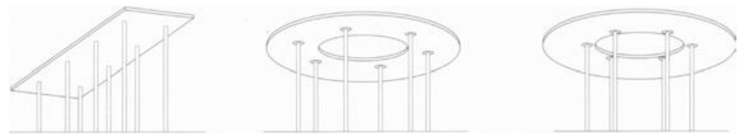
The circular ring girders are of particular interest to the structural engineer. Here, the bridge deck is circular in the horizontal plane. These structures may be suspended at only one edge by a suspension cable or cable-stay system, which presents an especially interesting technical challenge. This is also an example of the necessity of a holistic approach towards the technical challenge, where the structural design, behaviour, deflections, fabrication and erection are so closely linked that all aspects of the design must be investigated simultaneously.

The designer can exploit the fact that a curved bridge may be supported by a single line of columns while a straight bridge requires two lines of support. One can easily imagine that the straight girder at the bottom left of the plan views supported by a single row of supports would cause the bridge deck to overturn, whereas the curved girder would remain stable. While a central support of the deck is possible at the underside of the deck, any hangers attached centrally above it would interfere with the walking surface. Circular

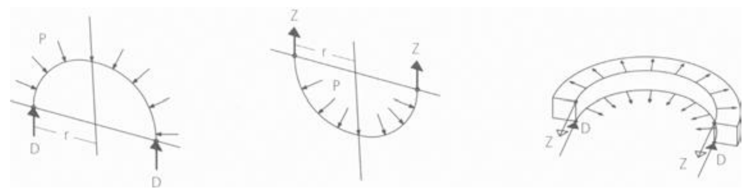
Plan views of curved bridges



Straight girder and circular ring girders with central and eccentric supports



Compression ring, tension ring, circular ring girder



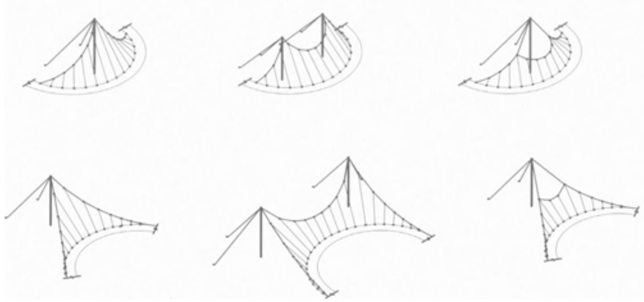
ring girders allow the deck to be supported at one edge without the deck overturning.

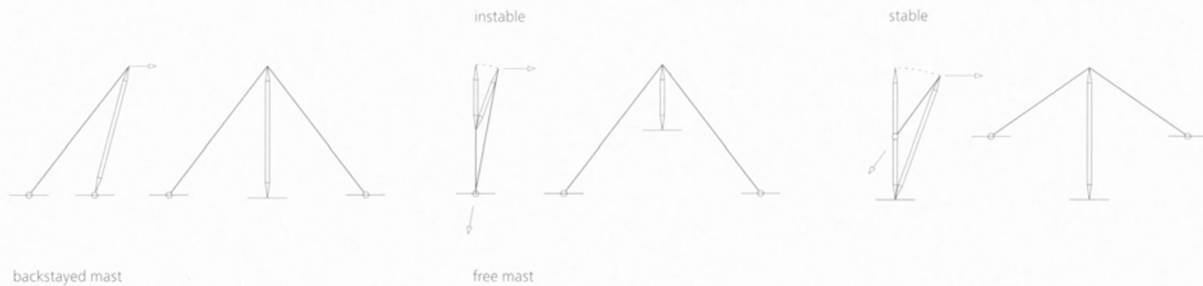
The structural behaviour of the edge-supported circular ring girder is at first difficult to comprehend, as we are used to thinking in two dimensions. In this case, however, the structural behaviour is truly spatial. In order to understand the concept, let us first look at the *boiler formula*, which allows us to calculate the tension force in a cable subject to radial loading. The tension force, Z, can be calculated according to the formula $Z = p \cdot r$ with the radial distributed load, p, and radius of the centreline of the cable, r. The formula got its name from being used to determine the tension force in the boilers of early steam locomotives. The same principle applies to an arch in compression. The compression force, D, can be calculated using the formula $D = p \cdot r$ with the radial distributed load, p, and radius of the centreline of the arch, r. If a compression ring and tension ring are laid atop one another, the two rings create a pair of equal and opposing forces, p, in every radial vertical section. With the distance, h, between rings, a moment equal to $m = p \cdot h$ may be supported by the structure. If the circular ring girder is supported eccentric to its centreline, an overturning moment of $m = g \cdot e$ is created, with dead load, g, and eccentricity, e. One can imagine supporting this moment with the pair of forces created by the compression and tension rings mentioned above. The overturning moment is in equilibrium with the radial forces of the ring pair, which can be determined according to the formula $p = g \cdot e/h$. Using the boiler formula, we can calculate the compression and tension forces $D = Z = g \cdot e \cdot r/h$. The overturning moment due to the eccentric support of the circular ring girder subject to vertical loading produces no torsion[1], but simply compression and tension forces that result in the moment $M = D \cdot h = Z \cdot h$ about the horizontal axis.

The dead weight of the deck and uniformly distributed dead load, or load cases with geometric affinity, may be supported in this manner. Point loads and unbalanced live loads are not geometrically affined, and cause bending in the tension and compression rings. This requires the appropriate bending stiffness in the horizontal axis.

1 In this case, there is no St Venant's torsion, even for circular curved girders with closed box sections. The pair of forces may however be interpreted as warping torsion.

Greenville, South Carolina, USA, 2004





A certain level of rigidity is also required to limit the rotation of the deck due to the overturning moment. Compression is created in the lower ring and tension in the upper ring should the ring be supported at the inner edge. The logic outlined above makes it clear that the lower ring is in tension and the upper ring in compression with an exterior edge support.

The structural behaviour of the circular ring girder is very clearly illustrated in the 27 m long circular ring bridge in the Deutsches Museum in Munich. The structure is the centre of attraction of the bridge engineering section of the Museum. The tension ring is created from cables and the compression ring is created from a solid round section. The West Park Bridge in Bochum (2003, p. 112) with its lower compression ring made of a round hollow section also clearly illustrates the structural behaviour of the bridge. In Bochum, the two rings of the bridge deck are connected by diagonals to provide additional stiffness. It is of course possible to exploit the structural behaviour of the compression and tension rings without bringing emphasizing their separation. In the Pedestrian Bridge in Sassnitz shown on p. 114, the bridge ring girder is created from a single steel box section. We can find compression in the underside of the girder and tension at the top of the girder. The earliest suspension bridge with a circular ring girder is the Footbridge over the Rhine-Main-Danube Canal in Kehlheim (1988), which has a concrete deck. In Kehlheim, the tension forces are taken up by high strength prestressing steel at the top of the section. The first circular ring girder bridge, Glorias Catalana in Barcelona (1974; see p. 106) is a cable-stayed structure, a deck from a steel box section.

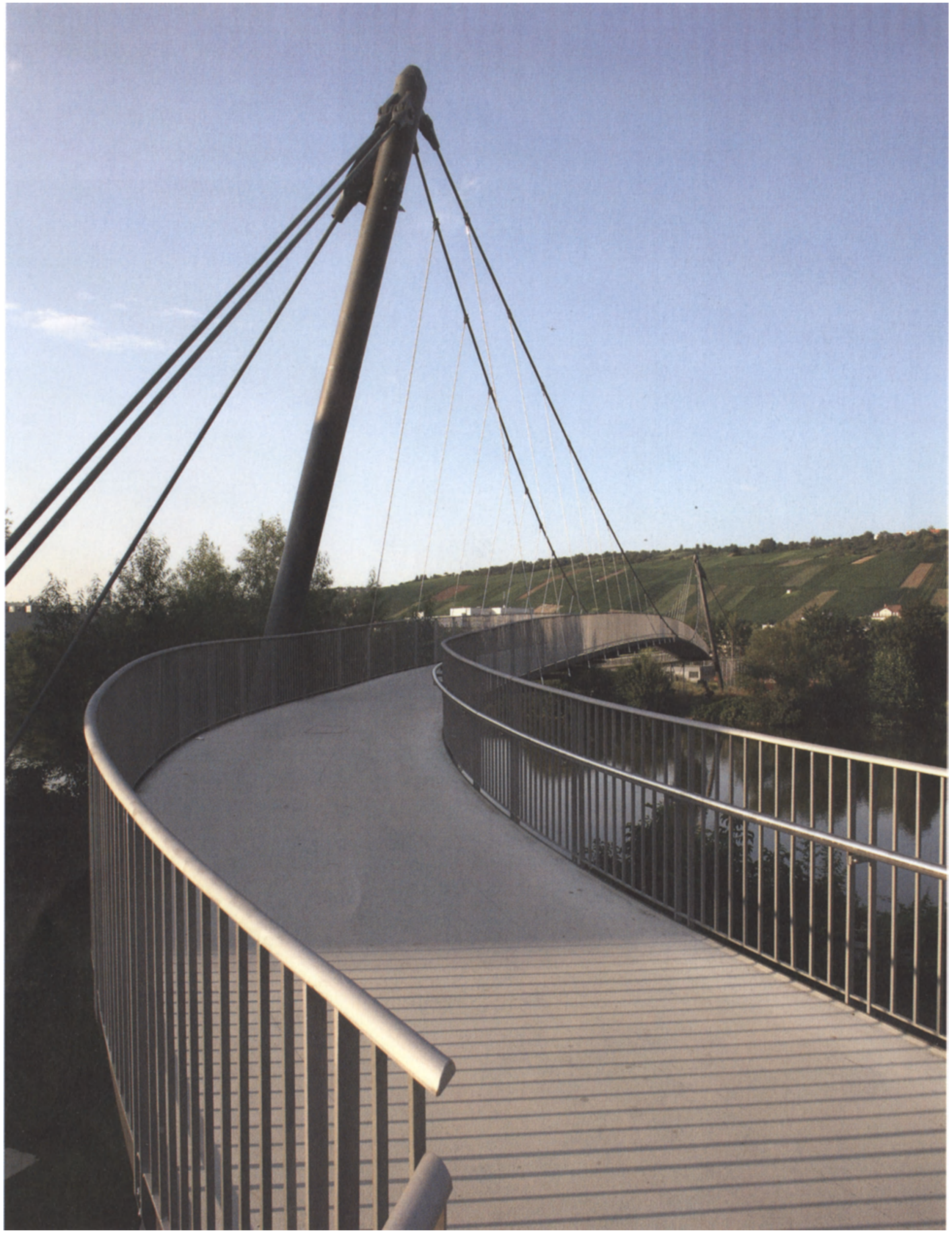
All the bridges mentioned above are supported by inclined hanger cables. The inclination of the hangers introduces horizontal loads into the bridge deck. It creates additional compression ring forces in the deck when supported at the inner edge and additional tension ring forces when support at the outer edge. The cable arrangements shown in the following figure show only a small portion of the design options available, but demonstrate the multitude of design possibilities that this plan form can open up.

A self-anchored suspension bridge with an interior mast is a particularly efficient solution: with the correct choice of hanger and suspension cable inclination, the anchorage force of the cable and the compression force of the deck can be designed to be in equilibrium. This applies only to uniformly distributed loads and anchorage of the suspension cable tangent to the ring girder. As non-uniform loading patterns are unavoidable, forces to the moments about the vertical axis and horizontal forces must nevertheless be taken into account when designing the abutments. A self-anchorage suspension system is not possible with the hanger anchored to at the exterior of the ring, as tension forces are created in the ring girder.
If a very lively structure is tolerated and the mast footing can be positioned in the centre of gravity of deck in the horizontal plane, an interior pylon can be completely without backstays.
The structure will always remain stable if the mast footing is below the deck.

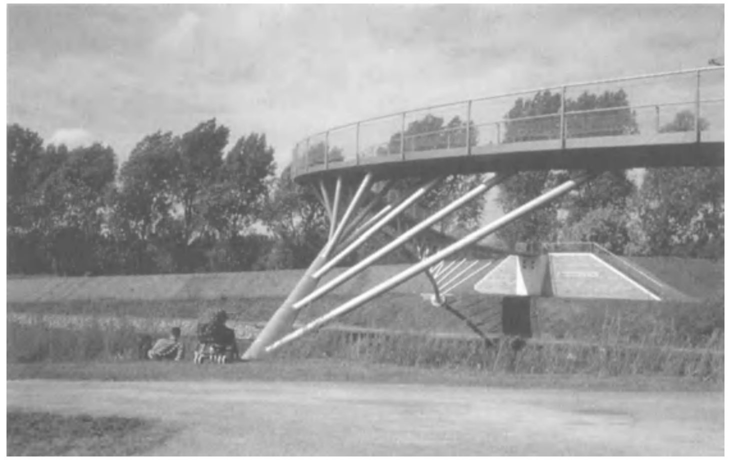
Spatial Arches

Just as the suspension bridge supported by a main cable can be interpreted as the inversion of the funicular arch bridge, suspension bridges with curved decks can also be inverted. The main cable of the curved bridge creates in interesting structural component, a three dimensional funicular tension member. The inversion of this tension member creates a spatial arch. The 77 m long bridge over the Rhine-Herne Canal near Oberhausen is the achievement of this structural principle, a steel arch supporting a curved deck and subject to compression forces, see p. 120.

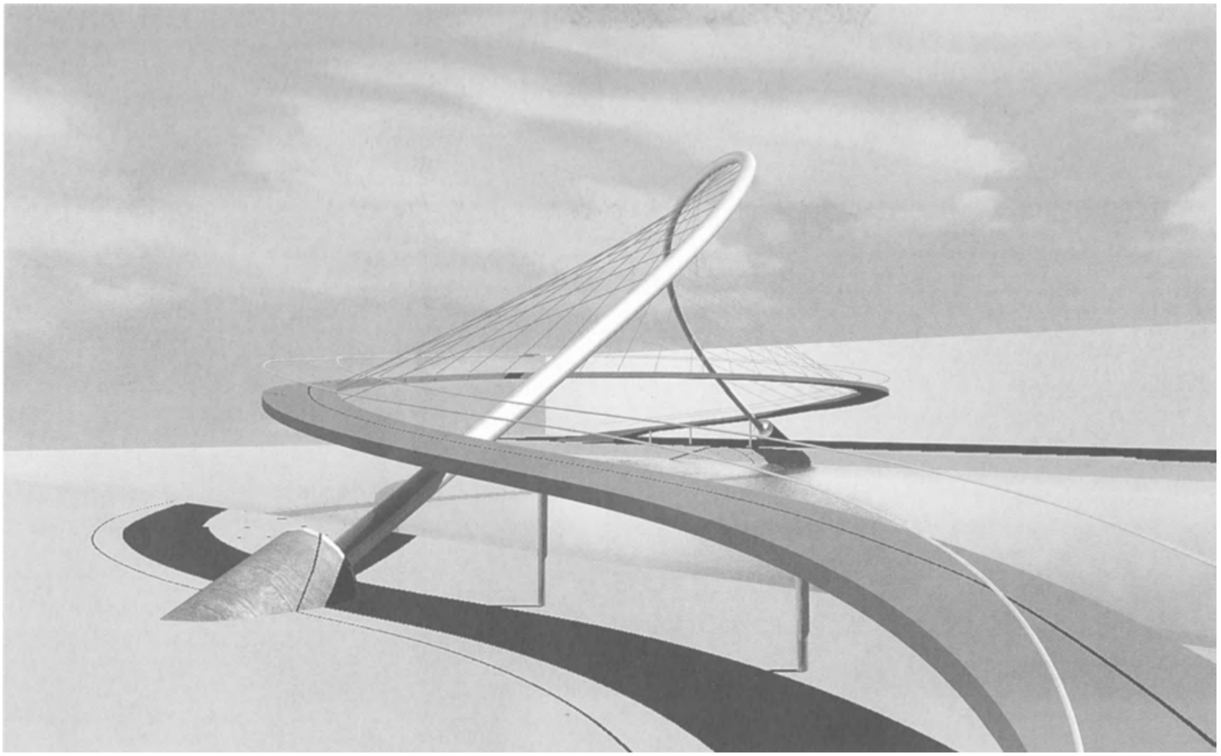
Bridge over the Neckar in Mettingen near Esslingen, 2006



Oberhausen-Ripshorst, bridge over the Rhine-Herne Canal, 1997



Design for a bridge in Deizisau



Such structural solutions may not be the most economical solution, but they demonstrate that this engineering approach can produce very interesting solutions without exorbitant cost.

We can also combine structural concepts, such as an edge supported circular girder bridge suspended from a spatial arch. The ring girder is most preferably supported at to the exterior to compensate for at least a portion of the arch thrust.

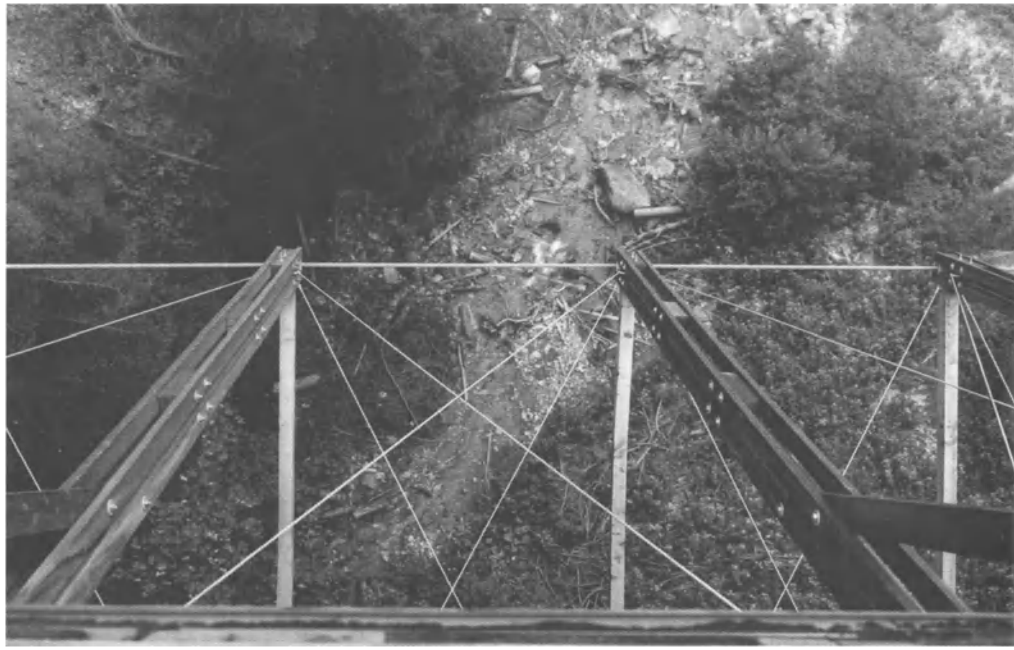
Keil, Andreas, The design of curved cable-supported footbridges, Venice footbridge conference, 2005

Strasky, Jiri, Stress ribbon and cable-supported pedestrian bridges, London, 2005

Schlaich, Jörg and A. Seidel, Die Fußgängerbrücke in Kehlheim, in: Bauingenieur, 1988

Schlaich, Jörg, Der kontinuierlich gelagerte Kreisring unter antimetrischer Belastung, in: Beton und Stahlbetonbau, January 1967

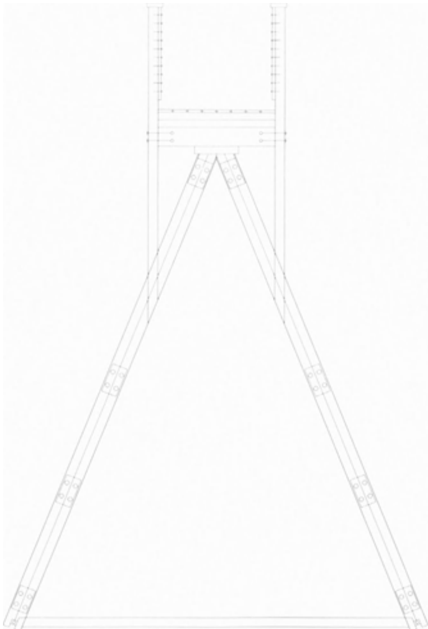
The view into the depths of the canyon is eased by the intermediate view of the bridge structure



Traversiner Footbridge I, Rongellen, Switzerland, 1996

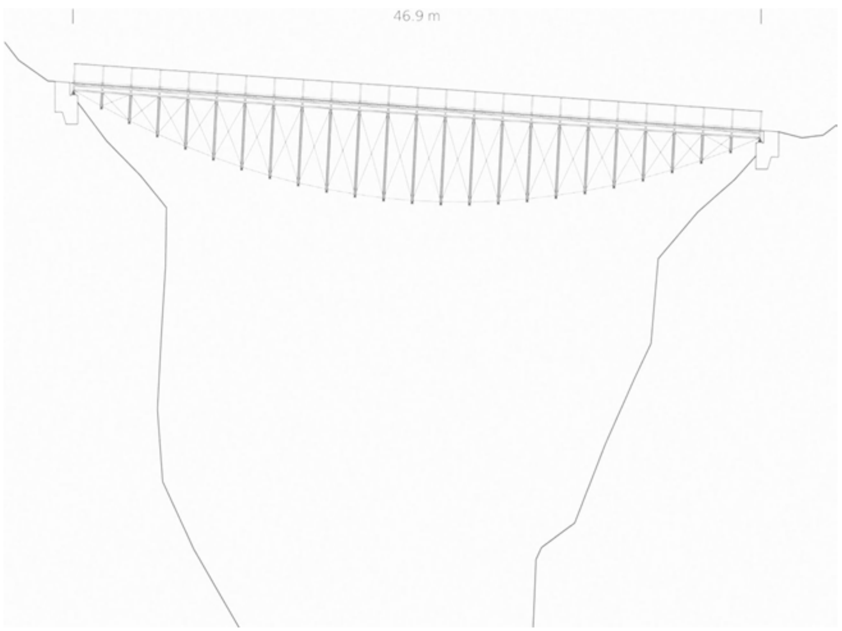
The old hiking trail through Viamala is one of the most beautiful in the Swiss Alps. In order to reanimate the hiking trail, the Cultural Association of Viamala connected one of the last gaps in the trail with a small bridge. Unfortunately, the footbridge met with its unfortunate destiny and fell in 1999 to the valley below due to the impact of a falling boulder. A replacement was built several years later a bit higher up the valley, see p. 212.

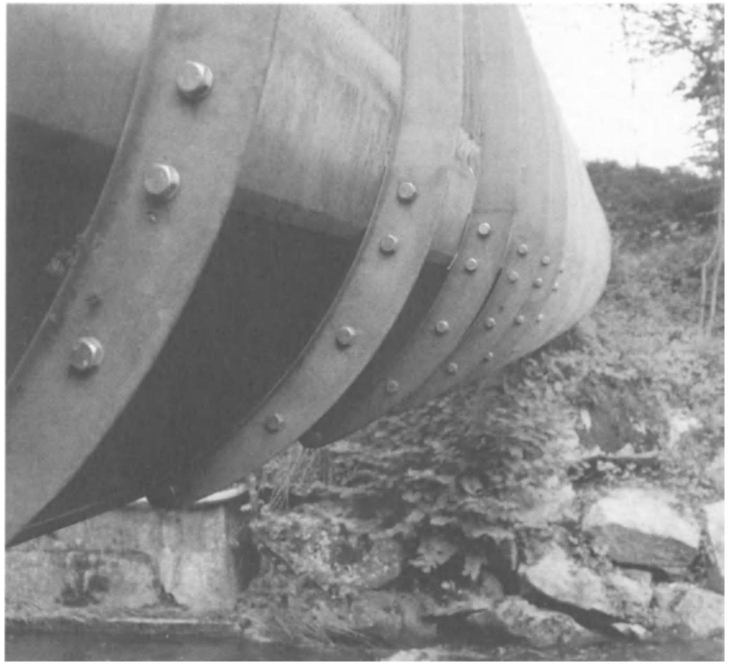
The first bridge is one to remember. A stiff supporting structure below the deck was flown by helicopter and placed in its final position. This erection procedure determined the maximum weight of the suspension system, 4.3 t. Jürg Conzett designed an exceptionally lightweight fishbelly truss from timber and steel, and a comparatively robust 1.2 m wide deck with massive railings. The bridge is a truss structure with upper compression chord. The suspension cables are splayed by up to 4 m to stabilize the compression member for side wind forces. To prevent the suspension structure from swinging laterally from its point supports, the railing was created as a massive railing, which can transfer torsional moments to the abutments. The two structural systems are thus overlaid. Larchwood and chrome nickel steel would stand up to weathering conditions on site. Individual compression struts could be replaced on the unload structure due to a high level of redundancy that created multiple load paths.

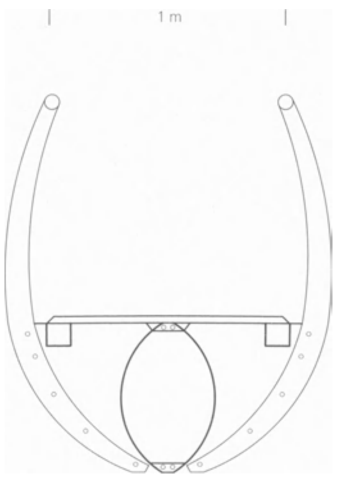


Structure as Space, 2006, pp. 120-125
db deutsche bauzeitung, 5, 1998, pp. 62-69
Detail, 8, 1999, pp. 1483-1486

The footbridge would have surely fulfilled its purpose for many decades, but nothing can be done against acts of nature such as falling boulders. The structure will rest in the memory of hikers and in photographs for the experts so that its historical importance is not forgotten.







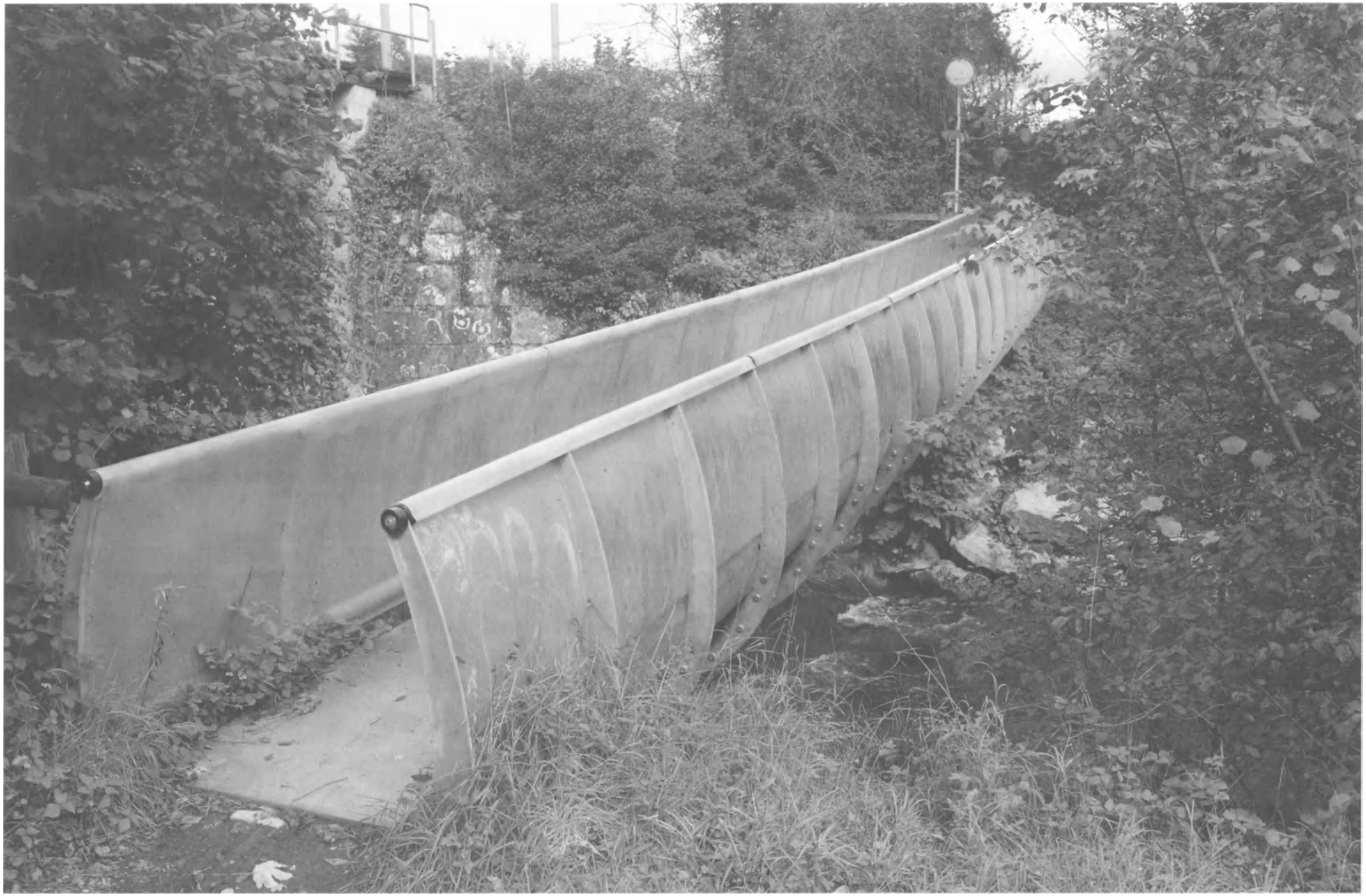
Plastic Footbridge in Winterthur, Switzerland, 2001

The use of new materials, in particular the use of high performance plastics, is also one of the experiments in construction. There is always a bit of uncertainty in the first examples, as designers learn to apply the appropriate construction methods and structural systems. A suspension bridge made of plastics, an arch bridge, or a truss bridge – these are examples that show how difficult it is to determine the optimum use of a construction material is not simple to determined. The first plastic bridges are small pedestrian bridges – in Aberfeldy 1992, Pontresina 1995, Kolding 1997, Lerida 2001, and Winterthur 2001.

The advantages of fibre-reinforced plastics – high strength, light weight and good corrosion resistance – make them very interesting materials for bridge construction. These materials are very well suited to temporary and moveable bridges, but unfortunately the construction of most of the built examples is not particularly suited to the material. The freely formed plastics are pressed into a steel form and bolted similarly to a metallic structure, although plastics can easily be glued or welded. Most of these fibre-reinforced plastic structures do not even appear to be plastic. Robert Maillart not only recognized the potential of the new construction material of his time, reinforced concrete, but also attempted to develop a structural approach suited to it. This led to the development of new structural systems, new construction approaches, and even a whole new sculptural vocabulary. The high price and low fire resistance are surely the reason that a material-specific structural and construction approach has not yet been found for plastics in bridge construction. In other areas of construction, such as long-span roofs, structural forms suited to the fibre-reinforced plastic membranes have been found. We should not give up so easily.

The small, 16 m long footbridge over the River Kempt near Winterthur is 90 percent fibreglass and weights only 850 kg. Only the bolts and tensioning rods are in steel. The interesting aspect of the structure – in contrast to the above-mentioned examples – is that its form is particularly suited to the characteristics of the material. The engineers at Staubli, Kurath & Partner worked in cooperation with the Federal Institute of Technology (ETH Zurich) and the manufacturers on this experimental project to gain experience for the Expo Bridge in Yverdon. The footbridge requires only four stressing rods, two at the top of the girder and two at the bottom. These are mostly necessary for erection; fibre-reinforced plastic slats later support the bending forces. The plastic elements are connected at circular diaphragms. Shear is transferred with lugs and slots. Concrete foundations were not necessary. It was possible simply to

Knippers, Park, 2003;
Sobrino, 2002
On Aberfeldy, Pontresina, Kolding: Structural Engineering International, Volume 9, SEI 4, 1999
On Lerida: Structural Engineering International, Volume 12, SEI 2, 2002



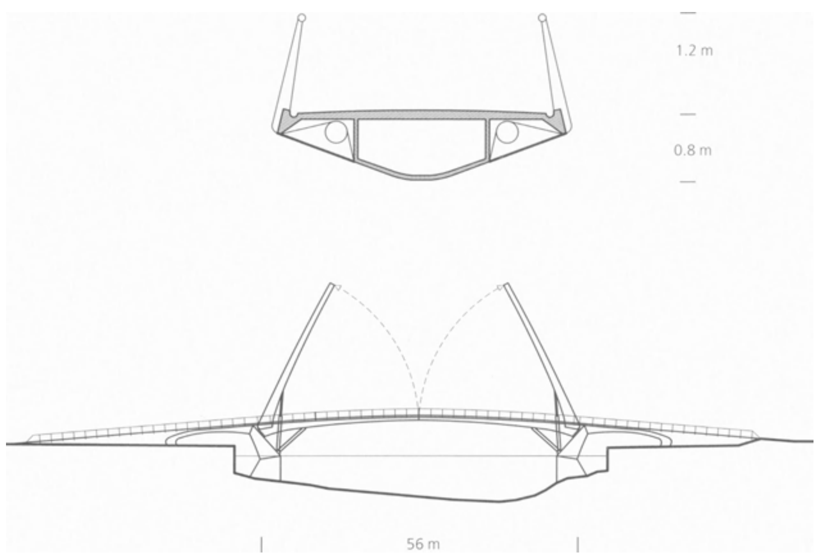
bury a portion of the girder in the soil at the approach, since fibreglass does not rot. A certain patina has developed on the bridge, complementing the structure. The sound of footsteps on the deck is slightly peculiar but not unpleasant.

Lighting from the interior made possible with plastics

Moveable Bridge in Fredikstad, Norway, 2006

This plastic moveable footbridge, with a span of 56 m, is an example of a design approach that particularly suits the material. The bridge crosses the Vesterelven River. Hydraulic cylinders lift and lower the two halves of the bridge. Each of the 28 m long bridge halves weighs 20 t and is so light that it can be moved without counterweight. Steel is used only at the moveable bearing, to transfer high local stresses into the girder. The deck girder is a box section with doubly curved sides and inner longitudinal girders with transverse diaphragms. The underside of the box section consists of one layer of 10 to 38 mm thick laminate. The deck surface is sandwich panel filled with an interlayer of balsa wood. These panels can support vehicles with up to 2 t axle load. Heating wires are incorporated into the sandwich panels, to prevent ice formation in the winter. The exterior of the girder is translucent, which means it can be lit from the inside of the section.

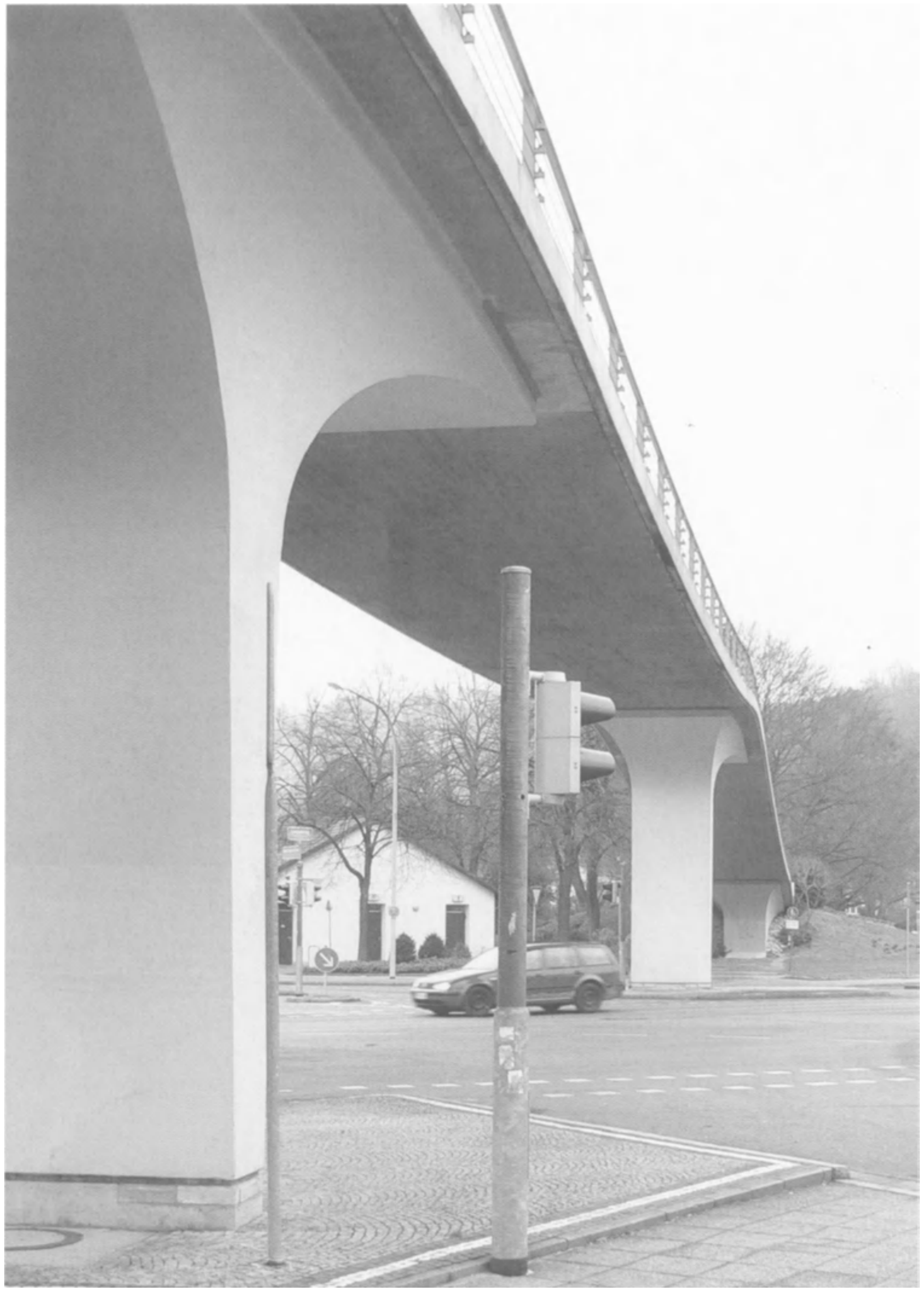
This bridge demonstrates the possibilities of continued development in fibre-reinforced plastic bridges.



Cars have become the real population of our cities. *Marshall McLuhan, 1964*

The car has not completely chased away all pedestrians in our cities, but since the Second World War, they have chased them into depressing pathways and dark underpasses. City planning has been designed to suit traffic flows since the beginning of the 20th century, an approach that was pursued aggresively following the world wars. The shortcomings of this approach to urban planning were recognized early on but too late to be corrected. Cities were maimed, made inhospitable and lost their original spirit. As highways began to divide the landscape, there was no choice other than to build footbridges to allow pedestrians to pass from one side to the other. The problem was more complex in city centres, as six- to ten-lane roads divided once-united neighbourhoods. Since the 1970s, pedestrian bridges have been preferred to underpasses, as claustrophobic users find it more difficult underground than in a structure above the roadway. No one would expect traffic to decline – rather the opposite. Any opportunity to keep cars and pedestrians at the same level is to be welcomed, but with rising traffic, this is almost impossible to maintain. This difficulty has however provided architects and engineers opportunities to design pedestrian structures.

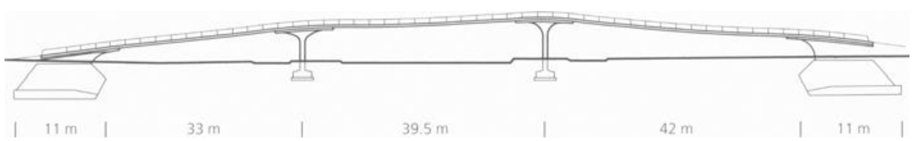
Many cities have neglected their rivers. Fallow industrial areas and shipping ways and canals are beginning to be transformed into residential and service centres. In order to improve the quality of the environment along the riverbanks, pedestrians should be offered the most direct routes possible. City expansion and renovation should bring improvement. In this development, footbridges not only create pathways, but can become attractive public spaces.



Stress Ribbon Bridge in Freiburg, Germany, 1970

Shortly after René Walther proved the efficiency of a stress ribbon structure for footbridges, Ulrich Finsterwalder, who had worked on stress ribbon bridge concepts prior to Walther, had a chance to build his first in Freiburg, Germany. The city centre was to be connected with a park over a heavily used roadway. A bridge with mast or pylons would be unthinkable in its setting in front of the Freiburg Cathedral, and a flat multi-span stress ribbon structure seemed ideal. While the approach from the park remains a beautiful area, the city-side approach is rather depressing: parking for buses and a low-quality suburban development destroy the area's atmosphere, thus losing the bridge's potential in the urban fabric of the city. The design is by Dyckerhoff & Widmann: "This alternative design was commissioned due to the slenderness and elegance of the structure and its integration in the difficult urban environment". While today, many owners seem focused on project cost, at that time the cultural responsibly of civic works was well understood. The stress ribbon structure consists of a 25 cm deep concrete ribbon, prestressed with threaded Dywidag rods. The ribbon rests on a layer of foil over the saddles at the intermediate piers and at the abutments, allowing the ribbon to lift above the saddles during stressing. This allows the bridge to rest on the saddle under increased loading without creating a kink in the deck, due to the compensation of the slender deck. The spans are 25.5 m – 30 m – 34.5 m. The pier footings are articulated with a concrete joint so that the piers can rotate under variable loads.

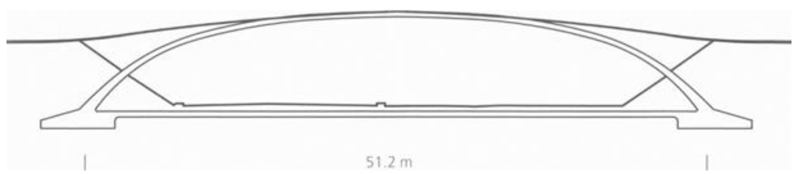
Batsch, Wolfdieter and Heinz Hehse, Spannbandbrücke als Fußgängersteg in Freiburg im Breisgau, in: Beton- und Stahlbetonbau, March 1972, pp. 49-52



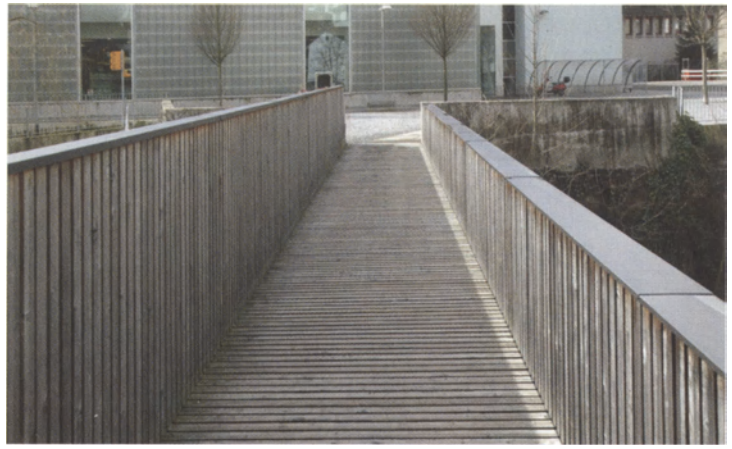
Footbridge in Stuttgart, Germany, 1977

As in Freiburg, many inner-city roads are dangerous for pedestrians to cross. This is also the case in Stuttgart. A provincial gardening exhibition provided an opportunity to connect the middle and lower Palace Gardens. The landscape architect's intention was that the pedestrian would not even realize that he or she was on a connecting structure. Vegetation was to line the path. The engineers at Schlaich Bergermann and Partner designed a 51.2 m long arch bridge that widens at the approaches, almost sucking the user in. The park continues to the bridge structure and the vegetation is planted on the bridge. The flat and slender arch has a light curl at the edge so that it works as an arch shell. Only after the soil for the vegetation was planted on the bridge did the structure take its final form; this weight helps to stabilize the structure.

After several years, the bridge disappeared under its vegetation and many drivers below do not realize that they are passing under a structure, but perceive it as a hanging garden or natural bridge. The vegetation of course does not fully reduce the noise of traffic, but it creates a kind of barrier between humans and vehicles. This is no antidote for all traffic situations, as such lush vegetation in urban centres may be a bit much. The Canstatter Footbridge can be appreciated as part of the Palace Gardens - a type of bridge that the user often does not recognize as a structure. At the opening of the gardening exhibition in 1977, the vegetation had grown lush, but was cut back by workers preparing for the exhibition, who thought it was merely weeds.



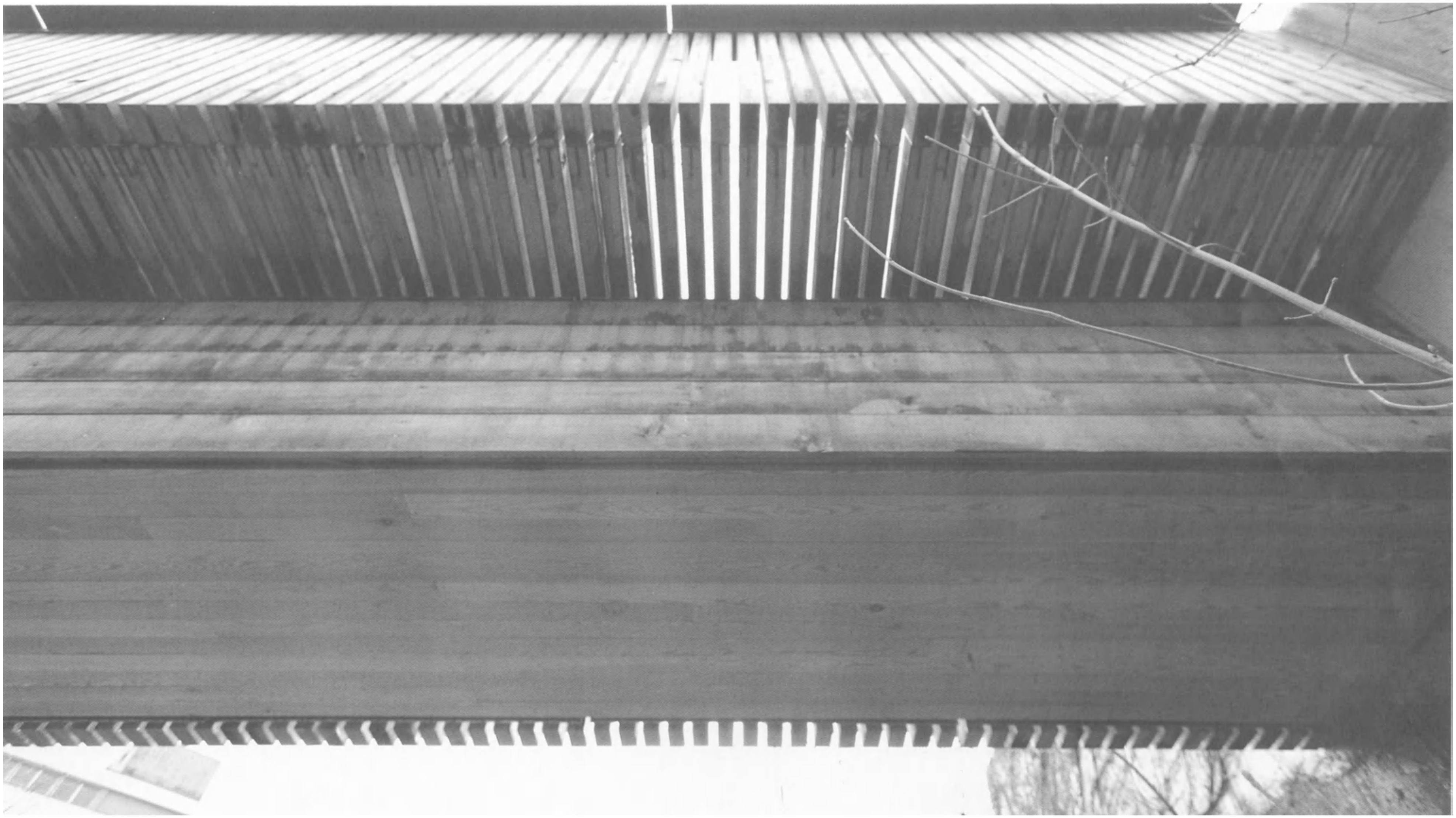
View towards the shopping centre

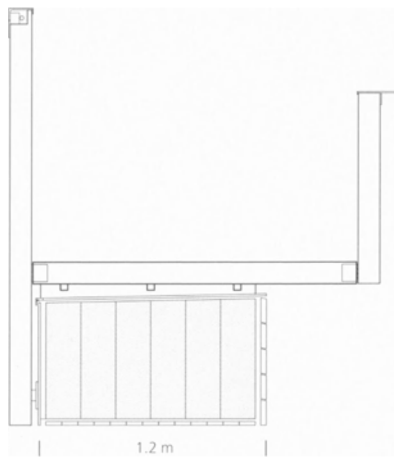


Footbridge in Frauenfeld, Switzerland, 2003

This small footbridge is part of an effective and pedestrian-friendly city planning strategy. Next to a new shopping centre, the structure sits on an impressive site below the town castle that sits high over the River Murg. The design by timber construction expert Walter Bieler connects the historical city-centre tradition with the modern consumer-oriented centre using elegant and refined design. The footbridge has an asymmetric cross section with the railing at a height of 1.30 m to the edge away from the city. The railing is lower for the view towards the castle and covered with a steel section so that the user can lean over as if looking over a windowsill. The railings and surfacing are made of larchwood slats (120 x 60 mm), serrated at a small distance so that the view of the flowing river below does not disturb the user. Walther Bieler heeds the fundamental rules of timber construction and follows a holistic design approach. The footbridge is supported by girders that are protected from the weather that attacks on all sides: six 65 cm high laminated spruce beams are pressed together using prestressing bolts to form one 115 cm wide, compact girder, which spans 20 m. The steel cladding with a slope of 2 percent covers the top of the girder. The surfacing segments consist of steel and timber components and placed on the main girder. The footbridge is elegantly lit at night.

Seraina, Carl, Schlossmühlesteg in Frauenfeld. Fragile Körperhaftigkeit, in: architektur aktuell, 10, 2003, pp. 122-129
Engler, Daniel, Brücke und Balkon, in: tec 21, 33-34, 2003, pp. 7-9



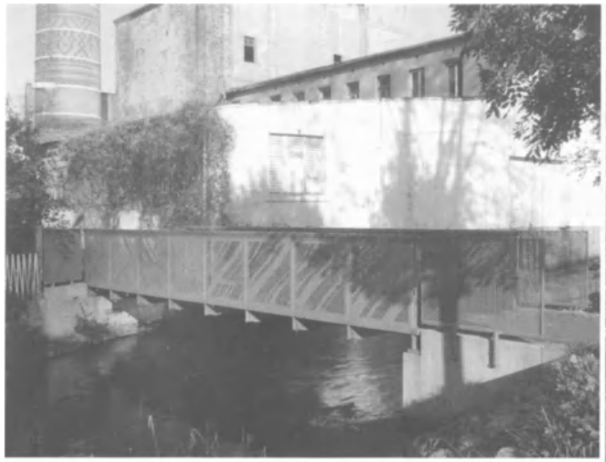

1.2 m

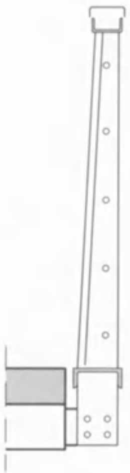
Bridge in Großenhain, Germany, 2002

The smaller the design challenge, the cleverer the solution? Walkways in small villages should also be made as direct as possible – as is seen here in Grossenhain, where several footbridges were constructed for a garden exhibition over the Grosse Röder River. The architect Martin Sauerzapfe, together with the engineers of ifb Berlin, designed a small footbridge with a span of 9.5 m, which could carry emergency vehicles of up to 5 t. The structural system consists of two truss girders that also form the railings. These girders are made from 8 plates. The plate segments are almost square, with a side length of around 1.15 m. The edges of the plates were bevelled twice at the factory. Plates forming the upper chord (U 100) and lower chord (U 160) are bolted to the plate segments. The verticals and diagonals of the truss are created and incorporated in an attractive ornamentation made using an automatic CAD-controlled laser cutter in the 4 mm thick plate. The plates are galvanized. The ornamentation follows the shear diagram of the structure and the diagonals become thicker near the supports.

An upside-down channel section acting as a handrail is bolted to the upper chord of the girder. The bridge playfully unites ornamentation and structure. The design is convincing and the total visual effect, including the interplay of light and shade, benefits from the combination.

Structure and ornament are seldom so unified





A symbol of the revitalization of the derelict land

A smooth approach rather than an abrupt transition

Merchants Bridge in Manchester, UK, 1995

Withby & Bird offer architecture and structure in one firm. In Manchester, the former industrial zone of Castlefield was to be rejuvenated. As part of this rejuvenation, Withby & Bird designed a sweeping arch bridge that won a design competition for the site with its powerful gesture. The structure crosses the river and quays with a sweeping, cantilevering arc. The bridge's elevation is such that the structure would be continually viewed from below, so the design of its underside was a particular focus. The abutments are elegantly placed and match the formal language of the design. A symbol of rebirth of the industrial zone, the structure is painted white.

We should note that the inclination of the arches in many recent bridges has been made for aesthetic reasons. The incline of the hanger cables increases while the loading stays the same.

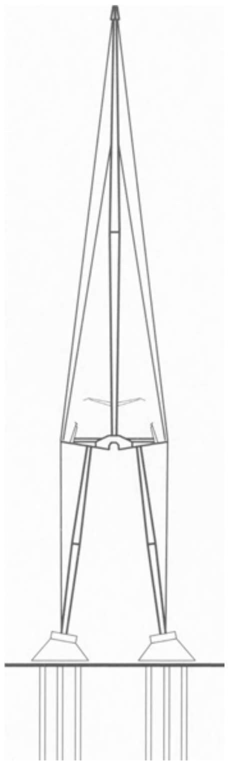
The dead load of the arch no longer lies in the plane of the arch and has an eccentricity at the apex, thereby requiring the arch to be fixed at the footing to support a moment . Another way to compensate for this moment is to give the arch a spatial curvature to follow its funicular line.

One-sided arches are particularly problematic. The inclination of the hangers creates horizontal forces and bending about the vertical axis in the deck girder. In addition, the eccentric support creates torsion in the deck. In the example of the Merchants Bridge, the torsion is supported by a steel tub and transferred to the abutments. Although these structures are not the most efficient, they often create exciting solutions and almost every contemporary footbridge-builder has designed one. This book shows inclined arches by Santiago Calatrava, Jiri Strasky, Wilkinson Eyre with Flint & Neil and Javier Manterola.

Bridge at the Royal Victoria Dock, London, UK, 1998

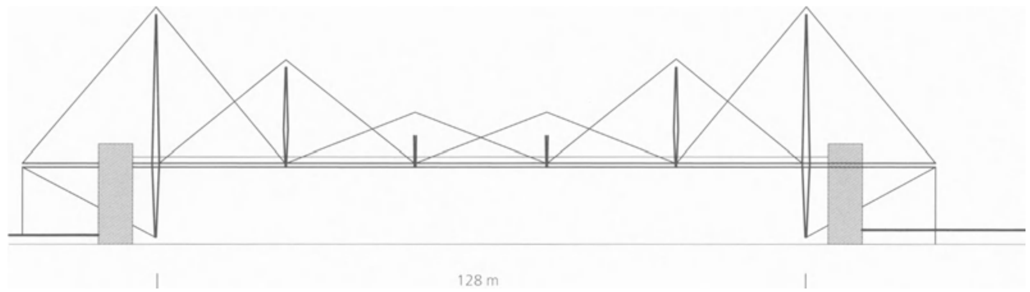
Anyone who knew the dockland area of London in the 1980s or earlier would not recognize it today: a light railway has been constructed that connects the port area. To the north and south, the quality of life has greatly improved. At Royal Victoria Dock, the question was raised as to how to allow pedestrians to cross the harbour while respecting very high clearance requirement for the masts of yachts from a neighbouring sailing club. The architects from Lifschutz Davidson and the structural designer Techniker Ltd won the competition with an idea from the 19th century: a gondola with a 40-passenger capacity would be suspended from the underside of a high open deck. The whole design is impressive, with its slender structure perfectly suited to the Victoria Docks site. The upside-down fink truss with a 128 m span gives the bridge its identity. Albert Fink was a German immigrant to the United States and presented his truss to the US market. Numerous fink trusses were built in the US before his death in 1897, only one of which survives.[1]

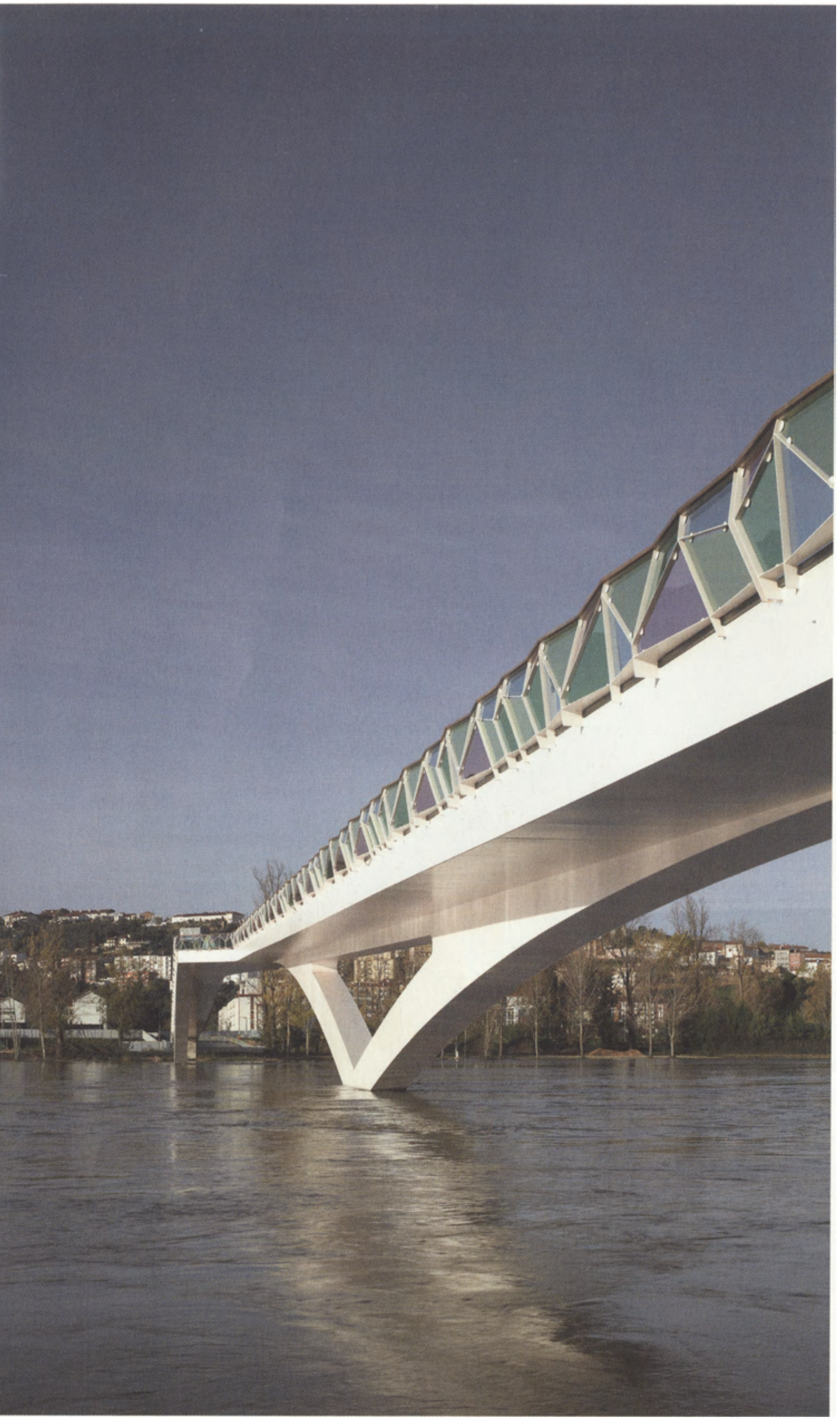
The great difference in elevation is bridged by stairways and elevations. The box section is deeper at the midspan between verticals. This haunch interrupts the wooden deck. The visual image from the deck reminds one of an overturned ship.

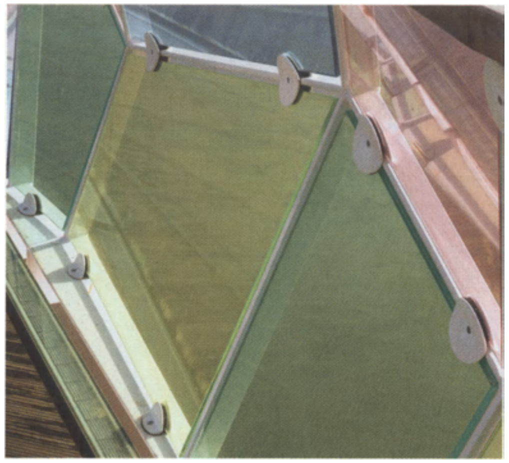


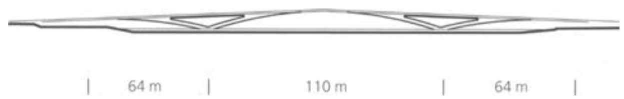
1 Plowdon, David, Bridges, Norton & Company, 1974, pp.63-64

Detail, 8, 1999, pp. 1474-1478
Architectural Review, 5, 1999, vol. CCVII, No. 1239


128 m





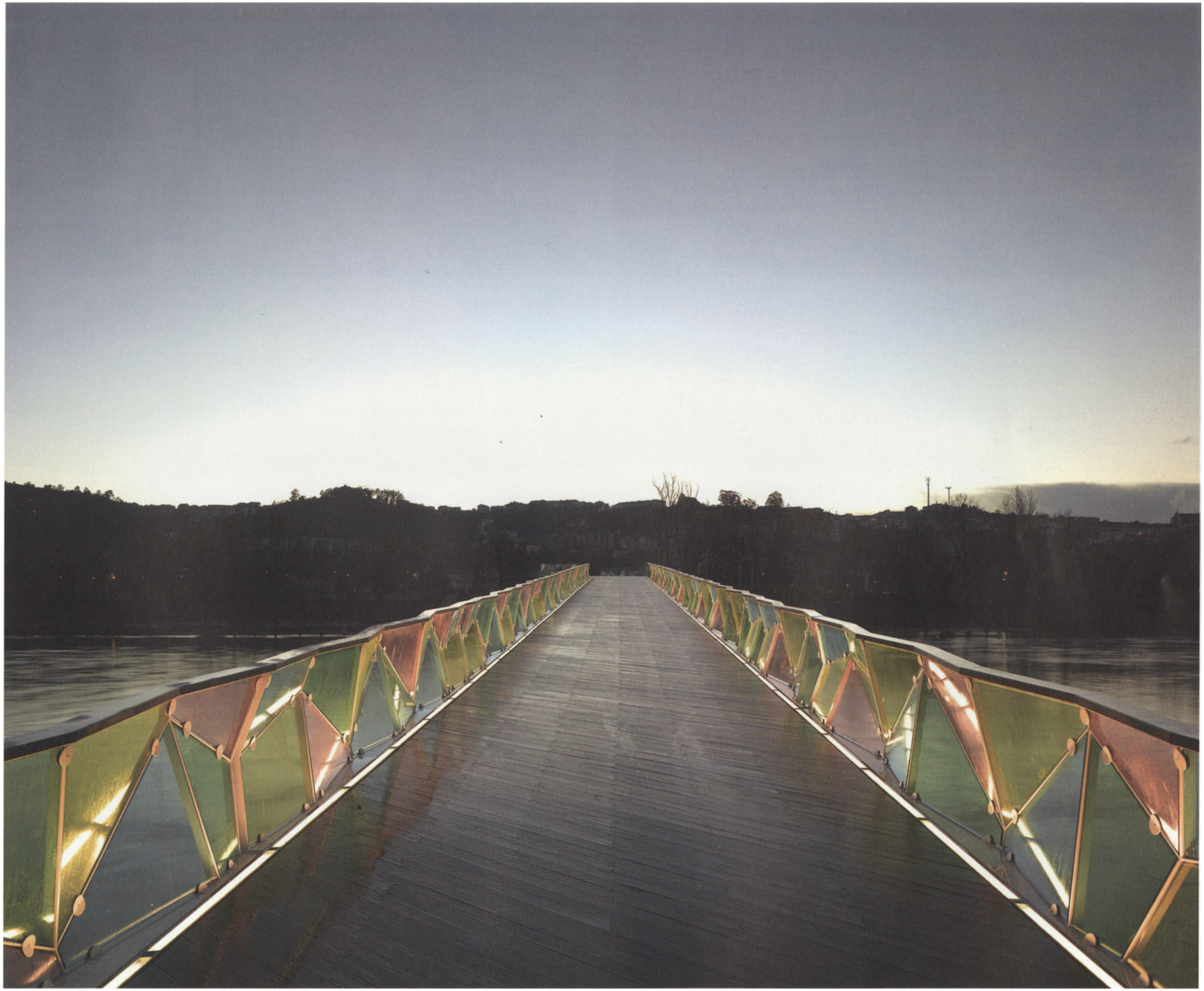


Bridge over the Rio Mondego in Coimbra, Portugal, 2006

In Coimbra, Portugal, a footbridge connects the historic city centre with a new residential area, with parks lying scattered in between. The structure's unusual geometry, choice of materials and colour create an extravagant, unique image, which can easily be can be called emblematic. The two halves of the bridge are offset at the midspan – those who are familiar with the tragic love story of King Pedro and Ines who never found one another would find resonance in the structure. The offset at the midspan creates a small platform in the bridge. The footbridge is a composite plate made of reinforced concrete and steel decking. A central parabolic arch and two half-arcs at each approach support the superstructure. Offsetting the arch and allowing the deck to cantilever out over the arch creates torsion and does not make much structural sense, but does not appear to affect the structural behaviour much. The bridge is 274 m long overall and the central arch has a span of 110 m. Cecil Balmond and his advanced Geometry Unit at Arup designed the structure together with the structural designers António Adão da Fonseca with AFAssociados. The most notable aspect of the structure is the railing. The multi-coloured, tilted glass panels are a type of folded construction in steel and play with the reflection of light – at night the railings appear crystalline. The handrail is in wood, as is the deck surfacing. The care with which the detail is executed demonstrates that the pedestrian is being considered as an increasingly important participant in city traffic. The border between architecture and design is blurred.

Adão de Fonseca, António, Cecil Balmont, Conceptual design of the new Coimbra footbridge, footbridges, 2005, 2nd International Conference, 2005

The arch offset at the midspan cuts the optical impression of the length of the bridge in half

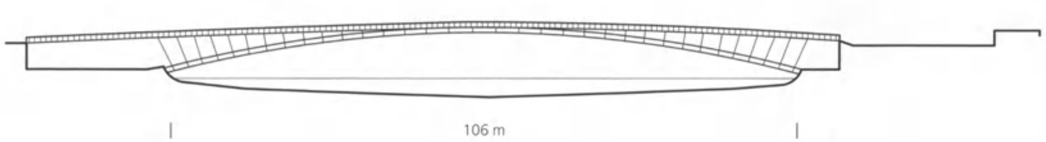


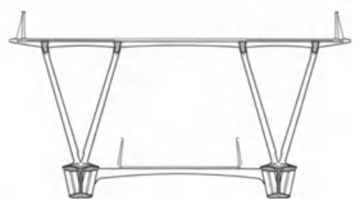
Passerelle Solferino over the Seine in Paris, France, 1999

No other city has the same sense of beauty along its riverbanks as Paris, where legends surround the bridges. Its bridges are also the subject of films – Leos Carax's 1991 film *Les Amants du Pont Neuf*, for example. In the story, the Pont Neuf is closed for renovation and the bridges becomes a refuge for a penniless circus performer and a painter who is going blind. In the story, the Pont Neuf becomes a footbridge, and a breathtaking one at that. The theme of urban renovation is a complex one. To the east of the Pont Neuf follows the pedestrian bridge Pont des Arts, the road bridges Pont du Carrousel and Pont Royal, followed by the Passerelle Solferino spanning between the Tuileries and the Quay Anatole France, connecting to the street of the same name. Marc Mimram, an engineer and architect educated in France and the United States with a pronounced ambition for quality in design. Mimram designed an arch bridge, echoing the structural form native to the city as in the Pont d'Arcole and the Pont Alexandre III. It sounds easy, no intermediate piers in the Seine, effective connections to walkways at different elevations on both sides of the Seine, and creating a light structure so as to minimize the disruption of the view of the Seine. The execution is a bit more difficult: one route at street level, two walkways at quay level that should meet at the mid-span – this follows the contours of the arch to perfection. The merging of the quay walkways and the street level is particularly elegant. The challenge of urban renovation is taken on and conquered, with a footbridge that perfectly continues the historic traffic routes. The construction of the bridge is another beautiful example of how the linearity of a bridge that simply connects one point to another can be playfully abandoned. With his light steel arch bridge of almost 110 m span, Marc Mimram created a structure where both the arch and the deck are pedestrian walkways. In order to keep the arch forces within reason and to respect boat clearances belong, a certain rise of the arch is necessary. The necessary rise leads to a slope of over 10 percent, making steps needed on the arch walkway. The deck walkway is 11 to 15 m wide and practically horizontal. The timber surfacing of the superstructure reminds one of a ship deck. Interesting interactions between pathways and the play between light and shadow are the result of merging the arch and deck walkways. The deck at street level acts as a roofing for the arch walkway. The bridge had the same fate as the Millennium Bridge in London, which was also closed shortly after its inauguration due to dynamic vibrations, and reopened only after the installation of damping devices. This event is long forgotten and pedestrians now use the bridge continuously.

Fromonot, Françoise, Marc Mimram/Passerelle Solferino, Basel, 2001
La passerelle Solferino, in: Ouvrages Metalliques, N° 1, OTUA, Paris, 2001

The approx. 100 m bridge spans the Seine on two levels





Grand Bibliothèque, the Finance Ministry, the Palais Omnisport, and the new bridge – symbols of urban transformation

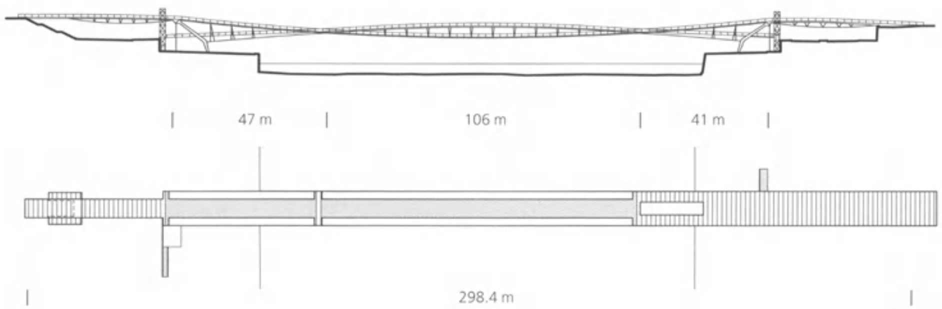
Passerelle Simone de Beauvoir, Paris, France, 2007

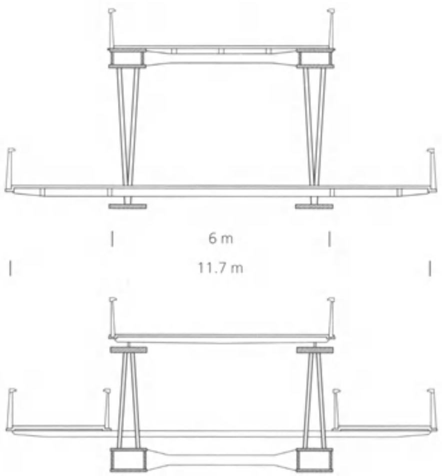
Bercy: the quarter south of the Seine where wine was cellared for centuries, fermenting the myth of France as the Grande Nation du Vin. By the time the French Ministry of Finance had moved from the Louvre to its new home in Bercy in the 1990s, a large sports hall had been built for spectacular events, the Parc de Bercy had been created, and finally the four towers of the Grande Bibliothèque Nationale had been constructed, the quarter had lost something of its old tranquillity. A new world of heavy public traffic emerged to the left and right of the Seine, leading to the construction of the Passerelle Simone de Beauvoir. The commission was awarded to an Austrian architect practising in France, Feichtinger Architekten, working with the engineers of RFR – Rice Francis Ritchie. Urban renovation in Bercy entails a complete change of neighbourhood atmosphere.

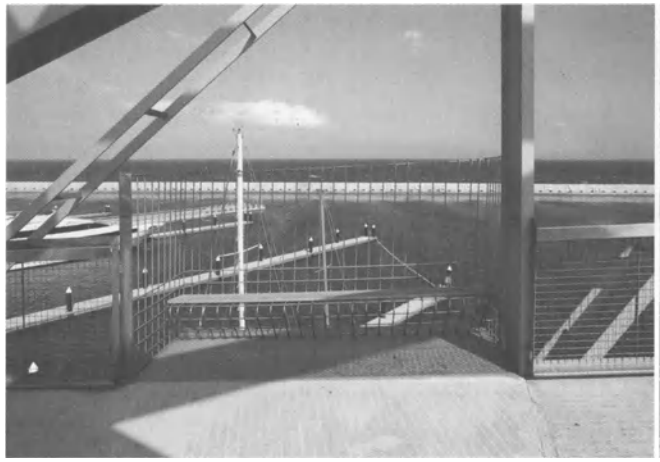
The connection of three elevations at each side is unusual: quay, street and parking or library level. The structure is worthwhile as it allows pedestrians to pass from the library to the park without crossing a major roadway. The free span of the structure is 194 m long and a very slender combination of arch and stress ribbon. The structure lies in two parallel vertical planes at a distance of 5.2 m on centre. An arch in compression and a tension chord lie in these planes. The arch is made of a welded box section 50 to 70 cm deep and 1 m wide. The tension chord is a 1 m wide steel plate with a depth varying between 10 and 15 cm The arch and tension chords are joined with a column of four steel rods every 7 m. The arch and tension chord cross one another around the quarter points of the span, dividing the bridge into three main sections: a 106 m long lenticular beam in the middle, a 47 m long cantilever to the north, and a 41 m long cantilever to the south. This is how the bridge was constructed. First, the cantilevers were anchored to the abutments. The 550 t middle girder was fabricated in Alsace and transported by barge from the Rhine via the North Sea to the Seine and hung from the two cantilever tips.

Feichtinger Architectes, Passerelle Simone de Beauvoir, with texts of Armelle Lavalou, Françoise Lamarre and Jean-Paul Robert, Paris, 2006
La passerelle Simone de Beauvoir, in: Travaux, 833, September 2006
Kieran, Rice, La passerelle Simone de Beauvoir, in: Construction Métallique, 4, 2006

The bridge responds the three levels of the quay



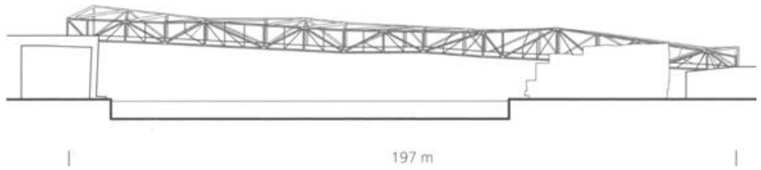




Port Bridge in Barcelona, Catalonia, Spain, 2004

Like may other cities, Barcelona neglected its privileged position near the sea for decades. The 1992 Olympic Games and the Forum 2004 were the catalysts to connect the city centre with the coast in a pedestrian-friendly manner. An urban master plan was developed, creating a marina with around 1000 slips in order to bring some life to the harbour. The main building of the yacht harbour and the pedestrian bridge linking the Esplanada with the Parque Litoral Noreste were designed by Mamen Domingo and Ernest Ferré and the engineer Angel C. Aparicio.

The bridge has a total length of 197 m and consists of a Warren truss with a free span of 148 m. The structure creates an envelope, which while not providing a roof, creates the visual impression of being in interior space. The varying depth, with an average of 6 m, prevents the structure from appearing as a strict tubular gangway. Offset balconies and seating make the structure an attractive place to pass the time. As the development continues, there will be more and more to see from the bridge balconies, making the bridge a destination in itself.



Aparicio, Angel C. and G. Ramos, Footbridge over the Sant Adria Marina in Barcelona, Spain, in: Proceedings of the Institution of Civil Engineers Bridge Engineering, 158, 2005, pp. 193-200

With its solid portal, the bridge is designed as a dominating structure in the new harbor area

The seriousness of the loadbearing truss is evident within. *Paul Bonatz, Fritz Leonhardt*

Bridges built in the same manner as housing, with a roof and side-walls, originally served as structural timber protection. It was and still is prudent to protect connections of sensitive material from weather. It is no wonder that the covered bridge developed into a classical bridge archetype in the raw mountainous settings.

Covered bridges are often also necessary in densely populated cities: When buildings are to be joined above a roadway, the bridge becomes a de facto continuation of building space: to the foyer, corridor, conference room. The dizzying heights of the Petronas Towers in Kuala Lumpur, with a covered pedestrian bridge joining two 90-storey high-rises roughly at the level of the 40th floor, have not yet been matched in Europe. Last but not least, air traffic requires elaborate swinging, telescoping motorized walkways so that passengers reach their seat with dry feet.

The criterion for the structure and form of such a bridge is the interior space. The structure can create and interior space, but the user's experience also depends on the views and on lighting. It is much more the work of architects than engineers to set the scene of such a covered structure. In certain settings, footbridges may be asked to house shops and multiple pathways, as was the case for Zaha Hadid's extravagant design direction for the 2008 Expo in Zaragoza. The line between a complete building structure à la Rialto and a covered footbridge is becoming more fluid.

Baus, Ursula, Verdichteter Weg. Brücke über die Areuse bei Boudry, in: db deutsche bauzeitung, 5, 2003, pp.62-67

Bridge over the Areuse, Boudry, Switzerland, 2002

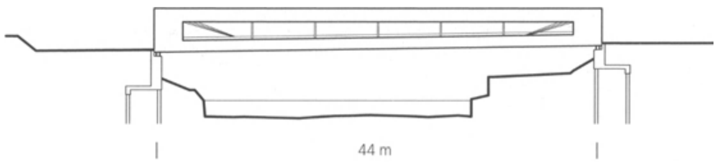
The Areuse gorge in the Jura south of Neuchâtel presents numerous enthralling spectacles of nature – but caution is advised in winter, when many paths become completely covered in ice and impassable. This small covered bridge over the Areuse can be found where the hiking trail through the high, narrow canyon merges with the wider, open valley. A light S-curve in the plan of the deck as well as the changes in elevation create an elegantly designed transition. This is another example of the cooperative effort between architects and engineers: Geninasca Delefortrie of Neuchâtel were the architects of the project, and Chablais et Poffet of Estavayer-le-Lac the engineers.

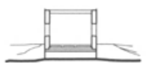
Exceptional pilots in a Russian helicopter flew the prefabricated truss girder into the valley, where the bridge spanning 27.5 m was built within two days. Attachments for the wooden slats were incorporated into the vertical steel frames.

The variation of the cross section – with a depth of between 2.5 and 3.0 m and a width of between 1.15 and 3.5 m – are often imperceptible to the user. Curiosity pulls one towards the end of the tunnel of the bridge enclosure, which is hidden by the horizontal curvature of the deck until one has ventured a few steps along the deck. This perspective does not appear uncanny, however, as the wooden slats allow views outside of the enclosure to orient the pedestrian. The bridge offers no protection from rain – the design of the bridge space is solely to affect the user's perception.

The other end of the bridge is not in sight, but the view to the exterior is constant

The structure is even visible from the inside of the covered structure





Covered Footbridge in Gaissau, Austria, 1999

Timber construction expert Hermann Kaufmann used the bridge enclosure, the original role of which was to protect the structure, to improve the quality of the interior space. Almost the entire span is open so that the user has free views, creating an astonishingly light interior. The bridge's compact volume uses the modern architectural variant of the flat roof as the gable roofs of older covered bridges (see p. 24) as an integral part of the architecture – the product of the cooperation between architect Hermann Kaufmann and engineer Frank Dickbauer.

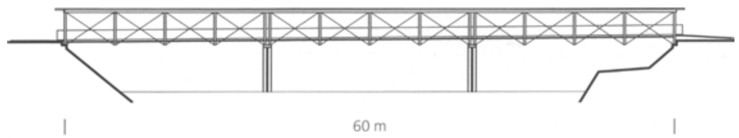
With a span of 44 m and a width of 4.5 m, the bridge crosses the border between Austria and Switzerland. Although the Swiss embankment is lower than the Austrian one, the roof remains horizontal, giving the structure a conical elevation. The two main girders made of glued timber sections create the sides of the enclosure. The steel tension member from four flat steel plates completes the suspended girder system.

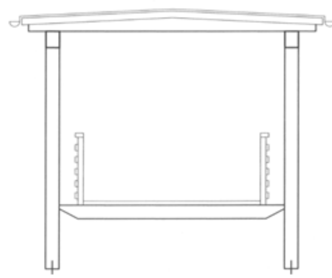
Edge glued timber and steel are combined in optimal manner with respect to structural demands

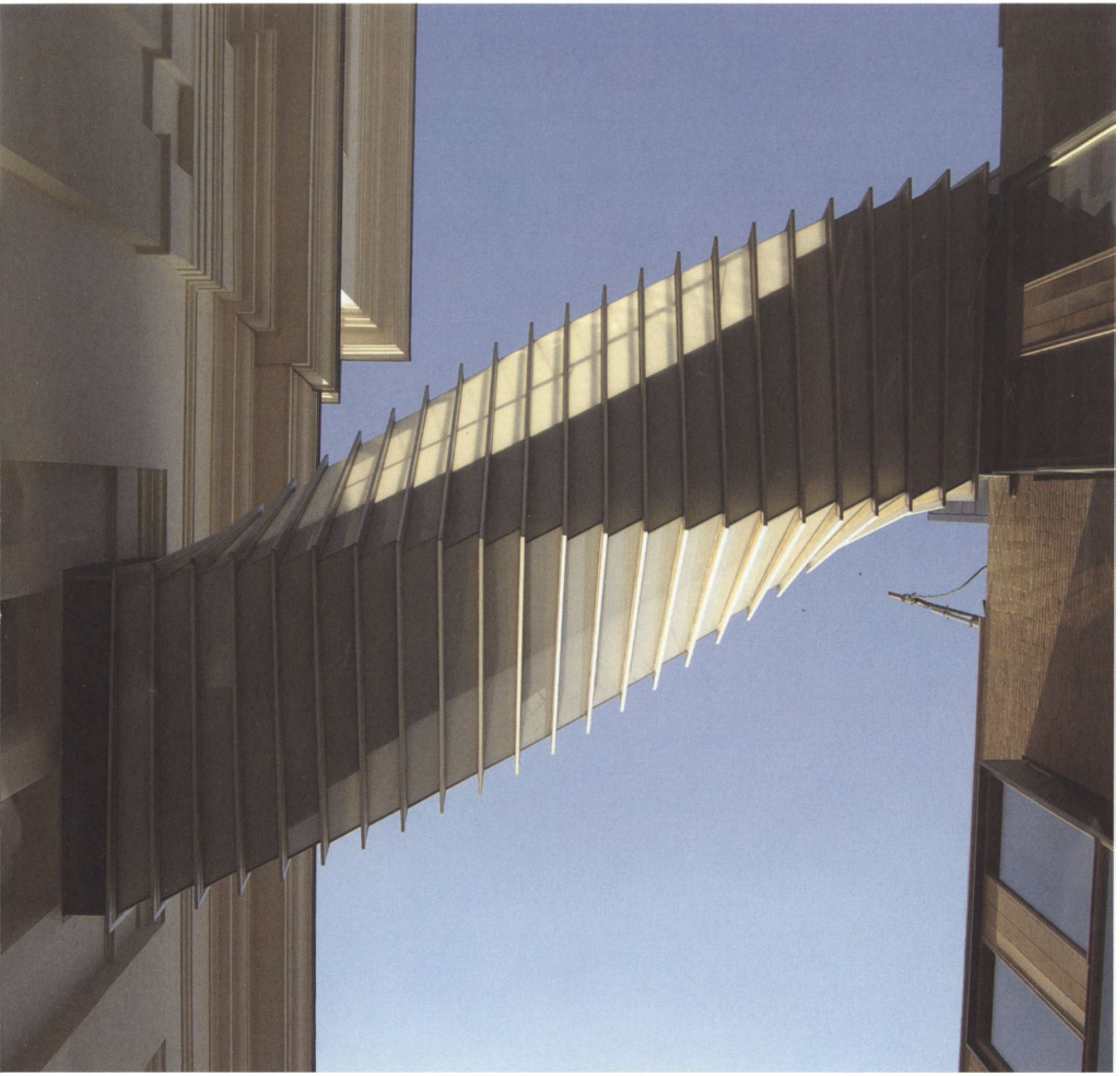
Covered Footbridge in Frojach, Austria, 1992

This new pedestrian bridge, designed by Johann Riebenbauer and planers Lignum Consult Angerer & Partner, replaces an obsolete road bridge between Frojach and Katsch. The three 20 m long bridge deck and roofing elements are stressed together with diagonal tension members of high-strength steel. Using the "plank pack lamination method", the more inexpensive exterior sections of the tree may be used. The resulting stiff, strong wooden plates can be simply nailed together.

The structure can be classified as a Fink truss. Both main truss members therefore lack a lower chore. Transverse girders connect the bridge deck or to the vertical members of the Fink truss by steel plates that do no penetrate any part of the vertical section directly exposed to the weather. The loading of all structural members increases as one approaches the midspan. The diagonals are prestressed at the abutments to add stiffness to the system. Additional prestressing of the system counteracts snow loads, as the tension members contract due to lower temperatures during the winter months.





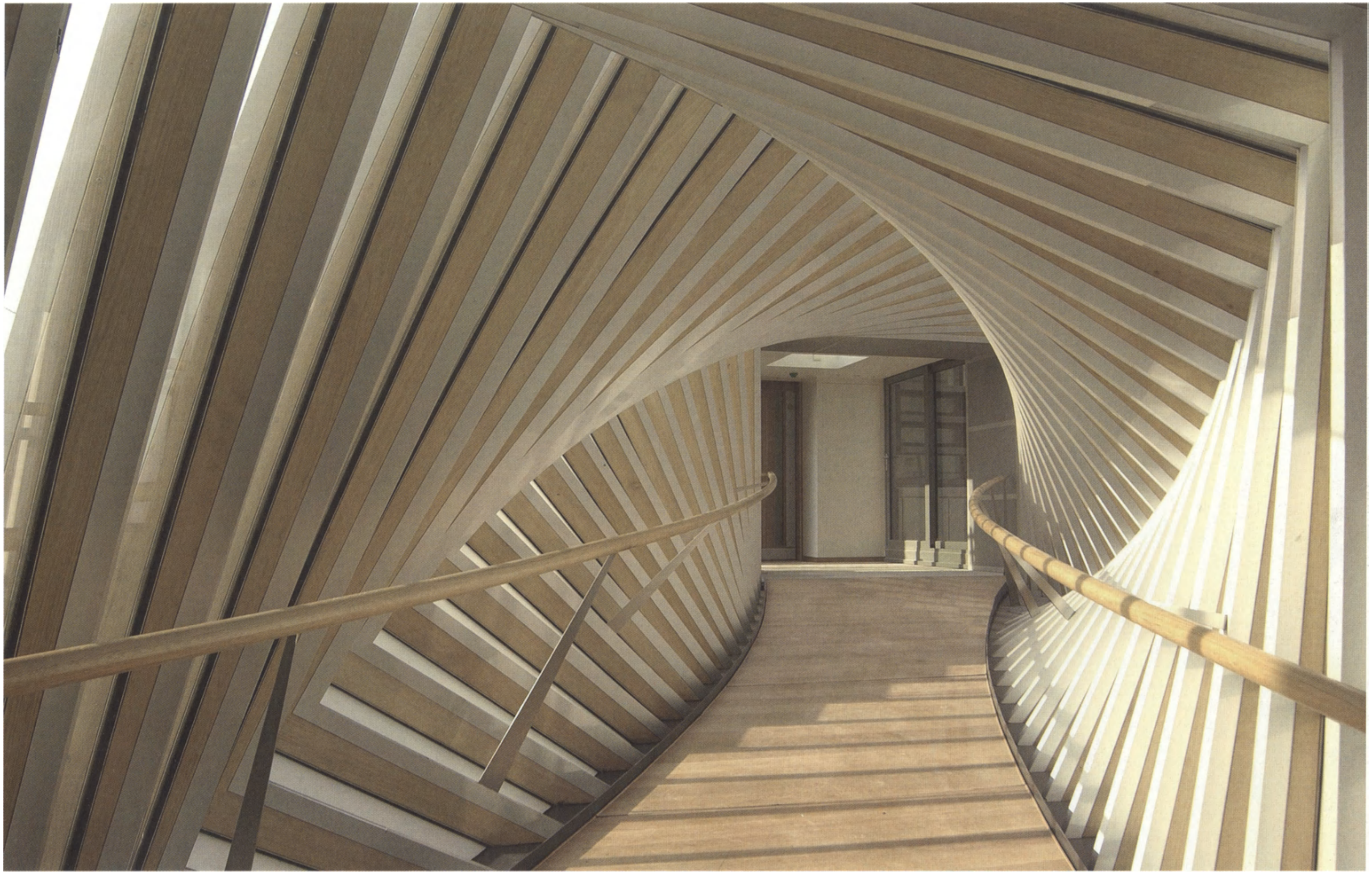


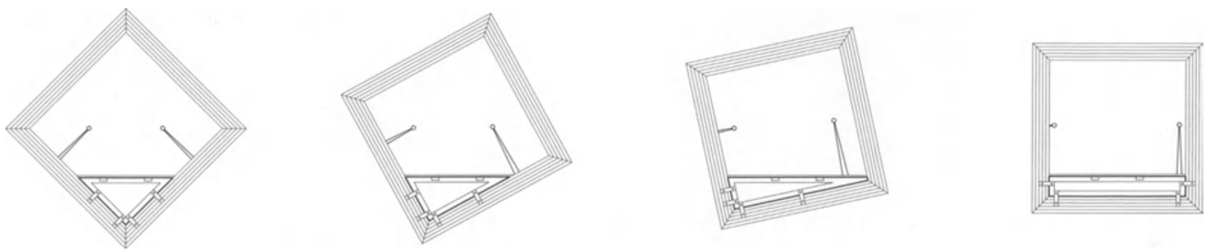
Royal Ballet School Bridge, London, UK, 2003

The new Royal Ballet School and the listed Opera House building in Covent Garden, London, are separated by only a few metres. The prospective dancers and ballerinas were to be spared the exterior crossing at street level. This led to the construction of a small bridge, high above Floral Street, to make the trip more comfortable. The challenge of the bridge competition in which five teams took part was to create a structure as an expression of dance.

The seemingly harmless 9 m span was complicated by the fact the building supports at both ends were offset in elevation and plan. Wilkinson Eyre convinced the jury with a simple light bridge with a spectacular enclosure: 23 square frames are each rotated 4° along the length of the structure, creating a total rotation of 90°. The frames are vertical at both building supports. Glass panels between the frames create a light transparent appearance, the sweeping form of which is reminiscent of the movement of a dancer. The geometry of the enclosure gives the bridge its charming visual aspect form both internally and externally – the structure plays an almost secondary role and is hardly noticed in the interaction between interior and exterior.

Firth, Ian, New Materials for Modern Footbridges, in: Footbridge 2002, Proceedings, OTUA, pp. 174-186
db deutsche bauzeitung, 6, 2004, pp. 82-83



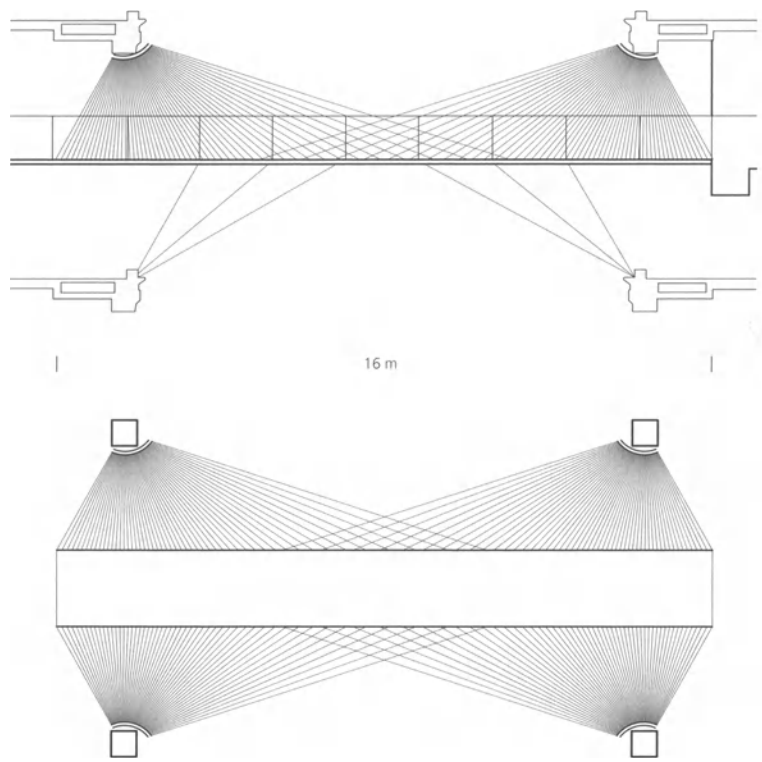


Science Museum Bridge, London, UK, 1997

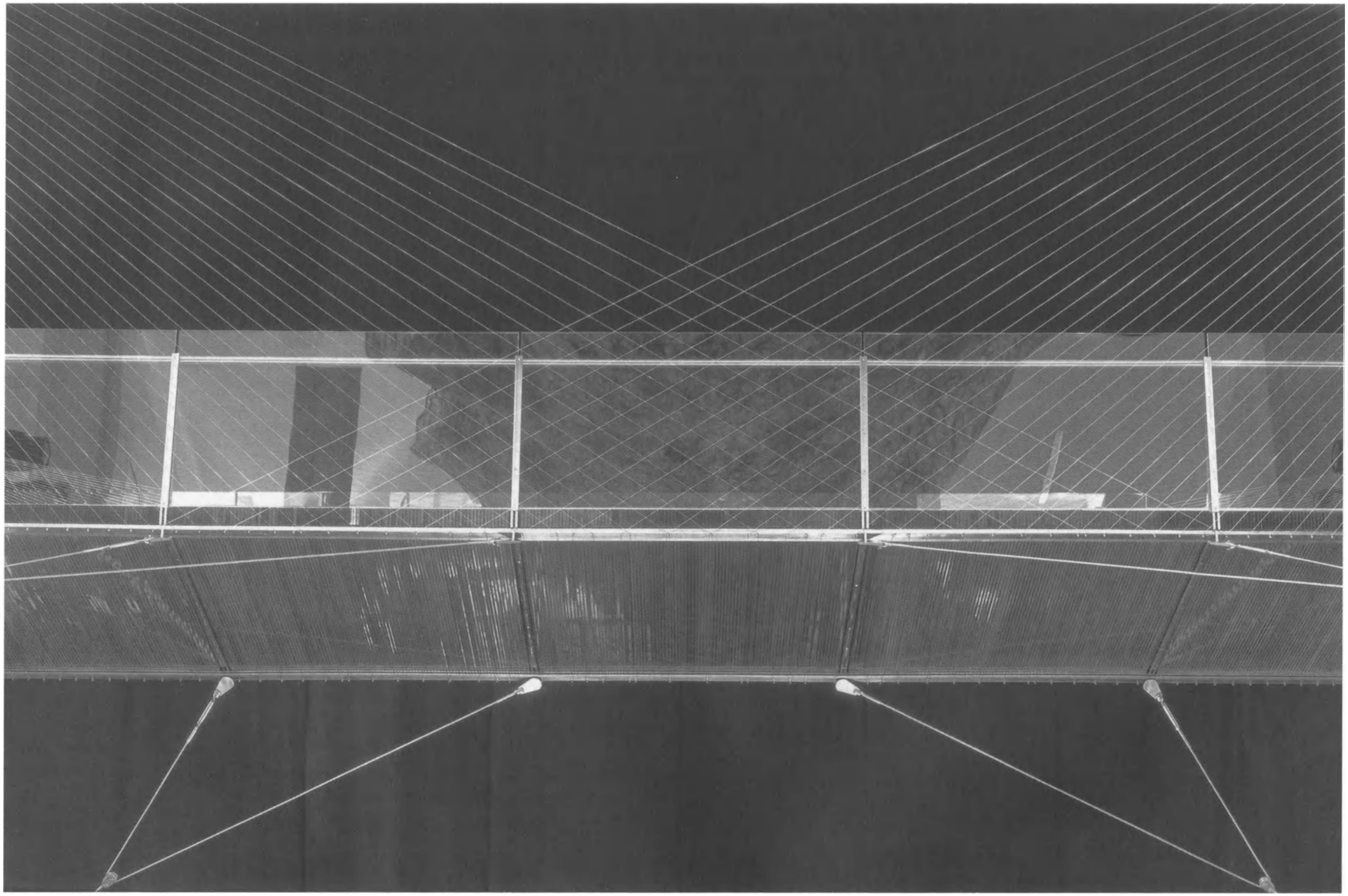
Strictly speaking, this is not a covered bridge, but it is a product of the interior space in which it is situated. A footbridge was built in the London Science Museum, protected by wind and weather. The structure is lightly suspended from heavy surrounding architecture. In the gallery s, Wilkinson Eyre created their first museum project. The bridge, which traverses a central atrium as if a spider had spun its a glistening net, symbolizes the theme of the gallery. The strength of glass and steel were pushed to the limit – this material-specific design approach comes form the team of Wilkinson Eyre in cooperation with the engineers Whitby Bird. In order to intensify the relationship between the pedestrian and the structure, the audio artist Ron Geesin developed a computer composition that reacts to the movements of the bridge and its pedestrians.

The structure has a span of 16 m and is supported by 186 exceptionally thin stainless steel wires (d = 1.58 mm) that overlap along the deck. The deck consists of a total of 828 glass strips. Every fifth glass strip is glued to a strip running parallel to the edge. A downward backstay system stabilizes the structure sufficiently against dynamic oscillations. The form of the stainless steel wires expands throughout the interior space and provides a fabulous connection between the bridge and the surrounding space.

Detail, 8, 1999;
Pearce, 2002, pp. 204-209



The thin cables create a delicate spatial net that however solidly supports the walkway



Zaragoza, Bridge pavilion at the Expo, Zaha Hadid, 2008

Covered and Enclosed Bridges

This section will show that the spectrum of covered greatly exceeds the traditional Alpine covered bridges and residential bridges. These bridges continue to find new application, in particular for structures in which the envelope – consisting of the deck, roofing, and wall – support loads by acting as a tube. This creates a much larger depth-to-span ratio than for other bridges.

Residential and Enclosed

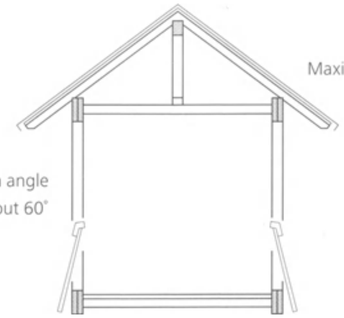
Some of the earliest bridges were not simply covered with roofing or provided with a small toll-house, but were completely covered with housing. London Bridge, built between 1176 and 1209, crossed the Thames with 19 arches and developed into its own city district. The reason these structures were used as housing was the lack of available real estate in the medieval cities and the hygienic advantages of houses above water, with their natural sewer systems. Some particularly beautiful examples remain, such as the Krämer Bridge in Erfurt, built in 1293, the Ponte Vecchio in Florence, and the Rialto Bridge in Venice. This structure shows high competition for these prestigious early structures. The competition was held in 1587 with Michelangelo and Palladio taking part. Antonio da Ponte won the competition with a 27 m arch bridge.

Functions

The classic wooden bridges were covered mainly to protect the structure from environmental effects. The shingled roofs of the wooden alpine bridges protect the structure from high snow loads, as snow will slide off of a steep roof. The roofing also protects the structure from rain. With the protection provided by the roofing and lateral shingle covering, the timber has been preserved for centuries. A very early and picturesque example is the Chapel Bridge in Lucerne, a simple continuous girder bridge supported by numerous timber pile piers. The structure was first built in 1333 and has been rebuilt several times after numerous fires.

Luckily, two bridges remain from the Swiss carpenter Hans Ulrich Grubenmann (see page 24). He was able to span up to 118 m with his multi-

Section through a typical bridge



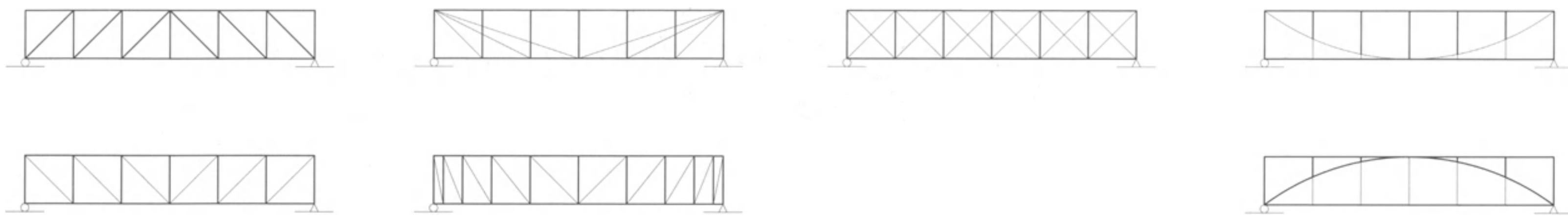
Kumma Bridge in Hittisau, 1720

strutted truss and arch structures 350 years ago.

In typhoon-prone areas, road and railway bridge superstructures and girders are often designed with sufficient structural depth to provide protected lanes for emergency vehicles at the interior of the structure. Noise pollution requirements sometimes call for side roofing and covering of urban road bridges (one example is the Nesenbachtal Bridge in Stuttgart). Other than these examples, covered bridges are practically only found for footbridges structures. Covered pedestrian bridges may fulfil a multitude of uses. The most common of such structures are bridges connecting buildings, where the enclosure provides protection from the elements. The pedestrian should be able to pass between a parking garage and a stadium, between one shopping mall or office building to another without getting his or her feet wet. In most cases, the enclosure does not simply provide protection from rain and wind but is often provided insulated. The level of pedestrian comfort should fulfil the requirements of the owner and the expectations of the user. One can see that the level of comfort provided to sighing prisoners on the Ponte dei Sospiri in the Doge's palace of Venice is much different than that provided to the skimpily dressed ballerina crossing the Bridge of Aspiration in London (see p. 154).

Passenger bridges such as the "Airport finger" also belong to this family of bridges. These structures bridge the distance between the airport gate waiting area and the plane. In addition to weather protection, these structures must provide noise insulation. The non-moveable portions of these structures are often glazed to provide interesting views of the airstrip to the boarding passengers. In hotter climates, such as the Madrid airport, the portions of the enclosure subject to solar exposure are opaque to avoid a greenhouse effect in the interior of the bridge. Passenger bridges for large ships are often completely enclosed, or at least provided with roofing to protect the passengers from wind and rain.

Unfortunately, as often seen in the US, the pedestrians using an overpass may pose a threat to the traffic below or even to themselves. In these cases, bridges resemble cages with chain



Typical structures that integrate the structure into the formal design of the bridge

link enclosures that prevent users from throwing large objects from the bridge or jumping off.

Loading

Covered bridges have much to support. Conventional bridges are not designed for snow loading, as this load case is in general much lower than live load and it is inconceivable that the maximum snow load and live load occur at the same time. For covered bridges, these load cases can coexist and the structure must support the additional weight of the enclosure. In addition, the enclosure creates an additional surface for the wind. The *British Standard BD 29/03* calls for and minimum clearance of 2.3 m at the interior of covered footbridges, increasing the depth of the structure and thereby increasing the wind loading acting upon it. For covered bridges connecting buildings, the loads transferred to the building must be taken into account in the earliest stages of the building design and the effects of the deformation of the buildings on the bridge structure must be analysed.

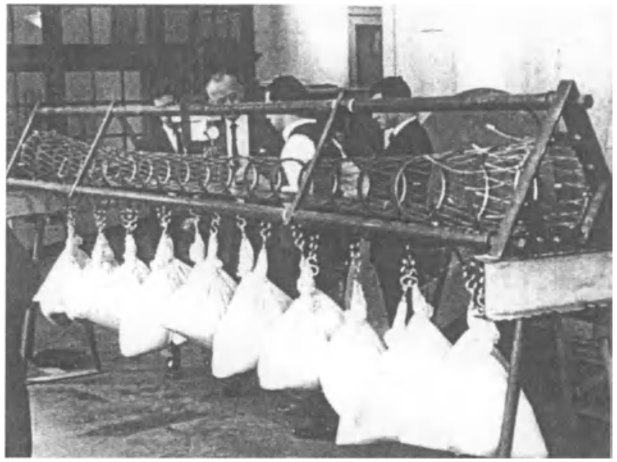
Structural archetypes

Taking into account all that is mentioned above, we might expect the bridge enclosure to be a burden on the structure. Not all covered bridges are as beautiful as the classical examples mentioned above. In bridges for which the enclosure and supporting structure are independent, the structure supports the additional ballast of the enclosure and often seems clumsy. Covered bridges, however, become particularly interesting to the designer who tries to make virtue of necessity and integrate the enclosure into the global loadbearing structure of the bridge. When the roof takes part in the structural behaviour, the structural depth is greatly increased, allowing the designer to create very transparent solutions. Lateral walls can provide the diagonals of a truss with the roofing structure acting as the compression boom and the deck as tension chord. When cables replace tension members, a multitude of variations becomes possible.

Structural tubes, which simultaneously provide structure and enclosure, have often been considered as a solution. The French engineer and architect Robert Le Ricolais experimented in 1962 with tubular cablenet structures in which bands were wrapped around stiff compression rings, creating a rigid structure. The adjacent buildings must however be able to support the high anchor forces required for these cable structures. In 1992 Jörg Schlaich proposed a structure made of a glass tube wrapped in cables "so that the cables follow the geometric stress trajectories a tube in bending" [Oster]. The adjacent buildings that the bridge was to join served as the anchors for the prestressed cables. A further innovation would be to anchor the cables to the tube, creating compression in the glass. The recent advances in structural glazing make such a structure almost within reach. A more conventional solution would be to replace the cables with rigid elements or anchor them with horizontal steel members. This solution was applied at the Corporation Street Footbridge in Manchester, which produced a relatively heavy structure.

One very beautiful example of a successful merging of enclosure and structure was built by the Artists of the *Eventstructure Research Group* in

LeRicolas's girder



Pneumatic bridge, 1970

1970. A 250 m long, floating, pneumatically supported tube bridged the Masch Lake in Hanover. The transparent tube had a diameter of 4 m. The PVC foil tube had walls only 0.4 mm thick. Protective fibre reinforcement provided the walking surface. A water-filled hose was attached to the underside of the structure to prevent rotation and stabilize the structure [Herzog].
This temporary structure was rebuilt in 1970 once again by the same team for the symposium "Pneumatic Structures". The air pressure necessary to maintain the stability of the tube can be calculated using the boiler formula given in the technical overview "Curved Bridges".

Herzog, Thomas, Pneumatische Konstruktionen, Stuttgart, 1976, p. 69

McCleary, Peter, Robert Le Ricolai auf der Suche nach der unzerstörbaren Idee, in: Archplus, 5, 2002, pp. 64-68

Murray, Peter and Mary Anne Stevens, Living Bridges, Munich, 1996

Oster, Hans, Fußgängerbrücken von Jörg Schlaich und Rudolf Bergermann, exhibition catalogue, 1992

Otto, Frei and Bodo Rasch, Gestalt finden, Fellbach, 1995

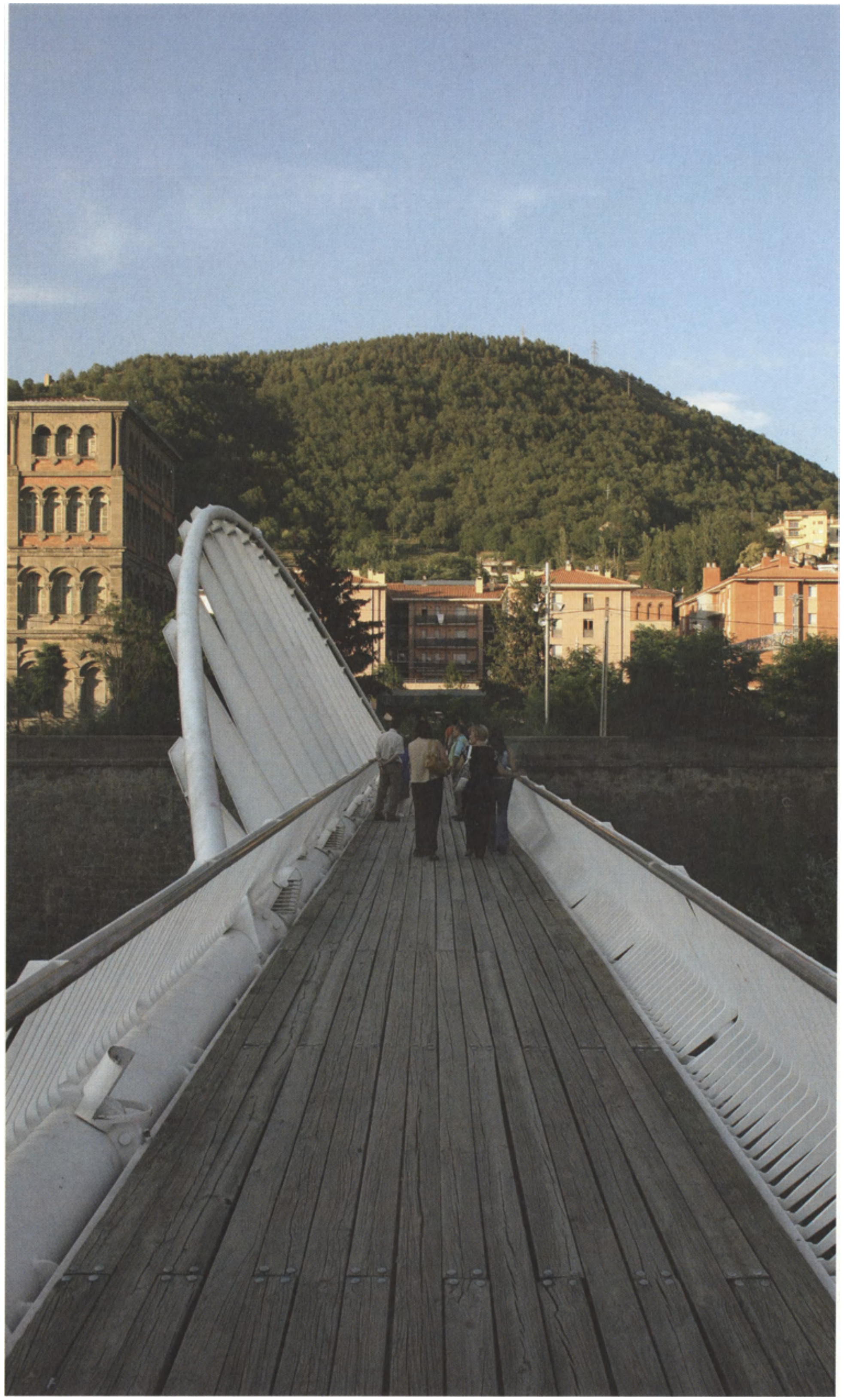
Schlaich, Mike et al., Guidelines for the design of footbridges, fib, fédération internationale du béton, bulletin 32, Lausanne, November 2005

Wörner, Sven, Überdachte Brücken, Diplomarbeit, Ilek, University of Stuttgart, September 2001

Hable con ella. Talk to her. *Pedro Almodóvar, 2002, Film*

This chapter deals with an international phenomenon: almost every city attempted to mark the turn of the century with a special event, constructing Millennium parks, towers and bridges to handle them. The attempt to mark important events with symbolic structures is nothing new: in particular, the World's Fairs beginning in the nineteenth century are among the best examples of this. Footbridges were some of the coveted construction projects of the new millennium.

Every structural form can be made a symbolic gesture when dramatically staged and spectacularly marketed. It is notable that high arches have recently taken centre stage, whether they be moveable, inclined or sculpted – the arch is linked with positive spiritual connotations and is a structural form that is relatively easy to control. The master of the new arch is doubtless Santiago Calatrava: beginning as a controversial figure among international engineers, his work incontestably deserves merit for breathing new wind into bridge construction since the 1970s. His approach, to create constructions that are experienced as sculpture, always to find a form particular to the site, and to value the structure's lighting as an integral part of the project, has since gained worldwide recognition. In England, the architects of Wilkinson Eyre in cooperation with various engineers have created extravagant and emblematic bridges. For footbridges, the emblematic component of these structures also celebrates the pedestrian reconquest of the city. Bridges with unique designs can create great local identity and become the subject of postcards or make an area attractive for tourists. A competition develops between financial cost and the increase in local symbolism, which is essential for European cities.



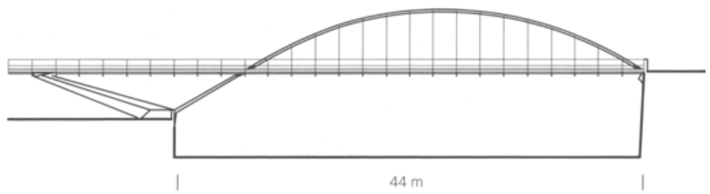
La Devesa Bridge over the Ter in Ripoll, Catalonia, Spain, 1991

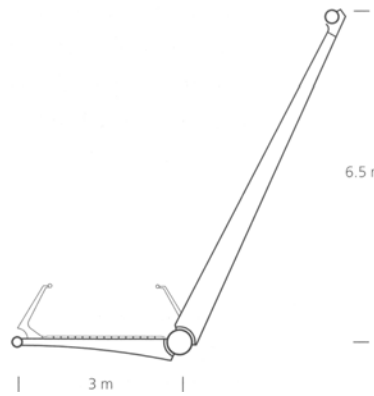
As in all of Calatrava's projects, the different banks justify the solitary figure of the snow-white bridge over the river. The difference of 5 m in elevation inspired the conspicuous stairway, which is further emphasized by a platform serving as a type of balcony. The inclined arch makes less visual impact – in the model, the cantilevered arch dominated the design while in the built structure, the abutment at the lower bank plays a greater role. The eccentric arch has a rise of 6.5 m and a span of 44 m. The weathered grey timber surfacing is laid upon steel girders in the longitudinal direction at an angle of 65° to the arch.

The unilaterally inclined arch is rigidly fixed to the deck both at the abutment, and also at each cantilevering hanger that transfers torsional moments in the box section of the deck. The deck is braced with diagonals to support the horizontal forces due to the inclination of the arch (for more on inclined arches, see p. 136).

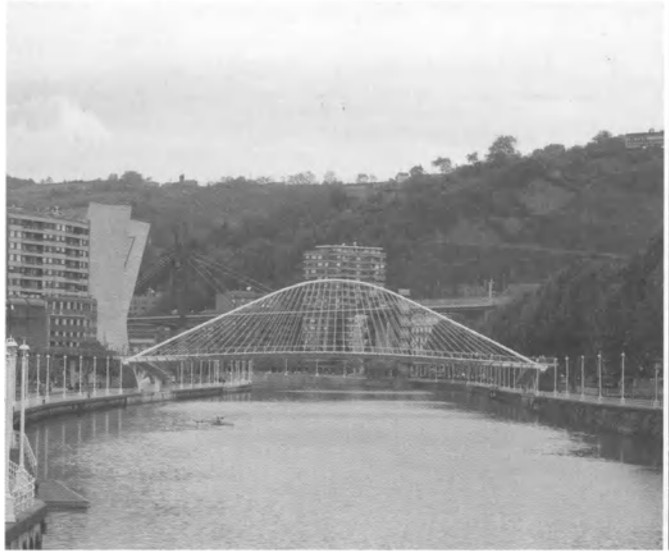
Calatrava, Santiago, Des bowstrings originaux, in: Bulletin annuel de l'AFGC, 1999, 1
Frampton, 1996, pp. 122-131

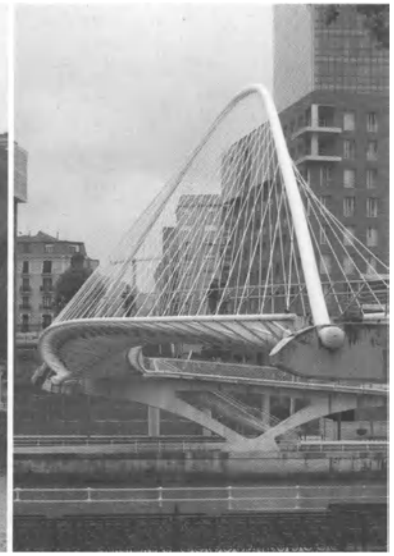
The bridge creates impressive forms from many perspectives





No fear of grand gestures: the symbolic requires courage in design with a span of 75m





Campo de Volantin Bridge in Bilbao, Spain, 1997

Frank O. Gehry's so-called "Bilbao effect" on architecture was revisited by Santiago Calatrava, with the effect his bridge structure opposite the museum had on frightened engineers. The Catalan architect and civil engineer – born in 1951 – studied in Valencia and at the Swiss Federal Institute of Technology (ETH Zurich). A better constellation could not be found to breathe new wind into the consciousness of established engineering

Calatrava is familiar with the Spanish bridgebuilding tradition – from José Eugenio Ribera to Eduardo Torroja and Carlos Fernández Casado – as well as the Swiss tradition where structure and form are not as separated as in Germany. Calatrava – a great draughtsman – founded his own office in the 1980s. Paris became a second or third home; no problem for the versatile engineer, who was much in demand. Cosmopolitanism is more often found in engineering than architecture.

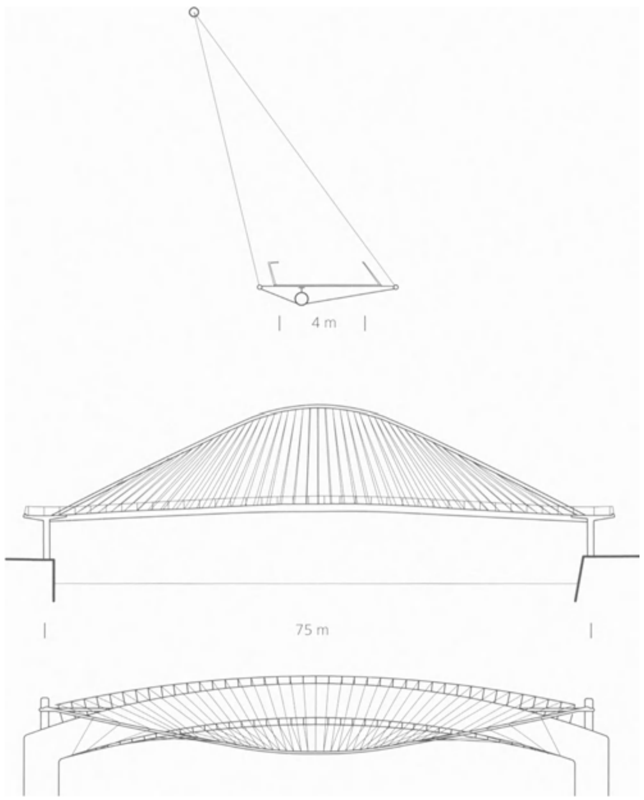
In bridge construction, the inclined arch dominates Calatrava's work – as seen here in Bilbao where a lively river promenade over the Nervión would be connected to a warehouse zone – in an attempt, as seen so often, to revitalize and rejuvenate an industrial area. Bilbao required a symbolic gesture to create an atmosphere of change in the country, and Santiago Calatrava was able to deliver it. The expressive arch, the dazzling white colour, and the theatrical lighting together offer everything necessary to create a symbol from its powerful visual image.

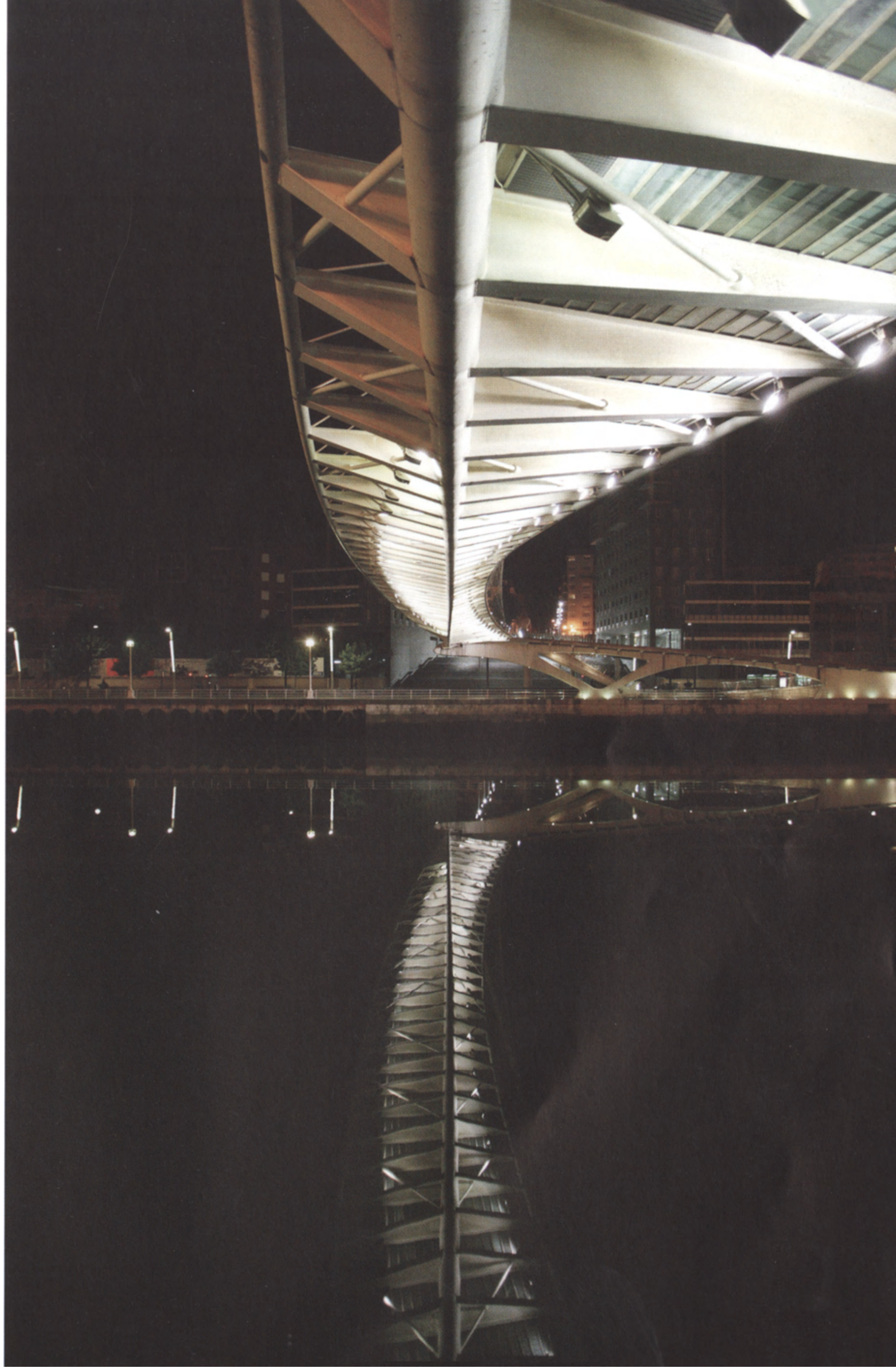
One essential point makes the structure unique: the arch and curved deck plate do not lie above one another in one plane, but cross each other. Half of the hangers run above the deck and seem to offer some protection for the pedestrians. The inclined parabolic arch spans over 75 m and creates a stable spatial structure together with its hanger cables. The slenderness of the arch indicates that its form is not random, but is the result of a complicated form-finding procedure to minimize bending moments in the arch.

The fact that sufficient room was provided at each side for approach ramps and abutments greatly helped the sculptural approach of the design. It should be noted that the bridge cannot simply stop at the abutment. The transition from the promenade to the structure must be theatrical and echo the movement of the structure in the urban environment. An exhausting planning process may have been the result. Santiago Calatrava seems not to fear such things.

Frampton, 1996, pp. 205-213; Torres Arcila, 2002, pp. 256-267; Wells, Pearman, 2002, pp. 58-63

Artificial lighting is part of urban renewal, Calatrava's white bridges are predestined for their role





Connections and vibration dampers

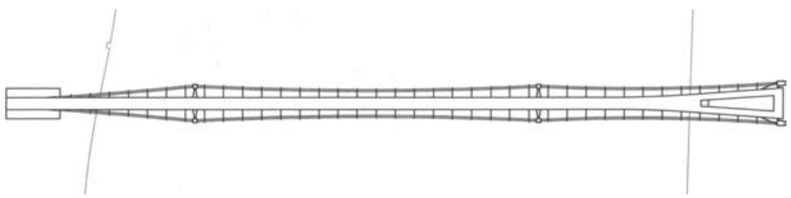
Millennium Bridge, London, UK, 2001

"Pedestrians only. No motorcycles, pedal cycles, scooters, roller-skates, rollerblades or skateboards" – so reads the sign at the entrance to the Millennium Bridge in London. The list of those who may not use the structure is long, which provokes the question of why this may be. The bridge was closed just a few hours after its spectacular opening in June 2000 due to vibrations. However, the structure was the product of adept design: the change in the entire urban zone characterized by Herzog & de Meuron's conversion of the old power plant into the Tate Modern is further symbolized by a footbridge. The new millennium brought a connection between the south side of the river and the city centre ; the pictures above demonstrate the challenge facing many footbridges as part of its role as a landmark and in urban renewal: they must provide a response to completely different urban situations at each shore. The offices of Foster Associates and Arup were able to meet this challenge with their competition laureate, slender structure.

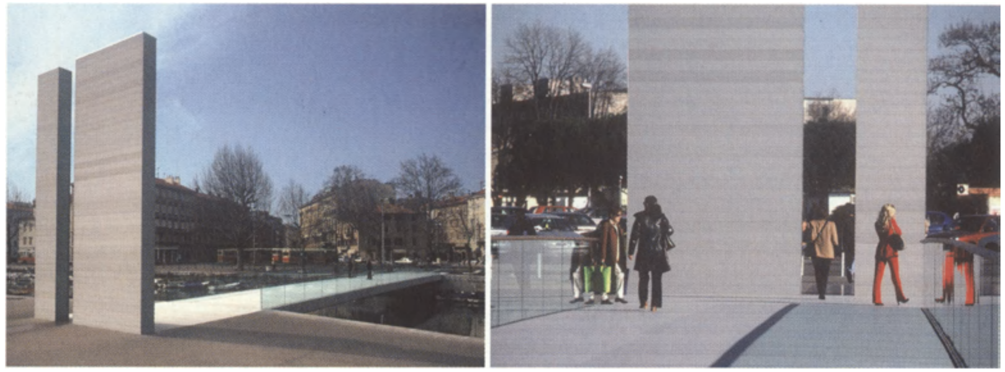
The first bridge built in London since Tower Bridge in 1894 – and the first pedestrian bridge – was required to be technically refined in the presence of the new millennium. The bridge is 330 m long with a central span of 144 m and a deck width of 4 m. It has been referred to as "probably the most delicate suspension bridge of our time". The shallow cable sag accentuates this effect. The ratio of span to sag is here 60, whereas for a normal ratio for suspension bridge is 10! This greatly affects its cost, due to the much higher cable forces. The inclination of the hangers makes the bridge susceptible to lateral oscillations. The bridge was closed, as mentioned above, due to high lateral vibration through pedestrian excitation (see "sailor's roll", p. 101). The problem disappeared only after the installation of numerous dampers.

Wells, Pearman, 2002, pp. 86-89; Millennium Bridge, London: problems and solutions, in: The Structural Engineer, 17 April 2001, n. 8 vol. 79

The view from the Tate Modern, the approach ramps become an observation deck – span 144 m, total length 370 m, cable sag 2.30 m



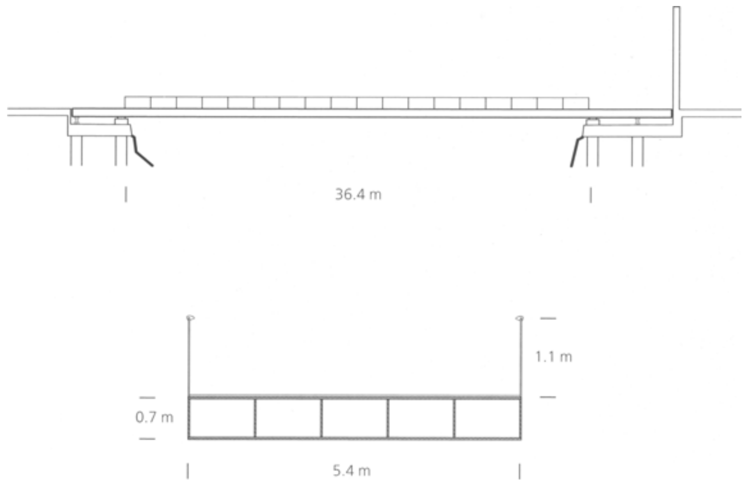
The contrasting form of each side of the bridge is an essential part of the design



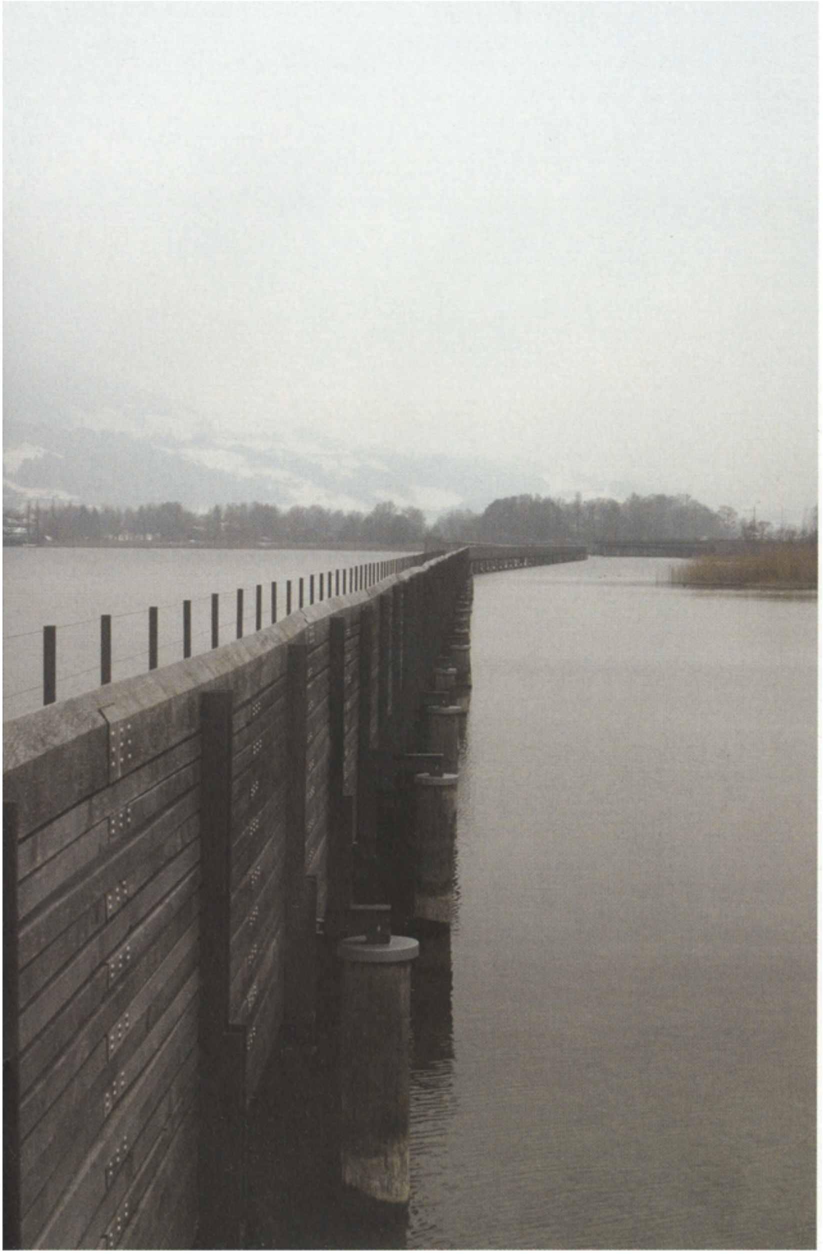
Memorial Bridge in Rijeka, Croatia, 2003

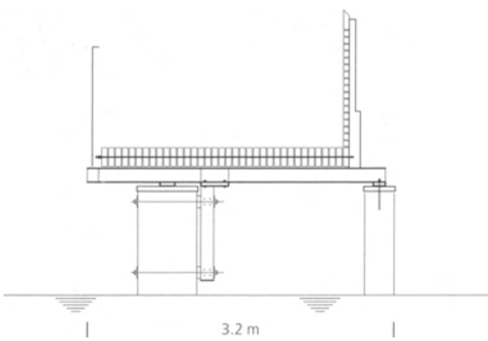
In Rijeka, some 50 km south of Trieste, Italy, this bridge serves as memorial to the recent violent history of the Balkans. The reserved symbolism of the bridge shapes a piece of the urban environment without becoming too visually brazen. The approach that begins in the historic city centre continues over the river to the former port, which has been made into a city park. The structure is 47 m long with a free span of 35.7 m. The vertical 3.15 m and 1.15 m wide upright concrete slabs project to a height of 12 m. The deck consists of a closed box section in steel, an aluminium plate surfacing, and railings from safety glass with wooden handrails. A specially designed crane was used to place the 150 t deck; the ebb of the tide helped to allow the deck to pass below two existing structures. The concrete piles below the abutments extend 17 m into the soil. Particular attention was paid to the details and surfacing.

The structure reminds one of the small but famous stone bridge from 1566 in Mostar, which was senselessly destroyed during the 1993 Balkan War; it was reconstructed for symbolic reasons and inaugurated in 2004.

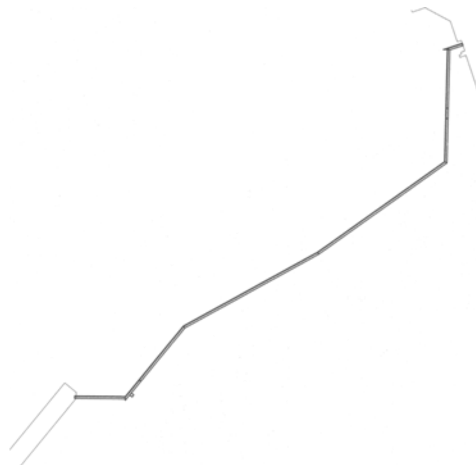


db deutsche bauzeitung, 5, 2003, pp. 38-45





Footbridge over Lake Zurich near Rapperswil, Switzerland, 2000



Walther Bieler is a timber construction specialist; without intimate knowledge of the material, one should not attempt to build such a bridge. The 841 m long wooden footbridge over Lake Zurich was intended to re-vitalize the centuries old pilgrimage Route of St James. It should be said this goal has been met given the sometimes ten thousand daily visitors, most of whom are not pilgrims. The path is an event, the bridge is not expressive, simply a reserved sign of the extraordinary path. Seating and viewing sills denote that pedestrians must stop and look around: the surroundings are simply beautiful. 233 oak piles support the 2.4 m wide deck. The piles were driven into the lakebed and then cut to the appropriate height; the lengths vary between 9 and 16 m, with diameters of 36 to 70 cm, and they are spaced 7.5 m apart. The deck lies approximately 1.5 m above the lake and consists of steel sections that are hot-dip galvanized and powder coated with a micaceous iron ore. The sections lie transverse to the deck on the piles. Continuous timber beams lie 1 cm apart from one another and are stabilized every 2.5 m by steel brackets. With its asymmetric profile, the footbridge causes the user to take a more suitable, slower pace. No lighting is provided for the footbridge, as wildlife are protected in this nature reserve.

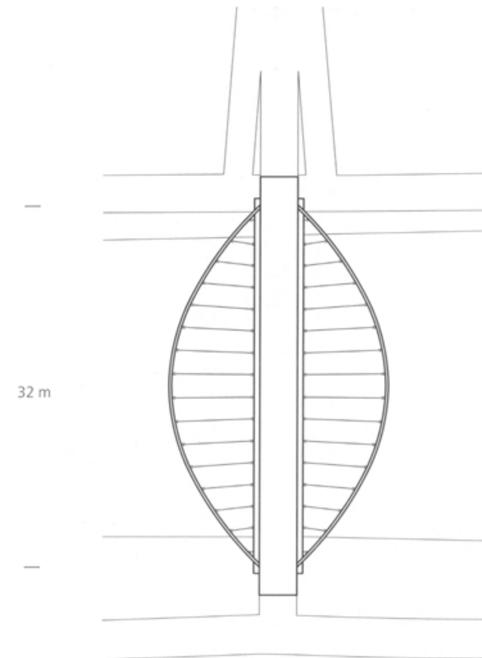
The pilgrim's pathway with a high wall toward the protected natural sanctuary

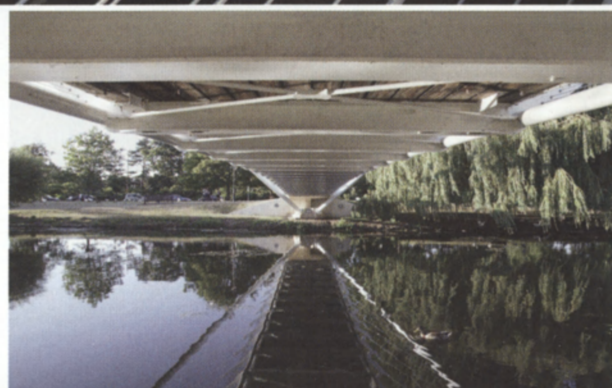
Arches – 1888 vertical, 1997 inclined

Butterfly Bridge in Bedford, UK, 1997

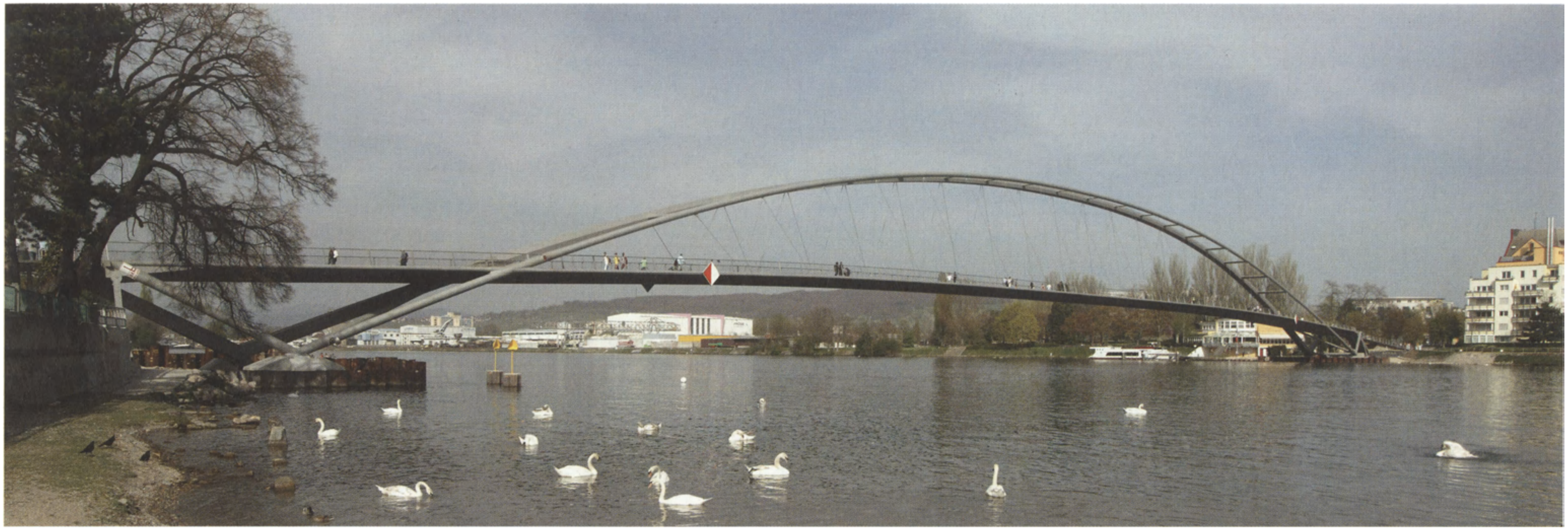
Creating a symbolic gesture with a footbridge is not limited to urban situations, where a functional improvement of an urban zone is to be expressed. A footbridge can send a symbolic message even in the most beautiful natural or garden environment. The architects of Wilkinson Eyre and the engineers of Jan Bobrowski and Partners won the 1995 competition for this footbridge, beating 78 competitors. A park and a festival site required that 32 m of the Ouse be bridged; it could have been done more simply, but that's not the point. The two inclined arches truly resemble insect wings from afar. As one approaches, the arches seem to lure passers-by with an inviting, sympathetic gesture. They are not connected overhead, leaving the sky open above the deck. The design is completely arbitrary, and reflects the adjacent bridge by J.J. Webster, built in 1888. Both arches are stable due to their rigid fixation at the abutments. The bending moments transferred to the abutments from each side cancel one another out and do not load the superstructure. The horizontal forces from the hangers at each side are also equal and opposed. The presence of the bridge is further accentuated by the professionally developed lighting design, a requirement for all such symbolic bridges.

Pearce, 2002, pp. 200-203

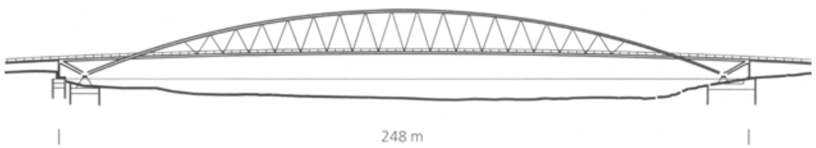




View towards Weil am Rhein



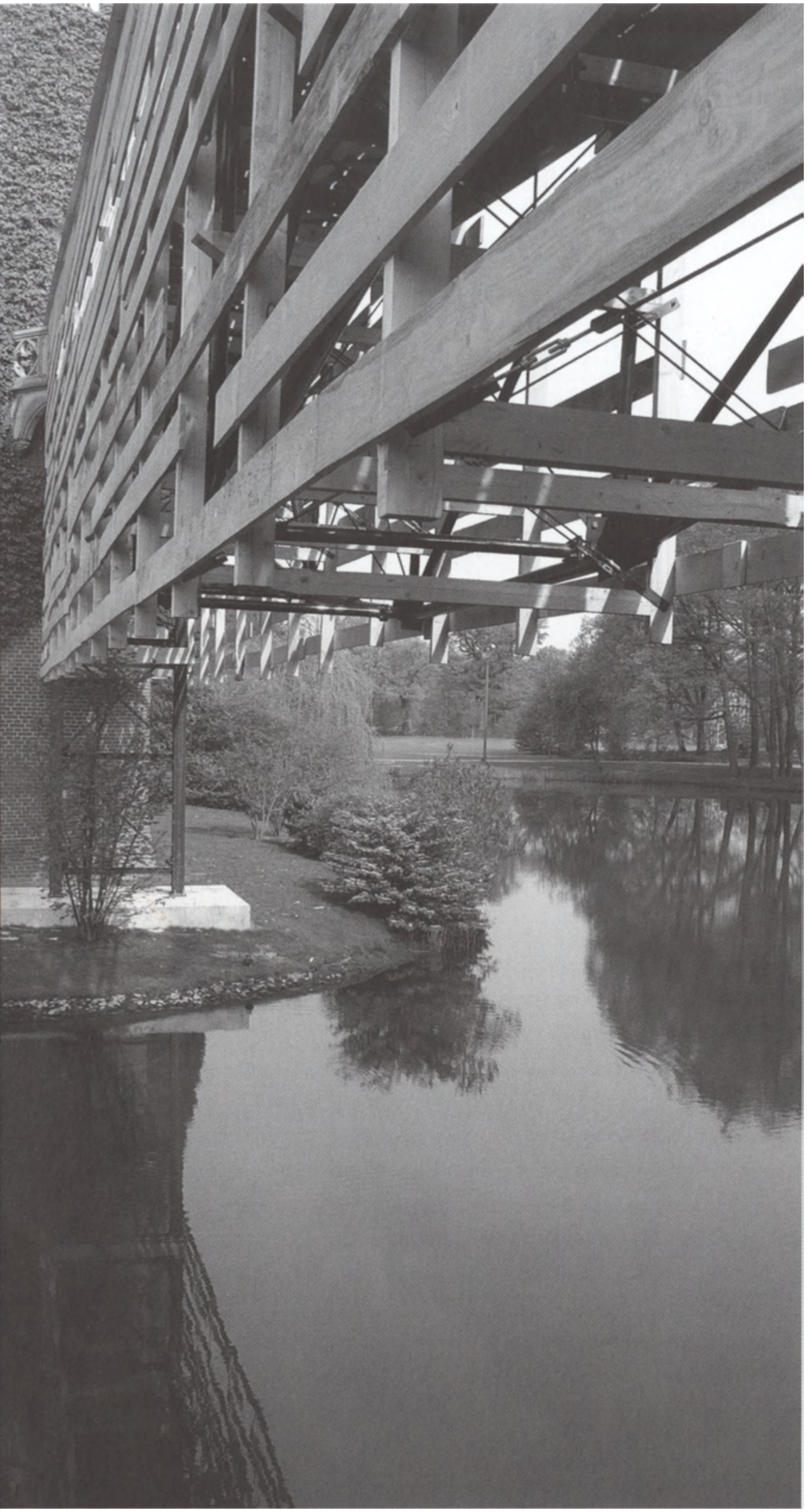
Rhine Bridge in Weil am Rhein, Germany, and Huningue, France, 2007



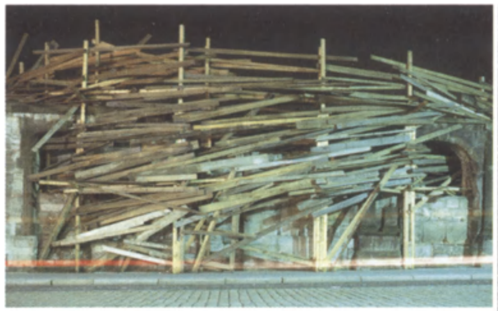
A structure bridging a border between two countries is by nature symbolic. In Europe, still searching for political identity, such structures are considered particularly important and worth any additional effort to make them suitable for their roles. The Rhine Bridge in Kehlheim (see p. 108) demonstrates the difficulties that arise when functional requirements are prioritised above design. In Weil am Rhein, a competition was held to a footbridge between France and Germany to provide access to a shopping centre and replace ferry traffic across the river. Feichtinger Architects with Leonhardt, Andrä and Partner were awarded the commission. Their project was a steel arch bridge with a span of 230 m over the Rhine. The bridge deck acts as a tension member, so that essentially only vertical forces would be transferred to the abutments. The position of the structure is set free by the visual axis of the asymmetric arch structure. The asymmetry is obvious: the northern arch is recognizably heavier and consists of two hexagonal tube sections; the circular tube of the southern arch leans on the northern one. The form of the arch was corrected according to aesthetic criteria. The original parabolic form was considered too steep, so the quarter points of the arch were raised by 40 cm - it now appears rounder and softer, and more steady and quiet when viewed at an angle. The abutments of most such large bridges are extraordinarily solid: the design presented by Dietmar Feichtinger and Wolfgang Strobl from Leonhardt, Andrä and Partner called the arch to be set upon a spatial truss where the piers disappear in the water below. This system solved the sole problem of finding a balance riverbank pathways and bearings. The approach on the French side has a lift for wheelchair users.

The span of 230 m makes this bridge the current world record-holder for arch footbridges, and the rise of only 23 m was a considerable engineering challenge. The bridge was built in a manner similar to the Passerelle Simone de Beauvoir in Paris (see p. 144). The sections of the bridge near the abutments were built as cantilevers, and the 1000 t central segment was lifted into place and suspended from the cantilevers. The Rhine was closed on 11 November 2006 for a single night for the erection of the central section.

The bridge is a symbol of cross-border coexistence; the requirements of both the German and French codes and standards had to be respected in the planning. The participants suffered under the discord of bureaucracy.



Destroyed Church, Kassel, 1987



Tadashi Kawamata, Bridge and Archives, Bielefeld, 2003

Temporary Bridge in Moyland, Germany, 2003

At the request of the Moyland Palace Museum, where brothers Franz Joseph and Hans van der Grinten keep their important collection of works by their friend Joseph Beuys, Tadashi Kawamata designed the temporary footbridge for the exhibition *Bridge and Archives*, which ran from 11 May to 26 October, 2003. In cooperation with the engineer Werner Wiegand and the students of the Düsseldorf Art Academy, Tadashi Kawamata built a bridge connecting the first floor of the palace with the gate fortification building that housed the exhibition. The result was a fascinating, transparent but voluminous footbridge, supported by a steel structure with suspension system clad in timber. As the structure only existed for the summer and early autumn of 2003, the project was documented in drawings and a series of photographs by Leo van der Kleij, who has photographed Kawamata's work for years.

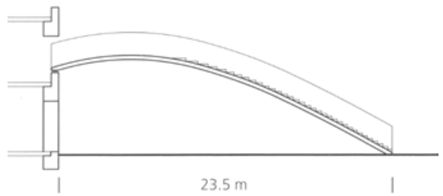
The Japanese artist Tadashi Kawamata continues to examine interior and exterior spaces with his forms from timber planks – similar to pick-up sticks, they seem random, but of course are not. The structure echoes his project *Destroyed Church* in Kassel 1987. Kawamata's bridges perform their obvious function while expanding the spatial experience. The influences of Walter Benjamin's passage works are noticeable.

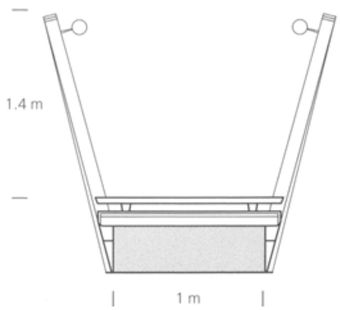
The red arch was also spectacularly set in scene at night

Temporary Bridge for Architekturwoche A1, Munich, Germany, 2002

The first *Architekturwoche* was held in Munich 12-21 July 2002: the public was to be made aware that the examination of architecture is important for everyone. It was clear that something must be staged in the public space in the central exhibition area. Architect Peter Haimerl and engineers Bielmeier & Wenzl created a fire-red arch footbridge based on a concept by Matthias Castorph, rising from street level to the first floor of the exhibition hall.

Glued timber beams similar to a bow – were used for the supporting spine of the structure. The cross section (110 x 30 cm) is constant along the total length and can be shortened to any length. This is important as, after the Architekturwoche, the bridge was to provide a crossing with a span some 7 m shorter over the Riedbach creek in Viechtach. A supporting structure with galvanized rectangular profiles made this possible.





Man is only wholly a man when he is playing. *Friedrich Schiller, Letters Upon the Aesthetic Education of Man*

Moveable bridges are not modern inventions. Already long before Van Gogh, traffic systems and routes had to be bridged so that neither traffic flow interfered with the other. Building bridges at an elevation that allowed clearance for ship masts would be absurd. A second reason would be the fear of attackers: the ancients already had drawbridges for their fortresses.

Faustus Verantius (1551-1617) was also naturally familiar with the problem of moveable bridges (see p. 34). Trade boycotts and military strategy led Napoleon to go an easily reversible route at the end of the 18th century: during the construction of the Grand Canal du Nord that was to connect the Rhine and Maas between Venlo and Neuss, and then in the direction of Antwerp, Napoleon had 11 moveable bridges constructed. However, he then annexed and controlled the Dutch ports, making the bridges unnecessary. The Pont Transbordeur in Marseilles is legendary, a transporter bridge from 1905.

There are many situations in which there is no other choice than to lift, rotate or flip a bridge. These days, this cannot really be accomplished without the aid of a mechanical engineer, when public bridges have to be moveable, and preferably by remote control. The movement becomes a spectacle, but comes with a certain technical investment and normally costs more than a fixed bridge. There seems to be no limit to the inventiveness of the mechanical engineers, especially when they are working in cooperation with structural engineers and architects. The selected projects considered here are only a fraction of the design possibilities of small footbridges.

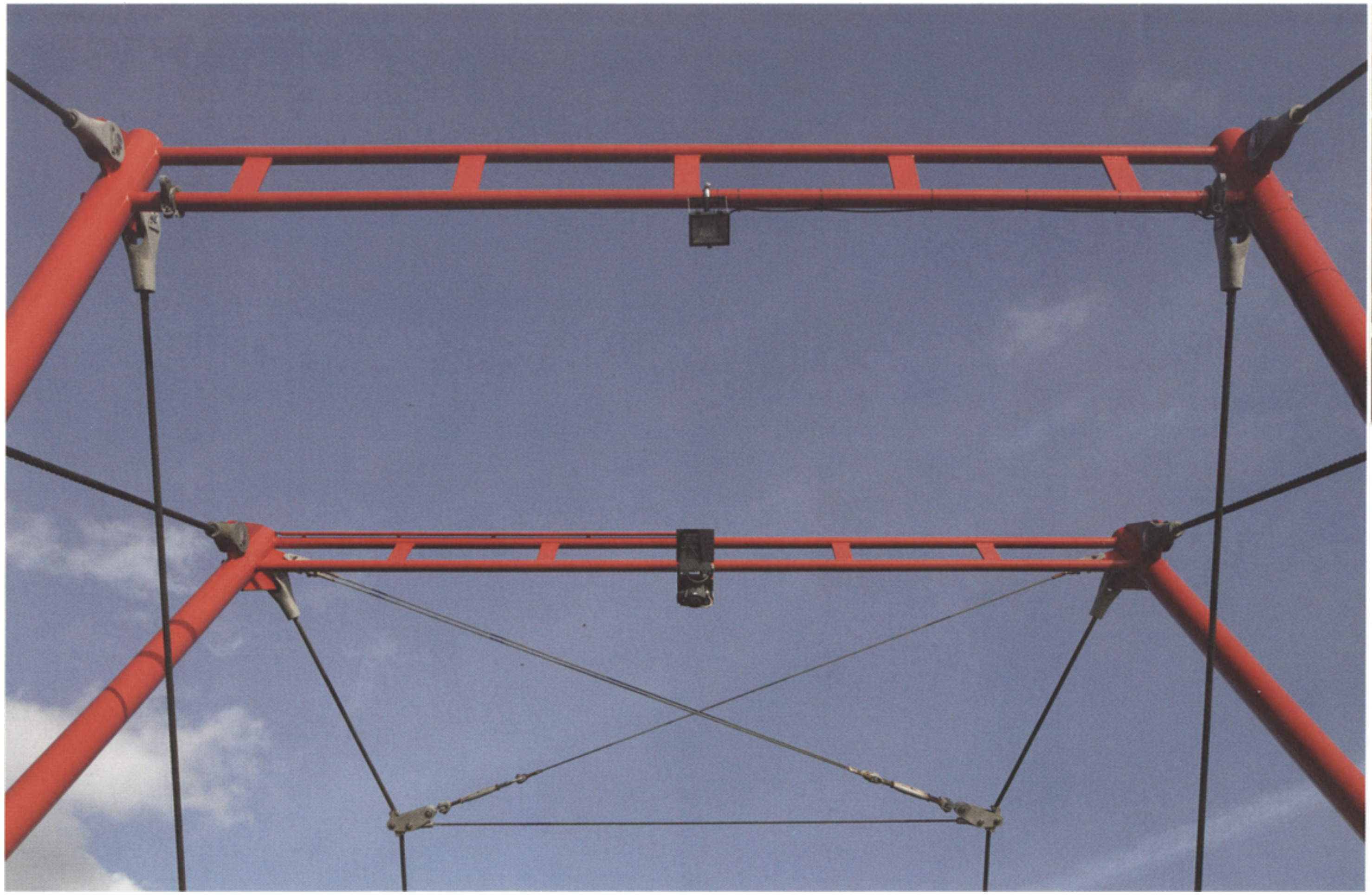
One aspect that a book can unfortunately demonstrate only indirectly, and that plays an important but often overlooked roll in the design of moveable bridges: their noise. They clap, grind, squeak, crack, snap, buzz – as with barking dogs, the loudest bridge is usually the smallest. The noise and movement are an allure for the designer. The bridge becomes a type of toy – as everything that moves and makes noise creates enjoyment and wakes the child in anyone.

Folding bridge at Firth of Kiel, Germany, 1997

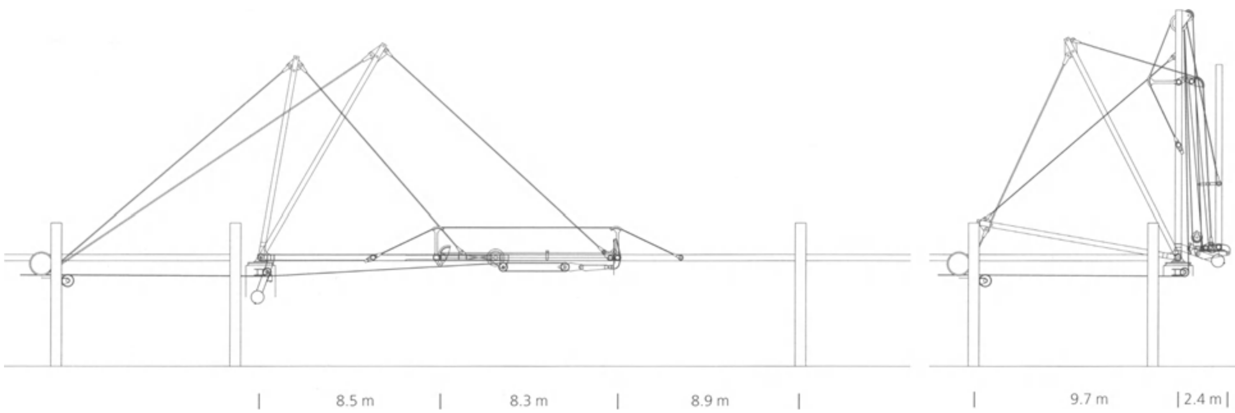
It is a privilege for a city to be on the water and be the site of internationally recognized sailing events. On the other hand, waterways subject to high traffic can be as much as a swath through the urban fabric as a highway or railway. The challenge is to make a virtue of necessity. Kiel, a beautiful city on the Baltic Sea, is divided into east and west by the Firth of Kiel. In the early 1990s, the Scandinavian ferries wanted to move to the less sought-after eastern area, they first waited for a bridge to be constructed 120 m over the water leading west. To allow ferries and yachts to pass, the bridge was required to be effortlessly moveable. The head of the planning office suggested a folding bridge with three sections. This was constructed by the engineers of Schlaich Bergermann and Partner and the architects von Gerkan Marg und Partner. In the closed position, the bridge is a classic, one-sided cable-stayed bridge with a 26 m span and a width of 5 m, supported to each side by two cables. The deck has articulations at the third points of the deck and can therefore fold together as the cables are tensioned upward. This not only makes the movement of the bridge interesting, but also decreases the surface area for wind loading. To ensure a robust, low-maintenance system – the bridge must open about ten times a day – a simple pulley system was developed rather than a complex hydraulic or electromechanical system. During opening, all the moveable cables, the main stay cables and an additional cable for the movement of the front of the superstructure, are controlled by one cable reel turning at a constant rate. This does not need to be synchronized with other systems. The rest of the movement is controlled by a second cable roll running at a constant torque, which pulls both pylons back so that the folded bridge has enough clearance. It is an astonishingly simple system for such a complex folding motion. Opening or closing of the bridge takes about two minutes.

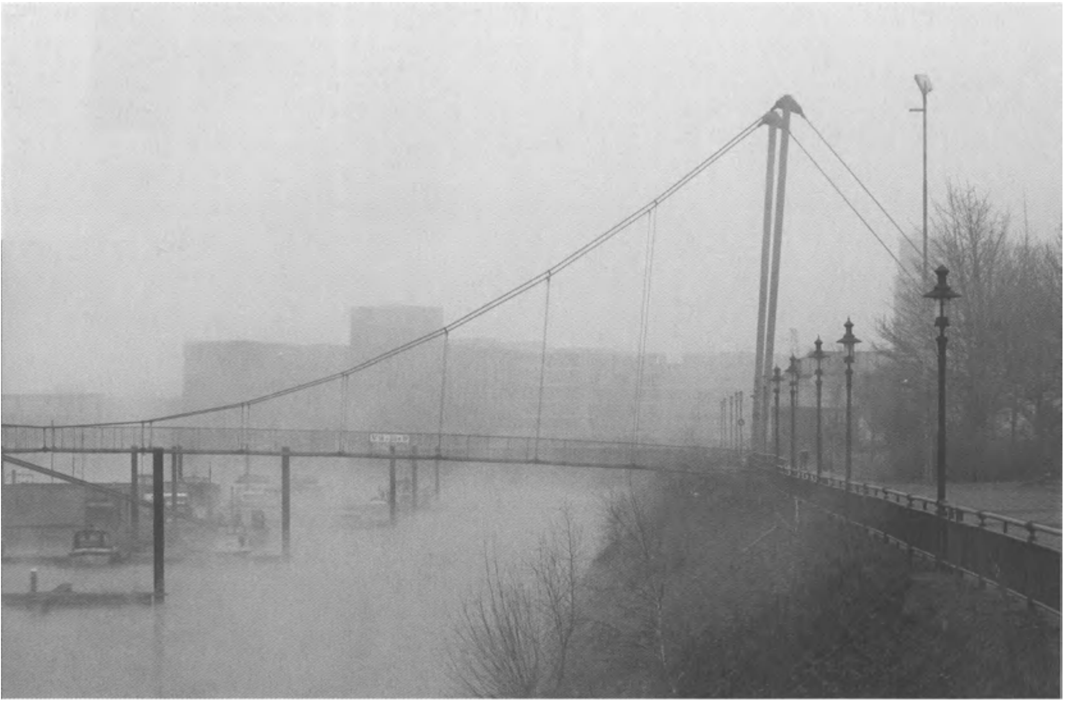
Leicht, weit, 2004, pp. 260-263; Knippers, Jan and Schlaich, Jörg, Folding Mechanism of the Kiel Hörn Footbridge, Germany, in: Structural Engineering International, 1, 2000, p. 50

Many ships pass through the bridge portal daily.

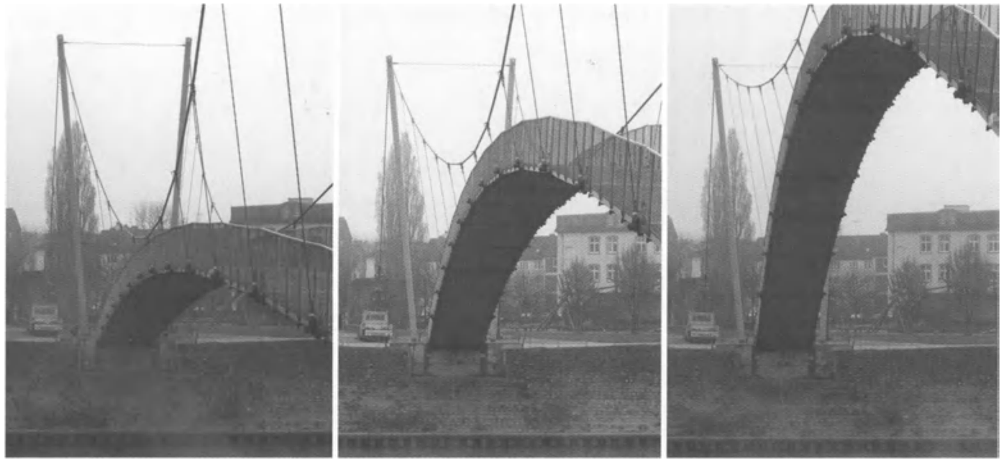


From the beginning, the construction of the bridge was accompanied by local political arguments that are always detrimental to the work of design engineers. The innovation that is at the heart of the structure unfortunately played little role in the debate.



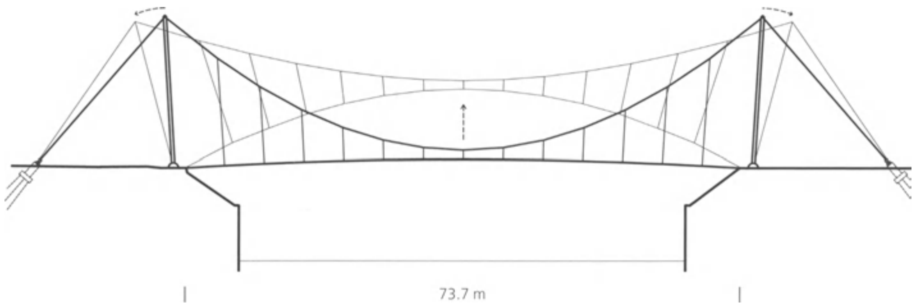


The suspension cable lifts the deck upward, the shipping clearance is thereby increased by 8.1 m



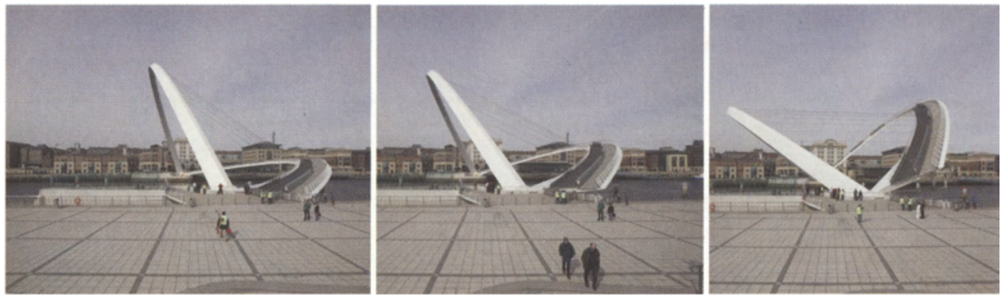
Katzbuckel Bridge in Duisburg, Germany, 1999

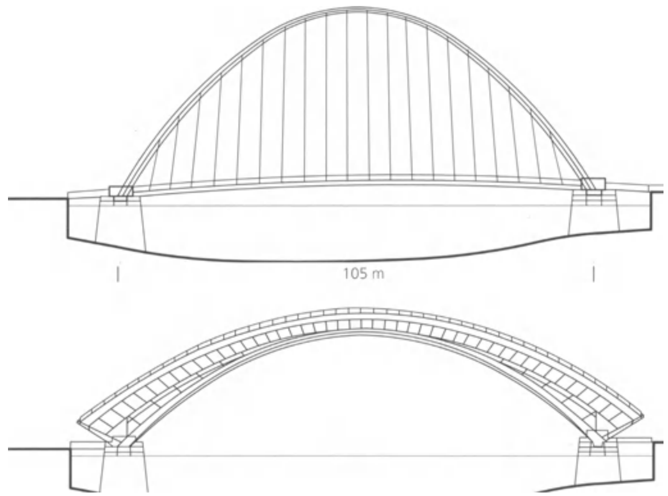
Europe's largest inland port consists of a wide, entangled network of harbour basins that extend into industrial zones. As part of the conversion of an industrial zone, an interior harbour was to be bridged to connect the park of the historic city centre with a new park area. The footbridge was to be 3.5 m with a span of 74 m, and be able to be lifted to allow large ships to pass. A suspension bridge, designed by Schlaich Bergermann and Partner, is suspended from four 20 m high steel tube masts (d=419 mm). The movement of the deck takes advantage of the principle that the vertical sag of a taut cable decreases greatly as a result of a small horizontal displacement of its bearings. Shortening of the backstay cables by 3 m with hydraulic cylinders causes the top of the masts to tilt 1.7 m to the outside. This in turn causes the bridge deck to rise 8.10 m, creating a *Katzbuckel* – the German term refers to the bowing of a cat's spine. The increased curvature of the deck would normally produce large bending moments – so the deck is conceived as a series of short articulated members acting similarly to chain links. The deck becomes 3.65 m longer as it is pulled upward. Additional deck elements are pulled from a chamber in the abutment as the structure rises. The movement appears spectacular, as it should. A lighting system was developed to emphasize the motion of the deck – unfortunately this has been out of operation for some time.



Leicht, weit, 2004, pp. 264-267

The bridge can be inclined within seven minutes to allow ships to pass





Millennium Bridge in Gateshead, UK, 2001

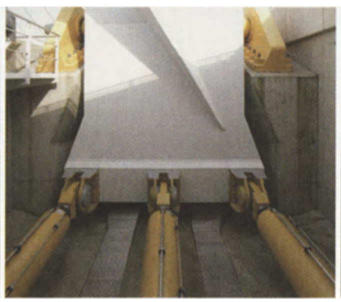
This spectacular structure completes a series of bridges constructed over the centuries over the Tyne between Gateshead and Newcastle. The Millennium Bridge was to be something special and to stand out against the deterioration of the riverbank area. A curved bridge deck with parabolic arch creates an impressive form. The fact that this form is moveable creates the true spectacle: the 105 m span, 46.5 m pair of arches rotate about a common abutment. The 30 m wide shipping lane has a clearance of 25 m.

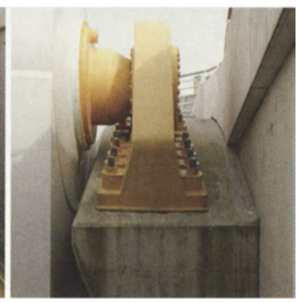
The architects of Wilkinson Eyre and the engineers of Gifford & Partners beat 50 other competitors with their idea of two arches – one forming the deck, the other the supporting arch – rotating about the support to provide the necessary ship clearance. The opening is certainly a spectacle, but the closed bridge is also impressively beautiful. The erection of the bridge can be viewed on the Internet. A 90 m long Asian Hercules II swimming crane transported the structure 8 km from its manufacturer to the construction site, where it was placed precisely to the millimetre. The structure is not exactly economical: due to the expenses of transport, the engine of rotation and the bearing, this bridge becomes the most expensive of all expensive bridges.

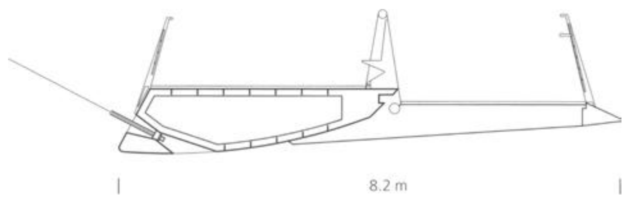
Contrary to a balanced bridge with a counterweight, which is easy to move, the Millennium Bridge required heavy motors that were able to push as well as pull, as the centre of gravity of the structure moves over the axis of rotation. The hydraulic jacks at both abutments can each create a compression force of 10,000 KN and a tension force of 4,500 KN, allowing the structure to open even under heavy wind.

Such an incredible machine, which is constantly in service, cannot simply be hidden in the dark of night. From the beginning, the engines were therefore part of the lighting system that theatrically accentuates the arch structure and its reflections in the water below.

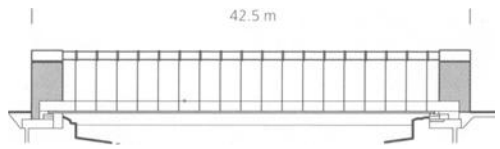
Curran, Peter, Gateshead Millennium Bridge, UK, in: Structural Engineering International, 4, 2003, pp. 214-216






8.2 m

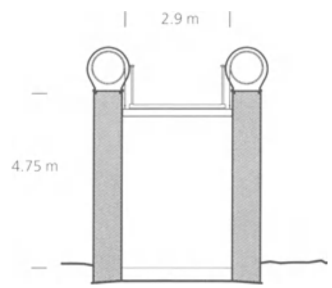
The bridge girder is lifted by 32 cables



Coupure Bridge in Bruges, Belgium, 2002

For once, it was not the new millennium that called for a renovation of an urban zone. Bruges was elected the 2002 Cultural Capital of Europe and used the opportunity to create a continuous network of paths for cyclists and pedestrians throughout the city of canals. As part of this project, a bridge was necessary over the Coupure Canal. The structure was to be moveable to allow ships from the city to cross to the Ghent-Ostend Canal via the Coupure Canal. The Swiss engineer Jürg Conzett designed a vertical lift bridge with a lightweight 2.5 m wide deck for pedestrians and cyclists. The deck plate is suspended from two stationary steel tubes 6 m above the deck, which can rotate about their axes. In order to lift the superstructure, the 17 hanger cables to each side are wound around the steel tubes like to a coil. The bridge can be opened with little force, as the deck only moves up and down and stays in place. The supports for the tubes at the top of the plate-shaped pillars have an elastic precamber at the midspan. Two bearings are therefore necessary parallel to the longitudinal axis of the deck at the head of each pillar. The outside bearing pulls the tube downward thereby creating the precamber. To rotate the tube, it had to be completely straight. The elastic restraint at the capitals of the pillars was the only way to avoid deflections of the tubes. The sleeves that house the hanger cables during rotation are welded with double fillet welds to both sides and a watertight connection to the supporting tube. The motors are housed in the two southern pillars and are hidden under moveable coverings. This bridge form seems primal, with the mechanics of its movement. The material chosen for the pillars and the surfacing is reminiscent of the Flemish building tradition. The Coupure Bridge shows its youth mostly in the fine execution of detail.

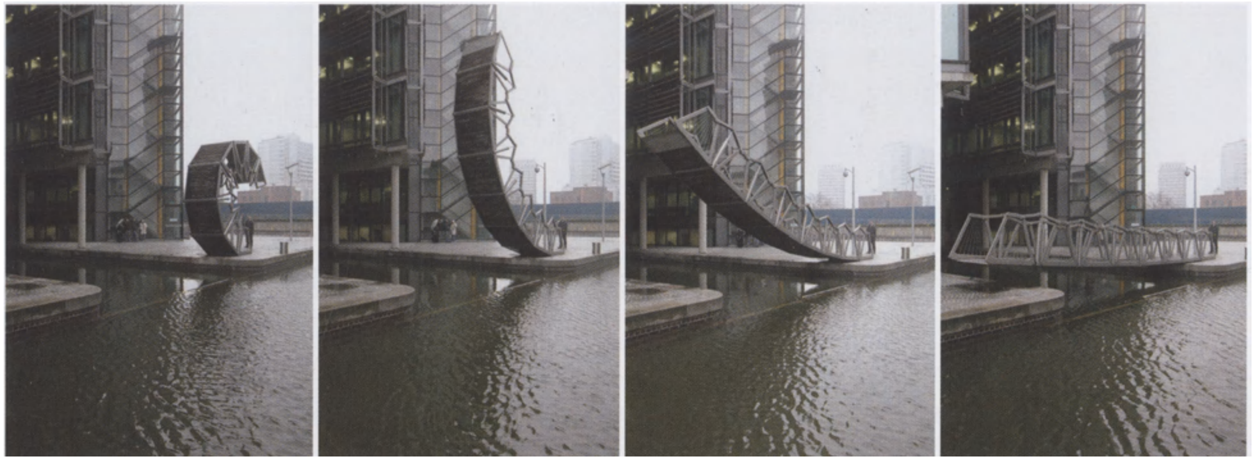
Structure as Space, 2006, p. 241 and p. 298
db deutsche bauzeitung, 5, 2003, pp. 46-53



The bridge acts like a ratation switch and rotates along with the pedestrians on the deck.

Ryck Bridge in Greifswald, Germany, 2004

Volkwin Marg and Schlaich Bergermann and Partner designed the Ryck Bridge in the museum port as a small swing bridge. The maritime character of the structure, with its high mast and two diagonal stiffening spars, is inconspicuously incorporated into its surroundings. The central 15 m, moveable portion of the bridge is stiffened by two inclined tension stays · to provide the necessary strength when open and subject to cantilevering moments. The tension members are designed so that no bearing forces due to self-weight are transferred to the fixed bridge approach. Only after the application of supplementary live loads do vertical bearing forces appear at this interface. The tension rods are suspended from a steel tube mast, which is fixed to the deck and creates an axis of rotation. The deck, mast and tension rods rotate about the footing and are supported by a rotating assembly. This assembly transfers all forces in open and closed states to the steel reinforcement at the head of the pier and onward to the piles below. Two inclined spars anchored into the quay wall stabilize the head of the mast. The spars act as the backstays of a cable-stayed bridge when closed. When the bridge is open and the deck swung to the side, the spars and mast create a stable tripod – and one of the spars is subject to compression. A hydraulic cylinder with electronic control provides the motor.



Rolling Bridge in London, UK, 2006

At noon every Friday, this small bridge is unrolled in the middle of London but in a hidden site. On North Wharf Street in Paddington, a gentleman arrives with a computer control and sets the bridge in motion with a simple touch of a button. It is the work of architects Heatherwick Studio and the engineers SKM Anthony Hunts. In a geometrically ingenious motion, started by very quiet hydraulics, the bridge rolls out over like a small caterpillar over a span of 12 m. To open the bridge, a small piece of the handrail is elevated over each of the seven supporting elements. The artistic idea, knowledge of civil engineering and structural design are remarkably united in the project.

The bridge is used often, but for which paper ships the bridge is opened every Friday at noon remains a mystery. Decadent? No, the child in all of us loves to play and such extravagance is a welcome diversion. The motion of the bridge remains in the memory as something extraordinary. The designer obviously spared no pains for such a structure.

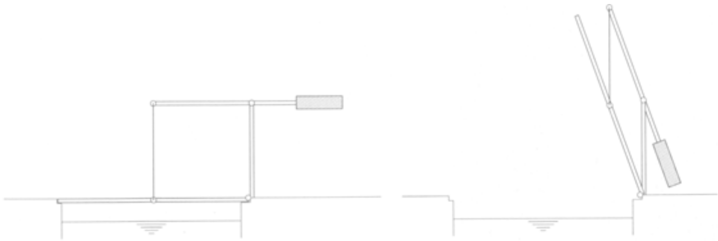
Leer, Bascule bridge, D, 2006

Moveable Bridges

Moveable bridges are now much more than the military drawbridges of the past. The medieval drawbridges that protected castles and fortresses have been replaced by bridges that perform the more peaceful function of enabling different flows of traffic to cross.

Moveable bridges are often over waterways, and are the typical solution when providing the necessary clearance for traffic passing below would mean a very expensive high bridge with complicated ramps, stairways or lifts. In these cases, moveable bridges may be more economical, in spite of increased construction and maintenance costs, which are often twice those for a fixed bridge with the same geometry.

Moveable bridges are one of the most fascinating fields of construction, as structural and mechanical engineering is necessary for the system changes during opening. This leads to an interdisciplinary design process. As footbridges are often lighter than their road and railway counterparts, they are easier to move. This section discusses the many types of movement for the structures and the challenges involved in designing such bridges.



Bascule bridge with arm of balance

Bascule bridge

Greifswald, Wiecker Bridge, 1887

Types

The classic moveable bridges are the drawbridge and bascule bridges. A drawbridge will often be designed with an arm of balance.
A counterweight is used for this as well as for the bascule bridge system, so that the bridge's centre of gravity coincides with the axis of rotation for all positions of the structure. The mechanism of rotation thus has only frictional forces to overcome, so that these bridges may even be moved by hand.

The superstructure of the drawbridge with an arm of balance is a simply supported beam. In the closed state, the bridge deck rests on the far abutment and in the open state is lifted from the abutment by tension members at each side of the deck. As a function of the dominant traffic flow, a light overbalance is provided so that the structure will automatically open or close if necessary.
A locking mechanism is thereby necessary for every state of rotation. The Dutch drawbridge was made famous by Van Gogh's painting. The Wieker Bridge in Greifswald, Germany is opened by hand. The structure was built and 1886 and is still in service. A more contemporary example is the Amtsgraben Bridge built in 1997 in Berlin Köpenick.

Bascule bridges also rotate about a horizontal axis. This horizontal axis lies near the bridge's centre of gravity, thereby dividing the bridge into a fore and an aft arm. Bascule bridges are often moved by a downward motion of the aft span. The fore span is often longer than the aft, which is often designed with a counterweight to minimize the energy of rotation. The moment of rotation from the aft span under full live load cannot exceed the dead load moment of the fore span so that the bridge will not suddenly open. The abutments must be quite wide and deep to provide enough space for the rotation of the counterweight. The flood protection of the counterweight chamber must be taken into account in the design. The opening of the bascule bridge does not interfere with any neighbouring surface in plan.

Descriptions of the many variations of bascule bridges can be found in the literature. The many other types of moveable bridge can only be cursorily described here.

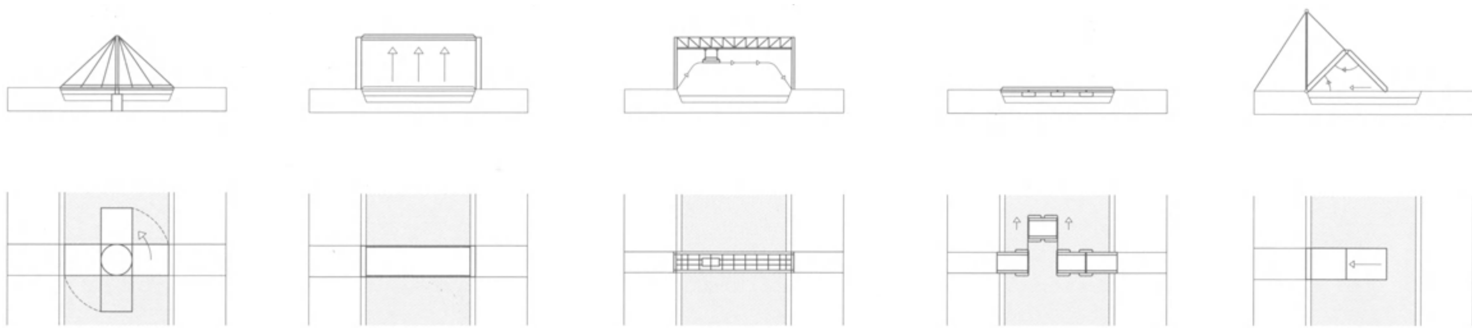
– Swing bridge: Rotation about a vertical axis creates symmetrical loading of the foundation. This advantage must be weighed up against the additional surface necessary for the structure (see p. 189).

– Vertical lift bridge: This system does not require a change in structural system, simplifying the design of the foundations. A simply supported girder is lifted up. Theoretically, pedestrians can stay on the bridge while it opens. The great disadvantage of this structure is its limited vertical clearance. This can be avoided by having the bridge lowered to the keel depth of the ship, as opposed to lifting the structure. This solution is uncommon due to increased corrosion protection and pollution of the deck. The *Katzbuckel* Bridge in Duisburg (see p. 184) is this type of structure.

– Rolled and sliding bridges: These are seldom used due to large space requirements.

– Folding bridges: These structures require little additional space. Due to the complicated mechanical mechanics necessary, they are seldom used (see p. 182).

Swing Vertical lift Transporter Pontoon Folding



– Telescoping bridges: These are similar to the folding bridges. These are mostly seen as airport fingers. The engineers at Atelier One planned a 43 m long telescoping bridge for the Rolling Stones' 1997 *Bridges to Babylon* tour (see p. 243).

– Passenger bridges: These are used for the passage from the quay to a ship. These can be vertically moved at the free end to adjust to the water level.

– Portable bridges: These are often pontoons used for temporary structures, often military, in areas with poor soils. To allow ships pass, a section of the bridge must be detached and floated to the side. Temporary bridges can be made so lightly with modern composite materials that they can be flown in by helicopter. A curious example is the Back Pack Bridge (see p. 231)

– Transporter bridges: Seldom used due to their limited capacity.

The choice of moveable bridge type is determined by the local framework conditions. The required clearance dictates how much the opened bridge must keep free in the vertical direction as well as the horizontal distance to the banks. The frequency of opening will have an influence on the type of motor. Some bridges are required to be opened several times daily under full wind loads and in any weather situation, while many are opened only a few times a year. In situations where corrosive saltwater may come into contact with the bridge, it may be advantageous to site the motor compartment well above the water level. Secondary responsibilities must also be taken into account: If the bridge's movement is to be dramatically set in scene, the planner is free to demonstrate technical advances in the control, mechanical and material technology, and try out new bridge forms. The bridges on the pages 182 to 191 are examples of this.

The designer is generally free in the choice of building materials, although most decks are of lightweight material in order to save the demands on the motor and the counterweight. Grid decks have the advantage of providing natural drainage and allow the waiting pedestrians to view through the deck while opened.
Steel is most often used as a counterweight due to shortage of space, as steel requires less volume than the more economical concrete, the density of which is a third of that of steel.

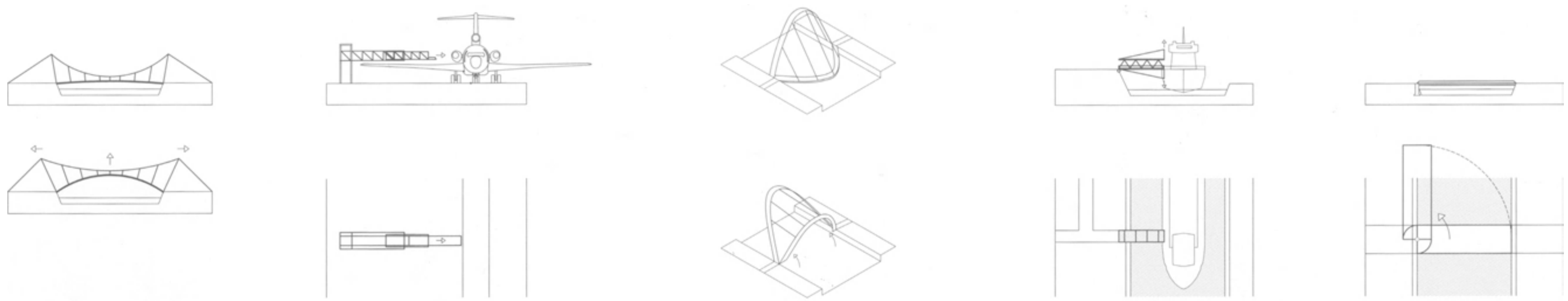
Design (Motor, Loads)

Moveable bridges must of course be designed for all strength and service requirements in all positions: open, closed, and in transition. Wind loading is often high on the structure while it is open. Swing and vertical transport bridges may be subject to live loads while in motion. The drive mechanism, locking mechanism and controls must be designed, as well as mechanical bearings or pulley ropes. These components are outside of the realm of experience for the designer of a fixed bridge. Dynamics, mechanical tolerances, and phenomena such as play and wear make the design of a moveable bridge a highly challenging experience.

Several drive mechanisms are often installed in large bridges: a main drive system, a supplementary drive system for rare cases of capacity overload, and a manual drive system for repairs and emergencies. Usually, the mechanism is designed only for the movement of the bridge, and is not loaded in the closed position when the bridge sits on fixed bearings. The locking devices also require a drive system. As mentioned for bascule bridges, changes in structural system occur during motion. For systems with two cantilevers meeting at the centre of the deck, pins may be used to transfer shear between cantilevers and avoid offset of the deck sections.

All early bridges were moved by hand. Hydraulic drive appeared in the beginning of the 19th century. Electric motors have been used since the beginning of the 20th century. Pneumatic or combustion engines are not known to be used. Hydraulic drives today work with oil pressure cylinders, as can be seen in bucket excavators. The hydraulic power unit can be safely sited on land in a machine room. The bridge merely houses the hydraulic cylinders and piping. Its motion is continuous and noiseless. A similar spatial separation between drive unit and motor is not possible for electrically driven systems. The electric drive unit is housed on the bridge and transfers power by cables, gears, belts, cog-rails or shafts. This allows a greater distance of motion. With an electric drive system, there is no danger of leakage in the

Arching Telescoping Tilting bascule Passenger bridge Swing bridge



hydraulic tubing. Precision landing of the deck is extremely difficult due to temperature expansion, wind and dynamic loading. The tolerances of the structure must be chosen generously enough to prevent jamming. At the same time, the bridge must be locked in the closed state so that there is no play, and to avoid impacts at the bearings leading to increased wear. A distinction must be made between *standing* and *floating* cables. By the regularly moved and dynamically loaded *floating* cables, fatigue leads to cable failure at loads well below the static breaking strength. The mechanical engineering standards require that cables be replaced according to service life, type and level of loading, diameter cable and bending radius.

There is a danger of the user becoming caught in the bridge or falling from the deck during opening and closing. It is for these reasons that owners and codes often require barriers, gates, and optical and audio warnings. These necessary elements can greatly affect the visual impact of the structure and must be taken into account at the earliest stages of design. It must also be determined who will operate the bridge. Boat captains may themselves disembark and operate smaller, seldom frequented bridges above canals. A bridge keeper is necessary in critical cases.

The planner and owner should consider allowing the contractor to optimize the drive system, and to invite tenders for the design of the mechanical system. This allows important details to be worked out together with a mechanical consultant in the construction documents phase. It must however clearly be laid out in the specifications that not only the mechanical aspects of the contracts be fulfilled but also the formal – optical and acoustic – requirements. In any case, with the multitude of challenges mentioned above, the structural engineer may quickly find his or her limits, and would be advised to invite a mechanical engineer into the design team. This previously rare cooperation opens up a great potential for innovation.

Fischer, Manfred, Stahlbau-Handbuch, Band 2, Stahlkonstruktionen, Köln, 1985

Dietz, Wilhelm, Der Brückenbau, Handbuch der Ingenieurwissenschaften, II. vol., 4. Abteilung Bewegliche Brücken. Leipzig, 1907

Schatz, Ulrike, Bewegliche Fußgängerbrücken, Diplomarbeit, Ilek, University of Stuttgart, September 2001

Schlaich, Mike et al., Guidelines for the design of footbridges, fib, fédération internationale du béton, bulletin 32, Lausanne, November 2005

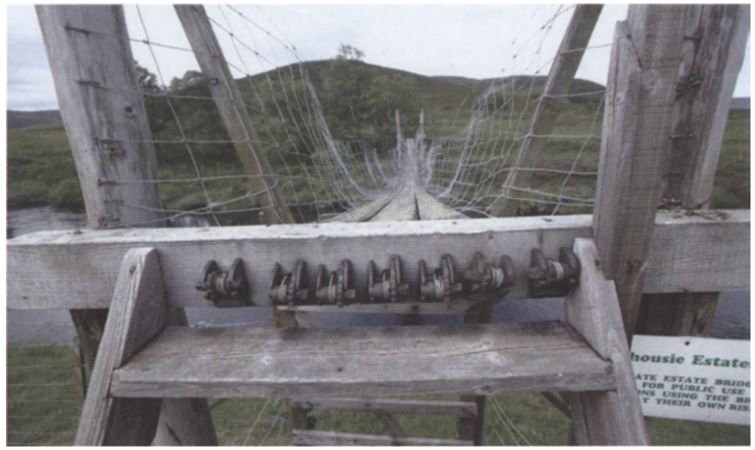
If this isn't nice, what is? *Kurt Vonnegut, Timequake*

Gardens, parks and landscapes remain the reserve of pedestrians, where motorized traffic has no place. But not all pedestrians are the same: strollers enjoy ambling along beautiful flowers, walkers escape the city, and hikers audaciously explore the most removed areas. Every now and again, a footbridge creates a moment of personal reflection. The demands on such structures could not be more different. Bridges in parks are seen as manmade ornaments that should theatrically emphasize the surrounding natural beauty – a tradition continuing since the 18th century. In an open landscape, more reserve is required to avoid dominating the surrounding environment. In high-altitude regions, the bridge plays a role of assistance to the experienced climber. One must be free from a fear of heights to cross a deep mountain canyon as the deck slats clatter under one's feet and a sole cable at chest height provides safety. As in many high alpine regions, this should only be recommended for experienced climbers.

Patent remedies should be avoided for bridges in beautiful natural environments -- just as for more urban structures. Every site wants to have its material, topographic and atmosphere qualities analysed and not have the spirit of the place degraded. All materials – timber, stone, concrete, steel, glass can be appropriate on their own or in combination. Every structural form wants to be accounted for -- in its pure form or as a hybrid. The erection of such structures far from traffic is generally spectacular, whether they are built using a cableway or a helicopter. The choice of materials can depend on what can be locally found and is therefore least expensive.

The seasonal change can more readily affect such structures. Some bridges are closed in the winter or placed in storage. It is therefore recommended to gather information on the structure before any bridge visit.

The detailing here also deserves notice



Bridge over the River Esk, Scotland, UK, 20th Century

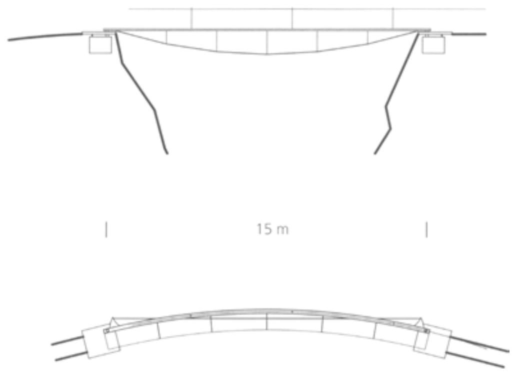
Trails off the beaten track, normally only visited by the occasional sheep, are a dime a dozen in England and Scotland. The River Esk is in a region that seems to have evaded building regulations. This small bridge is in an idyllic setting, which many nature lovers would defend against the intrusion of modern civilization or large numbers of tourists. How our photographer came across the structure in these surrounding is a mystery, and should stay one.

Simple, quickly constructed bridges are life-savers in areas subject to natural catastrophes. Toni Rüttimann, "Toni El Suizo", has dedicated the last 20 years to these structures. With the help of local workers, he has constructed more than 300 bridges with spans of up to 260 m in areas such as Ecuador and Cambodia. His suspension bridges are built almost completely with donated materials, such as tubes from pipelines given by oil drilling companies and recycled cables from Swiss cable cars.

Glass Bridge in a Private Garden near Nice, France, 2003

A 50 m high canyon was to be bridged on privately owned property in the Haute Provence. The structure was not to be more than just a line in the landscape; the English owner found his architect while reading a glass magazine. The structure was required to bridge 15 m in a zone very difficult to access. Architect Renate Fehling and engineer Johannes Liess thought of a footbridge in glass with a coherent form created with small, easy-to-transport elements. The result: a steel box section curved in a radius of 33 m, with a suspension structure below the deck that is in one line in the horizontal plan. Glass plates (830 x 2410 mm) cantilever out from the box section consisting of three panes of glass, one 20 mm TSG and two 12 mm HSG. Should the main pane fail, the two remaining ones would guarantee the stability of the structure. A simple stainless steel rod with a diameter of 16 mm serves as a railing. The theatrical approach to the delicate glass crossing is created with the roughly hewn stone surfacing at the abutments.

Structurally, the footbridge is a partially fixed, suspended torsional beam on two supports. The beam is stabilized be the spatial suspension system below the deck. The cantilevering beams cause a rotation in one direction and the suspension system creates rotation in the opposite direction. The construction of the abutments was difficult. The structural design was not carried out under the normal standards and codes, as it was considered an artwork rather than a bridge to support pedestrian traffic.


15 m

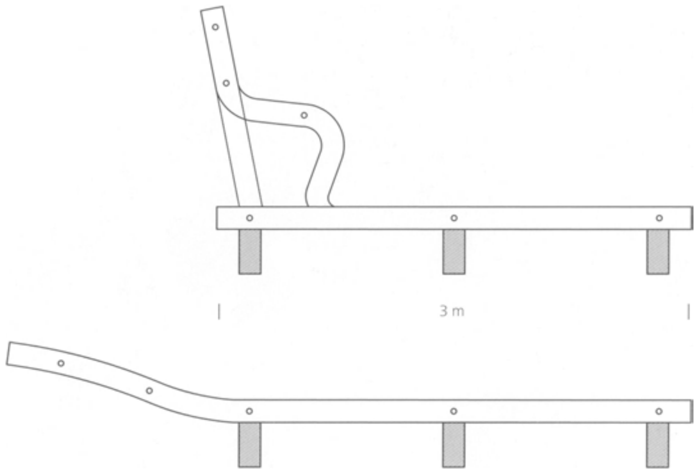
Bridge and park bench combined into one

Park Bridge in Baruth, Germany, 2004

The small Mark Brandenburg town Baruth lies about 50 km south of Berlin. The zu Solms family had Peter-Joseph Lenné build the park there in 1838. The family fled to South Africa from the Nazis, and since then the local farmers have suffered from land drainage and the Park has run to seed. In 2004, design competitions were held for five new 6 to 8 m long bridges on the site as part of a cultural project. The timber bridge showed here was the first of these structures.

The idea behind this wooden sculpture is surprisingly simple. Form and structure are not directly related to one another, as it seems to have been made from a lightweight formable foil pulled up from the deck. This form is created by rigid oak slats, making the structure very stable. The slats are created from 48 mm thick oak planks that were sawed using a template and fixed to the structure below with stainless steel bolts. Every tenth plank is anchored down. The wood has quickly taken on a silver-grey patina, but this change in colour does not affect its structural stability.

There is a wonderful view of the park from the seating area on the bridge. This structure signifies the beginning of small, draping park bridges that latch on to the tradition of Kew or Wörlitz with their theatricality and relation to nature.



Park Bridge in Sophienholm, Denmark, 1993

The Sophienholm Park north of Copenhagen plays a unique role in the history of Danish gardens. The park began in the 18th century as a romantic garden in the style of Ramée, but the park has had many owners since and has seen many changes. Sophienholm was built as the country seat of Theodor Holmskjold in 1769, and serves today as an exhibition hall for modern art. The artists Hein Heinsen and the architect Torben Schønherr created a new observation platform for the park in 1993. This small bridge was created as part of this expansion in cooperation with the engineer Erik Reitzel. It connects the main path with the observation platform, where one can enjoy a lovely view of the sea and observe a steel sculpture from many different angles.

The bridge has a spiral of more than 140°: all forces and tension, compression, shear, bending and torsion moments must be taken into account in the design. It is debatable whether the structure is a bridge or a stairway – as with Jürg Conzett's Second Traversiner Footbridge, we will classify it as a bridge.

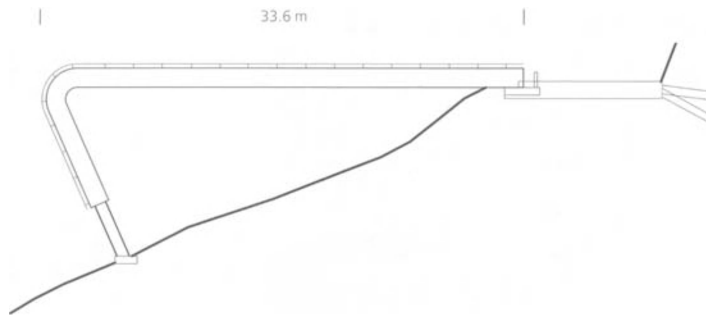
Takenouchi, Kyo, The Aesthetics of Danish Bridges, Kopenhagen, 1995

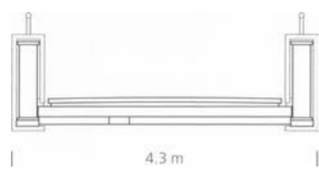
Ring girder and stairway in one – the bridging of the embankment protects the vegetation and sets the stairway in scene

Not a ski-jump, but rather a secure pathway to the observation point

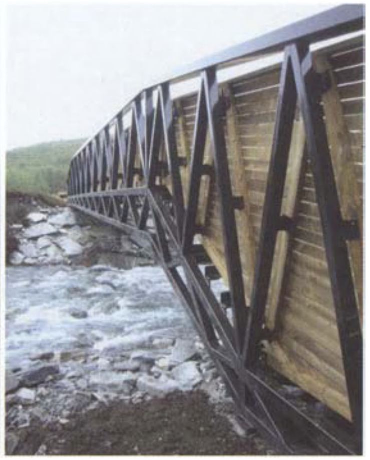
Observation Bridge in Aurland, Bergen, Norway, 2006

Visitors to the Grand Canyon are led around a horseshoe-shaped observation platform bridge cantilevering 22 m out above the canyon. It can be considered a failure in terms of efficient structural design, as it ignores the fundamentals of ring girder mechanics (as explained in the technical overview on p. 116). In Bergen in southwestern Norway, the number of tourists may not be comparable to the Grand Canyon, but the view of the fjords are simply terrific. Todd Saunders and Tommie Wilhelmsen won the competition for this observation platform 600 m above the Sognefjord. The 4 m wide footbridge leads 30 m out from solid ground and could not be more dramatic. The massive railings to the side give the user a sense of total security; but one may feel a sense of vertigo as the view straight ahead leads to a void. The sweep of the bridge is reminiscent of a ski jump, and the visitor has to recognize the barely noticeable glass barrier at the end before feeling safe and enjoying the view. The bravest visitors lean over the glass barrier and enjoy the view to the bottom. The structure is designed for heavy winds and a snow load of 7 m – Node Engineers from Bergen were the engineers.




4.3 m

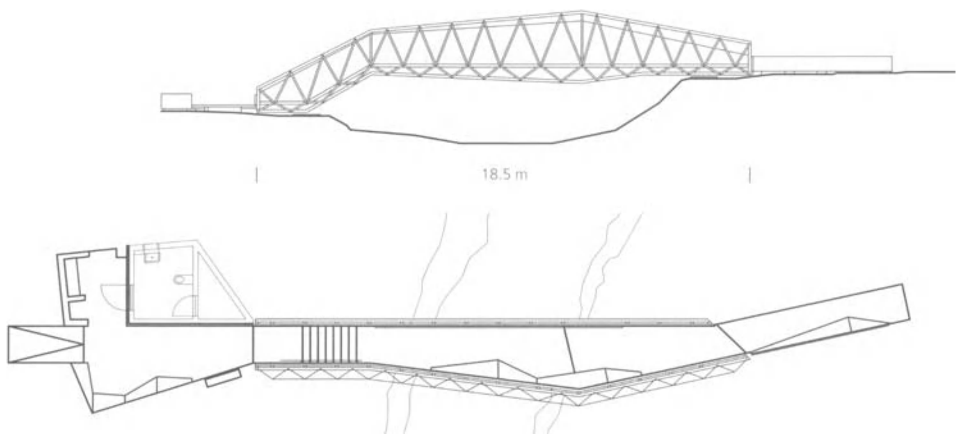
Steel truss with timber cladding

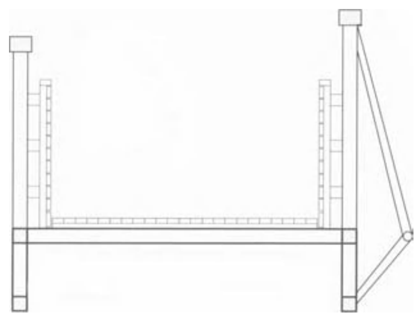


Resting Station in Lillefjord, Norway, 2006

The German expression for the saying "the grass is always greener on the other side" literally translates to "happiness always lies on the other side of the river". As if the there were not sufficient beauty on this side, the structure bridges a river not for a pure joy of hiking, but so that the visitors can reach an attractive waterfall. The park station is a combination of seating, bridge, toilets, litter bins and protective structure built by the Norwegian Highway Authority. Pushak arkitekter merged all of these elements into a complete structural sculpture, stretching over the water like a lizard. The building, bridge and seating banks seem as if they are product of one holistic model, even though the exterior steel truss dominates the visual image. The spatial unity is created as the wooden surface that covers the building and acts as cladding for the steel truss. The banks are not treated as furniture and are part of the bridge pathway. The depth of the rectangular steel tubes making up the steel truss varies between 80 and 260 cm.

It is striking that the separation between structure and envelope can be useful even for simple types of footbridges that appear to be a single structure.





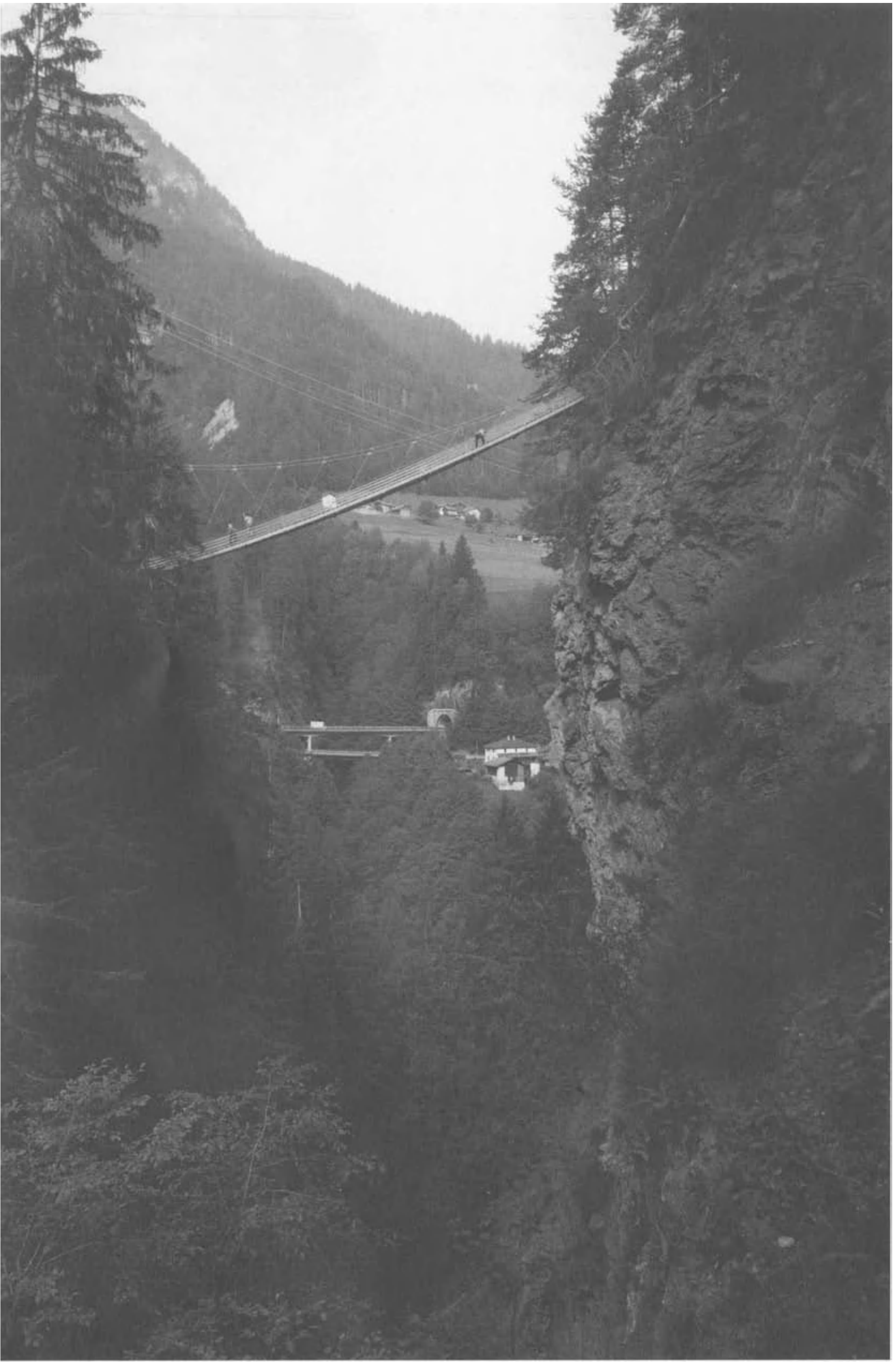
The end of the bridge can hardly be seen – the path leads to the unknown

Bridge in the protected landscape Maggia Valley, Switzerland, 1997

The Maggia Valley is still an insiders' tip for hikers – but you are no longer completely alone in this Swiss valley. The bridge in Giumaglio spans 230 m over the entire floodplain of the river, so that hikers do not disturb the environment below. The transparency of the structure is imperative, so as disturb the view through the valley as little disturbed as possible.

The inherently simple structure, by Fabio Torti | Andreotti & Partners, Locarno, was conceived in three sections each with a free span of 82.8 m. A long suspension bridge with a sufficiently braced walking surface, three thin cables as railing and handrails to protect pedestrians from the worst, and every now and again a bracing guy – that's it. This is precisely the allure of the bridge: it does not dress itself up in an attempt to compete with the beauty of the landscape. The bridge swings of course, so you can't be squeamish. Hopping and jumping create movement in the structure, but the bridge's flexibility makes it very stable.

The view downward steers one's attention to different sections of the floodplain. The structure is similar to the walkways above archaeological sites; it protects the natural surroundings while offering views of the beauty and complexity of the environment. One cannot see both ends of the bridge from any point of the deck, so that one idyllic surprise after another awaits the user.

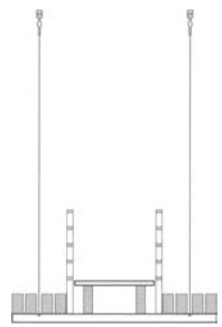


Second Traversiner Footbridge, Viamala, Switzerland, 2005

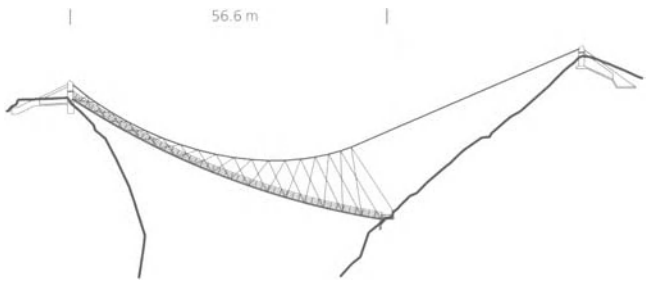
After the first Traversiner Footbridge was destroyed by a falling boulder (see p. 122) a second bridge was built only two years later with help of communal and private investment: the Viamala hiking trail is too beautiful to stop here. The new stairway bridge, with a free span of 56.6 m, connects the trail. The diagonal length of the bridge is 61.2 m and the main suspension cable is 95 m long.

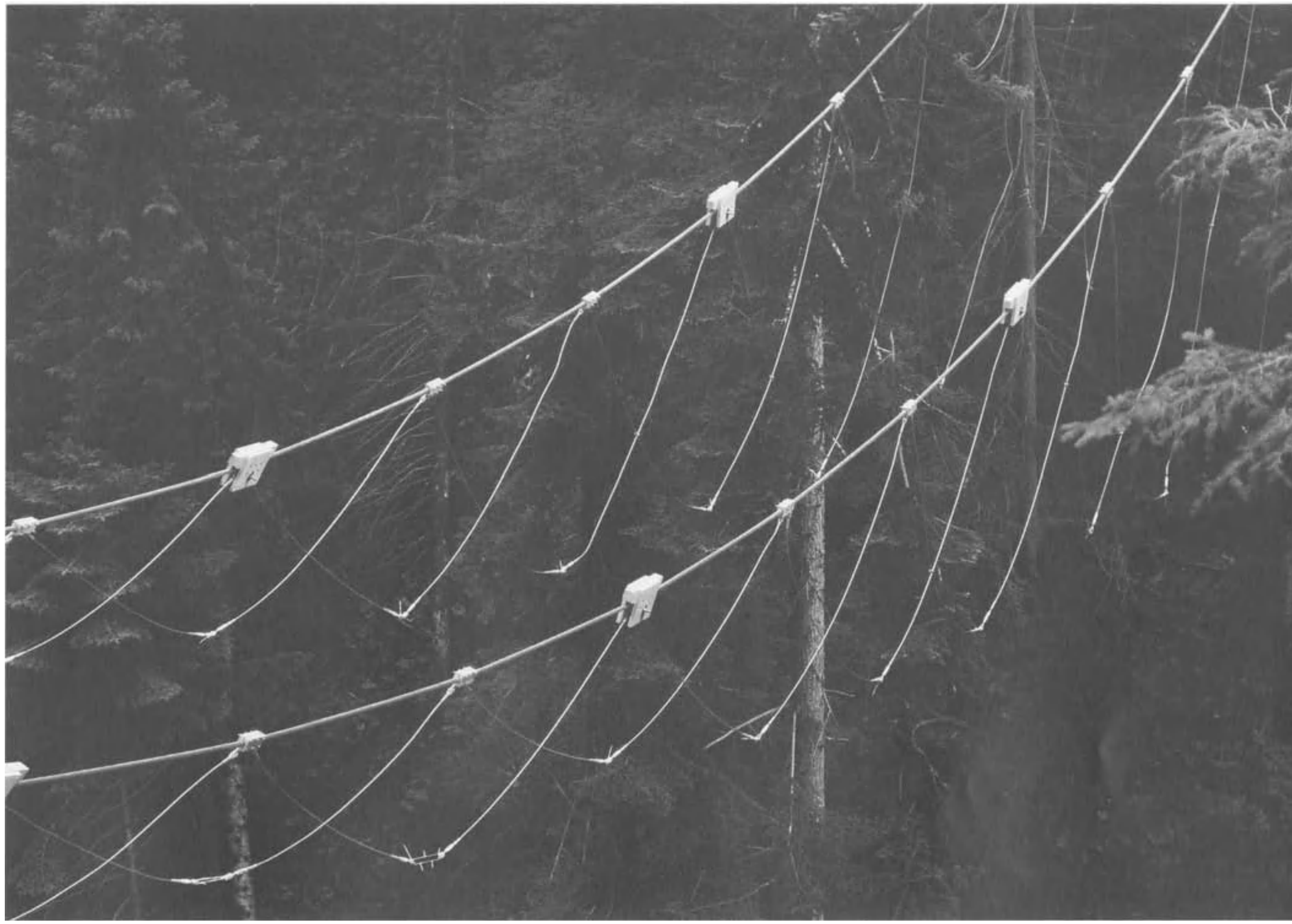
Inspired by the topography, the Jürg Conzett and Rolf Bachofner decided on a prestressed cable truss in two parallel and vertical planes. The challenge: the two cable anchorages are at different heights and the deck leads from a lower approach upwards to the opposite cliff. Diagonal cables are stressed between the main suspension cables and the deck. To find the form of the cable, the position of the cable clamps, and the length of the secondary cables, we require the help of graphic structural analysis and a Cremona diagram. Jürg Conzett is well versed in these matters, in the tradition of Swiss engineering. Erection procedures: a temporary cableway was constructed to transport concrete for the abutments, the cable and the prefabricated bridge deck segments from a forest trail to the construction site 50 m above. The lower abutment to the south was concreted first, after which the northern abutment was completed to serve as anchorages for the main suspension cables. The mass of the abutments, increased with soil ballast, works as a counterweight to the cable forces. A section of rock was used at the northern abutment to aid in anchoring the cables. The third abutment at the southern end of the bridge deck was only required to transfer vertical compression forces to the soil below.

The two main suspension cables (Galfan-coated spiral strand, d=36 mm diameter) are anchored in the abutments. A spelter socket is provided at each end of the cables, which are stressed with steel plates



Structure as Space, 2006, p. 100f.
Dechau, Wilfried, Traversinersteg. Fotografisches Tagebuch, Berlin/Tübingen, 2006





and shims to the abutment using hydraulic oil jacks. Two experienced cable experts carefully installed the cable clamps that join the diagonal cables (d=10 mm) to the suspension cables. Precision is required here, as any difference between calculated cable forces and site execution would change the final geometry. Transverse girders in steel, 3.6 m long, are suspended from the diagonal cables. Ten parallel laminated larchwood beams (140 x 220 mm) are laid longitudinally between the transverse girders. These beams provide sufficient stiffness to prevent unpleasant dynamic oscillations. The main cables are also prestressed to create additional compression forces in the wooden deck. Bracing from diagonal steel tension rods in conjunction with the wooden beams guarantee the lateral stiffening effects of the deck. Also noticeable in the section: two small beams are also bolted to the two inner laminated beams to serve as attachments for the stairs.

The position, height and design of the railings greatly affect the overall design of a footbridge of this scale. The handrail is at a height of only 1 m, but the compressed longitudinal girders at both edges of the deck block an immediate view of the depths below.

This is Jürg Conzett's third bridge in the Viamala – after the Punt da Suransuns and the Traversiner Footbridge I. The structures could hardly be more different; it is almost as if his command of so many structural systems is like that of a gifted linguist's command of seven languages. Most bridge designers stay true to one structural form throughout their career. This is not the case with Jürg Conzett, who has no fear of the spectacular. His readiness to study the complexity of seemingly simple challenge of a footbridge has, in the Viamala, led the design of a scarcely reproducible work of structural art.

It is good to collect things, but it is better to take walks. *Anatole France*

Nothing – no picture, no description – can replace personal observation. The abundance of footbridges we have been able to see in the last several years can no longer be stuffed between two book covers to invite you to visit. But we want to deprive the reader of as few of these beautiful bridges as possible. The bridges described here briefly have been selected subjectively – as has the rest of the book and are arranged alphabetically according to country, and then sorted by city name. The index of names and places on page 250 should ease the search for the structures and travel arrangements.




Ill Footbridge in Feldkirch, Vorarlberg
A, 1989

Engineer: Bollinger + Grohmann, Frankfurt
Architect: Martin Häusle, Feldkirch

Girder bridge from a spatial truss with a triangular section, lighting integrated into the handrail
Total length: 44 m
Maximum span: 36 m
Width: 4 m
Material: steel

Literature: Wettbewerbe, 90/91, pp. 41-44
Schmal, Peter C. (ed.), workflow: Struktur – Architektur, Basel, 2002, pp. 98-101
Kapfinger, Otto, Brücke über die Ill, in: Baukunst in Vorarlberg seit 1980. Ein Führer zu 260 sehenswerten Bauten, Ostfildern, 2003

Erich Edegger Footbridge in Graz
A, 1992

Pedestrian and cycle bridge over the Mur River between Schlossberg- and Mariahilferplatz
Engineer: Harald Egger, Übelbach
Architect: Domenig & Wallner, Graz

Simple girder with suspension system below deck and cantilevering ends, integrated lighting
Free span: 55.8 m
Width: 4.4 m
Material: steel, Railing: fully tempered glass with stainless steel handrails

Literature: Brichaut, Fiona, Graz, Erich Edegger Steg, in: Innovations in Steel. Bridges around the world, 1997, p. 13
Wells, Matthew and Hugh Pearman, 30 Brücken, Munich, 2002, pp. 104-107
Pearce, Martin, Bridge Builders, London, 2002, pp. 72-77

Mur Footbridge near Murau in Styria
A, 1995

Covered timber bridge between railway station and the city centre over the River Mur
Engineer: Conzett Bronzini Gartmann, Chur
Architect: Marcel Meili, Markus Peter Architekten, Zurich

Covered timber bridge with a central laminated timber
Total length: 89.3 m
Free span: 47.2 m
Width: 3.4 m
Material: spruce, larch

Literature: Schlaich, Mike (ed.), Mursteg Murau, Austria (1995), in: Guidelines for the design of footbridges, fib, Lausanne, November 2005, p. 115
Architektur Aktuell, 12, 1995
werk, bauen + wohnen, 12, 1995
Pearce, Martin, Bridge Builders, London, 2002
Mohsen, Mostafavi (ed.), Structure as Space, London, 2006, p. 70




Altfinstermünz Bridge in Nauders

A, 1472, destroyed 1875, rebuilt 1949

Bridge in the upper Inn valley, the temporary reconstruction lies 4 m higher than the original, a reconstruction of the original bridge was carried out in 1949

Two bridges with a central fortification tower, drawbridge to the left, and covered suspension bridge to the right
Total length: 37 m
Maximum span: Ostbrücke: 19 m
Maximum width: Ostbrücke: 3 m
Material: timber, Fortification tower: Masonry

Literature: Caramelle, Franz, Historische Brückenbauten in Nord- und Osttirol, in: Industriearchäologie Nord-, Ost-, Südtirol und Vorarlberg, Innsbruck, 1992, p. 82

Bridge over River Rosanna, Strengen

A, 1765

Bridge in the Stanzer Valley, originally used to connect farms on the right bank of the River Rosanna, renovated in 1975

Covered wooden bridge with double trapezoidal king post truss, constructed without iron connection elements with timber shingling at the western side
Total length: 18 m
Maximum span: 13.5 m
Width: 1.5 m
Material: timber

Literature: Caramelle, Franz, Historische Brückenbauten in Nord- und Osttirol, in: Industriearchäologie Nord-, Ost-, Südtirol und Vorarlberg, Innsbruck, 1992, p. 89
Mucha, Alois, Holzbrücken, Wiesbaden, 1995
Ziesel, Wolfdietrich, Dream Bridges/Traumbrücken, Vienna, 2004, pp. 132-141

Frödisch Bridge in Sulz, Vorarlberg

A, 1999

Bridge connecting the communities of Sulz and Zwischenwasser (Muntlix) for pedestrians and cyclists
Engineer: M + G Ingenieure, Feldkirch
Architect: Marte.Marte Architekten, Weiler

Steel trough bridge from steel plate, extension of an existing masonry bridge
Total length: 46 m
Free span: 41 m
Width: Pedestrian lane 2.3 m, Roadway 3.2 m
Material: weathering steel (Z shape from 30 mm thick plate), Railing: weathering steel (vertical plate of Z shaped profile serves as balustrade)

Zollamt Bridge in Vienna

A, 1900

Footbridge over a railway bridge and the Wienfluss
Engineer: Martin Paul, A. Biró
Architect: Josef Hackhofer, Friedrich Ohmann
Arch bridge
Free span: 31.3 m
Width: 7.6 m
Material: steel

Literature: Pauser, Alfred, Brücken in Wien. Ein Führer durch die Baugeschichte, Vienna/New York, 2005


Hackinger Footbridge in Vienna
A, 1994

Footbridge over multi-lane arterial road and the Wienfluss canal near the Hütteldorf tram station. The structure bridges the Wienfluss canal and connects the 13th and 14th districts in Vienna.
Engineer: Wolfdietrich Ziesel, Vienna
Architect: Henke-Schreieck Architekten, Vienna

Lightweight steel structure, mostly tension-loaded members
Total length: 64 m
Maximum span: 26 m
Width: 4.5 m
Material: steel, glass

Literature: Ziesel, Wolfdietrich, Dream Bridges/Traumbrücken, Vienna, 2004, pp. 142-155

Erdberger Footbridge in Vienna
A, 2003

Bridge over the Danube Canal near the Erdberger Lände
Engineer: Alfred Pauser, Vienna
Architect: Zeininger Architekten, Vienna

Frame structure from individual compression and tension elements
Total length: 85 m
Maximum span: 53 m
Width: 3.7 m
Material: timber

Literature: Steinmetz, Mark, Architektur neues Wien, Berlin, 2000


Bridge over the Ourthe in Hotton
B, 2003

Bridge between Hotton Island and the city centre
Engineer: Ney & Partners, Brussels
Architect: Ziane, Liège

Shallow arch bridge
Total length: 30 m
Free span: 26 m
Width: bridge deck: 2 m
Material: Arch: steel, Deck girder: steel grid

Literature: Concours Construction Acier 2004, in: Staal-Acier, 5, 2004, p. 200

Bridge in Woluwé Saint-Pierre
B, 2002

Footbridge over the Avenue de Tervuren
Engineer: Ney & Partners, Brussels
Architect: Pierre Blondel, Brussels

Deck arch bridge with the deck integrated to the side of the arch, walkable arch, asymmetric cross section
Free span: 70 m
Width: 2 x 3 m
Material: steel, Surfacing: timber

Literature: Moritz, Benoît, Passerelle Avenue de Tervuren. Woluwé Saint Pierre, in: A+, 1, 2002, pp. 74-75
Concours Construction Acier 2002, in: Staal-Acier, 2002, p. 198

Footbridge in Basel-Birsigtal

CH, 1865

Footbridge in the Birsig valley under the Doren bach Viaduct, one of the oldest remaining steel footbridges in Switzerland

Lattice structure
Material: iron

Literature: Federal Roads Office (pub.), Historische Verkehrswege, Bern, 2004, p. 6

Chapel Bridge in Lucerne

CH, c. 1365

Bridge in the city centre of Lucerne, originally part of the city fortification

Covered frame girder, major fire in 1993, rebuilt according to original design
Total length: originally 285 m, shortened several times in the 19th century to 202 m
Maximum span: 9.3 m
Width: 3.2 m
Material: Piers: sandstone, Frame and longitudinal girders: oak, Roof: silver fir and spruce

Literature: Pantli, Heinz, Kapellbrücke und Wasserturm, in: Denkmalpflege im Kanton Luzern 1994, Jahrbuch der Historischen Gesellschaft Luzern, 1995, pp. 70-74
Flury-Rova, Moritz et al., Kapellbrücke und Wasserturm. Der Wiederaufbau eines Wahrzeichens im Spiegel der Restaurierung und Forschung, Lucerne, 1998
Graf, Bernhard, Of Swiss Heroic Deeds. The Kapell Bridge in Lucerne, in: Bridges that Changed the World, München, 2002, pp. 34-35

Bhutan Bridge near Ovronnaz

CH, 2005

Bridge over the Illgraben between upper and lower Valais, entrance to Pfynwald nature reserve

Suspended deck structure modelled after Bhutanese bridges
Free span: 134 m
Width: 1 m
Material: steel, Deck: timber,
Abutment: concrete

Fibre-reinforced Plastic Footbridge in Pontresina

CH, 1997

Footbridge over the River Flaz
Engineer: Otto Künzle, Zurich

Truss bridge, with bolted connections at one span and glued connections at the adjacent span
Total length: 25 m
Moveable section: 2 x 12.5 m
Width: 1.9 m
Material: fibre-reinforced plastic

Literature: Keller, Thomas and Otto Künzle, Urs Wyss, Fußgängerbrücke Pontresina in GFK, in: SI+A Schweizer Ingenieur und Architekt, 12, 1998
Keller, Thomas, Towards Structural Forms for Composite Fibre Materials, in: Structural Engineering International, vol. 9, November 1999, pp. 297-300

Ganggelibrugg in St. Gallen

CH, 1882

Footbridge in Rechen, earlier footbridges continually destroyed by flooding, renovated in 1925 and 1936

Suspension bridge
Free span: 65.7 m
Width: 1.2 m
Material: iron

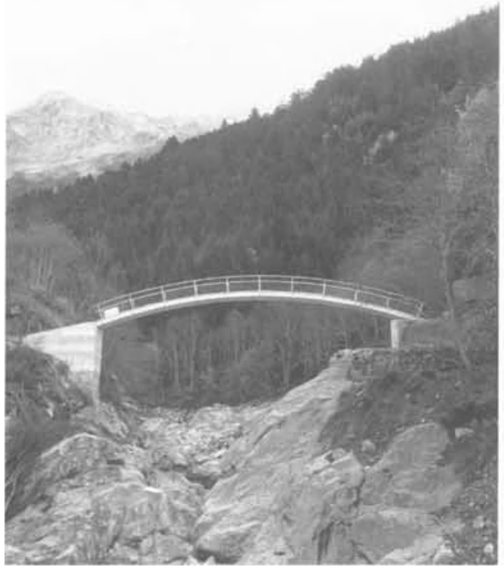
Literature: Stadelmann, Werner, St. Galler Brücken, St. Gallen, 1987, pp. 46-47

Ruinaulta Bridge in Trin

CH, planned 2007

Footbridge over the Rhine gorge connecting the Trin railway station with the Ruinaulta Natural Monument
Engineer: Walter Bieler, Bonaduz

Suspension bridge, deck as a horizontal vierendeel girder
Total length: 98 m
Maximum span: 74 m
Width: 1.5 m
Material: Pylon and Cables: steel, Bridge deck and handrail: larch



Passerelle SOJ, Val Soj in Ticino

CH, 2006

Wooden bridge over the Soja River in Bleniotal, replaces a metallic structure that was destroyed during flooding in August 2003
Engineer: Laube, Biasca
Architect: Martin Hügli, Iragna

Compression arch to minimize forces and costs, five arches lying one over another
Free span: 22 m
Width: 1.2 m
Material: laminated timber, Surfacing: laminated timber plate surfaced with bitumen, Abutment: concrete

Literature: Lignum (pub.), 18 Ingenieurholzbauten, Zurich, February 2007, pp. 20-21
Hügli, Martin, Einfacher geht Brückenbau wohl nicht mehr, in: bauen mit holz, 5, 2007, pp. 18-21
Schweizer Holzbau 7, 2007

Milk Bridge in Vals Platz

CH, planned 2008

Moveable bridge over the Valser Rhine in the centre of Vals Platz
Engineer: Conzett Bronzini Gartmann, Chur

Simple girder with a box section, bridge can be lifted during flooding, structure works as a frame
Total length: 23 m
Free span: 21 m
Width: 1.1 m
Material: steel

Expo-Bridge in Yverdon-les-Bains

CH, 2002

Two parallel bridge to the Swiss regional exhibition Expo 2002
Engineer: Staubli, Kurath & Partner, Zürich and Swissfiber, Zürich
Architect: Diller Scofidio + Renfro, New York

Continuous girder, all members translucent
Total length: 2 x 120 m
Free span: 12 m
Width: 2.5 m
Material: fibreglass, Piers: steel: Railing: translucent, lit from below

Literature: Der Wolkensteg, in: Fiberglas, supplement to Hochparterre 4, 2004, Zurich, p. 21
Entwicklungen im Bereich Faserkunststoffe im Bauwesen an der Zürcher Hochschule in Winterthur, in: Der Bauingenieur, 12, 2005

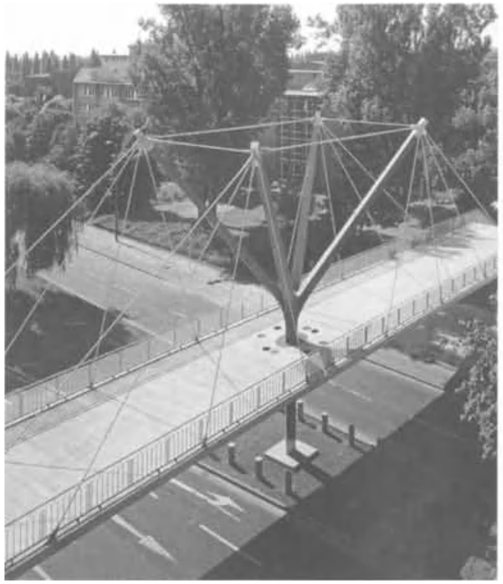
Bridge over the Vltava in Prague-Troja

CZ, 1986

The stress ribbon bridge connects the Prague Zoo and the Stromovka Park
Engineer: Jiri Strasky, Prague

Total length: 249 m
Maximum span: 96 m
Width: 3.8 m
Material: concrete

Literature: Strasky, Jiri, Stress ribbon and cable-supported pedestrian bridges, London, 2005, p. 76



Bridge in Bad Homburg von der Höhe
D, 2002

Urban footbridge above the Hessenring highway
Engineer: Schlaich Bergermann und Partner, Stuttgart

Cable-stayed bridge with stone mast, deck plate suspended by 16 tension rods
Total length: 76 m
Free span: 46 m
width: 6.9 m
Material: Mast: Nero Assoluto, an igneous rock Gabbro

Literature: Russell, Lisa, Footbridge Awards 2005, in: Bridge Design and Engineering, vol. 11, 41, 2005

Bridge over the A5 highway near Baden-Baden
D, 1996

Pedestrian and cycle bridge
Engineer: Ingenieurgruppe Bauen, Karlsruhe

Simple girder, fabricated next to the autobahn, lifted into place during a 30-minute break in traffic
Free span: 40 m
Material: steel

Footbridge in Bensheim
D, 2006

Pedestrian and cycle bridge over the Highways 3 and 47 conneting the southern city centre with the western section of the city
Engineer: Schlaich Bergermann und Partner, Stuttgart
Architect: Heinz Frassine, Bensheim

Arch bridge with column-supported ramp
Free span: 30.3 m
Width: 2.5 m
Material: Arch: steel, Deck girder: reinforced concrete

Gericke Footbridge in Berlin-Mitte
D, 1915, 1949

Footbridge at the tram station Bellevue over the Spree River, originally called *Bellevue Footbridge*
Engineer: Bruno Möhring

Longitudinal system: Frame with two articulations serving as an arch system with suspended deck; Transverse system: Girder grid with reinforced concrete plate
Total length: 56.8 m
Free span: 52 m
Width: 5 m
Material: Superstructure: steel,
Surfacing: mastic asphalt, Abutment: concrete with limestone

Literature: Senator für Bau- und Wohnungswesen (pub.), Gerickesteg über die Spree, in: Fußgängerbrücken in Berlin, Berlin, 1976, pp. 24-25




Abtei Bridge in Berlin-Treptow

D, 1916

Footbridge over the southern tributary of the Spree connecting Treptow Park with Abtei Island
Engineer: Städtisches Verkehrsbauamt Neukölln

Deck arch bridge, arch built between two tower structures
Total length: 100 m
Free span: 75.7 m
Width: 3.8 m
Material: reinforced concrete,
Reinforcement: wrapped cast orin tubes

Gotenburg Footbridge, Berlin-Wedding

D, 1957

Bridge over the Panke forming an extension of the Gotenburger road, connecting the park areas at each riverbank

Simple composite girder, sinusoidal guardrail filling
Total length: 16.1 m
Free span: 15 m
Width: 2.8 m
Material: steel, reinforced concrete, Surfacing: mastic asphalt, Railing: steel

Literature: Senator für Bau- und Wohnungswesen (pub.), Elsensteg in Neukölln, in: Fußgängerbrücken in Berlin, Berlin, 1976, pp. 34-35

Nordpol Bridge in Bochum-Hamme

D, 1999

Footbridge at the entrance to the Westpark in Bochum
Engineer: Bollinger + Grohmann, Frankfurt
Architect: Hegger Hegger Schleiff Planer + Architekten, Kassel

Lying truss girder, diagonal tubes as bracing, interactive lighting system
Free span: 100 m
Width: 2.2 m to 3.8 m
Material: Superstructure and Piers: steel, Surface: grating, Railing: cantilevering fully tempered glass

Literature: Schmal, Peter C. (ed.), workflow: Struktur – Architektur, Basel, 2002, pp. 142-145

Murkenbach Bridge in Böblingen

D, 1995

Footbridge in the city park
Engineer: Decker Ingenieur-Gesellschaft, Böblingen
Architect: Janson + Wolfrum/Architektur + Stadtplanung, Munich

Simple girder with platform
Total length: 14.8 m
Free span: 13.5 m
Width: 2.8 m
Material: laminated timber from larch planks on steel cross beams

Literature: Janson, Alban and Sophie Wolfrum, Garten und Landschaft, 7, 1996, p. 41f.

Bridge in Brandenburg an der Havel

D, 2001

Footbridge over the Jacobsgraben canal
Engineer: Ingenieurgemeinschaft Härtel & Schiermeyer, Bad Oeynhausen
Landscape architect: Uwe Tietze & Partner, Berlin

Simple girder
Total length: 24.2 m
Free span: 22.5 m
Width: 2.9 m
Material: Structural members and railing: hot dip galvanized steel, Surfacing: Bongossi timber

Port Bridge Vegesack in Bremen

D, 2000

Pedestrian bascule bridge between Alt-Vegesack and the newly built Areal Haven Höft
Engineer: Arup, Düsseldorf
Designer: Designlabor Bremerhaven, Bremerhaven

Closed bridge works as a continuous girder. Bascule motion uses the elbow lever technique, integrated lighting
Total length: 42 m
Width: 3.5 m to 7 m
Material: steel, concrete, Deck surface: perforated stainless steel plate

Zoo Bridge in Dessau

D, 2001

Bridge over the River Mulde, connecting the city centre with the zoo
Engineer: Stefan Polónyi & Partner, Cologne
Architect: Kister Scheithauer Gross, Cologne

Tubular arch with suspended curved deck girder
Total length: 133 m
Free span: 111.3 m
Width: 2.8 m
Material: steel

Literature: Bundesingenieurkammer (pub.), Ingenieurbaukunst in Deutschland. Jahrbuch 2003/2004, Hamburg, 2003, pp. 102-104

Footbridge in Duisburg

D, 1958

Cable-stayed bridge for the world expostion 1958 in Brussels, transported after the exposition to the Duisburg Zoo, currently connecting the University campus with the Mühlheimer Forest
Architect: Egon Eiermann, Sep Ruf

Unilaterally supported deck with a single asymmetric mast.
Total length: 65 m
Maximum span: 43.5 m
Width: 4 m to 4.4 m
Material: Deck and abutment: reinforced concrete, Mast, cables and railing: steel

Literature: Walther, René, Schrägseilbrücken, Lausanne/Düsseldorf, 1994, pp. 154, 157

Essinger Bridge, Essing, Altmühl Valley

D, 1986

Footbridge over the Main-Danube Canal
Engineer: Ingenieurbüro Brüninghoff und Rampf, Ulm
Architect: Büro für Ingenieur-Architektur Richard J. Dietrich, Traunstein

Timber stress ribbon bridge
Total length: 190 m
Maximum span: 73 m
Width: 3.1 m
Material: timber, Railing: larch timber with Niro-steel guardrail filling

Literature: Brüninghoff, Heinz, The Essing Timber Bridge, Germany, in: Structural Engineering International, vol. 3, Mai 1993
Dietrich, Richard J., Faszination Brücken, Munich, 1998, pp. 206-213
Wells, Matthew and Hugh Pearman, 30 Brücken, Munich, 2002, pp. 140-143

Iron Bridge in Frankfurt

D, 1869, 1946

Footbridge over the River Main

Truss bridge
Total length: 173.6 m
Maximum span: 82.5 m
Width: 5.4 m
Material: steel

Literature: Gorr, Wolfram, Frankfurter Brücken. Schleusen, Fähren, Tunnels und Brücken des Main, Frankfurt, 1982, pp. 115-138
Mäckler, Christoph, Frankfurter Brücken, in: Jahrbuch für Architektur 1984. Das neue Frankfurt II, Berlin, 1984, pp.61-98
Möll, Reiner, Altstahlschweißen und Nieten im Zuge der Grunderneuerung des "Eisernen Steges" in Frankfurt am Main, in: Der Stahlbau, vol. 66, January 1997, pp. 1-11

Holbein Footbridge in Frankfurt

D, 1990

Footbridge between city centre and the Sachsenhäuser Museum bank
Engineer: König und Heunisch Planungsgesellschaft, Frankfurt
Architect: Albert Speer & Partner, Frankfurt

Suspension bridge, staged lighting
Total length: 214 m
Maximum span: 142 m
Width: 2.4 m
Material: steel

Literature: Christian Bartenbach, Umlenk- und Spiegelwerftechnik: Hohlbeinsteg, in: Werk, Bauen + Wohnen, Oktober 1994
Setzepfandt, Wolf-Christian, Architekturführer Frankfurt am Main, Berlin, 2002, p. 85

Serie of bridges in Hamburg

D, Project

Footbridges between Willy-Brandt-Straße and the Zoll Canal
Engineer: Werner Sobek Ingenieure, Stuttgart
Architect: Jan Störmer Partner, Hamburg

Continuous box girder, 30 round columns are continued above the deck providing bridge lighting.
Total length: 200 m
Maximum span: 40 m
Width: 2.3 m to 4.2 m
Material: steel

Skywalk in Hanover

D, 1998

Pedestrian walkway between Laatzen railway station and the Expo 2000 grounds
Engineer: RFR Ingenieure, Stuttgart
Architect: Schulitz + Partner Architekten, Braunschweig

Double tube with one storey-high structure
Total length: 338.4 m
Maximum span: 28 m
Width: 8.8 m
Material: steel, Facade: bent glass

Literature: Karl J. Habermann and Helmut C. Schulitz, Werner Sobek, Stahlbau Atlas, Munich, 1999, pp. 225, 336-339
Meyer, Lür, Freakshow. Die Architektur der Expo, in: db deutsche bauzeitung, 6, 2000, pp. 60-69
Pearce, Martin, Bridge Builders, London, 2002, pp. 150-153

Expo Bridges in Hanover

D, 2000

Four bridges on the Hanover Expo grounds
Engineer: Schlaich Bergermann und Partner, Stuttgart
Architect: Gerkan Marg & Partner, Hamburg

Cable-stayed bridges, all bridges on a grid of 7.5 m x 7.5 m
Greatest total length: Eastern bridge 135 m
Greatest span: Southern bridge 45 m
Greatest width: Central bridge 45 m
Material: steel, cast steel, Deck plate: permanent plate in reinforced concrete, temporary plate from surfaced larch timber planks

Literature: Torres Arcila, Martha, Bridges – Ponts – Brücken, Mexico City, 2002, pp. 472-481
Cruvelier, Mark, Footbridges of the world's fairs, in: Footbridge 2002, Paris, pp. 104-105

Nesse Bridge in Leer

D, 2006

Bridge over the trade port connecting the historic city centre and pedestrian zone with the newly constructed Nesse grounds
Engineer: Schlaich Bergermann und Partner, Stuttgart

Cable-stayed bridge with bascule centre, deck bent in plan
Total length: 82 m
Length of the bascule section: 2 x 7 m
Width: 3 m to 5 m
Material: Bascule section: steel, Deck girder: composite, Abutment: reinforced concrete

Börstel Bridge in Löhne

D, 2000

Pedestrian and cycle bridge over the River Werre
Engineer: Schlaich Bergermann und Partner, Stuttgart
Architect: Claus Bury, Frankfurt

Stress ribbon bridge with concrete arch
Total length: 96 m
Maximum span: 35 m
Width: 3.5 m
Material: Arch: reinforced concrete, Deck: prestressed concrete

Footbridge in Minden

D, 1994

Pedestrian and cycle bridge over the River Weser
Engineer: Schlaich Bergermann und Partner, Stuttgart

Suspension bridge with reinforced concrete deck plate, inclined masts
Span: around 105 m
Width: 3.6 m
Material: steel

Literature: Pearce, Martin, Bridge Builders, London, 2002, pp. 174-177
Torres Arcila, Martha, Bridges – Ponts – Brücken, Mexico City, 2002, pp. 438-441

Footbridge in Munich

D, 1985

Footbridge over the Mittlerer Ring
Engineer: Ingenieurbüro Suess und Staller, Gräfelfing
Architect: Büro für Ingenieur-Architektur Richard J. Dietrich, Traunstein

Spatial cable suspension, suspension structure from triangular cross section
Free span: 69 m
Width: 3.5 m
Material: Superstructure, cables: steel

Literatur: Detail, 5, 1987
Dietrich, Richard J., Faszination Brücken, Munich, 1998, pp. 214-219
Stahl-Informations-Zentrum (pub.), Hängeseilbrücke in München, Deutschland (1985), in: Dokumentation 577. Fußgängerbrücken aus Stahl, Düsseldorf, 2004, p. 24

Bridge to the Wiesn grounds, Munich

D, 2005

Pedestrian and cycle bridge over the Bayerstrasse
Engineer: Christoph Ackermann Beratendes Ingenieurbüro für Bauwesen, Munich
Architect: Ackermann und Partner Architekten, Munich

Hybrid polygonal arch bridge
Free span: 38 m
Width: 4 m
Material: steel, high-strength steel

Literature: Brückenbauen mit neuen Werkstoffen: Die Fußgängerbrücke über die Bayerstraße in München, in: Stahlbau, October 2005, pp. 729-734
Packer, Jeffrey A. and Silke Willibald (eds), Tubular Structures XI, London, 2006

Footbridge in Oschatz

D, 2006

Bridge over the River Döllnitz, state botanical exposition 2006
Engineer: Silvio Weiland and Dirk Jesse, Technical University Dresden

Bridge consisting of ten U-spaced prefabricated concrete segments, each receiving six prestressed steel tendons
Total length: 9.1 m
Free span: 8.6 m
Width: 2.5 m
Depth: deck plate and sides: 3 cm
Material: concrete with textile fibre reinforcement

Literature: Curbach, Manfred and Silvio Weiland, Fertigteilbrücke für die Landesgartenschau 2006 in Oschatz aus textilbewehrtem Beton, in: BFT, vol. 70, 2, 2004, pp. 102-103

Ladenberg Bridge in Potsdam
D, 2001

Bridge over a portion of a newly dug city canal in the centre of Potsdam
Engineer: Fichtner + Köppl, Rosenheim
Architect: Büro für Ingenieur-Architektur Richard J. Dietrich, Traunstein

Simple girder, series of steel girders with lenticular suspension system
Free span: 13 m
Width: 3 m
Material: steel, Surfacing: timber

Literature: Dietrich, Richard J., Faszination Brücken, Munich, 1998, pp. 266-267
Dietrich, Richard J., Eine neue Brücke in Potsdam, in: Umrisse – Zeitschrift für Baukultur, 2, 2001, p. 42

Dragon's Tail Bridge in Ronneburg
D, 2006

Pedestrian and cycle bridge over the Gessental River near Ronneburg/Gera for the federal botanical exposition 2007
Engineer: Fichtner + Köppl, Rosenheim
Architect: Büro für Ingenieur-Architektur Richard J. Dietrich, Traunstein

Timber stress ribbon bridge with three spans
Total length: 235 m
Maximum span: 65 m
Width: 2.5 m to 3.8 m
Material: Stress ribbon: laminated timber blocks, Piers: steel tubes, Substructure: concrete

Literature: Keim, Mario, Brückenbau mit Sinn für gestalterische Qualität, in: VDI-Nachrichten, 10 November 2006
Werner, Hartmut, Längstes Spannband Europas, in: bauen mit holz, 11, 2006, pp. 6-11

Mahlbusen Bridge in Rostock
D, 2002

Pair of steel bridges for the International Botanical Exposition 2003
Engineer: Schlaich Bergermann und Partner, Stuttgart
Landscape architect: WES & Partner Landschaftsarchitekten, Hamburg

Continuous beam girder bridge with two main girders, steel girder bridge
Total length: 35.5 m and 48 m
Maximum span: 25.5 m and 2 x 24 m
Width: 4.4 m
Material: steel, concrete

Literature: Dechau, Wilfried, Die IGA in Rostock, in: db deutsche bauzeitung, 8, 2003, p. 24
Schlaich, Mike, Die Fußgängerbrücken auf der Internationalen Gartenausstellung IGA 2003 in Rostock, in: Bauingenieur, 10, 2003, p. 441

Stieber Valley Bridge in Roth
D, 2002

The bridge creates the shortest possible connection between the railway station and the city centre
Engineer: Grad Ingenieurplanungen, Ingolstadt
Architect: Vogel + Partner, Munich

Integral steel box girder fixed to abutments, deflects laterally under temperature loads.
Total length: 170 m
Maximum span: 36 m
Width: 3 m
Material: mechanically galvanized and coated steel

Literature: Habermann, Karl J., Schrägseilbrücke in Roth, in: db deutsche bauzeitung, 5, 2003, pp. 54-61
Grad, Johann, Stiebertalbrücke in Roth/Bayern, in: Stahlbau, 12, 2003, pp. 868-871

Bridge in Schnaittach

D, 2002

Entrance bridge to Rotenburg Castle
Engineer: Ingenieur-Büro Ludwig Viezens, Eckental

Girder bridge with transverse frame for railings, historic structures are reflected in modern timber construction
Total length: 24.4 m
Width: 3.6 m
Material: Superstructure and substructure: laminated larch timber, steel, Foundation: reinforced concrete

Literature: Viezens, Ludwig, Brückenschlag zur Festung, in: bauen mit holz, 12, 2002, pp. 17-20

Queen Mary's Bridge near Schwangau

D, 1866, restored 1978

Bridge over the Pöllat's Canyon with a view of Neuschwanstein
Engineer: Heinrich Gerber (1832-1912)

Rivets steel truss, the original timber footbridge was replaced in 1866 by a freely spanning iron structure, railings are original
Free span: 34.9 m
Material: iron, Surfacing: timber

Tower Bridge in Singen am Hohentwiel

D, 2000

Footbridge for the State Botanical Exposition, connects two portions of the city park
Engineer: Baustatik Relling, Singen
Landscape architect: Michael Palm, Weinheim

Covered timber truss bridge with stairway tower as continuous girder on three supports with a cantilever, prefabricated in the workshop in two segments
Total length: 43.5 m
Free span: 28.2 m
Width: 2.2 m
Material: timber

Literature: Fußgängerbrücke in Singen, in: Detail, 3, 2001, pp. 446-449
Gedeckte Fachwerkbrücke mit Turm, in: bauen mit holz, November 2000, pp. 12-14

Pragsattel I and II in Stuttgart-Nord

D, 1992

Bridges for the International Botanical Exposition 1993 over the Heilbronner Straße
Engineer: Schlaich Bergermann und Partner, Stuttgart
Architect: Planungsgruppe Luz, Lohrer, Egenhofer, Schlaich, Stuttgart

Bridge I:
Concrete footbridge supported by steel tube arch, branching steel piers
Free span: 52 m
Width: 4.5 m
Material: steel, concrete

Bridge II:
Branching column bridge
Total length: 83.9 m
Width: 4 m
Material: steel, concrete

Footbridge in Stuttgart-Vaihingen

D, 1992

Footbridge over the Allmandring on the University of Stuttgart campus
Engineer: Ingenieurbüro Lachenmann, Vaihingen an der Enz
Architect: Kaag + Schwarz, Stuttgart

Cable-tensioned polygonal arch bridge, eleven bridge segments with articulated connections
Free span: 34 m
Width: 3.2 m
Material: steel

Literature: Kaag, Werner and Rudolf Schwarz, Fußgängersteg in Stuttgart, in: archplus, 118, 1993, p. 33
Kaag, Werner and Gustl Lachenmann, Fußgängersteg in Stuttgart-Vaihingen, in: archplus, 124/125, 1994, p. 70
Lachenmann, Gustl, Fußgängersteg über den Allmandring in Stuttgart/Vaihingen, in: Stahlbau, 11, 1994, pp. 337-342
Kaag, Werner and Rudolf Schwarz, Fußgängersteg in Stuttgart, in: Detail, 8, 1999, pp. 1459-1461
Schlaich, Jörg and Matthias Schüller, IngenieurbauFührer Baden-Württemberg, Berlin, 1999, pp. 196-197
Wells, Matthew and Hugh Pearman, 30 Brücken, München, 2002, pp. 108-111

Heilbronner Straße Bridge in Stuttgart

D, 1992

Bridge for the International Botanical Exposition 1993 near Nordbahnhof
Engineer: Schlaich Bergermann und Partner, Stuttgart
Architect: Planungsgruppe Luz, Lohrer, Egenhofer, Schlaich, Stuttgart

Back- and self-anchored suspension bridge
Total length: 125 m/130 m
Width: 5 m
Material: steel, concrete

Literature: Schlaich, Jörg and Matthias Schüller, IngenieurbauFührer Baden-Württemberg, Berlin, 1999, pp. 190-191

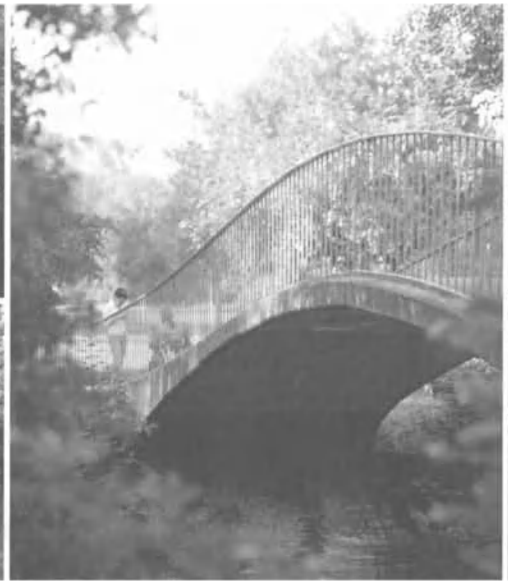
Footbridge in Stuttgart-Pragstraße

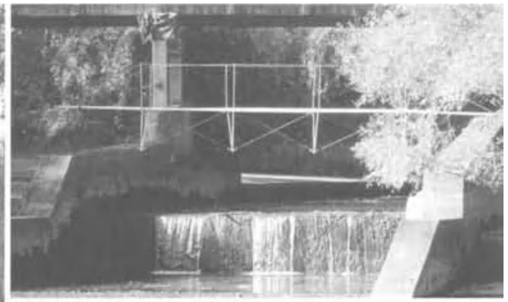
D, 1992

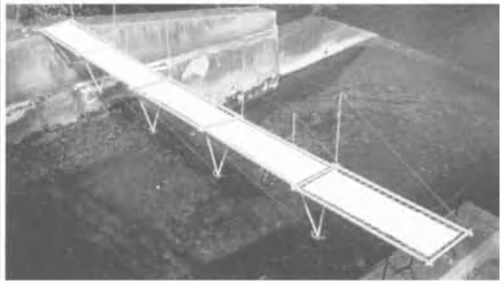
Cablenet Footbridge for the International Botanical Exposition 1993
Engineer: Schlaich Bergermann und Partner, Stuttgart
Architect: Planungsgruppe Luz, Lohrer, Egenhofer, Schlaich, Stuttgart

Cablenet footbridge, an inversely arranged cablenet supports the footbridge
Free span: ca. 75 m
Width: 3.1 m
Material: Cablenet: steel

Literature: Schlaich, Jörg and Matthias Schüller, IngenieurbauFührer Baden-Württemberg, Berlin, 1999, pp. 188-189







La-Ferté Footbridge in Stuttgart-Zuffenhausen

D, 2001

Pedestrian and cycle bridge over the Haldenrainstraße
Engineer: Peter und Lochner, Stuttgart
Architect: 'asp' Architekten Stuttgart

Frame bridge, the deck axis is a circular arc in plan with a radius of 53.7 m, integral bridge without bearings or joints
Total length: 118.5 m
Maximum span: 28.5 m
Width: 3.5 m
Material: reinforced concrete, Piers: cast steel, steel, Railing: stainless steel

Literature: Peter, Jörg and Matthias Schüller, Fuß- und Radwegbrücken über die Haldenrainstraße in Stuttgart, in: Beton- und Stahl-betonbau, November 2002, pp. 609-614

Footbridge in Waiblingen

D, 1978

Bridge over the River Rems between Großer Erleninsel and Brühlwiesen
Engineer: Ingenieurbüro Leonhardt und Andrä, Stuttgart

Arch bridge
Total length: 39 m
Free span: 28 m
Width: 3.7 m
Material: Superstructure: reinforced concrete, Surfacing: urethane surfacing, Railings: steel

Literature: Leonhardt, Fritz, Brücken/Bridges, Stuttgart, 1994, p. 97
Schlaich, Jörg and Matthias Schüller, IngenieurbauFührer Baden-Württemberg, Berlin, 1999, pp. 216-217

Footbridge in Waiblingen

D, 1980

Footbridge between Großer and Kleiner Erleninsel
Engineer: Ingenieurbüro Leonhardt und Andrä, Stuttgart

Arch bridge
Total length: 23 m
Free span: 18 m
Width: 2.4 m
Material: Superstructure: reinforced concrete, Surfacing: urethane surfacing, Railings: steel

Backpack Bridge

D, 1999

Foldable bridge, can be erected by a single person
Architect: Maximilian Rüttiger, Unterwössen

Dynamic folding structure, fits in the boot of an estate car
Free span: 10 m
Weight: 38 kg
Material: aluminium

Literature: Kaltenbach, Frank, Rucksack-Brücke, in: Detail, 8, 1999, pp. 1442-1443

Bridge in Assens

DK, 1850

Bridge on the Brahesborg grounds

Suspension bridge
Free span: 22.9 m
Material: iron, Surfacing: timber

Literature: Cortright, Robert S., Bridging the World, Wilsonville, 2003, p. 114

Pont Vell in Alfarràs

E, 2007

Bridge over the Noguera Ribagorçana

Some remnants of the original bridge remained and were incorporated into the construction of the new structure; an arch bridge in the older section, the newer section is a continuous girder and an arch bridge with suspended deck
Material: Original remnants: stone, New structure: steel

Bridge in Andoain, Basque Country

E, 2005

Bridge over the Oria, connecting the city centre with a recreational area
Engineer: Pedelta, Barcelona

Simple girder, frame structure
Total length: 68 m
Width: 3.6 m
Material: weathering steel, Abutment: reinforced concrete

Literature: Sobrino, Juan A. and Javier Jordán, Two examples of innovative design of footbridges in Spain, in: Footbridge 2005. 2nd International Conference, Dec. 6-8, 2005, Venice, proceedings, pp. 223-224

Bridge in Bilbao

E, 1997

Footbridge in front of the Guggenheim Museum on the Abandoibarra Promenade
Engineer: IDOM, Bilbao
Architect: Frank O. Gehry and Associates, Los Angeles

Free span: 135 m
Width: 7.3 m
Material: cement, concrete and expanded polystyrene

Literature: van Bruggen, Coosje and Frank O. Gehry, Guggenheim Museum Bilbao, Ostfildern, 1997

Pasarela Padre Arrupe in Bilbao
E, 2003

Footbridge over the Nervión to the Universidad de Deusto
Engineer: IDEAM, Madrid
Architect: Estudio Guadiana, Madrid

Girder bridge, folded section with steel rib stiffeners, integrated lighting system
Total length: 142.5 m
Maximum span: 84 m
Width: 4.1 m to 11 m
Material: stainless steel, Interior cladding: Lapacho timber

Literature: Millanes Mato, Francisco, La nouvelle passerelle d'Abandoibarra devant le musée Guggenheim, Bilbao, in: Bulletin ouvrages métalliques, 3, 2004, pp. 26-49
Euro Inox (pub.), Trogbrücke in Bilbao, Spanien, in: Fußgängerbrücken aus Edelstahl Rostfrei, Luxembourg, 2004, pp. 18-20

Iron Bridge in Girona
E, 1877

Footbridge over the Onyar in the Pescateries district, also known as *Pont de les Peiscateries Velles*
Engineer: Gustave Eiffel, Paris

Truss girder
Material: iron

Literature: Asensio, Paco, Gustave Alexandre Eiffel, Düsseldorf, 2003, pp. 38-43

Pont d'en Gòmez in Girona
E, 1916

Bridge also known as *Pont de la Princesa*
Architect: Luís Holms

Material: reinforced concrete

Literature: see p. 55

Pasarela de Sant Feliu in Girona
E, 1996

Footbridge over the Onyar, connecting the oldest city section near Sant Feliu church and Devesa Park
Engineer: Pedelta, Barcelona
Architect: Blázquez-Guanter Arquitectes, Girona

Simple girder frame structure
Free span: 58.4 m
Width: 3.5 m
Material: weathering steel, Abutment: reinforced concrete

Literature: Gómez-Pulido, M. Dolores and Juan A. Sobrino, Sant Feliu Footbridge in Girona, Spain, in: Footbridge 2002, Nov. 20-22, 2002, Paris, proceedings, pp. 124-125
Schlaich, Mike (ed.), Saint Feliu Footbridge, Spain (1996), in: Guidelines for the design of footbridges, Lausanne, November 2005, p. 116

Footbridge in Lleida
E, 2001

Bridge over a roadway and two railway tracks approximately 2 km outside of Lleida
Engineer: Pedelta, Barcelona

Arch bridge with two arches and tension cords. The entire bridge was prefabricated and lifted and set into position on site.
Free span: 38 m
Width: 3 m
Material: fibreglass, Ramps and piers: reinforced concrete

Literature: Gómez-Pulido, M. Dolores and Juan A. Sobrino, A New Glass-Fibre Reinforced-Plastic Footbridge, in: Footbridge 2002. Design and dynamic behaviour of footbridges, Nov. 20-22, 2002, Paris, proceedings, pp. 187-188

Bridge over the Guadalentín in Lorca
E, 2002

Footbridge in the city centre
Engineer: Carlos Fernández Casado, Madrid

Arch bridge with suspended deck
Free span: 86 m
Width: 2 x 4 m
Material: steel

Bridge over the Manzanares in Madrid
E, 2003

Footbridge in the city centre
Engineer: Carlos Fernández Casado, Madrid

Cable-stayed bridge
Free span: 147 m
Width: 3 m
Material: steel

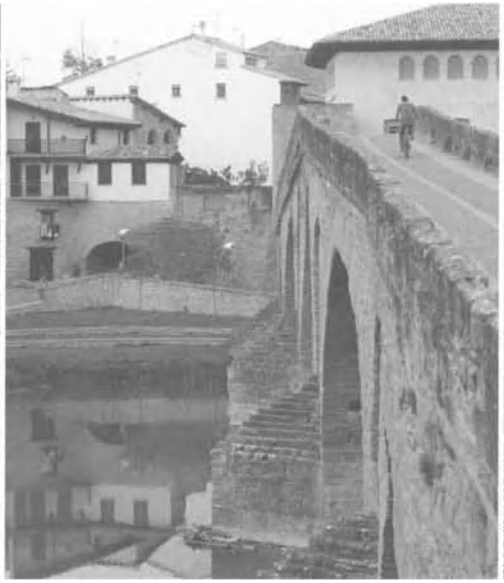
San Juan de la Cruz Bridge in Palencia
E, 2004

Bridge over the Carrión, connecting the Islas Dos Aguas sports centre
Engineer: Fhecor Ingenieros Consultores, Madrid

Cable-stayed bridge, curved bridge deck, no additional ramps despite elevation difference of the two bridgeheads
Free span: 70.7 m
Width: 3 m
Material: Bridge girder: steel

Literature: Romo Martín, José, Pasarela sobre el río Carrión en Palencia, in: Una reflexión sobre el proyecto de puentes y pasarelas sobre ríos en el ámbito urbano, pp. 2-4
III Congreso de ingeniería civil, territorio y medio ambiente: Agua, Biodiversidad e Ingeniería, Zaragoza, 25-27 October 2006






Bridge in Pontevedra

E, 1997

Bridge over the Lérez
Engineer: Fhecor Ingenieros Consultores, Madrid

Arch bridge with suspended walkway, bridge was constructed parallel to the riverbank and rotated into its final position using two boats.
Free span: 82.5 m
Width: 4 m
Material: steel

Bridge in Puente la Reina, Pamplona

E, 11th century

Footbridge at the delta of the River Robo in Arga as a pathway for the pilgrims travelling to Santiago de Compostela, also known as *Puente de los Peregrinos*

Bridge with six arches

Literature: Graf, Bernhard, Whence there is only one route. Puente la Reina: the Pilgrims' Bridge, in: Bridges that Changed the World, Munich, 2002, pp. 26-27

Pont Trencat in Sant Celoni

E, 2003

Renovation of a medieval bridge over the Tordera, destroyed during the Napoleonic Wars
Engineer: Alfa Polaris, Sant Vicenç de Montalt

Arch bridge, box section, integrated lighting system
Total length: 72 m
Maximum span: 24 m
Width: 3.4 m
Material: weathered steel, concrete

Literatur: Font, Xavier, Restauration of the Pont Trencat (Broken Bridge), in: Footbridge 2005. 2nd International Conference, Dec. 6-8, 2005, Venice, proceedings, pp. 119-120
Russell, Lisa, Footbridge Awards 2005, in: Bridge Design & Engineering, 41, 2005, pp. 35-49

Pasarela Vallparadís in Terrassa

E, 2007

Bridge near the recently renovated park in the city centre
Engineer: Pedelta, Barcelona

Continuous girder over four supports, simple piers serve as supports.
Gesamtlänge: 100 m
Free span: 3 x 33 m
Material: steel, Bridge girder: steel and concrete, Abutment: reinforced concrete





Bridge in Zaragoza
E, 2002

Footbridge over the inter-city highway *Ronda de la Hispanidad* connecting two park areas
Engineer: Carlos Fernández Casado, Madrid

Arch bridge with inclined arch and central deck
Free span: 56 m
Width: 4 m
Material: steel

Literature: Astiz, Miguel A. and Miguel A. Gil, Javier Manterola, The Ronda de la Hispanidad pedestrian bridge in Zaragoza (Spain), in: Tubular Structures X, Oxford, 2003, pp. 25-32
Schlaich, Mike (ed.), Footbridge across the "Ronda de la Hispanidad", Spain (2002), in: Guidelines for the design of footbridges, fib, Lausanne, November 2005, p. 127

Expo Bridge in Zaragoza
E, planned for 2008

Multi-storey footbridge over the Ebro, entrance to the World's Fair 2008
Engineer: Arup, Madrid
Architect: Zaha Hadid Architects, London

Combination of box girder and truss beam
Total length: 270 m
Maximum span: 123 m
Width: 11 m to 30 m
Material: Structure: steel, Exterior cladding: fibreglass concrete, Surfacing: shotcrete

Literatur: Arregui, Inés, Expo Saragosse 2008, in: Le Courrier d'Espagne, August 2006
Pabellon Puente, in: Architectura y critica, 7, 2006

Footbridge in Agen
F, 1841, renovated 2002

Bridge over the Garonne
Architect: Cabinet d'Architecture Stéphane Brassie, Agen

Back anchored suspension bridge with diagonal hangers
Total length: 263 m
Maximum span: 174.3 m
Width: 2.3 m
Material: Mast and cables: steel

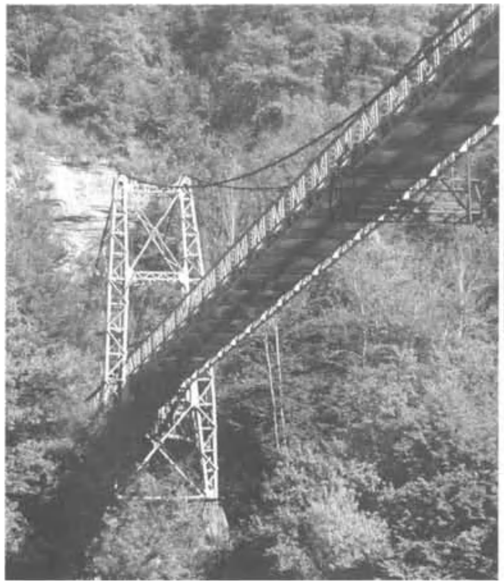
Literatur: Passerelle d'Agen: le sauvetage d'un ouvrage historique, in: Chantiers de France, March 2003, pp. 22-23
Petit, Sébastien, Deux réhabilitations novatrices, in: Travaux, November 2003, pp. 52-55
Lecinq, Benoît and Sébastien Petit, Rescue Mission, in: Civil Engineering Magazine, January 2004

Passerelle de la Fraternité, Aubervilliers
F, 2000

Pedestrian and cycle bridge over the Canal Saint-Denis between Quai Jean-Marie Tjibaou and Quai Adrien Agnès
Architect: Mimram Ingénierie, Paris

Arch bridge
Free span: 44 m
Material: Arch: steel, Abutment and platforms: reinforced concrete,
Surfacing: timber

Literature: Footbridge over the Canal Saint-Denis, in: Bridge Design & Engineering, 29, 4, 2002
Méhue, Pierre, Deux siècles de passerelles métalliques, in: Bulletin ouvrages métalliques, 2, 2002



Pont de Grésin, Bellegarde-sur-Valserine

F, 1947

Footbridge over the Rhône. Originally there were numerous bridges here, the most recent was destroyed in 1940; a renovation of the current bridge is planed for 2007

Back-anchored suspension bridge with truss stiffening girder
Total length: 137.8 m
Span: 114.2 m
Width: 3 m
Material: steel

Literature: Brocard, Maurice, L'Ain des Grands Ponts, Peronnas, 1993

Passerelle Mataro in Créteil

F, 1988

Also known as *Pont Oudry-Mesly*
Architect: Santiago Calatrava, Zurich

Arch bridge, suspended deck
Total length: 120 m
Maximum span: 55 m
Material: steel

Literature: Calatrava, Santiago, Des bow-strings originaux, in: Bulletin annuel de l'AFGC, January 1999, pp. 59-61
Frampton, Kenneth, Calatrava Bridges, Basel, 1996, pp. 44-53
Montens, Serge, Créteil. Passerelle en bow-string, in: Les plus beaux ponts de France, Paris, 2001, p. 121

Footbridge in Dôle

F, 2005

Bridge over the Doubs
Engineer: Quadric, Montluel
Architect: Alain Spielmann Architecte, Paris

Suspension bridge with two vertical masts, simple girder
Free span: 70 m
Width: 3 m
Material: metal

Literature: Ganz, Hans-Rudolf, Dole Delight, in: Bridge Design & Engineering, November 2005, p. 13

Célé Footbridge in Figeac

F, 2003

Bridge over the Célé
Architect: Mimram Ingénierie, Paris

Truss arch
Total length: 42 m
Free spans: 2 x 21 m
Width: 3 m to 5 m

Holzarté Bridge near Larrau, Pyrenees
F, 1920

Footbridge over the Olhadubi River canyon

Suspension bridge

Passerelle du Commerce in Le Havre
F, 1969

Pedetrian and cycle bridge over the Bassin du Commerce, also known as *Pont de la Bourse*
Architect: Guillaume Gillet

Assymmetric cable-stayed bridge, A-shaped pylon
Total length: 105 m
Maximum span: 73.4 m
Width: 5.5 m

Literature: Grattesat, Guy, Ponts de France, Paris, 1982, pp. 266-267
Walther, René, Schrägseilbrücken, Lausanne/Düsseldorf, 1985, p. 160

Bridge in Meylan
F, 1980

Footbridge over the Isère
Engineer: Campenon Bernard Construction, Boulogne-Billancourt
Architect: Cabinet Arsac

Cable-stayed bridge with upside down Y-shaped pylon
Total length: 119 m
Maximum span: 79 m
Width: 6.7 m
Material: Cables: steel, Deck: prestressed concrete, Pylons: reinforced concrete

Literature: AFPC (pub.), Passerelle de Meylan (Isère), in: Bulletin 1980-81-82, pp. 397-403
Walther, René, Schrägseilbrücken, Lausanne/Düsseldorf, 1985, p. 167
Marrey, Bernard, Les Ponts Modernes – 20e siècle, Paris, 1995, pp. 213-214

Passerelle Debilly in Paris
F, 1900

Bridge for the 1900 World's Fair between Rue de la Manutetion and Quai Branly, renovated 1991
Engineer: Amédée Alby, André-Louis Lion, Jean Résal

Arch bridge with two articulations and intermediate deck girder
Total length: 120 m
Maximum span: 75 m
Width: 8 m
Material: steel

Literature: Gaillard, Marc, Quais et Ponts de Paris, Amiens, 1996, p. 169
Poisson, Jérôme, Passerelle Debilly, in: Les Ponts de Paris, Paris, 1999, p. 223
Montens, Serge, Passerelle de Billy, in: Les plus beaux ponts de France, Paris, 2001, p. 115

Granité Footbridge in Paris-La Défense

F, expected September 2007

Footbridge at the Société Générale Towers connecting the square of the *Grande Arche* with the new *Tour Granite* in Nanterre
Engineer: Schlaich Bergermann und Partner, Stuttgart
Architect: Feichtinger Architectes, Paris

Unilaterally suspended curved cable-stayed bridge with inverted system, runs parallel to the glazed facade of the *Société Générale*, a 1.8 m high glass plate offers wind protection for the pedestrians
Free span: 88 m
Width: 4.5 m
Material: steel, Wind protection and railings: imprinted glass

Literature: La passerelle Granite en chantier, in: Le Moniteur des Travaux Publics et du Bâtiment, 8 September 2006, p. 20

Passerelle Bonnets Rouges in Rennes

F, 1994

Bridge some 500 m north of the TGV station
Engineer: Groupe Alto, Gentilly
Architect: François Deslaugiers, Marseille

Folding bridge, motor situated between the box section girders of the bridge deck
Total length: 40 m
Free span: 12 m
Length of cantilever: 8 m
Width: 3.5 m
Material: stainless steel

Sarre Bridge in Sarreguemines

F, 2001

Pedestrian and cycle bridge over the River Sarre connecting the city centre with the Casino park
Engineer: Jean-Louis Michotey, Michel Virlogeux
Architect: Alain Spielmann Architecte, Paris

Self-anchored, asymmetric suspension bridge with single mast, diagonal hangars
Total length: 90 m
Maximum span: 54.4 m
Material: steel, reinforced concrete

Literature: Michotey, Jean-Louis und Alain Spielmann, Michel Virlogeux, La passerelle de Sarreguemines, in: Bulletin ouvrages métalliques, 1, 2001, pp. 116-127
Duclos, Thierry, La passerelle de Sarreguemines, in: Bulletin annuel de l'AFGC, January 2001, pp. 59-63

Passerelle du Francs Moisins, St Denis

F, 1998

Pedestrian and cycle bridge over the Canal Saint-Denis as part of urban project to revitalize the canal bank
Architect: Mimram Ingeniérie, Paris

Arch bridge
Free span: 43 m
Width: 3.5 m to 5 m
Material: steel

Literature: Passerelle sur le canal de Saint-Denis, in: L'acier pour construire, Oktober 1998
Mimram, Marc, Passerelle piétonne au-dessus du canal de Saint-Denis, in: Bulletin ponts métalliques, 1999
Méhue, Pierre, Deux siècles de passerelles métalliques, in: Bulletin ouvrages métalliques, 2, 2002






Passerelle du Barrage in Saint-Maurice
F, 1997

Footbridge over the Marne River between the road Fernand Saguet de Maison-Alfort and a promenade
Architects: Mimram Ingénierie, Paris

Arch bridge with double arch and three braces, depth of the box section minimized at the centre of the bridge
Total length: 110 m
Free span: 3 x 37 m
Width: 3.5 m to 7 m
Material: Arch: steel

Literature: Passerelle sur le barrage de Saint-Maurice, in: L'acier pour construire, October 1998, pp. 36-37
Mimram, Marc, Passerelle de Saint-Maurice. Maisons-Alfort, in: Bulletin ponts métalliques, 19, 1999

Passerelle des Deux Rives in Strasbourg
F, 2004

Bridge connecting both sides of the park for the border crossing 2004 Gardening Exhibition
Engineers: LAP Leonhardt Andrä und Partner, Stuttgart and Mimram Ingénierie, Paris

Deck with a slope of up to 18 percent, less steep bridge for pedestrians and cyclists
Total length: 390 m
Free span: 183.4 m
Width: walkway: 2.5 m, Bike path: 3 m
Material: steel

Literature: Morgenthal, Guido and Reiner Saul, Verbindendes Element der grenzübergreifenden Gartenschau, in: Stahlbau-Nachrichten, 1, 2004, pp. 9-11

Passerelle PSO in Toulouse
F, 1988

Bridge over a beltway with an asymmetric structure, oriented according to the landscape
Architects: Mimram Ingénierie, Paris

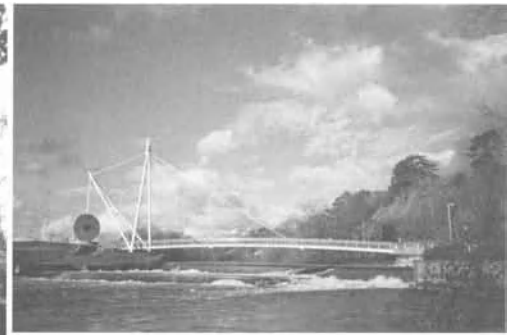
Console bridge with double curvature
Free span: 75 m
Material: Deck girder: steel plate, Surfacing: timber

Footbridge Parc du Val Joly near Trelon
F, 1980

Engineers: Arcora, Arcueil
Architect: Michel Marot

Back anchored suspension bridge, thin bridge deck
Free span: 56 m
Width: 2.5 m
Material: Cables: steel, Surfacing: wood, Railing: textile membran

Literature: Baus, Ursula, Superbe. Fußgängerbrücke im Parc du Val Joly, in: db deutsche bauzeitung, 7, 1989, p. 92



Mobius Bridge in Bristol

GB, scheduled 2009/10

Pedestrian and cycle bridge between Finzels Reach and Castle Park
Engineers: Buro Happold, London
Architects: Hakes Associates Architects, London

Truss girder
Free span: 60 m
Width: 2.7 m to 3 m
Material: steel, Railing: glass, Handrail: steel

Literature: Landmark bridge gains planning permission, in: BSEE Building Services and Environmental Engineer, 28 July 2005
Mobius Bridge, Bristol, in: A10, November/December 2005, p. 18

Dryburgh Abbey Bridge in Dryburgh

GB, 1818, 1872

Footbridge over the Tweed, original bridge collapsed and was replaced in 1872
Engineers: John und William Smith

Suspension bridge with cable stays
Maximum span: 79 m
Width: 1.4 m

Literature: Stevenson, Robert, Description of Suspension Bridges, in: Edinburgh Philosophical Journal, vol. 5 , 10, 1821
Troitsky, M. S., Cable-Stayed Bridges. Theory and design, London, 1977
Fernández Troyano, Leonardo, Tierra sobre el agua. Visión histórica universal de los puentes, Madrid, 1999, pp. 661-662

Shakkin' Briggie in Edzell

GB, c. 1900

Footbridge over the River North Esk, Scotland

Chain suspension bridge, later braced with cantilevering transverse girders; four chains at each side
Span: around 30 m
Width: around 1.2 m

Millers Crossing Bridge in Exeter

GB, 2002

Pedestrian and cycle bridge over the Exe between Exeter and Exwick
Engineers: Engineering Design Group, Devon County Council, Exeter

Asymmetric cable-stayed bridge, tufted form, mill stone acts as counterweight
Free span: 54 m
Width: 3 m
Material: Pylon, bridge girder and cables: steel, Mill stone: granite, Abutment: reinforced concrete

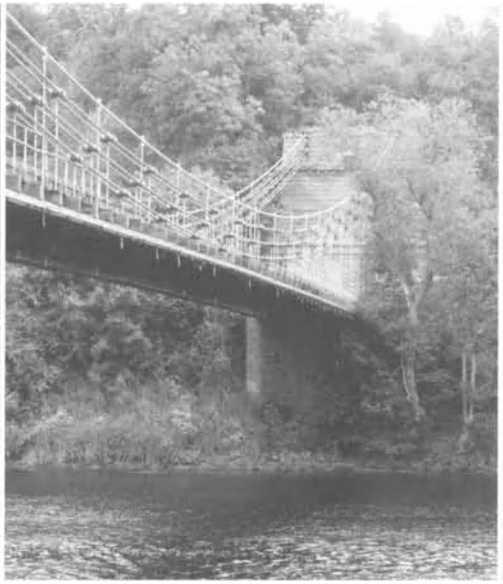
Pier 6 Airbridge in Gatwick

UK, 2005

Bridge between Pier 6 and the North Airport Terminal
Engineer: Arup, London
Architect: Wilkinson Eyre Architects, London

Truss girder, bridge was prefabricated at the limits of the airport grounds and assembled and erected within ten days on site
Total length: 197 m
Free span: 128 m
Maximum width: 11.5 m
Material: steel, glass

Literature: Gatwick Pier 6 Air Bridge, in: New Steel Construction, July 2006, p. 15
Gatwick Airport, new footbridge linking Pier Six, in: The Architects' Journal, 24 June 2004, pp. 4-5



Union Chain Bridge in Horncliffe

UK, 1820

Bridge crossing the Tweed River and connecting England and Scotland
Engineer: Sir Samuel Brown

Back anchored chain suspension bridge
Maximum span: 112 m
Width: 5.5 m
Material: Bridge girder and chain: wrought iron, Surfacing: timber

Literature: Stevenson, Robert, Description of Suspension Bridges, in: Edinburgh Philosophical Journal, vol. 5, 10, 1821
Prade, Marcel, Les grands ponts du monde. Ponts remarquables d'Europe, Poitiers, 1990
Picon, Antoine (ed.), L'art de l'ingénieur, Paris, 1997, pp. 523-525
Miller, Gordon, Union Chain Bridge, in: Conference Report of the Institution of Civil Engineers 159, May 2006, pp. 88-95

Sackler Crossing Bridge in Kew

UK, 2006

Footbridge over a lake in the Royal Botanic Gardens
Engineer: Buro Happold, London
Designer: John Pawson, London

Footbridge spanning in the longitudinal axis
Total length: 70 m
Free span: 70 m
Width: 3 m
Material: Walkway: granite, Railing: bronze, Substructure: steel

Literature: Russell, Lisa, Route Master, in: Bridge Update, January 2006
Walk on water at Kew, in: The Observer, 14 May 2006
Landscape: John Pawson's bronze-railed bridge is in the tradition of landscape interventions at Kew, in: Architecture Today, June 2006, p. 77

Bridge in Kingston-upon-Hull

UK, scheduled 2008

Bridge over the Hull connecting the city centre with the development plans on the east side of the river
Engineer: Alan Baxter & Associates, London
Architect: McDowell + Benedetti, London

Wing bridge with 35 m long cantilever
Free span: 60 m
Width: 2 m to 4.5 m
Material: epoxy coated steel, Surfacing: Epoxy with mineral aggregate, Seating and terrace: timber

Literature: Taking a turn on the river, in: bd Building Design, 12 May 2006
Boom town, in: Building, 12 May 2006
Swinging bridge clinches competition, in: Plan Magazine, June 2006

New Telford Bridge in London

UK, 1994

Footbridge in Saint Katherine marina, original construction in 1829, parts of which remain alongside the modern structure
Engineer: Morton Partnership, London

Roll bridge
Material: steel

St Saviour's Dock Bridge in London

UK, 1996

Footbridge over historic St Saviour's Dock
Engineer: Ramboll Whitbybird, London
Architect: Nicholas Lacey & Partners, London

Cable-stayed bridge
Total length: 34 m
Maximum span: 15.2 m

Literature: Pearce, Martin, Bridge Builders, London, 2002, p. 139

Bridges to Babylon in London

UK, 1996

Bridge of for the Rolling Stones Tour connection the main stage with an side stage in the middle of the Millennium Dome
Engineer: Atelier One, London
Designer: The Mark Fisher Studio, London

Temporary, moveable bridge structure, bridge is mounted to the main stage, which serves as a counterweight, in closed position, the side stage serves as a support.
Free span: 43 m
Width: 2 m
Material: steel

Literature: Lyall, Sutherland, Ingenieur-Bau-Kunst. Die Konstruktion der neuen Form, Stuttgart, 2002, pp. 110-117

South Quay Bridge in London

UK, 1997

Footbridge at the Canary Wharf grounds
Engineer: Jan Bobrowski & Partners, London
Architect: Wilkinson Eyre Architects, London

Asymmetric cable stayed bridge, diagonal hangers
Free span: 180 m
Width: 6 m
Material: steel

Floating Bridge in London
UK, 1999

Bridge at the West India Quay in London Docklands
Engineer: Anthony Hunt Associates, London
Architect: Future Systems, London

Moveable floating bridge
Total length: 80 m
Free span: 15 m
Width: 2.4 m to 3.6 m
Material: Piers and supports: steel, Bridge girder: aluminium

Literature: Field, Marcus, Docklands-Brücke 1996, in: Future Systems. Bauten und Projekte 1958-2000, Heidelberg, 1999, pp. 84-91
Wells, Matthew and Hugh Pearman, 30 Brücken, Munich, 2002, pp. 90-95
Watanabe, Eiichi, Floating Bridges. Past and Present, in: Structural Engineering International, vol. 13, May 2003, pp. 128-132

Plashet School Footbridge in London
UK, 2001

Footbridge connecting the two buildings of the Plashet Grove School
Engineer: Techniker, London
Architect: Birds Portchmouth Russum Architects, London

S-form curved bridge, spanning over asymmetrically formed bridge, membrane roofing
Free span: 67 m
Width: 2.2 m
Material: steel and Teflon, Membrane: PTFE-coated fibreglass

Literature: Fußgängerbrücke in London, in: Detail, 5, 2001, pp. 864-867
Pearce, Martin, Bridge Builders, London, 2002, pp. 30-35
Wells, Matthew and Hugh Pearman, 30 Brücken, Munich, 2002, pp. 48-53

Hungerford Bridge in London
UK, 2003

Two bridges one on each side of the Charing Cross Rail Bridge, connecting London's South Bank with the West End
Engineer: WSP Group, London
Architect: Lifschutz Davidson Sandilands, London

Continuours girder, inclined mast, deck suspended by cables
Total length: 315 m
Width: 4 m
Material: Masts and cables: steel, Bridge girder: reinforced concrete, Surfacing: stone tile, Railing: polished stainless steel

Bellmouth Passage in London
UK, Project

Two bridges in Canary Wharf on the Isle of Dogs
Engineer: Techniker, London
Architect: Birds Portchmouth Russum Architects, London

Moveable bridge, South bridge: Two part swing bridge, North bridge: bascule bridge
Free span: South bridge: 32 m, North bridge: 23 m
Width: Southbridge: 3 m to 10 m, North bridge: 1.6 m to 4.5 m
Material: Northbridge: steel folded structure

Lockmeadow Bridge in Maidstone
UK, 1999

Bridge adjacent to the Archbishop's Palace
Engineer: Flint & Neill Partnership, London
Architect: Wilkinson Eyre Architects, London

Cable stayed bridge, integrated lighting system, deck as slender as possible to minimize the impact on the surroundings
Total length: 80 m
Free span: 45 m
Width: 2.1 m
Material: Cable and mast: steel, Bridge girder: aluminum

Literature: Firth, Ian, Tale of Two Bridges, in: The Structural Engineer, vol. 80, 2002, pp. 26-32
Pearce, Martin, Bridge Builders, London, 2002, pp. 216-221

William Cookworthy Bridge, St Austell
UK, 2005

Bridge over Bodmin Road
Engineer: Sustrans, Loddiswell
Architect: David Sheppard Architects, Ermington

450 mm deep box girder
Free span: 25 m
Width: 2.5 m
Material: weathering steel

Literature: Bridge, St. Austell, Cornwall David Sheppard Architects, in: Architectural Review, December 2005, pp. 68-69

Trinity Bridge in Salford
UK, 1995

Footbridge connecting Salford and Manchester
Architect: Santiago Calatrava, Zurich

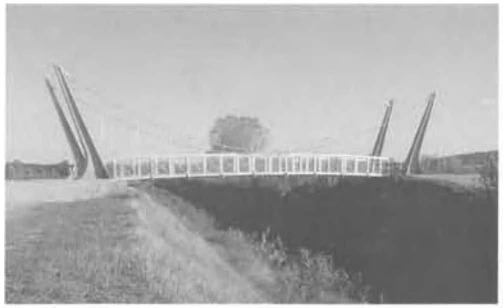
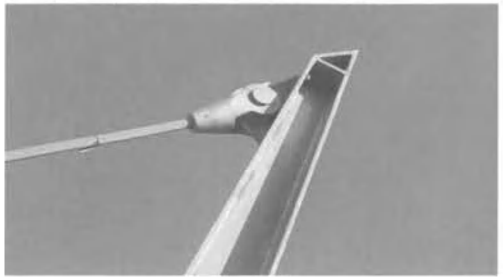
Asymmetric cable-stayed bridge, inclined mast
Total length: 78.5 m
Free span: 54 m
Width: 6 m to 11 m
Material: steel

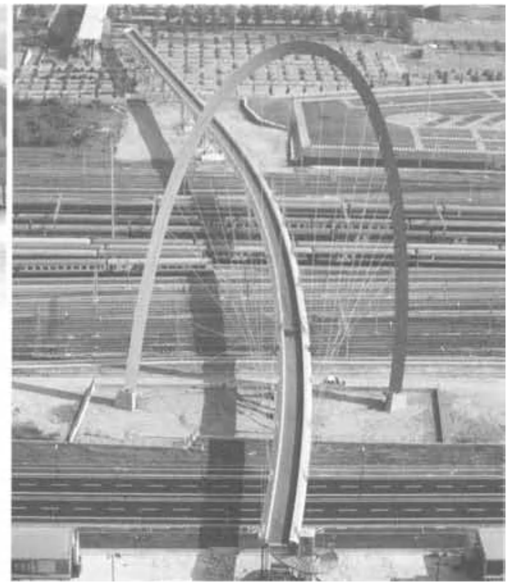
Literature: Sharp, Dennis, Landmark link. Architectural design of a cable stay bridge in Salford, England, in: Architectural Review, March 1996
Frampton, Kenneth (ed.), Calatrava Bridges, Basel, 1996, pp. 188-195
Jodidio, Philip, Santiago Calatrava, Cologne, 1998, pp. 148-151

Northbank Bridge in Stockton
UK, Project

Pedestrian and cycle bridge over the Tees near the city centre
Engineer: WSP Group, London
Architect: Lifschutz Davidson Sandilands, London

Cable stayed bridge with two asymmetric consoles, bridge girder constructed as a frame, integrated lighting
Maximum span: 27.5 m
Material: Console: concrete, weathering steel

Bridge in Cascine di Tavola

I, 2003

Footbridge over the Filimortula, orignal bridge destroyed by retreating German troops in 1944
Engineer: Alessandro Adilardi, Prato and Lorenzo Frasconi, Prato

Back-anchored suspension bridge, cables fixed to the ends of the mast
Free span: 18.4 m
Width: 2.6 m
Material: steel, Surfacing: timber

Literature: Opere 09 – Rivista Toscana di Architettura, vol. 3, June 2005

Trepponti in Comacchio

I, 1634

Footbridge in the city centre at the confluence of three (originally five) canals, also known as *Ponte Pallotta*, rebuilt several times
Architect: Luca Danese di Ravenna

Arch bridge, five with stairways leading to a high platform, flanked by two towers
Material: Pietra d'Istria, a type of stone

Literature: Cortright, Robert S., Bridging the World, Wilsonville, 2003, p. 181

Passerella Rari-Nantes in Padua

I, Project

Pedestrian and cycle bridge between the Via Isonzo and the Via Vittorio Veneto
Engineer: Enzo Siviero, Padua
Architect: Progeest, Padua

Arch bridge with two articulations
Free span: 75 m
Width: 4 m
Material: steel, timber

Passerella Olimpica in Turin

I, 2006

Bridge over railway platforms between the former Mercati Generali and the Lingotto
Architect/Engineer: Hugh Dutton Associés, Paris

Arch bridge with 69 m high arch, suspended deck
Total length: 385 m
Maximum span: 150 m
Width: 4.3 m
Material: Arch: steel

Literature: Aydemir, Murat, Olympic arch gives Lingotto a lift, in: Bridge Design & Engineering, vol. 12, March 2006, p. 16
Beideler, Julien and Philippe Donnaes, L'arc sous toutes ses formes, in: Le Moniteur des Travaux Publics et du Bâtiment, 30 March 2007, pp. 64-70




Bridge in Venice

I, 1963

Entrance to the Palazzo Querini Stampalia, near Campo San Marco
Engineer: Piero Maschietto
Architect: Carlo Scarpa, Venice

Arch bridge
Free span: 8 m
Width: 1.6 m
Material: Arch and railing: iron, Several stairs: stone, Surfacing and handrail: timber

Ponte Piazzale Roma in Venice

I, under construction

Bridge over the Canal Grande connecting the railway station with the Piazzale Roma
Architect: Santiago Calatrava, Zurich

Total length: 94 m
Free span: 77 m
Material: steel, glass

Nesciobrug in Amsterdam

NL, 2006

Pedestrian and cycle bridge over the new suburb of IJburg over Amsterdam's Rhine Canal
Engineer: Arup, London
Architect: Wilkinson Eyre Architects,London

Suspension bridge with one main cable, curved bridge girder
Total length: 790 m
Free span: 168 m
Width: Walkway: 2 m, Cycle path: 3.5 m
Material: Bridge: steel, Approach ramps: concrete

Dunajec Footbridge, Sromowce Nizne

PL, 2006

Footbridge over the Sromowce Nizne in Poland and Cerveny Klastor in Slovakia
Engineer: Mosty Wroclaw Design and Research Office, Wroclaw, Jan Biliszczuk

Cable-stayed bridge
Total length: 150 m
Maximum span: 90 m
Width: 3,5 m
Material: Pylon, half frams and wind protection: steel, Deck girder: laminated timber, Surfacing: stone pine timber

Literature: Russell, Lisa, Elegant footbridge connects border resorts, in: Bridge Design & Engineering, vol. 12, December 2006, p. 8

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Footbridge 2005, 2nd International Conference, December 6-8, 2005, Venice, proceedings

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Fuchtmann, Engelbert, *Stahlbrückenbau*, Munich, 2004

Gerlich, Franz, *Brücken in Tirol*, Innsbruck (1956)

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