Interview with Princeton University Professor David Billington for Program Three: "Bridging New York"

Note: This transcript is from a videotaped interview for the "Bridging New York" segment of "Great Projects." It has been edited lightly for readability.

David Billington (DB): It's a curious fact that at least the three leading bridge designers in our tradition in America were immigrants from German-speaking countries: Roebling, John Roebling then, in 1831, Gustav Lindenthal, who came over in 1875, and Othmar Ammann in 1904. And a major reason for that, I think, is their educational system. The fact that, at least in Roebling's case and in Ammann's case, they were trained in the very best engineering schools at the time. Those schools also, particularly in Ammann's case, emphasized strongly the study of completed structures rather than just merely the tools of analysis, as so often happens in engineering schools. And so when, during Ammann's education his head was filled with images of all kinds of structures and, therefore, he came with a strong urge to design large-scale works. So did Roebling.

DB: What they found when they came to this country, these immigrant engineers, in fact in a way what drew them to the country in the first place was the wide expanse of the country which meant the wide or the great possibilities in building. And in the sense of New York City, for example, this river, the Hudson River, which was an extraordinarily wide river close to a major city. So that this was a great challenge. Ammann had seen in his, from his teacher the earliest serious design of that by Gustav Lindenthal and this kind of huge project, far in excess of anything one would need in Europe, drew engineers to this country. Also one has to say that the political situation had an influence, particularly in Germany, all the disruptions in 1831. It's no accident that Roebling came in 1831, the year of revolutions in Europe, that other engineers came in 1848, and that they were leaving a politically unstable situation where it was difficult to build large works and where they were not often appreciated and also, in Roebling's case, where the actual political climate of constriction, bureaucratic control was offensive to him.

DB: Well, of course, in this country the engineering profession, particularly in the 19th century, was not very well established as a fixed profession as it was in Europe, particularly in Germany and Switzerland and France, where engineering schools had become quite powerful already in the first half of the 19th century and where the bureaucracy of the profession was quite strong. In America it was much freer. A lot of the engineers never went to school. They worked their way up out of the field and they were, therefore, more attuned to the practical matters of how things get built and also to the visuary matters of building things that had never been contemplated before.

DB: New York City, as a magnet for engineers, begins, I think, with Jervis and the High Bridge bringing water into the city, the first and most essential ingredient in any city, pure water. But the era of big bridges, starting with the Brooklyn Bridge, marks the true beginning of New York as a world city and as a city of great bridges. This is because of the intense population concentration between the near Long Island and Manhattan Island. And that concentration was separated by a fairly substantial waterway. This was a great

challenge to bridge builders: how do you get across that waterway? It certainly stimulated Roebling and really provided him with a kind of, with a vision of the possibilities for, in effect, restructuring the whole country, as he wrote, most romantically, late in his life. So that was the first, in a way you might say the first great challenge to bridge builders, was the East River. And by 1909, it had the three longest spanning bridges in the country. So that it became, in a way, the standard against which all bridge builders thought about their designs. Also it didn't hurt a bit that the Brooklyn Bridge came along just as the American Society of Civil Engineers was reforming itself after the Civil War, and its first volumes in the 1870s had many articles dealing with the bridge. So that it began to work its way into the consciousness of the profession, again, as a kind of a benchmark, a kind of a standard against which people thought about large-scale building.

DB: The direct influence of the Brooklyn Bridge, of course, is what John Roebling had foreseen, namely, it connected the civic centers of Brooklyn and Manhattan and then led, led to the direct incorporation of Brooklyn into New York City. Originally it was the third largest city in the country and New York being the first largest. Then in the 1890s, just a decade after the Bridge opened, Brooklyn became part of New York City. So that was a, that was a direct influence of the Bridge itself.

DB: Well, the engineering, the engineers, of course, were drawn to this work and they were, the engineers in fact were in New York City already and it was already an important city, and that was in part due to the railroads, which had nothing to do with the Bridge, but the, bridge itself provided a home for engineers who later then became important in the profession. Roebling's assistants, those people who had worked on the building of the Bridge, all were, but I don't think it's fair to say that the Bridge itself was the cutting point in the actual profession in New York.

DB: It's always inspired engineers. Brooklyn Bridge has always had that influence. It was perhaps lost from the, the scene for a short while, but you only have to read what Ammann wrote and how Ammann felt in the early '20s to realize how much of a model the Brooklyn Bridge was for him once he had gotten to America and begun to practice in this country and then in New York City or around New York City. So there's a clear heredity there.

DB: Ammann begins to write articles in the early '20s that deal with the history of bridge design and which present a summary of major bridges mostly in the United States. It's rather clear that what he's really doing is preparing the groundwork for his George Washington Bridge design. And in these articles, Brooklyn Bridge always plays a role. It's a model for him. It's an idea. He's fascinated by the proportions of the Bridge, by the way in which the stone towers and the very slender deck react to, or impress upon the viewer this contrast between the ancient and the modern, between what might almost be called architecture and engineering. These are things that touch Ammann because up to this time he has not been so involved in thinking about designing his own bridges, at least not publicly. He'd been working for Lindenthal. He'd been a key person on the Hell Gate Bridge, but he had not really himself tried to think out ideas about bridge design.

And so the historical exercise of looking at past works provided him with the inspiration to think out from scratch his own ideas, which resulted, first, in the George Washington Bridge and then, of course, in the whole series of bridges which we know so well, right up to the Verrazano.

DB: These bridges in the late 19th and early 20th century reflect and in a way symbolize the emerging dominance of the United States as the world's leading industrial nation. That begins with the great steel industry that began to appear after the Civil War. It includes the Port of New York and its great commercial trading wealth. It also includes the attraction of this country to some of the most talented people from abroad. These factors all combined to create a, a nation of immense industrial wealth. Only such nations can afford to build these huge structures, structures that far exceed the capacity of the size of ones done elsewhere. And, therefore, starting with the Brooklyn Bridge and really ending with the Verrazano Bridge, America dominated not just in bridges but in its industrial might. The bridges characterized that because of the, the daring and the vision that they required, not just the daring and the vision of the engineers either, but the engineers had to convince the general public mostly through civic leaders and through politicians, that such things were not only possible but desirable.

DB: The engineers themselves gained a great confidence. Somebody like Roebling, of course, was born with a sense of supreme confidence. And in a way the best of these engineers did possess a kind of internal security of their own vision that their education helped them to build that, but they still possessed it. It was a characteristic of their personalities. Ammann was a particularly good example of that and a kind of internal stability and ability to, to think on his own and to push his own ideas.

DB: These engineers helped to build the attitude in the country during the late 19th and early 20th century of the greatness of engineers. There were, for example, in the 1920s a series of movies in which engineers were portrayed as the heroes, builders, people like Ronald Coleman striding across the plains building dams and bridges and it was a time of the heroic engineer. Ammann, Roebling helped to provide models for that, although not directly so. They did not become movie stars or they did not become even the object of movies, although one could have made a wonderful movie out of Roebling and I believe also out of Ammann. Still, they were part of the culture of the country, which saw engineering as the way to solve most of the problems that arose in this big, uncoordinated, disconnected continent.

DB: These great bridges were, clearly, we see them today as symbols of both of their time and of our time. When they were first completed, however, they were accepted in a slightly different way. They were seen, of course, as great technological marvels which were coming one after another at this time. Don't forget that Brooklyn Bridge opened just exactly at the time that Wall Street was being lit by the systems of Thomas Edison. So that there were these marvels that were arriving and people flocked to them.

DB: These bridges are certainly an integral part of the culture of New York City. And when people began to think, after they were completed, about the meaning of the city

and, through that, the meaning of our society, the bridges became part of that description, part of that understanding. And in the 1920s, for example, when the country was searching for a usable past, as they called it, critics and poets and painters, writers in New York City focused on, among other things, the great Brooklyn Bridge. And they focused on it because they saw it as prototypically American and as prototypically urban and also as a symbol of industrialization, all of those issues which were providing the culture with so much hope, particularly in the '20s, in the early '20s, and following the end of the "war to end all wars," and also giving these people a sense that a bridge or a work of technology was not just a utilitarian object, but also something that would be part of the more traditional view of culture, namely, a work of art.

DB: Beginning in the early 1820s, the suspension bridge became this major form for long-span bridges. And the reason is very simple, because a bridge, which is a horizontal member that must carry vertical loads, would be, can be very heavy and if it gets very heavy, then all of the material is used just to carry the dead load and nothing is left for the live load. In the case of a suspension bridge, that thin cable stretched between the towers is able to carry these vertical loads by its single tension force. You just imagine you have a string and you put the weights on a string. The cable automatically takes the shape which will carry those loads with a minimum of need for materials. Once you have the minimum amount of materials, that means you have strength left over to carry loads across, which is the whole purpose of the bridge: to carry carriages originally and then trucks and trains and cars. So the suspension bridge became, starting with Thomas Telford's Menai Straits Bridge, which is really the break in bridge design, that's the first major long-span bridge in the world and it's the one to which Roebling always referred himself and Ammann, too. And so, starting with that, these bridges became, therefore, the ideal for engineers for long spans. And so that when one approached these relatively long-span situations, the East River, to begin with, and then the Hudson River, it was natural to think in terms of suspension bridges.

DB: The problem with suspension bridges has always been, and is today, the fact that they are ideal for their dead weight, that is to say they reduce the dead weight greatly, but they are susceptible to various kinds of live loads, various kinds of transient or loads that come on and off. They are perfect, if we hang the weights from it, they give a perfect shape for one set of loads, and usually it's a dead load or a live load uniformly distributed. On the other hand, if you have the live load over only half the bridge or if you suddenly have gusts of winds coming to the bridge, it can be very flexible and susceptible to large movements. And so the problem, starting with the Menai Straits Bridge, was always how do you first get this very light shape to begin with and then how do you prevent that light shape from being transformed into a moving bridge under its various live loads? And Roebling provided one solution with the Brooklyn Bridge and earlier bridges, but most clearly seen in the Brooklyn Bridge, by using these diagonal stays that come down and give that bridge its webbed look. So that that provided a stiffness against these possible oscillations. And Roebling's bridges were, by and large, successful because of that. So the modern bridges had to, had to take up that problem with much greater and greater live loads coming on them.

DB: It was the Industrial Revolution and the development in Britain in the late 18th century of inexpensive iron that allowed the building of bridges in an entirely new way: first, by means of arches which are carrying loads by compression. That means that the vertical loads in the arch are transformed into squeezes, into a force on the arch metal, which squeezes it together. So the load tends to make the arch shorter. The danger with that is that when you take a thin piece of metal and you put a load on the top of it to squeeze it together, long before it will crush, the material will buckle outwards, take a new shape. That means that arch bridges have to be braced carefully or they will buckle. And there have been some dramatic failures of such buckled members. Suspension bridges, on the other hand, do the reverse. Instead of carrying the loads by compression, they carry the loads by tension, which is the same thing as if we have our column now and, instead of squeezing it, we catch it at the top and put a weight on the bottom and we stretch it. So that's pure tension. The idea of the compression bridge, of the suspension bridge is to carry the loads by this pure tension. That does not need any bracing. Therefore, because the steel or the metal will therefore not buckle under pure tension, it is the ideal way to load a metal structure.

DB: The great advantage of a suspension bridge is that you can take very large loads by means of very small amounts of material. And since the material is now in tension, the cable is in tension, you can reach the full strength of the member without any change in its geometry. It just simply stretches. On the other hand, if you have it in compression, when you try to squeeze it together it's very likely to buckle outwards and, therefore, fail long before it reaches its full strength, which means that in compression members such as arches, one needs to have two members braced together or, as we can see, we see in the Bayonne Bridge or the Hell Gate Bridge, a top and a bottom chord with a lot of bracing in between. So that has the advantage of extra stiffness, of course, but it uses a lot more material and, therefore, restricts the span of arches compared to suspension bridges. And one must also say that in the imagination of the engineer, the suspension bridge has always appealed visually, that, starting with Telford and including Roebling and coming up to Ammann and other great designers like Steinman, the appeal of suspension bridge was this flat graceful curve that seemed to be carrying these loads with almost no effort at all, carrying them to the, the strong towers and anchorages. Arches can be very elegant, too, but the long-span arches do need to be braced and, therefore, have an appearance which is quite different, and hasn't had the same effect on engineers as had the suspension bridge.

DB: Well, certainly the most famous of all the quotes of Montgomery Schuyler, our first real critic of structures and bridges, he was impressed immediately by this "aerial bow," as he called it, just lighting the sky going across the river in this, yes, effortless way. And so that was a, struck him and he was the most articulate spokesman for the day. It surely struck a lot of people that way, no question about it, right up to the marvelous poetry of Hart Crane in the '20s.

DB: The Hell Gate Bridge was certainly a milestone in bridge design in the United States. It was designed by the man who is probably the greatest bridge designer between Roebling and Ammann. The bridge is creature of its time, but it's also of its designer. It's

impossible for me, anyway, to think about that bridge apart from both the time at which it was conceived in the early 20th century and the man who did it. So that in thinking about these kinds of works, we have these two coordinates that come together. The man, of course, is a product of his time in some sense, but still he's outside of it a little bit. So that Lindenthal's ideas arose out of a climate in late 19th and early 20th century when the railroad was building a large number of bridges following on a period in the middle of the century when there had been a great number of failures. And so the railroads became quite conservative, and understandably so. And the idea of a railroad bridge was to be something that was permanent, something that looked permanent, that looked solid and, nevertheless, would carry the loads with some degree of economy. So in that climate, Lindenthal himself, looking at what had been done throughout the country with bridge design, was repelled by many of the ugly truss-like forms that had appeared in which there was, as Ammann's teacher Wilhelm Ritter said, "no thoughts to the appearance." So it was in this light that Lindenthal approached this great project, this 1,000-foot, almost 1,000-foot span, arch bridge in 1907 or 1908 when he began seriously his design. What he did that was different from Roebling and would turn out to be different from what Ammann was to do, is Lindenthal made a separation in his mind between the technical design and the esthetic design.

DB: And this separation was symbolized by the hiring of Henry Hornbostel to make the esthetic design, whereas he, Lindenthal, would make the physical or the technical design. That's the principle defect of the Hell Gate Bridge, is the fact that there is this dichotomy between the utilitarian side of it and the esthetic side of it. And the dichotomy shows up most clearly in the form of the arch and in the great towers at either end of the arch, because the arch looks like it gets deeper, the two chords get further apart as you get close to the support, when, of course, all the loads are gradually being taken only by the lower chord. By the same token, the tower themselves, the towers themselves, which are then, in a way, esthetically necessary, in Hornbostel's view, because they must contain this widening arch, are, of course, carrying nothing. They are simply applying dead weight to the foundations. And so all of this could be scooped away and one would be left, for example, if one wants to build an arch such as the Hell Gate in which the two supports are actually hinges, in other words, actually reduce almost to vanishing points instead of being, giving the impression of being heavy, one would then lead, that would lead one to the great arches of Gustave Eiffel, in which this form is so elegantly expressed in the Massif Central of France or in the bridge over the, over the Douro River at Oporto.

DB: The Hell Gate Bridge is characteristic of a, a work in which there is a fundamental confusion of values. Compare it, for example, to Penn Station, built just before that and really part of the same project in a way. … [A] building like that the architectural vision is absolutely essential, the engineering is important, but the architectural vision is central, whereas a bridge it's the other way around. The engineering vision is central and architectural decoration is really quite irrelevant. So that's the basic problem I see with this work and which prevents it from being a great work of structural art. At the same time, it was built at just the time that the railroad was beginning to lose its dominant position as the transport--main transportation mode of the nation. And it is rather characteristic at times that people build such things when their golden era, so to speak, is

over, or least is beginning to wane. So this is a kind of a monument to the end of the Railroad Age in a certain sense, and we'll see later on with bridges of Ammann how gradually Ammann moves away from that esthetic. Even though it still has a strong impression on him, made a strong impression on him, as it did on many people, but at the same time he feels the need, because of the new mode of transportation, the automobile, because of this real transformation that is beginning to take place in the country in the 1920s, that he must move away from that kind of a vision and to one that it reflects the lighter, more mobile, more decentralized image of the automobile.

DB: The bridge is a very important training ground for Ammann. He, first of all--and this is so crucial to understanding these things--he, first of all, takes with him the sense that a bridge has to be very, very carefully worked out. And he does that in the Hell Gate Bridge. His prizewinning article is a demonstration of engineering of some of the best engineering that's ever been done. So that is the ground of all engineering. Without that, no pretty pictures, no renderings mean anything. So he takes that, first of all, with him. The second thing he takes with him is the importance of how something looks. And surely Lindenthal influenced him there because Lindenthal was deeply concerned about that.

DB: Lindenthal, in the 1920s, was clearly the senior bridge engineer in the country. He had created a series of major bridges, beginning with the Smithfield Bridge in 1883 and coming up to the Hell Gate and this, and the great truss bridge over by the Ohio River. These were major designs, which, all of which received awards from the American Society of Civil Engineers. He was not a bureaucratic person in the sense that he was not an officer of the American Society of Civil Engineers. He wasn't active in that sense, but he was certainly revered, and his technical competence was beyond dispute. Therefore, it was of great value for Ammann to have worked with him, but all great bridge designers need to work to some extent alone. To be in the shadow of Lindenthal would not have led Ammann, I believe, to his great works. Therefore, a break was essential regardless of what the means for it would have been. It's perhaps possible to conceive of Ammann never having left Lindenthal and staying with him in some sense, and then it seems possible that he would not have created his great works. So the chance to do that was of great benefit for Ammann. It was also personally quite difficult for him because he had originally hoped to talk Lindenthal into a quite different design for the Hudson River, or the North River crossing. It was Ammann who saw clearly that the bridge had to be lighter and more focused on automobiles and less on railroads. And Lindenthal was essentially tackling an almost impossible problem: designing a suspension bridge for railroad traffic. Now, of course, it's technologically conceivable that one can do that. Roebling had done it with his Niagara River Bridge, but, of course, the trains had to go exceptionally slowly, 3 to 5 miles an hour across. It was not a reasonable modern solution, although it was a reasonable solution in Roebling's day. But since that time nobody had succeeded in doing that in a major bridge, so Lindenthal was fighting a difficult problem right from the start. And it, I think, took Ammann a while to realize that it was impossible for Lindenthal's vision to actually, to succeed. So that this break was difficult for Ammann and yet, I believe, it was essential.

DB: Ammann himself agonized over it and particularly difficult for him was the fact that he had no real job. He didn't go immediately with some commission in hand, as many people do when they start a new business. He had nothing, and so it was really a risk for him and this made it unusually difficult, I think.

DB: Ammann's proposal is the first major bridge to be built essentially for automobiles. In his original designs, of course, he did include the idea of a second deck for rapid transit. And that was the standard way at the time. The Manhattan Bridge, the Delaware Memorial Bridge, now the Ben Franklin Bridge, had been conceived that way, but in both of those designs the idea of automobiles as the primary vehicle, or automobiles and trucks as the primary vehicles, was not yet fully addressed. And it was Ammann who, as far as we can tell, was the first person seriously to address that problem, what should be the proper loading on a bridge, which has just cars and trucks. So he made a careful study of this and it was on this basis that he determined that it was reasonable to use what seemed to the profession at the time, or at least seemed to those who looked at the profession at the time, to have been quite a daringly low load. And yet today we now accept that load as being the reasonable one for all bridges.

DB: It was a certain leap for Ammann to take to move to this very much lighter bridge when his boss, Lindenthal, was so committed to a heavy bridge focused on railroad traffic. Ammann began to see in the early '20s that that was not a practical solution, that it was far too expensive, that it was in the wrong location because it would disrupt the city streets to build this huge bridge with big approaches, dumping all kinds of traffic into the middle of the city. So it was a dramatic and daring idea and it goes together with what was happening at the Port Authority, because the Port Authority had been constituted to solve the railroad problem. And in the early '20s, it was grappling with that problem unsuccessfully. And so there's an element, one might say, of the right person at the right time, in this case, but Ammann saw clearly that that was the case. And at the same time there's another factor here which can't be neglected, and that is that as the more Ammann thought about the impracticality of the Lindenthal design and the more he tried to think of what would be a practical design, the more he became emotionally attached to this new form that he saw possible, this lighter, more elegant form. And it was this emotional attachment which, I am convinced, was behind what he then did.

DB: So it was not so much a clear, careful traffic analysis or a rational understanding of how cars were going to take over railroads. Very few people could see that at that time and the railroads were still very powerful. Cars were still mucking around in unpaved roads. They were still a novelty in the early '20s. So I think that the most important thing for Ammann was the fact that here was a new project of unprecedented size that he could do himself and that it would be not just utilitarian, but beautiful. So I think that was, in a way, driving all of these other issues, but coming from the tradition of Lindenthal and engineering, that is inseparable of very careful analysis of everything you could think of. He made analysis that discussed the traffic questions, the economic questions, the technological questions. All of those were important, so it was not just this emotional wish to do it that was there, and I believe very important, but along with that comes this long experience because, after all, Ammann was by now not a young man.

He had already had lots of experience and was coming with that. And that combination of the experience, the sensitivity to detail working out of an engineering project, combined with the emotional charge of a new form of great elegance that is what carries engineers out into the risky world of entrepreneurial behavior.

DB: It seems out of character for Ammann to have taken on the role of entrepreneur selling his bridge, but that's in character for the greatest engineers. Roebling was, of course, an entrepreneur in getting the Brooklyn Bridge. He worked with the politicians. He worked with the civic leaders. Lindenthal was also an entrepreneur in trying to get his great projects accepted and built. And so this carries through. It's just that the profession and the general public had this image of engineering as a kind of a dry subject, purely technologically oriented, not realizing the emotional charge that is necessary for these great works to come into being. So it is, it is consistent with past engineers who have been successful in this kind of work. There are plenty of engineers who are successful in doing other things, but in succeeding in getting these major works, these major innovations through, they really must turn to this kind of activity.

DB: The Port Authority, at just this time, had come to the conclusion in 1924 and '25 that it couldn't solve the railroad problem which had been, which it had been constituted to solve. And, therefore, here was an institution looking for a mission, so it was a question, in a way, of survival. And since no institution likes to declare itself dead, the, they were receptive to some kinds of new ideas. And the bridge itself, therefore, symbolized for them new life, new activity, and one which, of course, was, to most people then, clearly on the horizon. Even though they couldn't predict how strongly it would change the culture, nonetheless, they could see that it was coming. And, of course, the tunnel was under construction, the Hudson tunnel, by this time and there were terrific problems of traffic. And so it was clear that something like this would be not clear, perhaps, it was taken by the Port Authority to be a new direction for them and Ammann, therefore, was the right person at the right time with the right thing.

DB: "The search for symbols" is perhaps, is perhaps a confusing term. For example, John Roebling clearly identified Brooklyn Bridge as a symbol. That was, in a way, part of his sales pitch for the Brooklyn Bridge, as it had been for the Cincinnati Bridge. And he saw this and Ammann did, too, but Ammann was not working in the same way as John Roebling. Ammann was working more quietly. And in the articles he wrote, particularly those in the early '20s, he is portraying this new bridge as a symbol of the society. He never says it quite as explicitly as Roebling did, but, of course, he had a copy of Roebling's report. We know that. We have a signed version of it in our own archive. And this, it's clear that this was the model for Ammann, not just the Brooklyn Bridge as you see it, but the very way in which the Brooklyn Bridge got accepted. So that he was conscious of this as being potentially a great new symbol. On the other hand, the use of the word "symbol" can be confusing because a symbol is not some fixed kind of a thing really. It changes over time as people begin to see with new experiences what this thing really represents. So that there is a, a lag and then people begin to realize what this really was. Just as there was a lag from the 1880s, to the 1920s in seeing the Brooklyn Bridge in its full meaning, so there is a lag, and, indeed, the engagement of historians now, right

now, in thinking about the past leads directly to these kinds of objects. There's a lot of writing today about the automobile and what it has done to transform America. And apart from the superficial obviousness of that there's the deeper issue of how it really came into being and what the automobile really does mean for individual people. And it's that sort of thing which is, in a way, yet to be done really fully for the George Washington Bridge and for those bridges that represent the 20th century dominance of New York from that to the Verrazano Bridge, in other words, Ammann's opus.

DB: The great appeal of the Brooklyn Bridge in the '20s came about when cultural figures, like Lewis Mumford, Joseph Stella, the painter, Hart Crane, the poet, were in a group of thinkers and artists searching for a usable past. One of their principle documents that rose at this time was *The Wasteland* by T. S. Elliott, *The Wasteland*, which essentially said that America was a wasteland. It was a negative view of the modern world, a view that there was nothing, there were no, nothing but hollow men and the whole thing would end with, as you remember, a bang and a whimper. It was in this context that Hart Crane began his poem *The Brooklyn Bridge.* And he began it on a very positive and optimistic note that by finding in the past this great symbol, it would, therefore, become a standard or inspiration for the future of building. He wrote about things like this. Later on he wrote things that seemed to be contradictory to it, but one must, of course, always remember that when you're reading what an artist says about what artists say about their own work, that's very, very suspect and what impels them to write, in a way almost as much as what impels a bridge designer like Ammann to design is something that's so highly personal and so emotional it can't be ripped out of the context of the work itself.

DB: So it's much better to look at the work than the contradictory statements that somebody like Crane would make about his own work. And the work is clearly a work of great cultural significance. It is, first of all, very beautiful. Second of all, exceptionally ambiguous, just as Crane's own discussion of it was, but, thirdly, it's got the bridge always there, connected with such beautiful lyrical poetry that it is impossible to separate. What does that mean for the future? Well, it means, first of all, in a concrete sense the Brooklyn Bridge was the model. It did serve people as a standard. It served Ammann clearly. He wrote about it. He actually designed the George Washington Bridge with the Brooklyn Bridge in mind. There isn't any doubt but what it served him as a model, as Crane perceived in one of his early statements about it. And Crane's own poetry itself has provided anyone who wants to study with the bridge. I don't know of anybody who's written about Brooklyn Bridge seriously who can avoid Hart Crane. And the very fact that you can't write about a bridge without invoking a poet says something about both of 'em that is so deeply cultural that it means that the goal for the future or the image or the vision of the future is just that kind of connection. Are we building things that have that poetic possibility? And if we aren't, then we had better go back and read Hart Crane and read the articles of Ammann and read what Roebling said and then go back to the beginning of all that, Thomas Telford, who was the first one to say, clearly and loudly, in the *Edinburgh Encyclopedia of 1812*, "These are works of art. Design them with that in mind." And so Telford has become, and is in fact, our Johann Sebastian Bach, you know, creating a cantata a week. He created a bridge a week, 1,200 bridges of

some, in his lifetime. And it's that sense that these were built to outlast us, these were built to change the environment, these were built to allow utility, yes, but also to inspire. And in that sense, I think Crane got the message, and it is a positive message, even though in his own life and even though in the poem there are all those ambiguities which we know exist, anyway, in life. Dangerous to ask me about a poet.

DB: When engineers thought about crossing the Hudson River, this very wide estuary, prior to the 1920s they thought more or less in two ways. First of all, they thought about railroad bridges. That led Lindenthal to propose very heavy suspension bridges. It led others to propose truss-like bridges of various forms. A second way they began to think about already, as the 20th century began, was tunnels. Tunnels were conceived of, first, of course, for railroads. The Pennsylvania Railroad built their tunnels then. And then the question of cars going in tunnels. So these were, in a way, the two competing images of how you get across this wide river, because the span would obviously have to be quite far beyond anything that had ever been done before to get it across in one swoop, because it is a major harbor, it does have to, it does require the passage of boats of great height, and, therefore, it would need to have 150-or-so feet in clearance. So these were the two ideas about bridge design that confronted Ammann, for example, in the 1920s when he began to design. And, of course, for Ammann the tunnel was an anathema. It has none of this emotional appeal that light suspended structure had. And so he was not at all, that did not at all appeal to him. At the same time, the, the heavy suspension bridge for railroads also didn't appeal to him esthetically.

DB: Well if they thought they were carrying railroads, then they had a mixed image. That is to say, there was no single image because everybody knew the problems with railroads and suspension bridges in the 19th century when many of them collapsed and only Roebling survived, and that had to be taken down in the 1890s because the engines got too heavy.

DB: Ammann's design process, the thinking he went through, would be characterized by three components, inseparable components. First would be what was built into him from his Lindenthal experience, would be the component of safety, the component of the bridge's performance in the environment. How would it work? And that's the ground of everything he was thinking about. But inseparably connected to that is that the bridge will never get built, he'll never realize his vision unless it is competitive, unless it is, in this case, reasonably economical. And that meant, of course, thinking hard about performance in the light of reduced materials. In a suspension bridge, perhaps as in no other kind of bridge, the cost is closely related to the materials, not so closely related to labor. Although the labor's included in the materials, it's nevertheless, if you save one pound in the middle of this span, that's a pound you don't have to carry and that means the material can be less and, having been less, then, indeed, the amount of material is then again less. So it is an augmenting factor. So the construction was the second thing in his mind, although, as I said, they're all inseparable. You really can't separate them. And the third was clearly the appearance. So these were the three things that he held together as he was thinking about his design, and he never spoke about the design without referring to all three. And that's the way the best designers think.

DB: Ammann's design choices can be thought about in three ways. First of all, he wanted to reduce the amount of materials and still make the bridge fully safe. Second, he wanted to have it built for as little money as possible, be as economical as it could be, and, third, in addition to that, he wanted it to look elegant. He wanted it to be a beautiful bridge. And these three all come together in his mind. They're inseparable, but we can, as analysts, look at them separately and see what decisions he made. But the basic idea underlying everything is, reduce as much as possible the materials in the main span because any additional weight in the main span has to be carried by additional weight in the main span plus, of course, additional tower and anchorage materials, as well.

DB: When Ammann thought about this reduction in materials, the first thing he thought about was the structure of the deck itself, the horizontal deck. The cable was a very simple issue. That was not something that was in dispute. It was easy to calculate, relatively easy, and to dimension, but the deck was in considerable dispute. And so Ammann's idea was to try to reduce it as much as possible, but he needed a scientific base for that reduction. And there was a new theory, the deflection theory, which said that if you consider the deck and the cable together in your analysis rather than separately, as been, had been the case in the past, if you considered them together, you will find, on the normal suspension bridge at that time, meaning bridges like the Williamsburg Bridge and the Manhattan Bridge and the Delaware Bridge, Memorial Bridge, you will find that you need less material in the deck.

DB: Other engineers knew that. They knew that by changing the basis of their analysis, they could reduce materials. But Ammann carried that one step further, and it was a fundamental step, because he drew not the conclusion that you could just save materials, but he drew the conclusion that the smaller he made the deck, the less materials you needed, and that meant, in the limit, you didn't need a deck at all. That is to say, the less stiff you made the deck, the less the force would be in the deck, the bending would be in the deck due to these difficult live loads coming from the trucks. And so he drew a conclusion that other designers had not drawn. They had simply said, "Two methods of analysis. Here's a bridge, already designed. If we analyze it both ways, we find that, using this more, more advanced method, we can reduce the materials a little bit." Ammann said, "We can change the form." And in changing the form, he found a justification for one of the most extraordinary design decisions in all bridge history, namely that the George Washington Bridge, this longest of all spans, could be built with essentially no stiffness in the deck, and that allowed him to build the bridge with no second deck at this immense span.

DB: What Ammann found when he looked at the results of the deflection theory and studied it carefully, was that the amount of force that would be in the horizontal truss was dependent not upon the loads, as one would normally think, but upon its stiffness. That means that if you reduce the stiffness, you reduce the forces in the truss. On that basis, Ammann realized that by making a much more slender truss for his two-deck bridge, he could save a very large amount of money. Indeed, as he spoke earlier, as he wrote earlier about the bridge, he said he could save on a $30 million bridge, or on a bridge

which was to cost $40 million, he could save $10 million, an immense amount, for this one idea. So that was the basis on which he believed he could make an economical design. Then when the issue came up of only a second deck, only a first deck, no second deck, the question was: could you reduce that stiffness essentially to zero, that deck stiffness? This same theory told him, yes, you could do that and, therefore, the bridge was built with no second deck and, hence, practically no deck stiffness.

Now, of course, there's a caveat to the whole thing, obviously.

Ammann's decision to build the bridge with only one deck turned out to be a good decision. The George Washington Bridge, as far as we know, never had any difficulties up until the time that the second deck was built and completed in 1962. So in that sense it was a reasonable decision. On the other hand, it was a bad model to follow because, unlike the George Washington Bridge, all the bridges that followed it, the major bridges in the '30s, were much lighter bridges. The Bronx-Whitestone Bridge, the Deer Island Bridge, the Thousand Island Bridges, and the Golden Gate Bridge, and then ultimately, of course, the poor Tacoma Bridge, were all substantially lighter bridges. So that the stiffness that Ammann counted on, which is called cable stiffness, which means the stiffness arising from the dead load forces in the cable that make it hard to deflect the cable when it's very taught, was very large in the George Washington Bridge and not so large in the others. And the idea of reducing the deck to almost no stiffness, while it was all right for traffic loads, was not all right for wind loads. And it was the wind loads that got the bridges into difficulties in the 1930s, culminating in the Tacoma Narrow Bridge failure.

DB: Well, there's, first of all, the geology of the foundations which indicate that in order to build the bridge economically, one wants to get the towers out of the main channel and out of the deep water. They will be much more easily built. So there was a basic reason for making a span of the order of 3,000 feet. That's the first and more or less basic idea. The second idea which Ammann spoke about was the fact that by having the back spans short, that aided in stiffening the main span. That was a consequence, I believe, of the geological reason for moving the, moving the, the towers out widely. So I think the first reason is because of the channel, but a, a second reason is because it does provide more stiffness.

DB: Ammann chose the dimension of 3,500 feet not on the basis, I believe, of strictly rational factors. The span had to be of that order, clearly, but the fact that 3,500 feet was exactly double the span of the Delaware Memorial Bridge, then the longest spanning bridge in the world when he set out to design his bridge, seems to me to be a determining factor in the exact number he chose. It's a little bit like the Eiffel Tower, which is exactly 300 meters or, later on, Ammann's decision to make the Verrazano Bridge just 60 feet longer then the Golden Gate Bridge or the Bayonne Bridge just 2 feet longer than the longest spanning arch then, which would have been the Sydney Harbor Bridge. So I believe engineers are motivated in this kind of effort by certain emotional factors. It is, after all, world's records and world's records are usually set by small differences and that means that this was not out of the consciousness of the designer when approaching such

things. But surely the Golden, the George Washington Bridge is unique not just in being the longest span, he would have had that with 3,400 feet, but in picking this exact number.

DB: The towers of the George Washington Bridge are surely unique. My own view of them is that it was basically a mistake to design them in that way. That is to say, to conceive of them as masonry towers built, in fact, structurally as steel towers. So that had they been covered, I think they would have, it would not have been as striking an effect as could have been done, as Ammann did do in his later bridges when he accepted the discipline of steel and then attempted to make them and did make them quite elegant. George Washington Bridge, as it is now, uncovered, the towers are surely very strange. There's no other suspension bridge in the world that has towers that are even close to looking like the George Washington Bridge. Now, of course, we're used to it. It's an old friend, and, therefore, since the bridge is a marvelous bridge in any case, I like it. But if you ask me is it appropriate, is it really an esthetic delight, those towers, I say no, it is not. They are not that, they are not at that level. They are not like the Brooklyn Bridge towers, which we know to have been appropriate from a constructional point of view. It's not like the Verrazano Bridge towers, which are appropriate from a design point of view of taking the material steel and doing something with it in a very simple, spare, but quite elegant way. So I think Ammann in a way was his own best critic. His later bridges, the towers of the Bronx-Whitestone and the Verrazano Narrows Bridge, are the best critique we have of the towers of the George Washington Bridge.

DB: There seems to be some kind of contradiction between the fact that starting with the George Washington Bridge and moving up all the way through to Golden Gate and so forth, there were these very large projects, and in New York also other projects, infrastructure projects, built at a time of depression, of economic depression. But I think there's, at least from the point of view of New York, I think the argument is, is better understood if we realize two things. First of all, that works like the George Washington Bridge, the Bayonne Bridge were all conceived, planned, and financed in the '20s, before the Depression. So that's one aspect. Even the Empire State Building is part of that same thing. That's one aspect of it. The other aspect is that the bridges we're talking about were toll bridges. Therefore, they were conceived of in a new way. It really wasn't as if somehow the government was pouring money into it, although they did pour lots of money into certain things, but at least in these bridges they were supposed to be self-sufficient. And initially they showed themselves to be very profitable. Of course, as the Depression wore on, they did have difficulties, but at the same time it was the concept that they would be toll bridges, that they would retire the bonds, that they would be done by an authority which was removed from the basic municipal issues that had clouded design and had, in the minds of many people, made government seem to be inefficient in these things. So new mechanisms went together with that, such as TVA, Bureau of Reclamation. So even though money was poured into them, they were special mechanisms removed from the direct political control of local bodies and even the Federal government.

DB: The failure of the Tacoma Narrows Bridge in late 1940 was surely a shock to the

engineering profession. There was little preparation for that. Indeed, the year before, Leon Moissieff, the designer of the bridge, had written an article with a title something like "We Know So Much Now About Suspension Bridges." It was a very positive article and it indicated the confidence of the profession and all the major designers, Ammann and Steinman and Moissieff, all of them had been designing bridges in this same mold. Moissieff was just the unluckiest of the group. So it was a, a great shock, a great surprise.

I don't know Ammann's immediate response, but surely we know his basic response because he was one of the three people chosen to write a detailed report of the failure of the Tacoma Bridge. And his response was that, of course, all of these bridges had been designed under the wrong ideas about wind. And he even went so far as to indicate that the George Washington Bridge has started that trend. And he even noted, when asked, that he would "do it differently today," he said. He didn't say exactly what he meant by that, but we know what he meant by that because we know how he designed the Verrazano Bridge and it is different than the way he designed the George Washington Bridge and it is very successful from that point of view. So his response was, of course, based on a very careful study of it and, in particular, based on the work of Professor Farquharson at University of Washington Seattle, who took, it seems to me, the exactly correct approach. And what Farquharson did in his report was to start with a detailed study of all those 19th-century bridges that had failed and he called the attention of the profession to the historical record and implied, and even stated, that had they known the record, had they realized that the Brighton Chain Pier and the Menai Straits Bridge problem, not total failure, but problems, were of a very similar nature to the problems of the Tacoma Bridge, had the profession realized that, they would have thought differently about these early designs.

DB: Those of us interested in the history of engineering would have been grateful to Ammann had he written down his own reflections of his own life in his own words, which he never did and which most engineers don't do. And I think the reason for that is, of course, first of all, he was running his office right up 'til, practically 'til the end. So he was actively engaged in practice. But I think also that the engineer and society itself has the view that engineering is a rather technical profession of filling in the numbers and getting answers and that you give the engineer the problem and the engineer solves the problem and that's it, and that there isn't anything more to it than that. And once you start talking about the engineer having emotions and those emotions controlling what's being done, the general public is certainly very confused by that. And it's, and yet as we, as we know with Ammann, it was his emotions that controlled so much of what he did.

So, therefore, since that is the case, and only because that's the case, his personal reflections would have been culturally very interesting and important. So it is that in the future with engineering as the history of engineering develops, and as people begin to understand that this is in effect cultural history, that since we live in a technological age, since we are an engineering culture, that the thoughts and ideas of the people who make it are indeed important. And this is something which in the first instance in my opinion is an obligation of academic engineers, because it is that type, we are that type of people

that have the opportunity to reflect on things and to teach it. And it is very important to teach to young prospective engineers that they can in fact connect their emotional and rational sides in the works that they're doing. And the only way to make that clear is to give them the histories of these people.

Engineering needs to be taught much more from the perspective of what individual people have done. Now this is not to say that this is purely the great man theory of history but rather that it is one central component of all history of any type, but certainly in engineering it must be seen that way as well and Ammann is a wonderful example of that. And the very fact that his entrepreneurial side, particularly in the twenties when he was selling his bridge, that that was left out of all of the discussions later on about Ammann, that in the testimonials and in the ceremonies commemorating him and in the articles about him, none of this was ever mentioned. He was portrayed as the engineers' engineer, always carrying out the works of other people, always sitting down and doing the calculations and thinking about the issues of construction and so forth but the idea that he would go out and sell this, the idea that he would act almost as a politician seemed to be so out of character with engineers that it was left out of the record. And of course it isn't out of character and it isn't wrong for engineers to operate that way particularly if they operated the way Ammann did, on the basis of this strong technical background, carefully worked out plans, not as a superficial salesman but as a salesman who really knew the product and had actually gone through in his mind the construction of the product and had gone through the actual experience of building similar things before that.

DB: It is common practice to attribute these works to individuals. We speak of the Brooklyn Bridge as John Roebling's bridge built by Washington Roebling. We speak of the Verrazano and the George Washington Bridge as Ammann's bridges. Ah, indeed there are in a way two caveats to bring to that, one is that in the public mind very often the only name ever associated with a bridge is the name of a politician. I mean after all George Washington was a politician and the Verrazano Bridge was for a long time referred to as Robert Moses' bridge.

DB: In talking about Ammann, we, we speak about his as getting the credit for the design of the George Washington Bridge and the others up to the Verrazano-Narrows Bridge. Is that fair? There are two sides to that. One is, often the politicians get the bridges named for them and they even get credit for it. On the other hand, there are many people working for the principal in the firm, in this case Ammann, who do substantial work in the creation of that bridge. They often don't get the credit they deserve for that. Nevertheless, it is fair to say, just as Ammann struck out on his own with the George Washington Bridge, that these works usually do require some kind of an entrepreneur or some kind of a leader who is capable not only of visualizing the overall form and the overall way it will be built, but also in choosing the right people to work together on the project. And so the very fact that talented people are chosen, people of great ability are chosen to carry out major tasks in the bridge, doesn't diminish the fact that there is a leader and the leader is the one that has the vision. Naturally, as the leader gets older, as Ammann did with the Verrazano Bridge, other people play a larger and larger role in the detailed design. That was only natural. But I believe it is still fair to call it a, an Ammann

bridge. It certainly fits with the development of his style as we see it through all the bridges.

DB: Is the Verrazano the climax of American bridge building? In certainly one sense it is. It is the longest spanning bridge in the world. It stays that way for several decades. It represents the high point of New York's dominance as the world's greatest port. So in those symbolic senses, it is the high point. It is also a high point in the sense that it is one answer to the Tacoma Narrows Bridge failure -- a very light design, a relatively light design for such a huge span, and yet one that has exhibited no difficulties, technical difficulties, at all. It was heavily criticized at the time as being backward. There were bridges in Britain which were built with air foil type decks which appeared to be more of an advance, and that's a question still debated, but I think from the standpoint -- from many standpoints, it does represent a high point in American design.

DB: The Verrazano Bridge does, in fact, historically note the end of American industrial dominance. That is to say, right after that bridge, New York loses its position as the world's dominant port and shortly thereafter, with the rise of industry in West Germany and in Japan, it becomes clear that the U.S. is no longer the dominant nation that it once was, that it was in fact bracketed by the building of the Brooklyn Bridge and the completion of the Verrazano Bridge. That doesn't mean, of course, that it's necessary to imagine that we now go into a state of decline. What it does mean is that the challenge for us has shifted. It has shifted from continuous building to maintaining. We have reached middle age, when we must maintain what we've got. And I don't believe completely in this biological analogy because middle age has no definition of time for us, you know, as a society as it does for us individually. But we have reached that and it is time now that we think about rehabilitation and the continuing use of the resources that we have and have built.

This is the meaning of what's going on in the East River today. The rebuilding, in effect, of those great bridges there, from the Brooklyn Bridge, the Williamsburg, the Manhattan and so forth. And we have found, to our surprise and to the surprise of many observers, that we can't build them again. We can't tear them down and rebuild them, that we must maintain them and maintain them while the traffic is still running, as the Port Authority has so beautifully done with the George Washington Bridge itself, to maintain traffic as it added the second deck, as it rehabilitates parts of it and so forth. So we're gradually learning this and the culture had to learn that in doing this, this is as creative a venture as building things new. It is a creative effort, or a re-creative effort in a sense, to build upon what others have done now in place, rather than always new.

Now the question is, are there new bridge possibilities? Are there brand new possibilities? And, of course, there are. There's a whole new set of forms. The cable-stayed bridge came in after World War II. And as an image of the lack of dominance of the United States, when these began to come into the world picture in the '60s, because we had lost that sense of dominance, these bridges did not flourish here. And, indeed, when they began to flourish here we had to go to Europe to get the designers for them, or at least collaboratively. And so the challenge there is not so much now with the longest-

spanning bridges in the world, but with those medium-span bridges, bridges of 1,000, 1,500, 2,000 feet in span, of which there are many to be built. The challenge now for us is to think, in terms of our own culture, how we build those bridges and how we can build them to be not the longest-spanning bridge in the world, but examples of exemplary bridge art in which they are economical, in which they perform well, and in which they are a pleasure to see on the landscape.

DB: My favorite American bridge, without much thought behind it, is clearly Brooklyn Bridge. And that's a very standard answer, but I give it because of its meaning for our culture, because of its technical importance, of its ambiguity, of its political context and, above all, of the epic of its design, on the one hand, in the life of John Roebling, and its building in the life of Washington Roebling. There are two other bridges that are important to, to bracket that. The George Washington Bridge is, I believe, the most important 20th century bridge because of its scale and because of all the problems that it raised, both engineering and esthetic. But, above all, my favorite bridge is the Salginatobel Bridge of Robert Maillart in Switzerland. And this is connected to Ammann because it brings us to the fact that Ammann was, after all, Swiss, trained by the greatest of all bridge teachers in the modern world, Wilhelm Ritter, who communicated to his students the importance of the technical and the esthetic. And so, therefore, to get a perspective on American design, from which Ritter himself wrote a whole textbook, we should go back to Switzerland and see there the world's most beautiful bridges of the 20th century, a whole series of them that would bring us face to face with the possibilities for not just bridge engineering, but all engineering, as a, both a rational and an emotional profession, one which calls forth civic virtue as well as an understanding of the scientific basis and the social basis of our modern society.

It's important for the general public to know about engineering. We live in an engineering culture. And it's important for them to see that engineering in its, in its true meaning is really an integration of science, the nature into which these things are built, of society, the political and economic context, and of art, the ultimate meaning of the best bridges. And, therefore, once they see this, then we can begin the process which we so strongly need in our country, of reintegration of knowledge, of combating the fragmentation and specialization that has forced discourse into separated boxes and doesn't allow, therefore, the technical to think about the esthetic or the political to think about the technical. And when it's seen through these works that in order for the best of them to be built, they had to think about, the designers had to think about all these things, then one puts technology or engineering into a different context, not as a special school like all the other engineering schools, all the other professional schools in university, but as part of the central core of understanding that is so essential to our society.