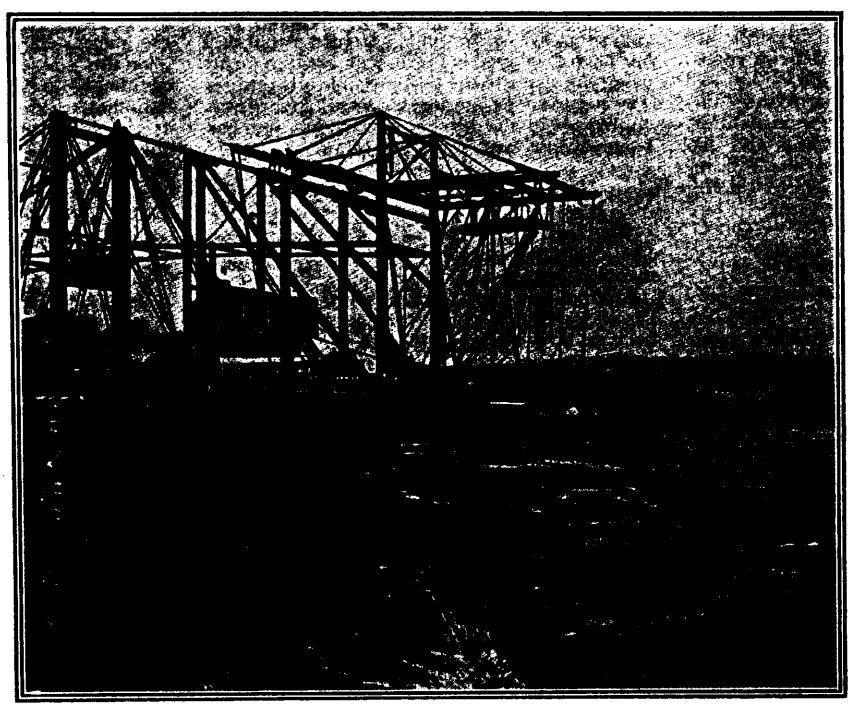
to them. The strains were adjusted to the new portions by heating the iron & carefully measuring the consequent elongation until exactly the right point was reached. In 1880 the old wooden stiffening trusses & floors were removed piecemeal, & replaced by steel, without impairing the integrity of the structure in the slightest. A few years afterward, it was found that the temperature elongations & contractions of the main cables had bent the towers back & forth until many of their solid stones were cracked & broken. These stones were removed & new ones inserted in their places. In 1886 new steel towers were built up outside the older ones of masonry, & the cables were lifted up by hydraulic pressure & deposited in new seats. All of these changes, affecting nearly every portion of the bridge, were made without interrupting the traffic across the structure, without serious mishap or the loss of a life. They form a series of brilliant achievements unprecedented in the annals of bridge construction or repair. The later ones were designed and executed by L. L. Buck, now the chief engineer of the new East River bridge in New York, which, with its six railway tracks, footwalks & bicycle paths, will be the greatest, though not the longest, span in the world.

Notwithstanding the repeated improvements in the Niagara suspension bridge, it finally became inadequate for the increasing volume of railway traffic. In 1896-97 it was entirely replaced by a new structure, built on the same site, & without interrupting traffic. This seems like an impossible feat, but the principles on which it was conducted are well established in bridge-building, & are well understood by bridge-engineers. The span of the massive 550-ft. steel arch was built out panel by panel from the opposite abutments in the form of cantilevers. These cantilevers were partly supported by forged steel bars temporarily anchoring their upper parts to steel beams bedded in masses of concrete which filled pits blasted out of the solid rock. The work advanced from both sides of the river at the same time, & the materials were carried into place by steel derricks running on top of the completed portions of the growing structure. Thus the old bridge was gradually enclosed by the upper part of the steel arch, which surrounded it on sides & bottom, but did not touch it or interfere with its daily functions. The two semi-arches were built so that their extremities would be a little too high and too far apart when the final joint between them was reached. They were then united by slightly extending the anchor chains from each side. It is a delicate matter to lengthen chains that are under a strain of more than a million pounds, but it was accomplished by means of an ingenious toggle arrangement. The two parts came easily together; the bridge was complete, & took up the duties of the older structure without the slightest hitch.

A few hundred feet above this bridge is the famous Niagara cantilever, one of the first of this type to be built. It is seen in the background of the illustration on page 35. In the foreground are shown the two semi-arches of the new structure that has replaced the old suspension bridge. They are shown as they approached completion, with the old bridge still intact above them. Thus are grouped in this view the three great types of long-span bridges, forming an historic trio that disappeared with the final removal of the suspension bridge. Just below the Falls is a beautiful steel-arch bridge of 840 ft. span and 135 ft. rise. It is by far the longest arch in the world. It was erected cantilever fashion much as was the one already described.

The loftiest trussed bridge in the world is the Kaiser Wilhelm, near Mungsten, which carries a double-track railway across the valley of the Wupper, 350 ft. above the stream. It has a clear span of 525 ft. The manner in which the bridge was built illustrates typical European methods, elaborate, slow & costly. The first step was to build a temporary service bridge across the river on steel & timber towers about 100 ft. high. Large shops & work-yards were established on one bank. Inclined planes & electric cable roads were run from both ends, parallel to the bridge, to serve for the distribution of material. Huge timber towers were built at each end of the arch for falseworks, from which the permanent steel towers were erected. This method was very slow & costly. In this country it would have been dispensed with entirely, and the towers would have been made self-supporting during erection. After the towers were completed, their tops were tied back with steel cables to the special anchorages provided, & then the arch trusses were built out & up from their springing lines at the abutments to the crown. While building, the semi-arches were partly sustained by steel backstay cables. The trusses were built out panel by panel without further support until they met at the centre. Then the huge semi-arches were tipped forward a few inches by lengthening the anchor lines, so as to secure the exact space required for the last pieces in the key of the arch. Finally, the strains on the towers were adjusted by hydraulic presses at their feet.



Building out one arm of the 477-ft. cantilever at St. John, N.B., 97 ft. above the water. Here the roaring tide rises and falls 30 ft., and it was impossible for falsework to withstand it.

One of the most interesting factors in modern bridge building is the workmen. Their experiences aloft tend to make them forget the matter of altitude entirely, & they will unhesitatingly assume the most daring risks in doing their work. But many of their exploits that are so nerve-shocking to the inexperienced observer seem very simple matters from the workman's point of view. They become so expert, cool-headed & sure-footed that they very seldom fall. They will run on a beam a few inches wide & lying a hundred feet in the air; will swing a sledge while standing on an ice-covered timber projecting at a dizzy altitude; or will walk across a springing plank when the wind blows so fiercely that they are compelled to lean far out against it to keep their balance. They will pose in the most startling positions whenever the work is being photographed; in one instance, a workman actually stood on his head, on the top of a derrick, a hundred feet above the water, in order to demonstrate his nerve & indifference.

In replacing the Niagara suspenion bridge nearly all of the workmen employed were floating mechanics & laborers, who had no previous knowledge of bridge-work; yet they did the work well, so perfectly & simply was it planned & so skilfully was it directed. Some of the men, when they applied for work, requested permission to stay mainly on one side or the other of the boundary line between the U. S. & Canada, which the bridge crossed, because on the opposite side their liberty had been jeopardized by various misdemeanors. Notwithstanding the great height at which the men worked above a maelstrom from which escape would have been impossible, most of them soon grew unconcerned, & some of them, indeed, vied with one another in reckless daring. So many valuable tools were dropped from the bridge that some of the more careless losers were discharged. Consequently one day, when a man dropped a wrench 200 ft. to the water's edge, he foolishly started to recover it by climbing down hand over hand on a steeply inclined thin wire cable nearly 500 ft. long. He had no sooner begun his insane exploit than a rival, not to be outdone, started out of sheer bravado to descend an adjacent rope. After going a few feet they tried in vain to return, & it seemed to their horrified companions on the bridge above that human muscles could not endure the increasing strain of their long journey. The foreman instructed them how to climb more easily & what to do at the bottom, accompanying his orders with violent abuse, wisely bestowed to divert them from the fright that added to their danger. By nothing less than a miracle both men held on until they had crossed over the water. Then one of them, watching his chance, dropped safely into a tree-top. The other finally gave out, & fell a considerable distance to the ground. But both escaped practically unhurt. Instead of being received as heroes, however, both were immediately discharged by the foreman. No serious accidents occurred on the bridge, but there were some hairbreadth escapes, as when one man, carrying in his tongs a white-hot rivet, ran along a well-oiled, narrow iron