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TABLEAU 1. — *Amplitudes maximales des variations de températures uniformes pour les ponts selon différentes sources.*

	ΔT_{max} [°C]		
	Ponts en bétons	Ponts mixtes	Ponts en acier
Grande-Bretagne [8]	51	59	75
Grande-Bretagne [8]	47	–	66
Italie [9]	50	–	73
Pologne [9]	59	–	91
Autriche [9]	56	–	84
Hongrie [9]	57	–	85
Nos résultats	56	64	84

ments des ouvrages. Elles ont été définies à partir des températures extrêmes de l'air; il s'agit donc également de valeurs extrêmes pour le calcul des mouvements des ponts qui ne nécessitent pas d'être amplifiées par un facteur de charge.

2. Dans la mesure où le format de la norme indiquera des valeurs nominales de charges, à multiplier par un facteur pour la vérification de la sécurité, les valeurs nominales correspondant aux amplitudes des températures uniformes des ponts pourraient être, si le facteur est égal à 1,4:
   - pour les ponts en béton: $T_m \pm 20°C$;
   - pour les ponts mixtes: $T_m \pm 23°C$;
   - pour les ponts en acier: $T_m \pm 30°C$.

   Les valeurs nominales ci-dessus correspondent fortuitement à des valeurs moyennes, car le rapport entre les amplitudes de températures maximales et moyennes de l'air est également de 1,4. Ces valeurs nominales ont une probabilité d'occurrence de 50%; c'est-à-dire que sur une période de 2 ans, les températures moyennes minimales et maximales des ouvrages peuvent être atteintes. Dans ce cas, elles peuvent être considérées comme valeur d'accompagnement au sens du projet SIA 160 mis en consultation [10].
3. Pour le positionnement des appareils d'appuis, il faut tenir compte des écarts entre la température effective au cours de l'exécution de l'ouvrage et la température moyenne T_m du lieu. La température de l'air, au cours des différentes étapes de l'exécution de l'ouvrage, n'étant a priori pas connue avec précision, on peut s'imaginer que des marges supplémentaires, notamment pour les dimensions des plaques d'appuis, sont nécessaires pour couvrir cette incertitude.
4. Les variations de la température uniforme des ouvrages traitées dans cet article ne sont qu'un aspect des effets de la température sur les constructions. Le gradient thermique qui se développe simultanément dans les ouvrages doit également être pris en compte, particulièrement pour les vérifications à l'état de service. Des informations au sujet des gradients de températures dans les ponts et sur la manière de les considérer dans le dimensionnement sont contenues dans la référence [1].

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Wilhelm Ritter: Teacher of Maillart and Ammann[1]

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This paper was first presented at the Convention of the American Society of Civil Engineers in Boston, April 1979, in a session honoring Othmar Ammann; it was later presented in June of 1980 at the Swiss Federal Institute of Technology in Zurich at the request of Professor Christian Menn, who himself stands in the same tradition begun by Professors Culmann and Ritter. The paper was first published in the "Journal" of the Structural Division of the American Society of Civil Engineers, Vol. 206, No. ST5, May 1980, pp. 1103-1116 and is reprinted by permission.

Introduction

This paper seeks to make the contemporary structural engineering profession aware of a 19th century tradition of education which has been almost lost. That educational tradition possessed ideas which do not go out of date and which can stimulate a healthy review of present research and teaching in structural engineering.

A good case can be made for the judgment that the two greatest bridge designers of the 20th century were Robert Maillart (1872-1940) using concrete and Othmar Ammann (1879-1965) using steel. It is a remarkable fact that both had the same Swiss educational background and even the same professor for bridge design: Wilhelm Ritter (1847-

[1] Presented at the April 2-6, 1979, ASCE Convention and Exposition and Continuing Education Program, held in Boston, Mass.

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1906). It thus seemed of interest to explore the career of that late 19th century academic to recapture something of his teaching and research, especially that part which may have influenced his two distinguished students. From documentation already published, it can be stated that Ritter had a powerful and lasting influence on Maillart's career [1][3]. Professor Fritz Stüssi in his book on Ammann also emphasized the significance of Ritter and even reproduces some of his early work on suspension bridges [2]. Because it seems correct to credit Ritter with direct influence, the substance of this present paper is to characterize that influence by briefly sketching first the engineering tradition within which Ritter studied, second his own career as a teacher and researcher in bridge engineering, and finally the ideas central to Ritter's vision of bridge design.

Founding of Zurich Polytechnikum

The revolutionary fervor that swept through Europe in 1848 played a major role in Swiss history by providing a setting in which the Swiss could form a centralized government based on a new Constitution. Although there had been a Swiss Confederation since 1291, it did not function as the national state we now know until after 1848. A very brief civil war in late 1847 actually precipitated the founding of modern Switzerland. Although to this day Switzerland is the most decentralized of the major European nations, its impressive economic strength owes much to the unity achieved in 1848.

A major goal of the new government in 1848 had been to establish two federal institutions of higher learning in Switzerland: a federal university in Zurich and a federal technological institute in Lausanne [3]. It was assumed that education, like the postal service, the railways, and the customs policy would benefit by a more centralized presence within the reconstructed Confederation.

There were in the Europe of 1848 two distinct traditions for engineering education. In the French tradition, founded during the Revolution, all education was standardized and controlled from Paris; indeed, most engineering was taught in one capital city. The other tradition was the German, in which educational institutions had been founded by individual states having different local characteristics, and in which engineering was also taught in many different places without there being one dominant school.

Common to both traditions was the principle that engineering should have an institution completely separated from the university, the latter of which taught the classical studies and the pure sciences. This clear division originated at least in part with the ideas that engineering was a new subject, that its content was barely if at all connected to subjects taught in the universities, and that its new subjects were closely connected to the new prosperity of an emerging industrial economy. The symbols of something new, something different, and something useful also made the technical school seem to early 19th century governments symbols of a national future.

Thus, when the new federal government in Bern tried to establish two institutions, it found two different responses. There was no major objection to an engineering school, but to a new federal university there arose strenuous dissent from the cantons which already had universities. The result was that a federal university never appeared but that a federal technological institute did, in Zurich, in 1855 [4].

There were at least three good reasons why conditions were excellent for the founding of a new Swiss engineering school in 1855. First, it came late; second, it came as a national enterprise; and third, it came after substantial and high-quality planning and debate.

Its lateness with respect to the French and German schools meant that its founders could benefit from a study of numerous working examples and could choose well-trained people for the first faculty. A first proposal drawn in 1851 by French Swiss followed closely French examples, especially those in the Parisian Ecole centrale des arts et manufactures, but a later proposal guided by the German Swiss Alfred Escher (1819-1882) the same year followed more the German example of Karlsruhe ([4], p. 70). One principle difference was in the organization of the faculty, which in the French-type system had individual professors and central administrators, while the German-type had groups of professors in departments *(Fachschulen)* with fewer central personnel ([4], pp. 75-76). Eventually, the Federal Assembly chose the Karlsruhe system.

With the Karlsruhe system chosen, it was only natural that the search for the founding faculty would turn in that direction as well. In 1854, 189 individuals were contacted as potential professors; of these 113 were German, 67 Swiss, 11 French, three Belgian, two Italian, and three English ([4], p. 175). The first group chosen was impressive; at least four of the original 31 professors were men whose international stature was so high that each could have been called the best academic in his field anywhere: architect Gotfried Semper (1803-1879), civil engineer Carl Culmann (1821-1881), physicist Rudolf Clausius (1822-1888), and historian Jacob Burckhardt (1818-1897) ([4], p. 221). Only Burckhardt was Swiss, the other three German and of those Semper and Culmann were of most significance to the education of Maillart and Ammann.

In addition to having the advantage of coming later the new school had the even greater benefit of being a national institute, the only one of its kind in Switzerland and thus a unifying symbol. Not only could it attract, thereby, the highest quality of faculty into the country but it could serve as a new center of cultural unity. At the opening ceremonies on October 15, 1855, the first president of the board of regents for the new institute, Senator Johann Konrad Kern (1808-1888) spoke of how this type of institute needed to bring together harmoniously Switzerland's different traditions of locality, of nationality, and of faith ([4], p. 234). Recalling clearly all the strife leading to the 1848 Constitution, Kern saw the new school as one where there could peacefully come together Protestants and Roman Catholics, French Swiss and German Swiss, those from the canton of Basel city (density of 830 people per square kilometer in 1850), and those from the Graubunden (density of 12,4 people per square kilometer). That this ideal would be made possible through an engineering school was characteristic of one midcentury view of technology.

But perhaps most important of all, to the success of the new school was the quality of the debate and planning that led finally on February 7, 1854 to the federal law establishing the school and then to the regulations passed by the Federal Assembly on July 31 of the same year. The two most important figures in the debate and planning were Alfred Escher from Zurich and Johann Kern from the Thurgau. Both were presidents of the Federal Assembly after 1848 and remained leading national figures to the ends of their lives.

It was people of such high national standing as Escher and Kern who debated and planned the new school and who saw clearly that it needed to be a great institution, both to help unify the country and to give the new nation international prestige. They succeeded largely because of the people they chose, the most important one for civil engineering being Culmann.

The Culmann Tradition

Following the designation of Semper as head of the department of Architecture, Culmann was Kern's second major appointment. Born in Bavaria, Culmann received an engineering diploma from Karlsruhe in 1841 after which he worked for the Bavarian state railways until called to Zurich in 1855. In addition to first-hand field experience with railroad structures built during the early days of the rail boom, Culmann was strongly motivated to study recently completed structures elsewhere and to systematize

[3] Les chiffres entre crochets renvoient à la bibliographie en fin d'article.

structural engineering. These goals led him in two directions that would both strongly influence Ritter. First he made a 2-year study trip to Britian and the United States to learn about bridge building and railway construction; the result was a widely-read 1851 report [6]. Second, he began detailed studies of structural analysis; early in his teaching career he began to systematize these studies and in 1866 published them in his book *Graphic Statics,* probably the single most influential book on structural analysis of the time [7]. The basic idea behind his work was to demonstrate structural behavior through geometric diagrams rather than through algebraic formulas. "Drawing is the language of the Engineers" he used to say and further [8]: "because the geometric way of thinking is a view of the thing itself and is therefore the most natural way; while with an analytic method, as elegant as that may also be, the subject hides itself behind unfamiliar symbols."

In 1875 a revised and expanded version of his book appeared and in 1879 it was translated into French. By the time of his death in 1881, Culmann's work was known and used throughout Europe but its value was not uncontested. As his quoted contrast between geometric and algebraic methods implies, there was another school of thought, one which believed more in abstract analyses and formulas.

In addition to his teaching and writing, Culmann was a consultant on practically every important Swiss bridge built during his tenure at Zurich. Moreover, he studied stream-flooding in Switzerland and retaining-wall problems as well as making a famous study in 1865 of the similarities between the stresses in the human hip bone and a loaded building crane.

But the Culmann tradition was more than just geometry over algebra; it had three components which set the tone for civil engineering in the Zurich school for half a century. These three bases for his influence were first, his intensive experience in the field from 1841-1855, second, his extensive travels for study of foreign public works, and third, his individual research leading to the development of visual methods for structural analysis.

The Culmann tradition, within which Maillart and Ammann studied, required more than just a gifted founding professor; it demanded a successor to carry forward teaching in the same vein. It is not too much to say that the second individual is crucial to the establishment of a tradition, as opposed to the enshrinement of a master. Culmann, Maillart and Ammann were fortunate that the professor chosen in 1882 to succeed the founder was Karl Wilhelm Ritter (1847-1906).

Although not as well known as some of his German contemporaries, a good case can be made for calling Ritter the outstanding structural engineering professor over the last quarter of the 19th century. He had one indispensible quality for the making of a successful follower: critical reverence of his master. We can see this in his two brief writings about Culmann.

Following Culmann's death in 1881, Ritter came back to Switzerland from Riga, where he had been professor, and he immediately began to think about completing Culmann's great project of writing up the second volume of *Graphic Statics.* The more he looked into the project, the more he became convinced that such an effort could not be done as Culmann had imagined it. Ritter finally decided to write his *Applications of Graphic Statics* as five separate volumes (only four ever appeared) in which he would think out on his own the organization and content. Clearly he was continuing the Culmann tradition but the new books were to be his own. There is a radical difference between taking over someone else's partially finished work and simply editing and completing it and taking someone else's basic ideas and using them as the starting point for a fresh approach. As Ritter put it in the forward to his first new part ([9], p. V): "Evidently Culmann had the idea to keep the second volume as close as possible to the first. The writer [Ritter] had a feeling of reverence leading him that same way; on the other hand by following Culmann's way the integrity of the treatment would have been prejudiced; and especially so when one looks at the recent developments... Thus it seemed more advisable for a fresh and independent work to appear."

Not only could Culmann's published approaches be substantially reworked but some of his general methods of presentation seemed to Ritter to be awkward. For example, in his second edition, Culmann had given both geometrical and algebraic methods of solution. Ritter felt this to be redundant and the algebraic treatment to be out of place in a work entitled *Graphic Statics.* Thus did Ritter at age 35 start out in Zurich in Culmann's own spirit of independent thinking and critical judgment, ironically in the form of respectful criticism of Culmann himself.

In his second writing of Culmann, a brief 1903 biographical sketch for the German biographical dictionary, Ritter near the end of his own career reflected on Culmann's influence in the following way ([8], p. 573): "Culmann's method of teaching was not easy to follow. Because of his lively temperament his thoughts often ran ahead of his words. Also his books lacked in many ways the desirable clarity and thoroughness."

But he followed that rather severe judgment by an image which perhaps because it follows a negative critique gains in both credibility and suitability: "He was like the eagle, who draws his circle high over the heads of his students. What his verbal presentation and his written publications lacked, was compensated for by the personal inspiration with which he enlivened his lectures and the warm personal interest which he took in each of his students."

However, mixed the metaphor, Ritter gives the sense of Culmann better than mere superlatives ever could. For Ritter it was much more important to have discovered the inspiration and personality of Culmann than the clarity and thoroughness of his work. Because of Ritter's own clear critique of that work, we are much more sympathetic toward his final eulogy to Culmann; it rings much more truly than it would in an article devoted only to praise: "The gifted mastery of his material, the astounding ease with which he answered the most difficult questions, and the underlying bases of his character–kindness and modesty–gained him the undivided respect and honor of all who sat at his feet."

This is not the uncritical adulation of a loyal assistant, but the human response of one great man to another. Indeed, it is not too far off to state that Ritter, very near the end of his own life, is unconsciously writing his own epitaph and indeed in a way the epitaph of a 19th century engineering education that was, even as Ritter was writing his appraisal of Culmann, already on the wane.

Wilhelm Ritter

Karl Wilhelm Ritter (he dropped his first name very early) was born the fourth of five children on April 14, 1847 in Liestal, a small town just south of Basel, where his father was a teacher in an elementary school for girls [10]. The family came originally from Altstätten on the Swiss Rhine in the canton of St. Gallen. Following school in the Liestal locality he studied at the Basel trade school (*Gewerbeschule,* now called *Realschule*) which in English would today be called a technical, not vocational, high school. In 1865 he entered the Polytechnical School in Zurich, graduating first in a class of 20 civil engineers in 1868.

After a year working on a railroad line in Hungary, he was invited by Culmann to be one of his assistants. After another year he qualified as a *Privatdozent* allowing him to run classes both on structural mechanics to architects and on practical geometry to students preparing to enter the school. Also, he began to help students who were having trouble, as many did, following Culmann's lectures. Then, in 1873, Ritter was called to Riga to become a regular professor, a highly unusual honor for an engineer only 26 years of age. The polytechnical school in Riga had been opened only in 1862 and had quickly become a major institute in

Russia thanks mainly to its German-language base and to its location so near to other Western European centers of industry and education. Because of Culmann's strong international reputation even by 1862, the new school invited one of his former assistants Henri Bessard (1837-1873) to be its first professor of civil engineering. Unfortunately, in the spring of 1873, Bessard fell from a bridge on a inspection trip and died. The Riga school sent back to Culmann for another assistant and he warmly recommended Ritter. In Riga, Ritter had a fine opportunity to develop new teaching ideas, to work on practical problems arising in the rapidly industrializing city of Riga, and to write. He quickly became head of the Civil Engineering Department and editor of the newly-founded engineering journal, *Die Rigasche Industriezeitung,* in which many of his early writings appeared. Between 1873 and 1882 he matured as a major European engineering academic and when the call came from Zurich he was ready, not as an assistant is ready to move into his master's office, but as Culmann himself was ready in 1855, an independent mind ready to take on major responsibilities but in what was by then a well developed school.

Ritter would later reflect that his first years back in Zurich were the best of his life ([10], p. 513): "The scholarly activity of my colleagues spurred me on to a great extent. Scientific study was highly respected here and found its way quickly into practice, while I was looking into questions of structural analysis more and more each year."

Culmann's field of teaching had so broadened by 1881 that he was actually replaced by two professors: Ritter for Graphic Statics and Bridges and Eduard Gerlich (1836-1904), who had been chief engineer for the construction of the Gotthard line, for the fields of Railroad Engineering and Management [11].

Ritter's work therefore focused more on developing the applications to Culmann's graphic statics, on studying structural problems in bridge design, and on a wide range of practical questions for which his advice was sought. His first major books were the two parts of his *Applications of Graphic Statics, The Internal Stresses in Beams,* in 1888 and *Trusses* in 1890. The last two volumes were *Continuous Beams* in 1900 and *Arches* in 1906. The last one he was too sick to complete so his son, engineer Hugo Ritter, completed it for him during the last year of his life [12].

In addition, Wilhelm Ritter wrote three other short books before 1890. One on continuous beams came out in 1871 and was Ritter's work under Culmann. This work was revised and reprinted in 1883 and translated into French in 1886. A second small book appeared in 1879 on tunnel vaulting which was translated into Italian in 1880. A third book on arches appeared in 1886. One further writing of great significance also appeared before 1890, a long article which appeared in the first six issues of the new *Swiss Building Journal* (*Schweizerische Bauzeitung SBZ*) of 1883, on the calculations for stiffened arches and stiffened suspension bridges. This article serves to emphasize the wide compass of Ritter's research and especially his deep inquiry into modern bridge forms.

This inquiry included a three-month trip to the United States in 1893 to visit the Chicago World's Fair and to study American bridges. In 1895, Ritter's book, *The Bridges of the United States,* appeared and his lectures in 1893-1894 were greatly enlivened as a result of this tour [13].

Meanwhile, Ritter did a wide variety of consulting work as well as study the full-scale load testing of completed bridges. In 1885 he became a member of the Zurich city building council. He was by the late 1880s so well known beyond Switzerland that in 1889 he received an offer from the prestigious Technical University in Munich, which he declined "out of love for the Polytechnical School and for his country" ([10], p. 516). The Federal Council, out of gratitude, granted him a lifetime appointment and the city of Zurich gave him and his family citizenship in that city as a token of their thanks. These were unusual honors for an engineering professor, and they seemed to express the nation's pride in their new school and the place it now held in European circles.

Ritter made a deep personal impression on his students and associates. He was a family man, known by his students for his hospitality. His wife was American, a Miss Jacoby from Boston, whom he met on a visit home from Riga in the summer of 1874. They had five children in whose early education Ritter played an important role, including personally teaching his sons how to do engineering drawing. Graphics even in the home.

Personally, Ritter possessed sensitive feelings. When one of his good friends died from a fall at the Sanetsch pass, Ritter gave up such high mountain hiking and his grief kept him in a state of sorrow for weeks on end. At such times his main solace was in music. He was a fine pianist and could play melancholy music with great feeling at moments of crisis.

He was also deeply religious, a devoted member of the Methodist church. At the same time, he understood and respected the beliefs of others. He was noted for his fairness and for his unwillingness to speak against anyone behind his back. He liked to say that he worked for knowledge and not for money.

In 1887 he was made the Director of the Polytechnical School, just as had Culmann 15 years before, and he remained in this position until 1891. Between 1896 and 1898 he was President of the Zurich Natural Science Research Organization and in 1898 the University of Zurich awarded him an honorary Doctor's degree. Ritter was much honored and had great talents, but his susceptibility to deep feelings almost depressions, seem to have been connected with the onset of a nervous agitation that began to make work difficult for him after the turn of the century. In the spring of 1902, the sickness forced him to give up work and plunged him into deep melancholy. He went from Locarno, to Albisbrunn, and to Spiez for rest. Finally in the spring and summer of 1904 he taught again but the effort was too demanding. He went into a sanatorium in Küssnacht until March 1905. He then moved to the Asyl Remismühle where he died on October 18, 1906.

Ritter's death concluded a half-century tradition of structural engineering education in Zurich which was to produce over the next half century at least two men who can be called the two most outstanding bridge designers of the 20th century; one in concrete and one in steel. Their general interest in bridges and much of their later works with special forms can be easily traced to the Zurich tradition and especially to the ideas of Wilhelm Ritter.

Ideas of Ritter

Ritter's ideas, like those of Culmann followed from local field experience, from international study travel, and from individual research which emphasized visual methods of analysis. These three components of a career permitted, in more general terms, a type of teaching which included first hand experience with structures in the natural environment, a wide variety of structural images drawn from the results of building in different social settings, and a type of scholarship in which the teacher alone worked out a new approach to older ideas. This new approach needed to be one that rose directly from design practice but was systematic and general enough to be of basic value to students throughout their entire careers. Such was the continuation of the Culmann tradition through Ritter and such was the intellectual context within which Maillart and Ammann learned structural engineering between 1890-1894 and 1898-1902, respectively.

To look in more detail at that context I shall take up three of Ritter's writings to give a sense of his approach: the first, about the value of first-hand field experience, the second, about international study, and the third, demonstrating Ritter's research insight into structural behavior.

On April 9, 1892, there appeared in the *Bauzeitung* a short note which argued that full-scale load tests on steel bridges were not only worthless but possibly even misleading. A lively debate followed, ending on July 9 with a brief report [14] of the opinion of Professor Franz Engesser from Karlsruhe who "protested against the situation in which load tests even on little structures of 2 meter span will be widely made, because such experiences are not only useless but also are actually detrimental since through them time, energy, and money are squandered and operations are blocked and endangered."

In the next issue, Ritter wrote a detailed defense of what had become the common Swiss practice of full-scale load testing [15]. In effect he presented a Swiss position at odds with a German one. In a broader sense, he reflected a more pragmatic and balanced attitude towards understanding structural behavior against a more theoretical and dogmatic approach which emphasized analysis. It would be wrong to overgeneralize this distinction; but in so far as one can characterize national attitudes, the Swiss tended to be less certain of the emerging mathematical theories in engineering and more open to the need for visual demonstrations of performance. The difference between Engesser, a distinguished German professor, and Ritter on this bridge question was primarily a difference in attitude and philosophy.

What Ritter presented was the viewpoint that public works set in a difficult environment are always built within uncertainty. There was no way in the late 19th century to predict mathematically the full response of a public structure; and in spite of many new mathematical theories, detailed text books, and immense computer power, the same condition exists in the late 20th century. The validity of any work rests, as Ritter emphasized near the end of his article, with "the probing expert" who must give "a reliable judgment." In short, it always rests finally on the judgment of a person and not on the solution to an equation.

Thus, for Ritter the first-hand field experience so useful to the engineer was to be gained partly through full-scale load tests. Unlike Culmann, he did not have extensive field experience himself; his early brilliance led him too soon into a professor's chair for that. But by way of a satisfactory replacement he put high value on the experience he got from those load tests. This tradition played a central role in Maillart's career because it allowed him to prove to the profession not only that his radically slender designs were safe, but even more importantly, that his radically simple methods of analysis were correct. It is not too much to state that Ritter's defense of such field experiences, against the German objections, allowed structures to be built for which complex and so-called more rigorous analyses would have obscured the design potentials.

Ritter applied this attitude directly to Maillart's first major design, the Zuoz bridge, for which Ritter could not provide, as consultant in 1901, a satisfactory mathematical analysis. Thus he directed and interpreted the full-scale load test which proved the validity of Maillart's simple calculations. It seems equally true that no such bridges were built in Germany during this period at least in part because of the unwillingness of persons like Engesser to abandon their central reliance on mathematical calculations.

The second aspect of Ritter's ideas, the one relating more to widening of the engineer's horizons, was illustrated by his trip to the United States, as reported in his 1895 book and in numerous articles in the *Bauzeitung*. These articles showed Ritter's breadth of view. They ranged from sketches of the Chicago Columbian Exposition itself, to reports on Chicago bascule bridges, to a study on engineering education in the United States, and finally to a report on bridges over the whole country [16].

The book itself was devoted to wood and metal bridges; the heading "Eiserne Brücken" includes both iron and steel bridges even though the proper translation of *Eiserne* is iron and the word for steel is *Stahl*.

Ritter was surprised that so little on bridges was exhibited at the Chicago World's Fair. As he reported, "with all its expanse and plentifulness, the Fair offered relatively little information on bridge structures in the United States" ([13], p. 3). Ritter, knowing the spectacular bridge works completed in the United States since the Civil War, assumed that such world leadership would be proudly displayed. Instead, the Fair represented much more the American romance with the machine that would so startle Henry Adams (1838-1918) and set off his contemplation of its potentially destructive force [17].

For Ritter, the structures were the main consideration and to examine them he had to travel throughout the country.

The book said little about his travels but did give a clear picture of what interested him: the wide variety of overall forms, the broad use of certain non-European details, and in relatively complete and elegant plates, a few bridge plans. In short, a broad view of forms, a description of new details, and the relatively complete technical picture of a few selected bridges. This is just the combination of insights that most intrigues the design-oriented student. Such a student is genuinely excited to see the wide visual variety of forms that have already been used to solve what is essentially the same set of problems.

Ritter did not hesitate to introduce esthetic judgments as, for example, in describing the high bridge built in 1888-1889 over the Mississipi River at St. Paul ([13], p. 52). "The structure, in spite of its extraordinary size, makes a rather insipid impression; it leads us to realize that esthetic ideas must have been fully withdrawn in favor of some utilitarian principles."

He went on to note that American tendencies to avoid complex analyses and to think only of utility rather than beauty had worked against the frequent use of arches, a point he illustrated with the Eads bridge of 1874 and its three-arch spans across the Mississippi at St. Louis. Ritter noted that because of its many difficulties, including very high cost, the bridge did not encourage Americans to use such arches. Ritter did, however, show the much less costly and still striking 1889 Washington bridge over the Harlem river in New York with its two-arch spans. Also included was a concise summary of American suspension bridges ending with a sketch of Lindenthal's proposal for a Hudson river crossing ([13], p. 63). This is the last text figure and a fittingly prophetic one, since one of Ritter's last students, Othmar Ammann, would go to the United States and begin his spectacular bridge career by designing the George Washington bridge that would, 36 years later, cross that river.

As every bridge designer knows, however, overall form means nothing if the details are not well done. All the pieces must fit together and none must be structurally weak. To the watch-making Swiss, details are an esthetic part of design because they require great care. About one third of the entire text and illustrations in Ritter's book were given over to a detailed review of joints, connections, eyebars, and rivets. Many of the drawings are elegant and Ritter criticized others as not elegant. He proceeded from overall form to detail and emphasized both.

The final part of his book consisted of 12 plates each giving the full details and overall form for individual bridges: three wooden bridges and the rest metal bridges, of which one was a plate-girder bridge, one a suspension bridge, one a cantilever, and the others truss bridges.

Overall Ritter's book was a unique work in the Culmann tradition, and Maillart's notes reflected his teacher's international study. Almost certainly this American focus stimulated Ammann as well and helped him decide to make his career in the United States. But Ritter's writings were far more significant than the two preceding examples might imply. A defense of load testing and a report on a study trip are very different from the type of solitary research needed for the numerous papers and books that Ritter published during his lifetime. One example of such a piece of research illustrates the high quality of his mind as well as his taste for simplicity and elegance in calculations.

In 1877 he had first written about stiffened suspension bridges. Then in 1883 he published a major article expanding that subject and introducing advanced ideas on the analysis for both suspension bridges and arch bridges [18].

This article probably represents as clear a study of suspension bridge design as any in the 19th century. It did not develop the deflection theory, credited to Josef Melan and first published 5 years after Ritter's article [19]. Its historical interest today is not for its presentation of a new analysis but rather for its elegant simplicity, its design ideas, and its essential correctness. It is correct in the sense that for the scale of the bridge illustrated in his paper even today Ritter's method of analysis would be a reasonable basis for design; the deflection theory became important only for longer spans.

In the late 20th century it has become common practice to read only the most recent works on any technical subject, the earlier ones being taken as outdated, like old machinery. But like some old bridges a few early articles on structural analysis and design retain their usefulness when they reflect the mind of a masterful teacher. Such is Hardy Cross' 1932 article on moment distribution [20] and such was Ritter's 1883 article on suspension bridges.

The paper begins with a clear statement of intention. Ritter referred to his 1877 paper, identified its omissions and stated that "the following development has the goal of making up for the earlier omissions; at the same time the essential thing will be to present that earlier work in as concise a way as possible for the reader who is unfamilar with it."

The paper is thus self-contained and written for a broad not a narrowly specialized audience.

He next emphasized that since the theory of elasticity must be used, complicated formulations result and thus "one is compelled to make simplifying assumption."

In fact his whole presentation avoids even calculus and yet it presents a sound analysis.

He then gives the theory of the beam-stiffened arch in just the simple, elegant and practical form that Maillart would use 40 years later to create his strikingly thin deck-stiffened arch bridges. Indeed, Ritter not only gives a simplified analysis method but he also considers the design implications: "the stiffer the beam and the more flexible the arch the greater the bending moment in the beam and the less in the arch."

Taking such simple ideas, he next applies them to the suspension bridge where the ratio of the horizontal truss stiffness to the cable stiffness determines how much bending goes into the truss. Ritter developed these stiffnesses by calculating separately the vertical deflections of the cable and of the stiffening truss under unit loadings, setting the deflections equal because the suspenders tie the two parts together, and thus determining the load carried by the truss and that carried by the cable. This is just the type of simple idea that Ammann would use about 60 years later to develop his stiffness index for modern suspension bridges [21].

Ritter's article is liberally illustrated with diagrams, some drawing on graphic statics, and his equations are always simple. Where they involve more than a few terms, he puts non-dimensional terms in tables for easier use.

Near the end he gives a fully worked-out example for an actual 57 meter span suspension footbridge in Switzerland. Following that comes a section on approximations that provide a reasonable basis for preliminary design as long as the final design is analyzed by the more exact procedure he has already given. At the end he gives a review of practical problems, such as construction sequence and trusses of variable section, and how they relate to the design.

In summary Ritter was doing research but writing the results for the designer not for other researchers. He was seeking to clarify the behavior of structures rather than to develop methods of analysis. Finally he used examples of actual

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structures with which to illustrate numerically his ideas and he considered construction questions along with those of analysis.

One further characteristic of Ritter's was his modesty and concern for clarifying and simplifying. In a footnote Ritter observed that Professor A. Ritter (no relationship) in a recent book has given essentially the same suspension bridge theory but that it was not clearly enough presented to be easily useful.

An old metaphor strikes one as useful in describing Ritter's influence. In his approach to his students' education, he stands very much as a bridge does in its environment. As an educator, carrying students for only small fractions of their lives, he was yet an essential link between their past inborn talents and their relatively long future careers. As a teacher, he communicated the recent tradition of his country and of his profession through the specific objects about which he lectured. Finally, as a writer, he took scientific formulations and shaped them with as little complexity as possible into simple clear ideas so that his students would see better the design potentials. He was not a designer, although he taught from designs; he was not a public official, although he taught public works; he was not a natural scientist, although he worked with science to reduce general formulations to specific applications. He thus stood at conjunctions and let the students pass on. He did not become in any way either a competitor to them by having a design office or a master of them by having a design ideology.

He was the essential link between the awkward and sometime unclear theories of Culmann and the elegant clarity of the late works of Maillart and Ammann. He was an interpreter of technical events: to his students through his lectures, to the profession through his writings, and to the public officials through his detailed consultant studies that led to Swiss codes for both metal structures and works of reinforced concrete [22].

Ritter's name has nearly been lost and his style of teaching and research has been out of fashion for years, but he touched students, of whom Maillart and Ammann were only the most spectacular examples.

It is thus that the occasion of honoring great designers like Maillart and Ammann has led for once to the question of how education influences practice. With these two it seems clear that Wilhelm Ritter played a significant role. More generally what the example of Ritter may stand for is a rethinking of education in structural engineering which considers the need for teaching and research that includes close contact with field experience, wide knowledge of international structures, and solitary individual writing that interprets new ideas for the profession in a practical and clear manner. The Culmann-Ritter tradition cannot be duplicated but it can stimulate education for the future.

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Comportement dans le temps et aptitude au service

par Renaud Favre, Lausanne

1. Introduction

L'étude et la vérification de l'aptitude au service sont devenues primordiales dans la conception des structures. Comme le béton subit des déformations à long terme par suite de son retrait et de son fluage, son comportement dans le temps doit être connu, ou du moins estimé, et introduit dans les raisonnements qui permettent de réaliser un bon projet d'ouvrages en béton armé ou précontraint.

Il est évident que la prise en compte du comportement dans le temps du béton se heurte à bien des réticences de la part de l'ingénieur de la pratique. Il se voit confronté avec suffisamment de problèmes dans l'accomplissement de son dur mais passionnant métier pour ne pas être très enclin à de nouvelles démarches. Il lui sera néanmoins utile de réfléchir à la pondération de ses efforts. Souvent, il y a en effet lieu de réduire la minutie de certaines vérifications au profit d'autres. Souvent, les critères à la base des choix intervenant dans un projet sont à revoir. Si on prend à titre d'exemple le nouveau pont qui va relier La Rochelle à l'île de Ré en France, l'aptitude au service ne sera que très modestement influencée par les charges concentrées du trafic prescrites par les normes, mais beaucoup plus par l'environnement marin, les chocs probables de bateaux, le comportement des fondations et du tablier à long terme.

L'ingénieur attribue souvent le fluage au béton et la relaxation à l'acier (de précontrainte). Or, fluage et relaxation sont des phénomènes liés de sorte qu'il y a également relaxation pour le béton et fluage pour l'acier.

Rappelons que la fonction relaxation r représente l'évolution de la contrainte dans le temps sous déformation unitaire constante $\varepsilon_o = 1$ (fig. 1):

$$r(t,t_o) = E_o \cdot \left(1 + \frac{\Delta\sigma_r}{\sigma_o}\right) = \frac{\sigma(t,t_o)}{\varepsilon_o}$$

La solution de l'équation intégrale dite de Volterra

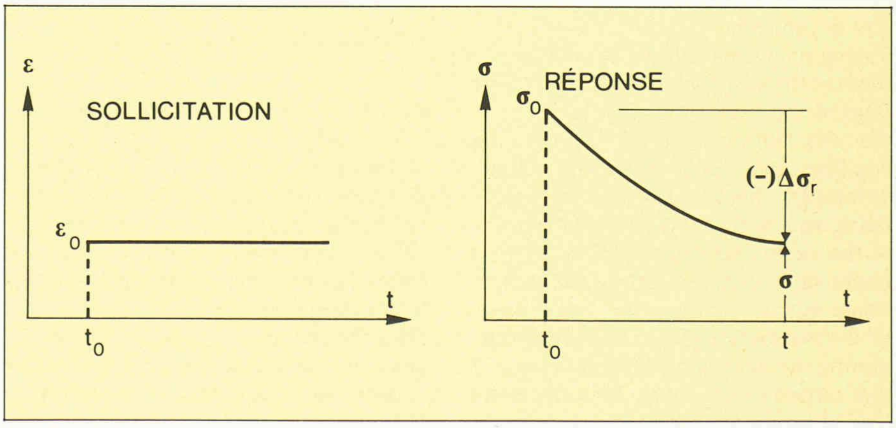

Fig. 1. — Relaxation.