

BELOW THE BROOKLYN BRIDGE.

From a painting by J. H. Twachtman, engraved by J. Clement.

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FEATS OF RAILWAY ENGINEERING.

By John Bogart.

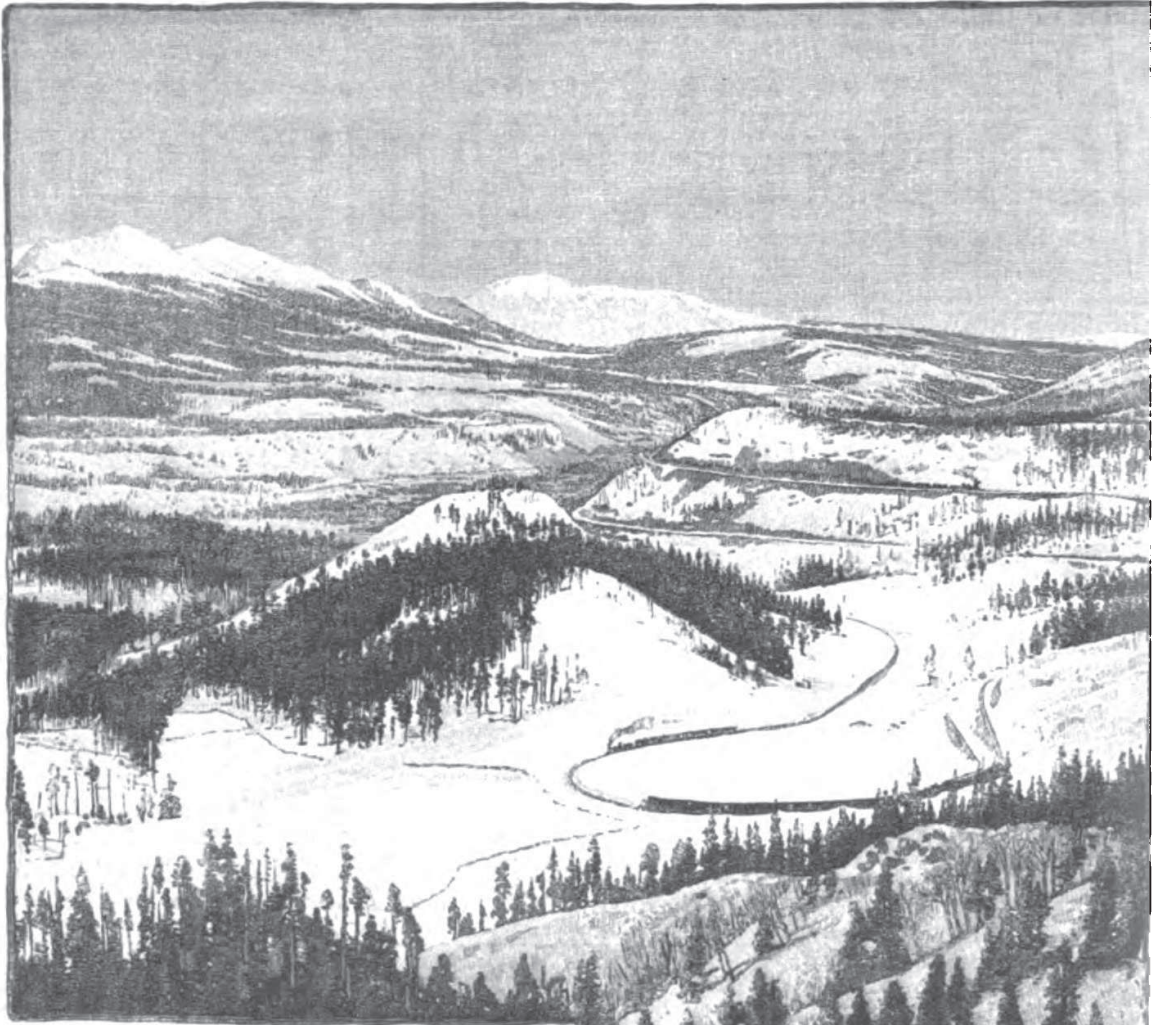


THERE are one hundred and fifty thousand miles of railway in the United States: three hundred thousand miles of rails—in length enough to make twelve steel girdles for the earth's circumference. This enormous length of rail is wonderful—we do not really grasp its significance. But the rail itself, the little section of steel, is an engineering feat. The change of its form from the curious and clumsy iron pear-head of thirty years ago to the present refined section of steel is a scientific development. It is now a beam whose every dimension and curve and angle are exactly suited to the tremendous work it has to do. The loads it carries are enormous, the blows it receives are heavy and constant, but it carries the loads and bears the blows and does its duty. The locomotive and the modern passenger and freight cars are great achievements; and so is the little rail which carries them all.

The railway to-day is one of the matter-of-fact associations of our active life. We use it so constantly that it requires some little effort to think of it as a wonderful thing; a creation of man's ingenuity, which did not exist when our grandfathers were young. Its long bridges, high viaducts, dark tunnels may be remarked and remembered by the traveller, but the narrow way of steel, the road itself, seems but a simple work. And yet the problem of location, the determination, foot by foot and mile by mile, of where the line must go, calls in its successful solution for the highest skill of the engineer, whose profession before the railway was created hardly existed at all. Locomotives now climb heights which a few years ago no vehicle on wheels could ascend. The writer, with some engineer friends, was in the mountains of Colorado last year, and saw a train of very intelligent donkeys loaded with ore from the mines, to which no access could be had but by those sure-footed beasts. And since then one of that party of engineers has located and is building a railway to those very mines. No heights seem too great to-day, no valleys too deep, no cañons too forbidding, no streams too wide. If commerce demands, the engineer will respond and the railway will be built.

The location of the line of a railway through difficult country requires the trained judgment of an engineer of special experience, and the most difficult country is not by any means that which might at first be supposed. A line through a narrow pass almost locates itself. But the approach to a summit

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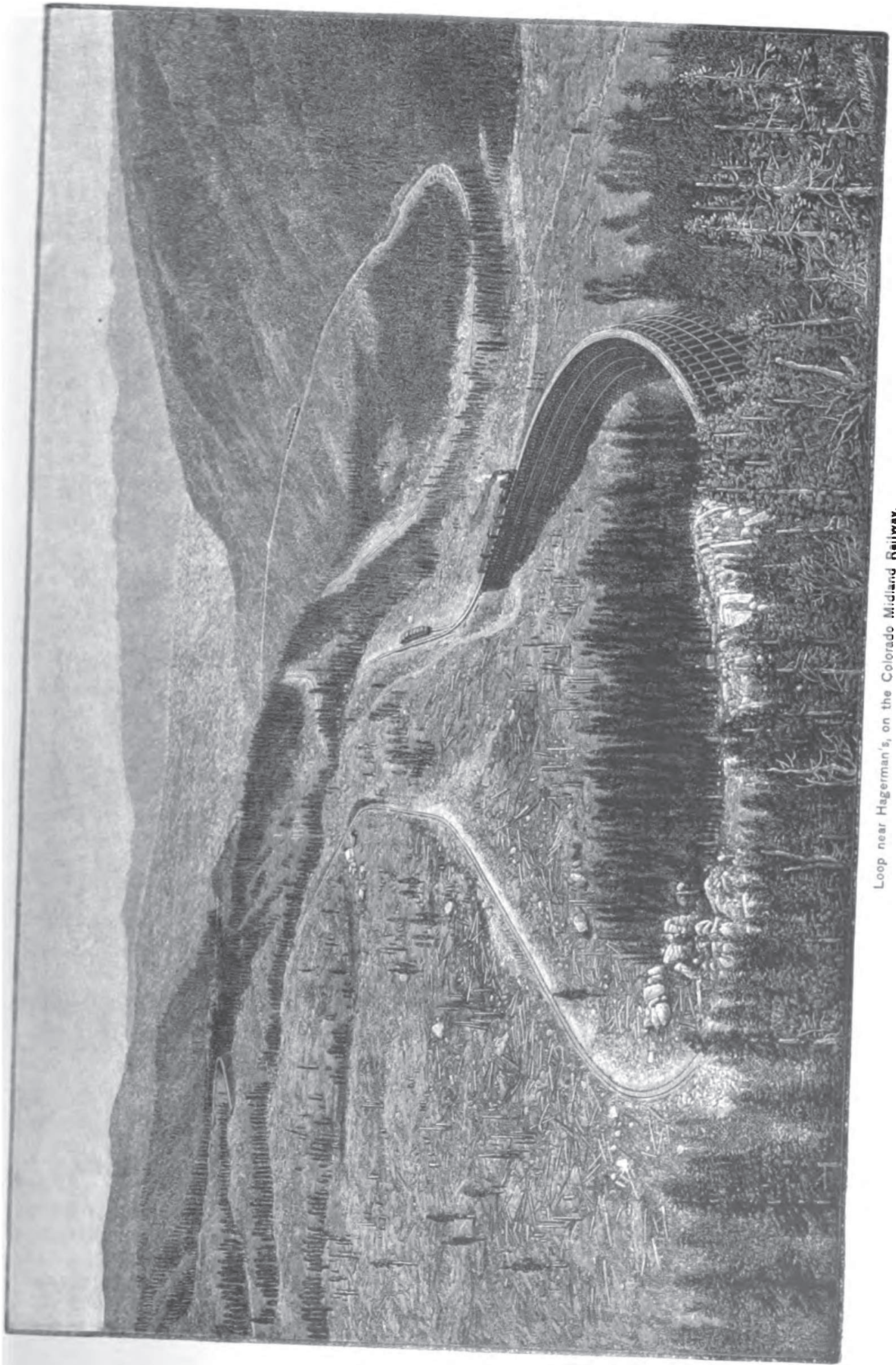
through rolling country is often a serious problem. The rate of grade must be kept as light as possible and must never exceed the prescribed maximum. The cuttings and the embankments must be as shallow as they can be made—the quantities of material taken from the excavations should be just about enough to make adjacent embankments. The curves must be few and of light radius—never exceeding an arranged limit. The line must always be kept as direct as these considerations will allow—so that the final location will give the shortest practicable, economical distance from point to point. Many a mile of railway over which we travel now at the highest speed, has been a weary problem to the engineer of location, and he has often accomplished a really greater success by securing a line which seems to closely fit the country over which it runs without marking itself sharply upon nature's moulding,



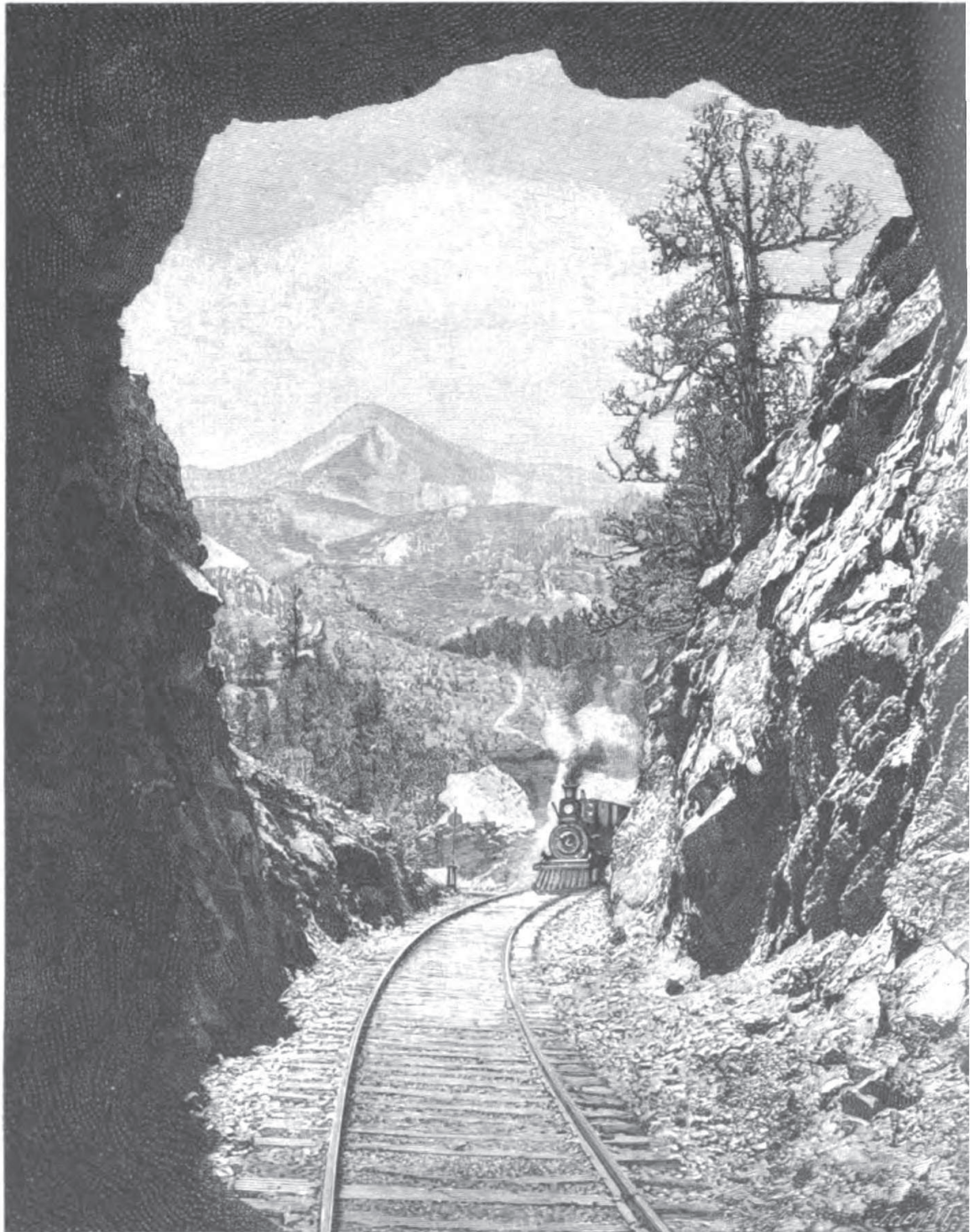
View Down the Blue from Rocky Point; Denver, South Park and Pacific Railroad; showing successive tiers of railway.

than if he had with apparent boldness cut deep into the hills and raised embankments and viaducts high over lowlands and valleys.

But roads must run through many



Loop near Hagerman's, on the Colorado Midland Railway.



Portal of a Finished Tunnel; showing Cameron's Cone, Colorado.

regions where very different measures must be taken to secure a location practicable for traffic. For instance, a line at a high elevation approaches a wide valley which it must cross. The rate of descent is fixed by the established maximum grade and the sides of the valley are much steeper than that rate. Then the engineer must gain distance—that is to say, he must make the line long

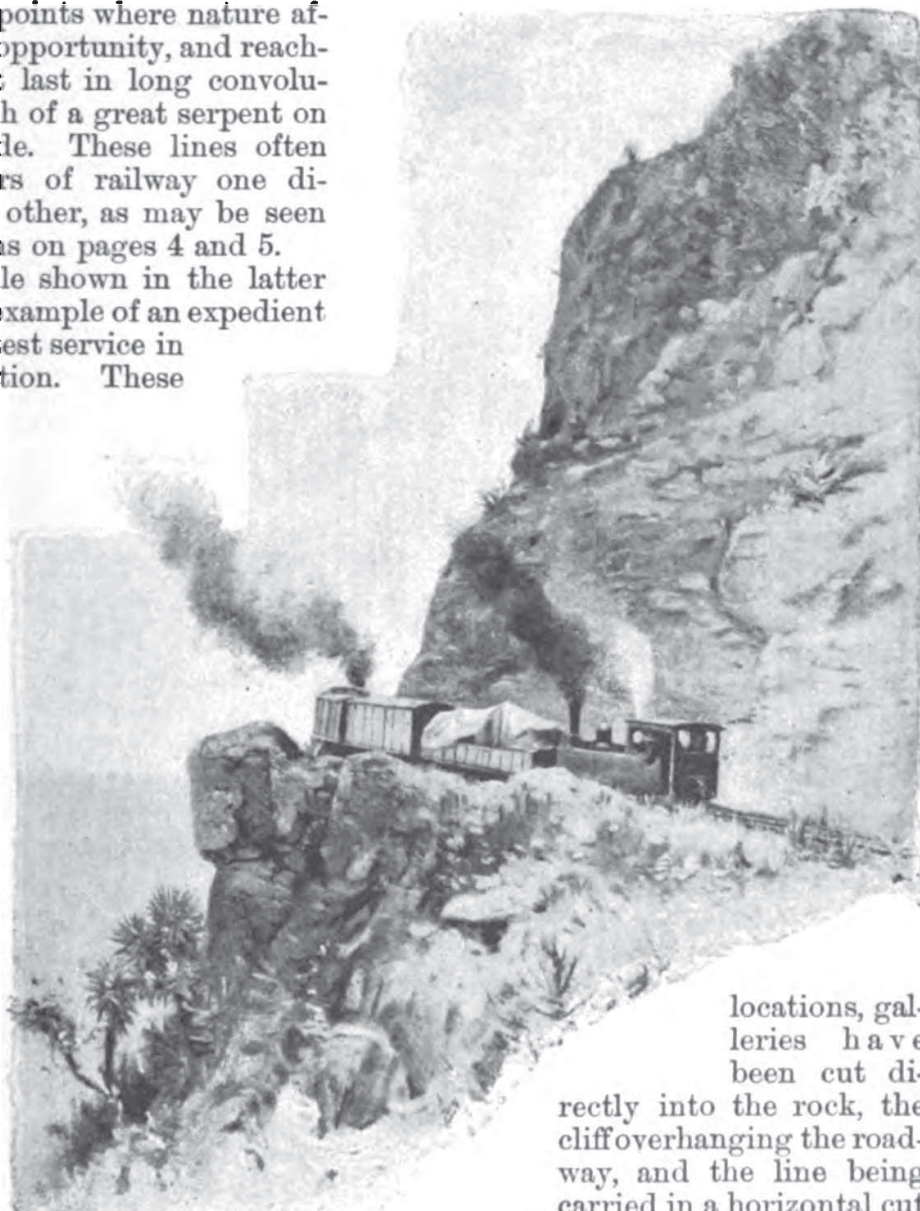
enough to overcome the vertical height. This can often be accomplished by carrying it up the valley on one side and down on the other. Tributary valleys can be made use of if necessary, and the desired crossing thus accomplished. But at times even these expedients will not suffice. Then the line is made to bend upon itself and wind down the hillside upon benches cut into the earth, c

rock, curving at points where nature affords any sort of opportunity, and reaching the valley at last in long convolutions like the path of a great serpent on the mountain side. These lines often show several tiers of railway one directly above the other, as may be seen in the illustrations on pages 4 and 5.

The long trestle shown in the latter illustration is an example of an expedient often of the greatest service in railway construction. These

trestles are built of wood, simply but strongly framed together, and are entirely effective for the transport of traffic for a number of years. Then they must be renewed, or, what is better, be replaced by embankment, which can be gradually made by depositing the material from cars on the trestle itself. The trestle illustrated is interesting as conforming to the curve of the line, which in that country, the mountains of Colorado, was probably a necessity of location.

Where the direct turning of a line upon itself may not be necessary, there may and often must be bold work done in the construction of the road upon a mountain side. It must be supported where necessary by walls built up from suitable foundations, often only secured at a great depth below the grade of the road. Projecting points of rock must be cut through, and any practicable natural shelf or favorable formation must be made use of, as in the picture above. In some of the mountain



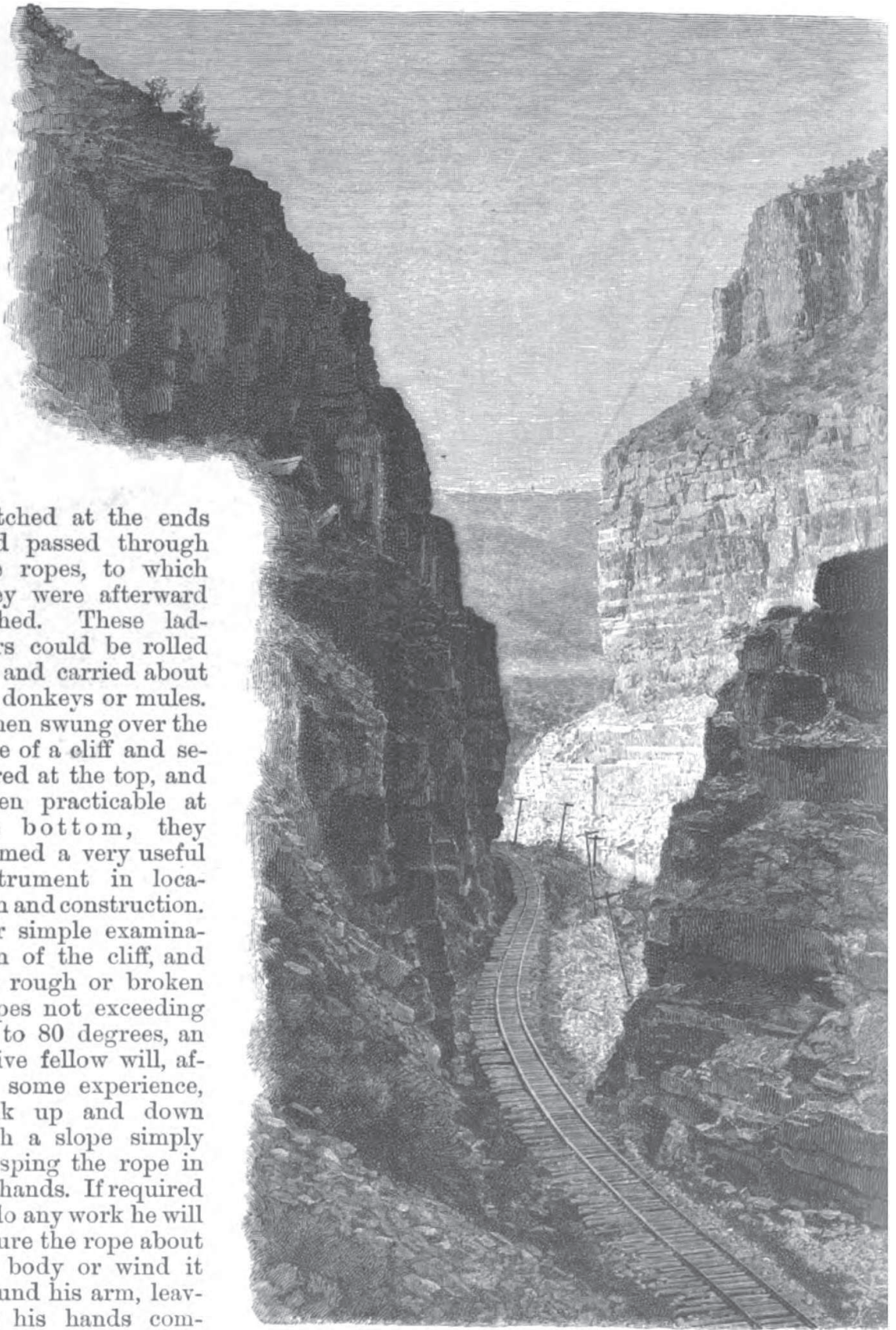
Peña de Mora on the La Guayra and Carácas Railway, Venezuela.

locations, galleries have been cut directly into the rock, the cliff overhanging the roadway, and the line being carried in a horizontal cut or niche in the solid wall. The Oroya and the Chimbote railways in South

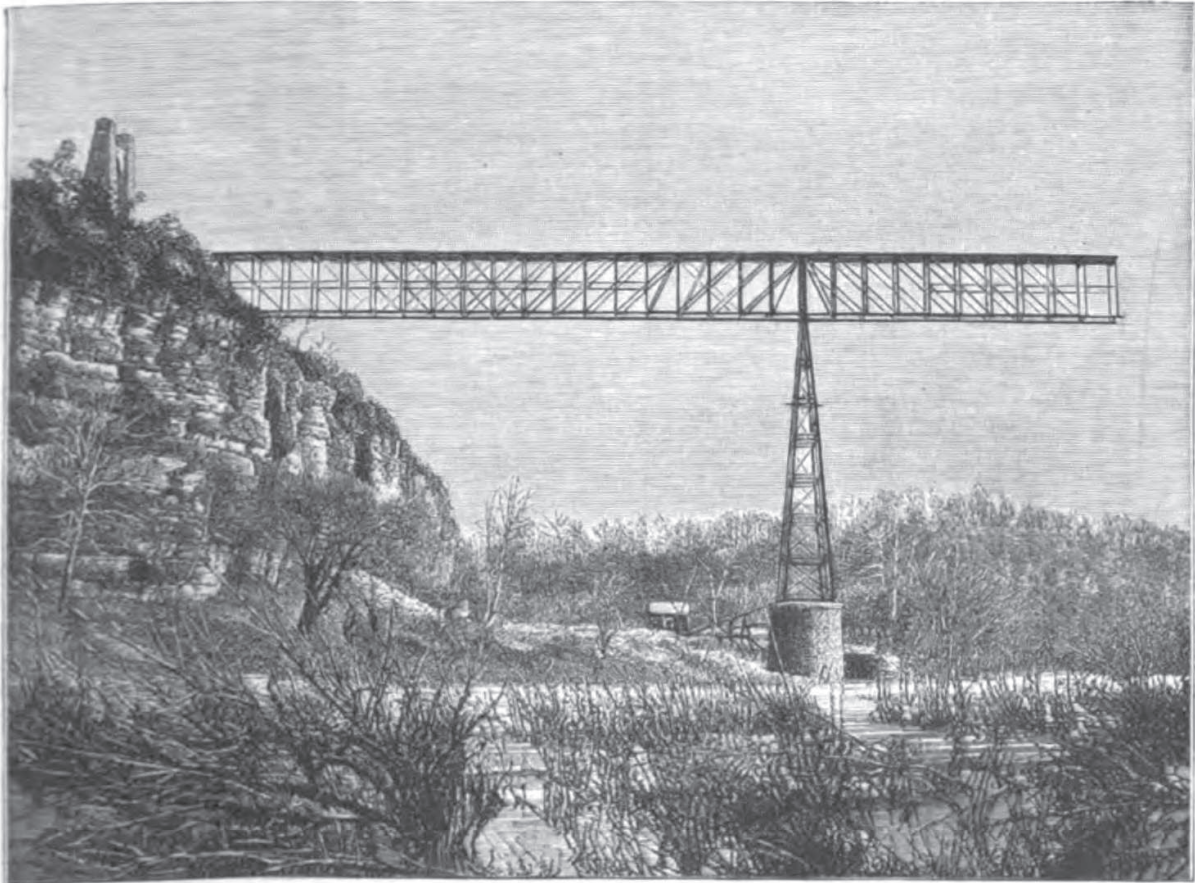
America demanded constant locations of this character. At many points it was necessary to suspend the persons making the preliminary measurements, from the cliff above. The engineer who made these locations tells the writer that on the Oroya line the galleries were often from 100 to 400 feet above the base of the cliff and were reached generally from above. Rope ladders were used to great advantage. One 64 feet long and one 106 feet long covered the usual practice, and were sometimes spliced together. The side ropes were $\frac{3}{4}$ and $1\frac{1}{4}$ inch in diameter, and the rounds of wood $1\frac{1}{4}$ inch in diameter, and 16 inches and 24 inches long. These were

notched at the ends and passed through the ropes, to which they were afterward lashed. These ladders could be rolled up and carried about on donkeys or mules. When swung over the side of a cliff and secured at the top, and when practicable at the bottom, they formed a very useful instrument in location and construction. For simple examination of the cliff, and for rough or broken slopes not exceeding 70 to 80 degrees, an active fellow will, after some experience, walk up and down such a slope simply grasping the rope in his hands. If required to do any work he will secure the rope about his body or wind it around his arm, leaving his hands comparatively free for light work.

The boatswain's chair, consisting of a wooden seat 6 inches wide and two feet long through the ends of which pass the side ropes, looped at the top, and having their ends knotted, is a particularly convenient seat to use where cliffs overhang to a slight degree. The riggers were generally Portuguese sailors, who



Denver and Rio Grande Railway Entering the Portals of the Grand River Cañon, Colorado



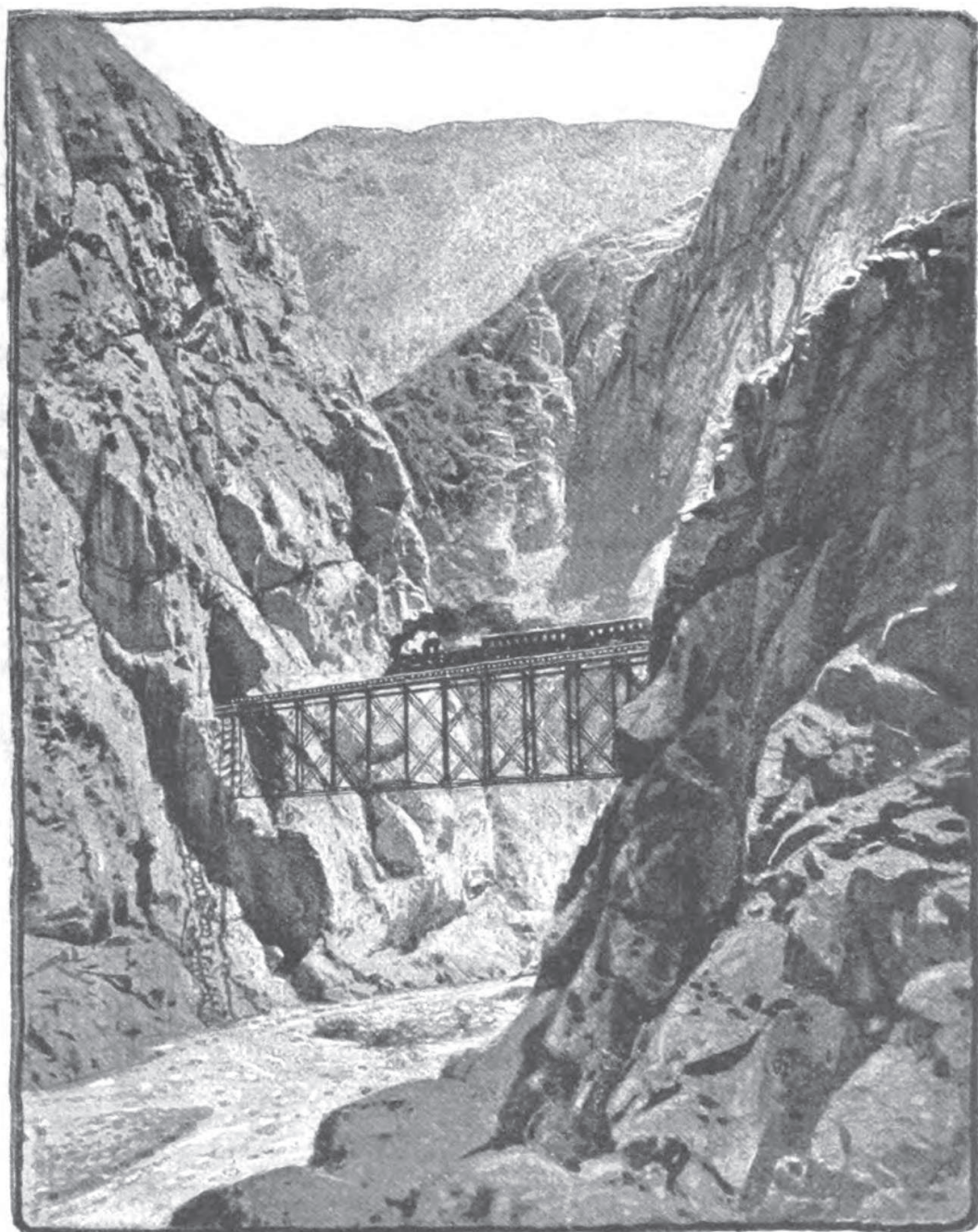
The Kentucky River Cantilever, on the Cincinnati Southern Railway.

seemed to have more agility and less fear than any other men to be found. At *Cuesta Blanca*, on the Oroya, a prominent discoloration on the cliff served as a triangulation point for locating the chief gallery. Men were swung over the side of the cliff in a cage about 2½ feet by 6 feet, open at the top and on the side next the rock. This was a peculiar cliff about 1,000 feet high, rising from the river at a general slope of about 70 degrees. The grade line of the road was 420 feet above the river. The Chileno miners climbed up a rope ladder to a large seam near grade where they lived; provisions, water, etc., being hoisted up to them. The first men sent over the cliff to begin the preliminary work were lowered in a cage and took their dinners with them, for fear they would not return to the work, and that unless a genuine start was made others could not be induced to take their places. It is safe to say that 80 per cent of the sixty odd tunnels on the Oroya and the seven tunnels on the Chimbote lines were located and constructed on lines determined by tri-

angulation, and the results were so satisfactory that the method may be depended upon as the best system for determining topographical data or for locating and constructing the lines in any similar locality.

Where the rocks close in together, as in some of the cañons of our Southwest, the railway curves about them and finds its way often where one would hardly suppose a decent wagon road could be built. The portals of the Grand River Cañon, as seen on the opposite page, show such a line, passing through narrow gateways of rock rising precipitously on either side to enormous heights.

When such a cañon or a narrow valley directly crosses the line of the road, it must be spanned by a bridge or viaduct. The Kentucky River Bridge, shown above, is an instance. The Verrugas Bridge on the Lima and Oroya Railroad in Peru is another. This bridge is at an elevation of 5,836 feet above sea-level. It crosses a ravine at the bottom of which is a small stream. The bridge is 575 feet long, in four spans, and is supported by iron towers, the central



Truss over Ravine, and Tunnel, Oroya Railroad, Peru.

one of which is 252 feet in height. The construction was accomplished entirely from above, the material all having been delivered at the top of the ravine, and the erection was made by lowering each piece to its position. This was done by the use of two wire-rope cables, suspended across the ravine from temporary towers at each end of the bridge.

On the line of the same Oroya Railroad is a striking example of the difficulties encountered in such mountain country and of the method by which they have been overcome. A tunnel

reaches a narrow gorge, a truss is thrown across—and the tunnel continued.

Nature's wildest scenery, the deep ravine, the mountain cliffs, and the graceful truss carrying the locomotive and train safely over what would seem an impossible pass, here combine to give a vivid illustration of an engineering feat.

The location of a part of the Mexican Central Railway through the cut of Nochistongo is peculiarly interesting. Far underneath the level of this line of railway there was skilfully constructed, in

1608, a tunnel which at that period was a very bold piece of engineering. It was designed to drain the Valley of Mexico, which has no natural outlet. This tunnel was more than six miles long and ten feet wide. It was driven through the formation called *tepetate*, a peculiar earth with strata of sand and marl. It was finished in eleven months. At first excavated without a lining, it was afterward faced with masonry. It was not entirely protected when a great flood came, the dikes above gave way, and the tunnel became ob-

structed. The City of Mexico was flooded, and it was decided that, instead of repairing the tunnel an open cut should be made. The engineer who had constructed the tunnel, Enrico Martinez, was put in charge of this enormous undertaking, and others took his place after his death. The cut is believed to be the largest ever made in the world. For more than a century the work was continued. Its greatest depth is now 200 feet. It was cut deeper, but has partially filled with the washings from the slopes. The cost was enormous, more than 6,000,000 dollars in silver having been actually disbursed! Wages for workmen were then from 9 to 12 cents a day. All convicts sentenced to hard labor were put at work in the great cut. The loss of life was very great. Writers of the time state that more than 100,000 Indians perished while engaged in the work.

When a line of railway encountered a grade too steep for ascent by the traction of the locomotive, the earlier engineers adopted the inclined plane. Such planes were in use at important

points during many years. Notable instances were those by which traffic was carried across the Alleghany Mountains, connecting on each side with the Pennsylvania railway lines. These old planes

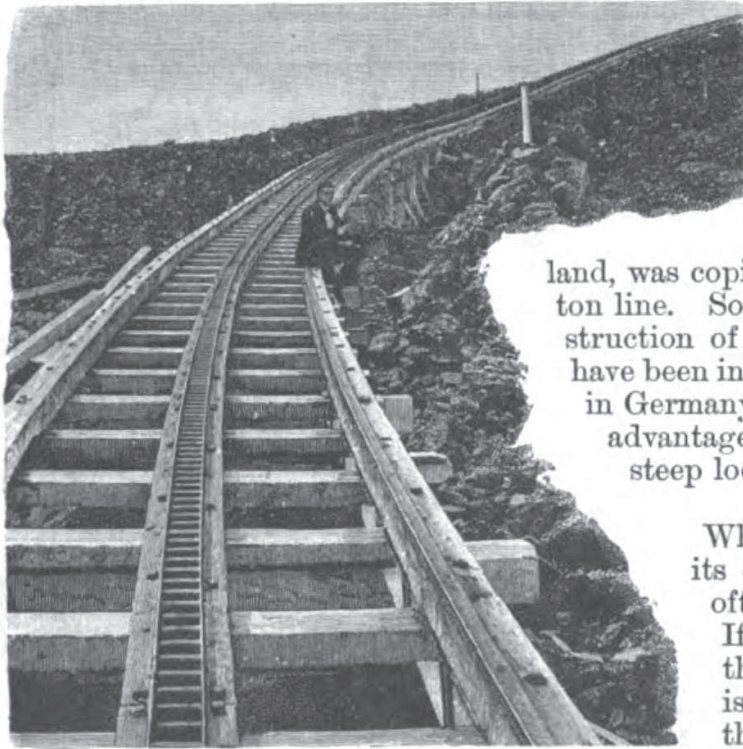


The Nochistongo Cut, Mexican Central Railway.

are still visible from the present Pennsylvania Railroad where it crosses the summit west of Altoona. The planes were operated by stationary engines acting upon cables attached to the cars. These cables passed around drums at the head of the planes, the weight of the cars on one track partially balancing those on the other. Similar planes were in use also at Albany, Schenectady, and other places.

Another effective expedient is the central rack rail. No better or more successful example of this method of construction can be given than the Mount Washington Railway [illustrated p. 12]. The road was completed in 1869. Its length is $3\frac{1}{2}$ miles and its total rise 3,625 feet. Its steepest grade is about 1 foot rise in every 3 feet in length; the average grade is 1 in 4. It is built of heavy timber, well bolted to the rock. Low places are spanned by substantial trestle work. The gauge of the road is 4 feet $7\frac{1}{2}$ inches, and it is provided with the two ordinary rails and also the central rack rail, which is really like an iron ladder, the sides being of angle iron and the cross-pieces of round iron

1½ inch in diameter and 4 inches apart. Into these plays the central cog-wheel on the locomotive, which thus climbs this iron ladder with entire safety. Very complete arrangements are made to prevent the descent of the train in case of



The Mount Washington Rack Railroad.

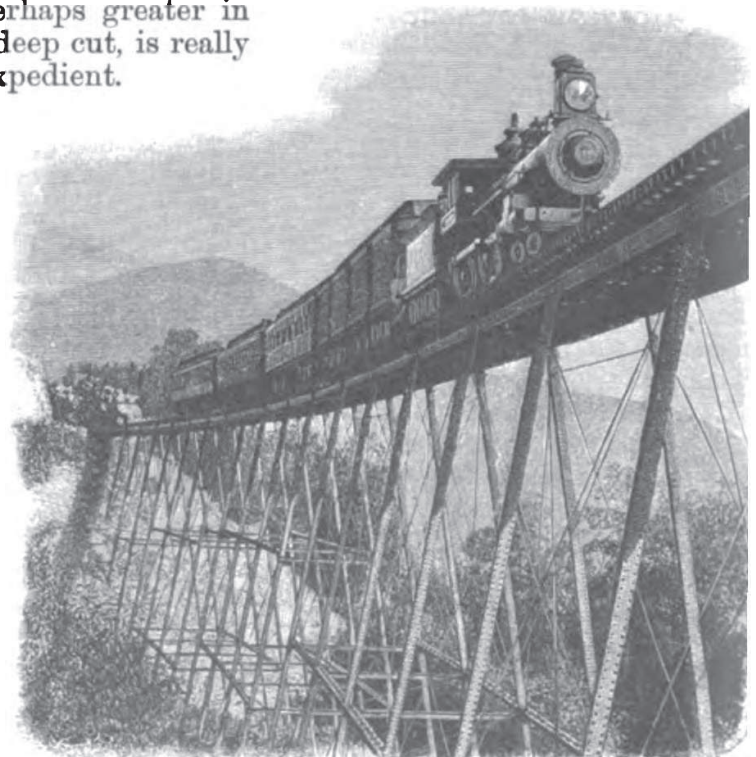
accident to the machinery. The locomotive is always below the train, and pushes it up the mountain. Many thousands of passengers have been transported every year without accident.

The rack railroad ascending the Righi, in Switzerland, was copied after the Mount Washington line. Some improvements in the construction of the rack rail and attachment have been introduced upon mountain roads in Germany, and this system seems very advantageous for use in exceptionally steep locations.

When a line of railway meets its course a barrier of rock, it is often best to cut directly through. If the grade is not too far below the surface of the rock, the cut is made like a great trench with the sides as steep as the nature of the material will allow. Very deep cuts are, however, not de-

sirable. The rains bring down upon their slopes the softer material from above and the frost detaches pieces of rock which, falling, may result in serious accidents to trains. Snow lodges in these deep cuts, at times entirely stopping traffic, as in the recent experience near New York. A tunnel, therefore, while perhaps greater in first cost than a moderately deep cut, is really often the more economical expedient.

And here is as good a place, perhaps, as any other in this article, to say that true engineering is the economical adaptation of the means and opportunities existing, to the end desired. Civil engineering was defined, by one of the greatest of England's engineers, as "the art of directing the great sources of power in nature for the use and convenience of man," and that definition was adopted as a fundamental idea in the charter of the English Institution of Civil Engineers. But the development of engineering works in America has been

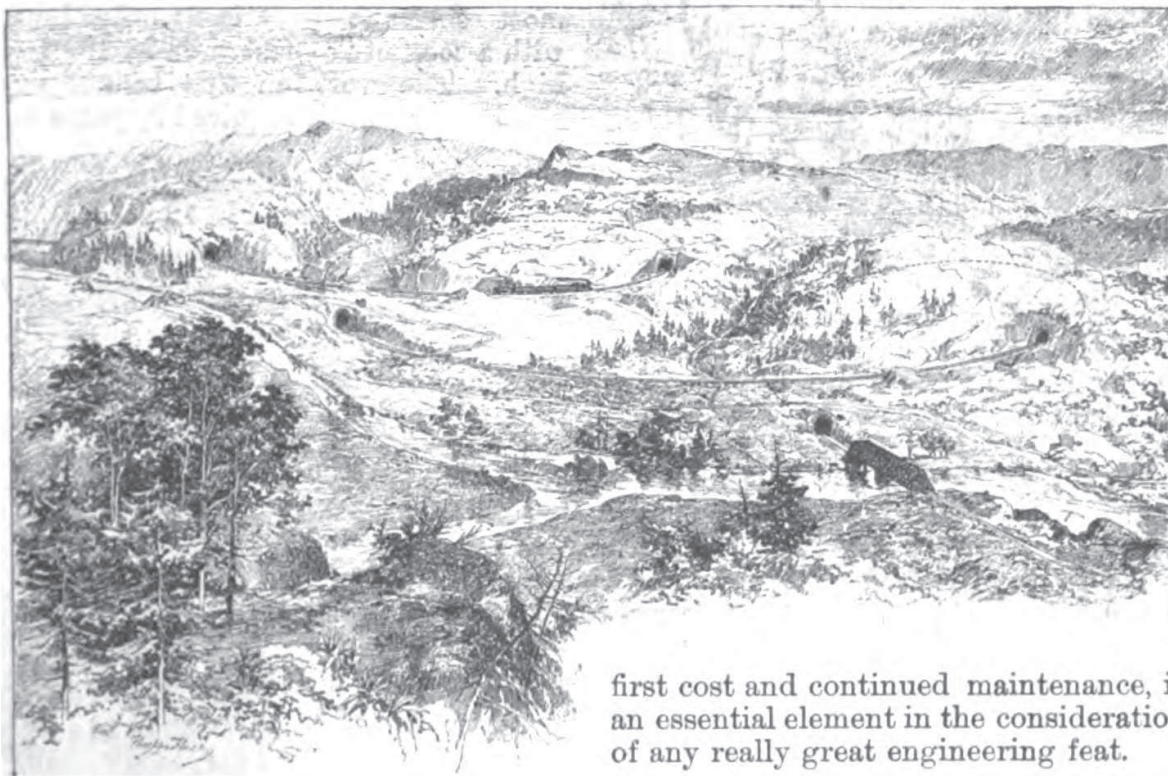


Trestle on Portland and Ogdensburg Railway, Crawford Notch, White Mountain

effected successfully by American engineers only because they have appreciated another side of the problem presented to them. A past president of the American Society of Civil Engineers, a man of rare judgment and remarkable execu-

object of our profession is to consider and determine the most economic use of time, power, and matter."

That true economy, which finally secures in a completed work the best results from the investment of capital, in



Perspective View of St. Gothard Spiral Tunnels, in the Alps.

tive ability, the late Ashbel Welch, said, in discussing a great undertaking proposed by an eminent Frenchman: "That is the best engineering, not which makes the most splendid, or even the most perfect, work, but that which makes a work that answers the purpose well, at the least cost." And it may be remarked, as to the project which he was then discussing, that after a very large expenditure and an experience of eight years since that discussion, the plans of the work have been modified and the identical suggestions made by Mr. Welch of a radical economical change have been this year adopted.* Another eminent American engineer, whose practical experience has been gained in the construction and engineering supervision of more than five thousand miles of railway, said, in his address as President of the American Society of Civil Engineers: "The high

first cost and continued maintenance, is an essential element in the consideration of any really great engineering feat.

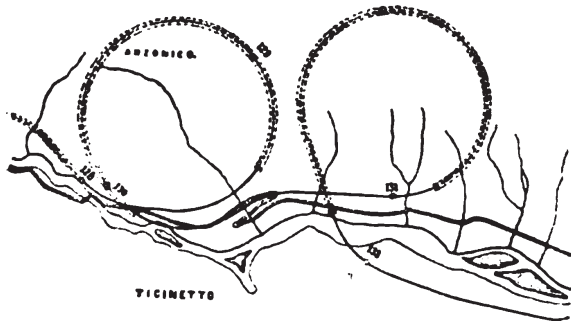
The difficulties involved in the construction of a tunnel, after the line and dimensions have been determined, depend generally upon the nature of the material found as the work advances. Solid rock presents really the fewest difficulties, but it is seldom that tunnels of considerable length occur without meeting material which requires special provision for successful treatment. In some cases great portions of the rock, where the roof of the tunnel is to be, press downward with enormous weight, being detached from the adjacent mass by the occurrence of natural seams. This was the case at the tunnel excavated for the West Shore Railroad near the bank of the Hudson River under the Military Reservation of West Point. The time occupied and the cost of building this tunnel were greatly increased by this unexpected obstacle.

At other places soft material may be encountered, and the passage then is attended with great difficulty. Temporary supports, generally of timber, and of

* Reference is made to the substitution of locks in the Panama Canal for the original project of a canal at the sea-level.

great strength, have often to be used at every foot of progress to prevent the material from forcing its way into the excavation already made.

In long tunnels the ventilation is a difficult problem, although the use of compressed air drills has aided greatly in its solution.



Plan of St. Gothard Spiral Tunnels.

Among the great tunnels which have been excavated the St. Gothard is the most remarkable. It is $9\frac{1}{4}$ miles long with a section $26\frac{1}{2}$ feet wide by $19\frac{3}{4}$ feet high. The work on this tunnel was continuous, and it required $9\frac{1}{4}$ years for its completion.

The Mont Cenis tunnel, $8\frac{1}{2}$ miles in length, was completed in 12 years.

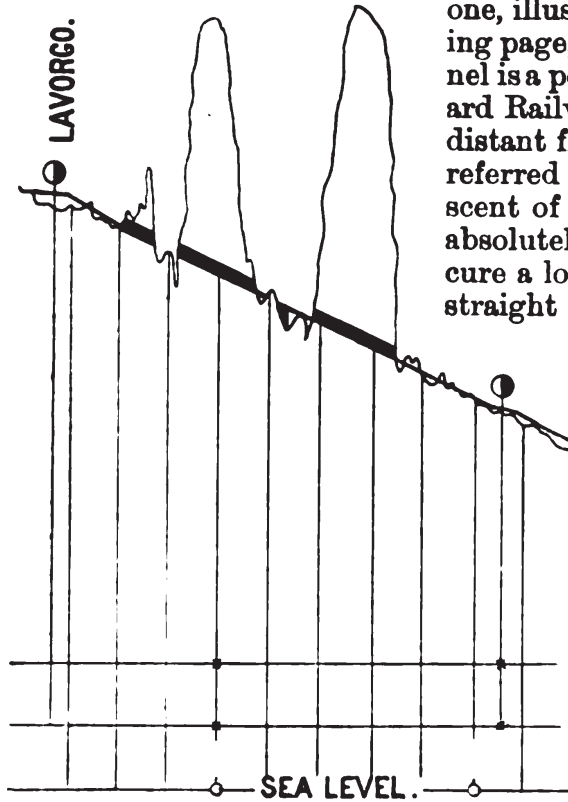
The Hoosac Tunnel, $4\frac{3}{4}$ miles in length, 26 feet wide and $21\frac{1}{2}$ feet high, was

not prosecuted continuously; it was completed in 1876.

These tunnels are notable chiefly on account of their great length; there are others of more moderate extent

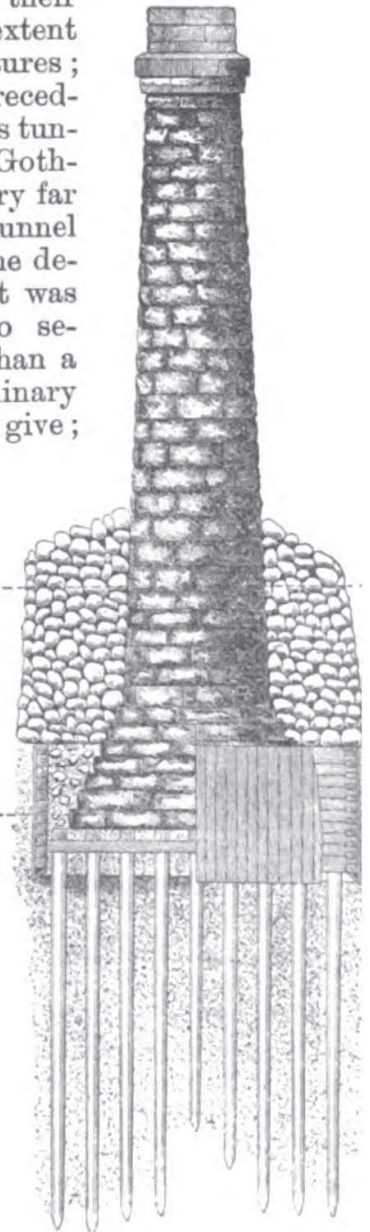
which have peculiar features; one, illustrated on the preceding page, is unique. This tunnel is a portion of the St. Gothard Railway, and not very far distant from the great tunnel referred to above. In the descent of the mountain it was absolutely necessary to secure a longer distance than a straight line or an ordinary curve would give;

the line was therefore doubly curved upon itself. It enters the mountain at a high elevation, describes a circle through the rock and, constantly descending, reappears under itself at the side;



Profile of the Same.

still descending, it enters the mountain at another point and continues in another circular tunnel until it finally emerges again, under itself, but at a comparatively short horizontal distance from its first entry, having gained the required descent by a continued grade through the tunnels. The profile above shows the descent, upon a greatly reduced scale, the heavy lines marking where the line is in the tunnel.

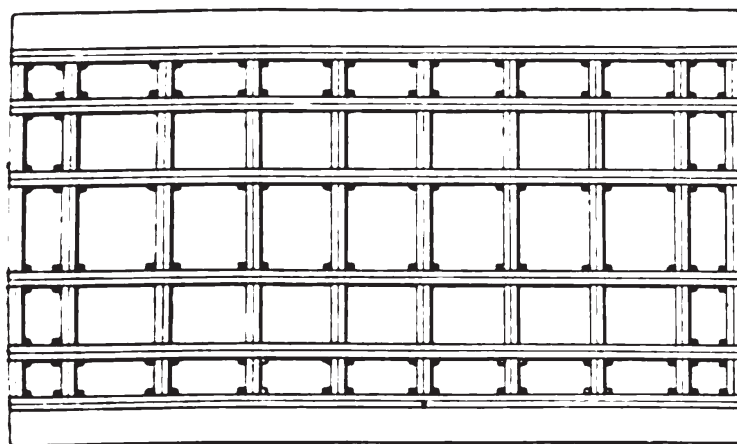


Bridge Pier Founded on Piles.

The remarkable success achieved by engineers in

securing suitable foundations at great depths is, of course, hardly known to the thousands who constantly see the

expedient is the use of piles, which are driven into the ground, often to a very considerable depth, and sustain the load placed upon them by the friction upon the sides of the piles of the material in which they are driven. It is seldom that dependence is placed upon the load being transferred from the top to the point of the pile, even though the point may have penetrated to a comparatively solid material. Wood is generally used for piles, and where the ground is permanently saturated there seems to be hardly any known limit to their durability. The substructure of foundations generally, where



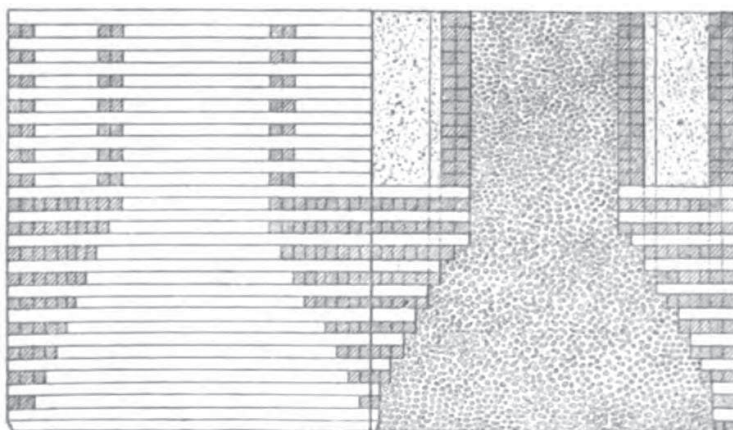
100 Feet

Foundation Crib of the Poughkeepsie Bridge.

structures supported on those foundations, but in any fair consideration of such engineering achievements this must not be omitted. The beautiful bridge built by Captain Eads over the Mississippi River at St. Louis, bold in its design and excellent in its execution, is an object of admiration to all who visit it, but the impression of its importance would be greatly magnified if the part below the surface of the water, which bears the massive towers, and which extends to a depth twice as great as the height of the pier above the water, could be visible.

The simplest and most effective foundation is, of course, on solid rock. In many localities reliable foundations are built upon earth, when it exists at a suitable depth and of such a character as properly to sustain the weight. Foundations under water, when rock or good material occurs at moderate depth, are constructed frequently by means of the coffer-dam, which is simply an enclosure made water-tight and properly connected with the bottom of the stream. The water is then pumped out and the foundation and masonry built within this temporary dam. When the material is not of a character to sustain the weight, the next

it is certain that they will always be in contact with water, can be, and generally is, of wood, and the permanency of such foundations is well established. An exception to this, however, occurs in salt-water, particularly in warmer countries, where the ravages of the minute *Teredo Navalis* and of the still more minute *Limnoria Terebrans* destroy the wood in a very short period of time. These insects, however, do not work below the ground-line or bed of the



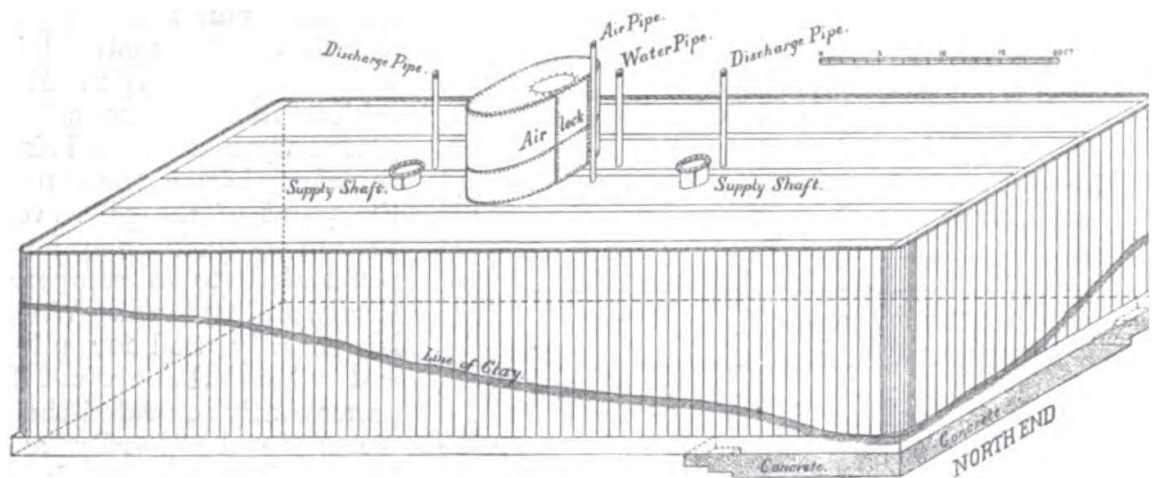
60 Feet.

Transverse Section of the Same.

water. In many special cases hollow iron piles are used successfully.

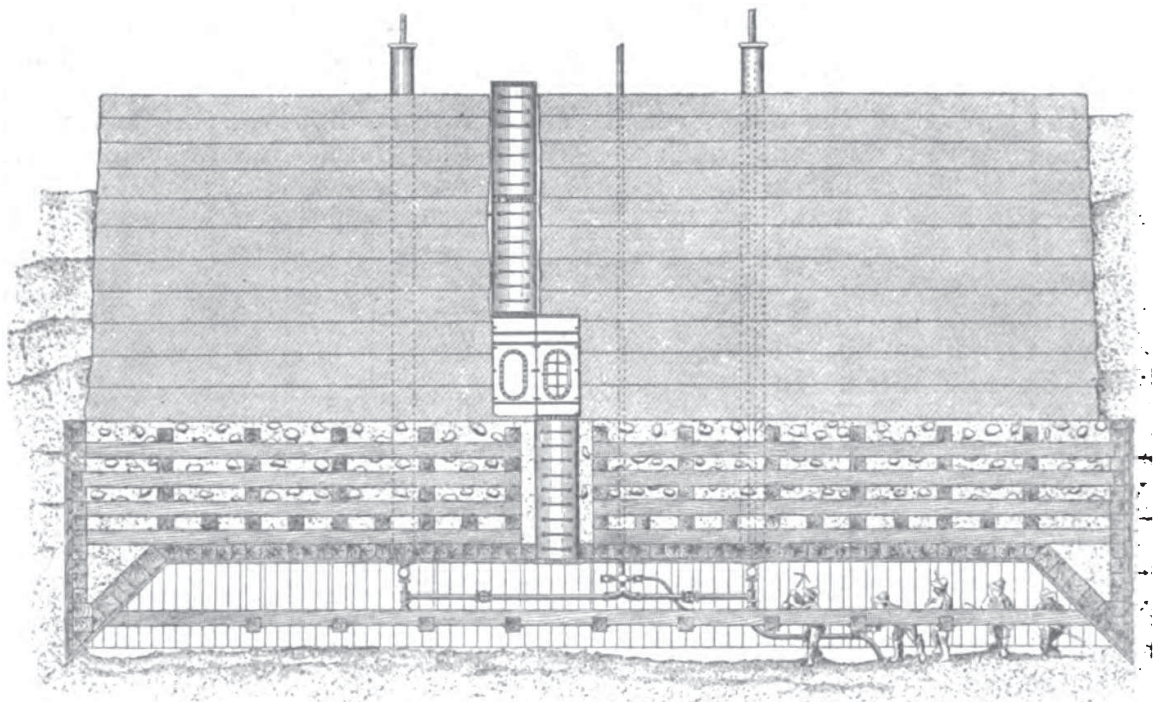
The ordinary method of forcing a pile into the ground is by repeated blows of a hammer of moderate weight; better success being obtained by frequent blows of the hammer, lifted to a slight

elevation, than results from a greater fall, there being danger also in the latter case of injuring the material of the pile. desired depth. The stream of water must be continuous, as it rises along the side of the pile and keeps the sand in



Pneumatic Caisson.

The use of the water jet for sinking piles, particularly in sand, is interesting. A tube, generally of ordinary gas-pipe, open at the lower end, is fastened to the pile; the upper end is connected by a hose to a powerful pump and, the pile mobile state. Immediately upon the cessation of pumping, the sand settles about the pile, and it is sometimes quite impossible to afterward move it. The water jet is used in sinking iron piles by conducting the water through the

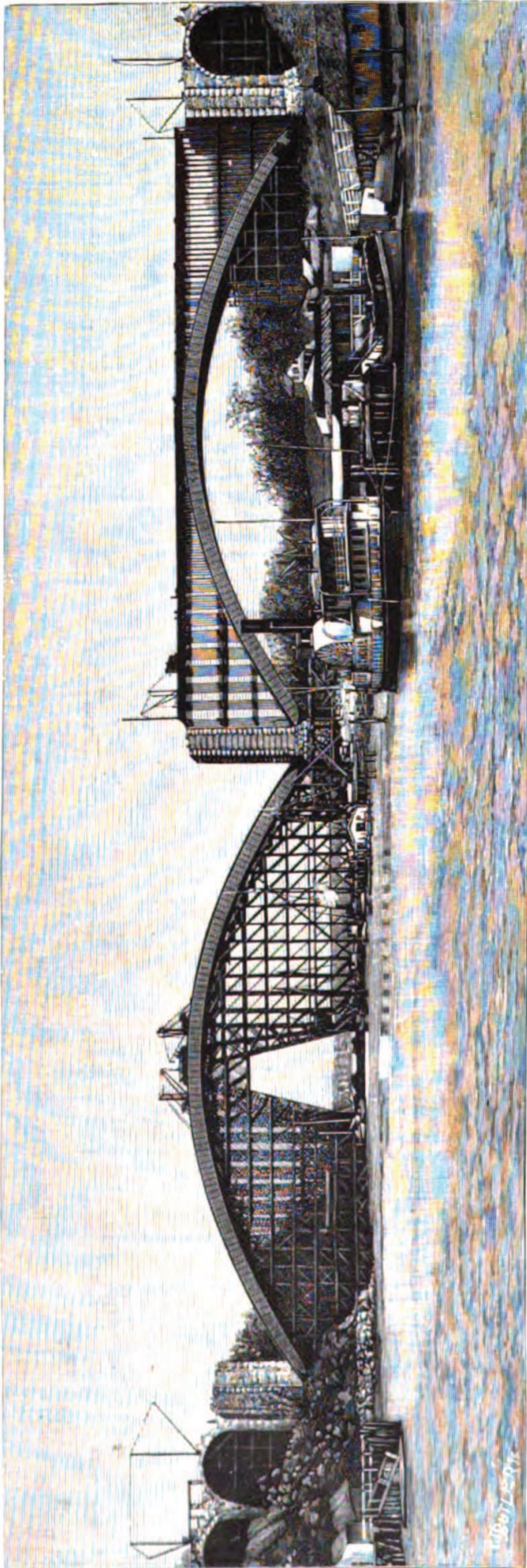


Transverse Section of Pneumatic Caisson.

being placed in position on the surface of the sand, water is forced through the tube and excavates a passage for the pile, which, by the application of very light pressure, descends rapidly to the interior of the hollow pile and out of hole at its point. The piles of the great iron pier at Coney Island were sunk with great celerity in this way. The illustration on page 14 shows one



At Work in a Pneumatic Caisson—Fifty feet below the Surface of the Water.



The 510-foot Span Steel Arches of the New Harlem River Bridge, New York.

the piers of a bridge founded upon wooden piling.

In many cases it would be impossible to drive piling in such a way as to insure the durability of the structure above it. This is particularly true of the foundations of structures crossing many of our rivers, where the bottom is of material which, in time of flood, sometimes scours to very remarkable depths; the material often being replaced when the flood has subsided. The expedient adopted is the pneumatic tube, or the caisson. Both are merely applications of the well-known principle of the diving-bell. In the former case hollow iron tubes, open at the bottom, are sunk to considerable depths, the water being expelled by air pumped into the tubes at a pressure sufficient to resist the weight of the water. Entrance to the tubes is obtained by an air-lock at the top, and the material is excavated from the inside, and sufficient weight placed upon the tube to force it gradually to the desired depth. When that depth is attained, the tubes are filled with concrete, and thus solid pillars of hydraulic concrete, surrounded by cast-iron tubing, are obtained.

The pneumatic caisson is an enlargement of this idea of the diving-bell. The caisson is simply a great chamber or box, open at the bottom; the outside bottom edges are shod and cased with iron so as to give a cutting surface; the roof and sides are made of timber, thoroughly bolted together, and of such strength as to resist the pressure of the structure to be finally founded upon it. The chamber in the open bottom is of sufficient height to enable the laborers to work comfortably in it. This caisson is generally constructed upon the shore in the vicinity of the structure and towed to the point where the foundation is to be sunk. Air is supplied by power-

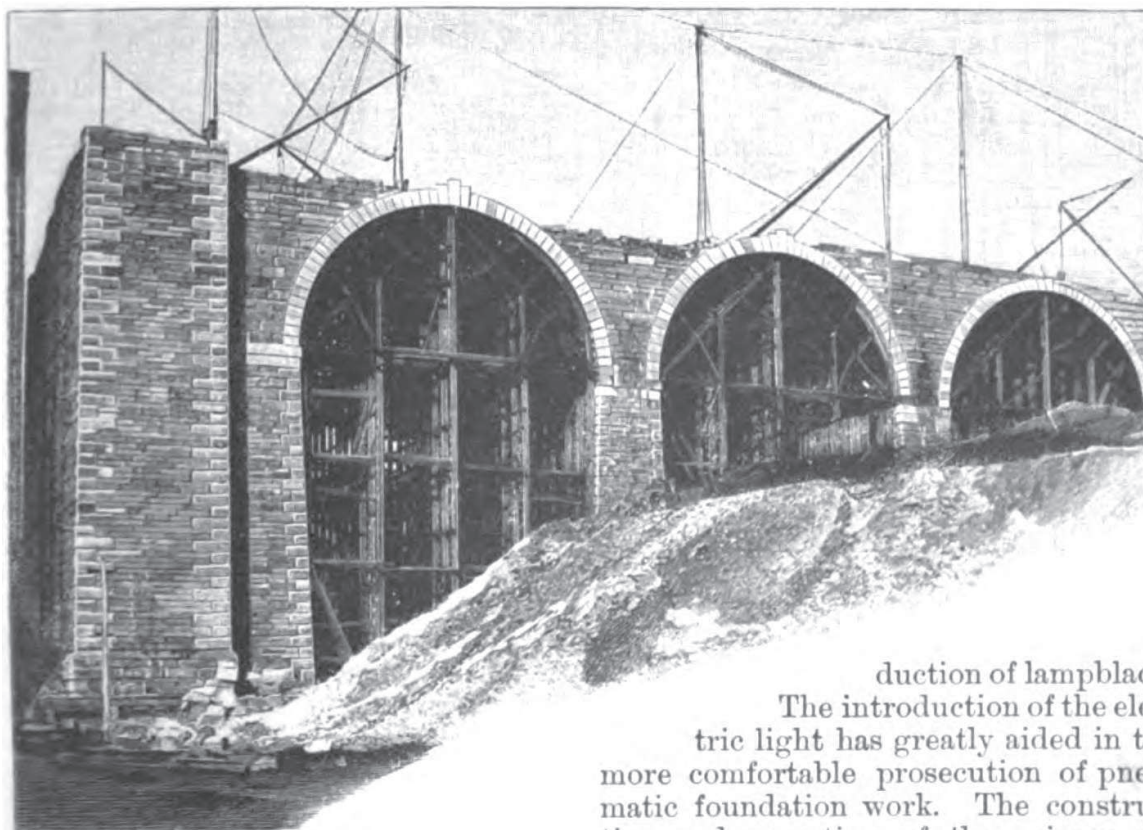
ful pumps and is forced into the working chamber. The pressure of the air of course increases constantly as the caisson descends; it must always be sufficient to overbalance the weight of the water and thus prevent the water from entering the chamber.

Descent to the caisson is made through a tube, generally of wrought iron, and having, at a suitable point, an air-lock, which is substantially an enlargement of the tube, forming a chamber, and of sufficient size to accommodate a number of men. This air-lock is provided with doors or valves at the top and at the bottom, both opening downward, and also with small tubes connecting the air-lock with the chamber below and with the external air above. Entrance to the caisson is effected through this air-lock. The lower door, or valve, being at the bottom, closes and is kept closed by the pressure of the air in the caisson below. After the air-lock is entered the upper door or

then opened gradually and the pressure in the air-lock becomes the same as that in the chamber below; as soon as this is effected the valve, or door, at the bottom of the air-lock falls open and the air-lock becomes really a part of the caisson.

A sufficient force of men is employed in the chamber to gradually excavate the material from its whole surface and from under the cutting edge, and the masonry structure is founded upon the top of the caisson and built gradually, so as to give constantly a sufficient weight to carry the whole construction down to its final location upon the stable foundation, which may be the bed rock or may be some strata of permanent character.

The problem of lighting the chamber was until recently of considerable difficulty. The rapid combustion under great pressure made the use of lamps and candles very troublesome, particularly on account of the dense smoke and large pro-

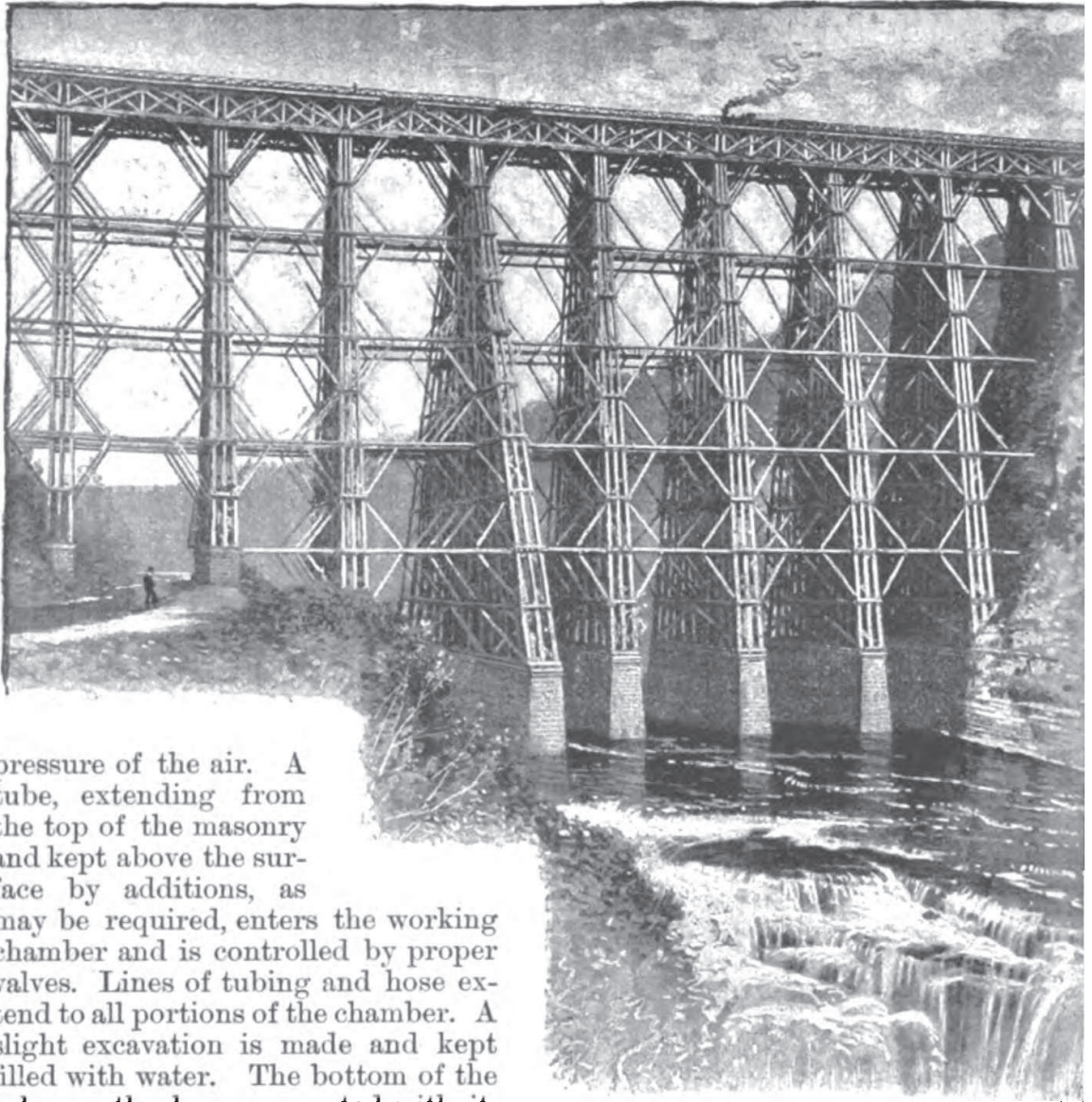


Granite Arched Approach to Harlem River Bridge.

valve is shut, and held shut a few moments, and the tube connecting with the outer air is closed; the small valve in the tube connecting with the caisson is

duction of lampblack. The introduction of the electric light has greatly aided in the more comfortable prosecution of pneumatic foundation work. The construction and operation of the caisson are illustrated on pages 16 and 17.

The removal of rock, or any large mass, from the caisson is effected through the air-chamber; but the removal of finer material, as sand or earth, is accomplished by the sand pump or by the



pressure of the air. A tube, extending from the top of the masonry and kept above the surface by additions, as may be required, enters the working chamber and is controlled by proper valves. Lines of tubing and hose extend to all portions of the chamber. A slight excavation is made and kept filled with water. The bottom of the tube, or the hose connected with it, is placed in this excavation, and, the material being agitated so as to be in suspension in the water, the valve is opened, and the pressure of the air throws the water and the material held in suspension to the surface, through the tube, from the end of which it is projected with great velocity and may be deposited at any desired adjacent point. This method, however, exhausts the air from the caisson too rapidly for continuous service. The Eads sand-pump is therefore generally used. This is an ingenious apparatus, somewhat the same in principle as the injector which forces water into steam-boilers. A stream of water is thrown by a powerful pump through a tube which, at a point near the inlet for the excavated material, is enlarged so as to surround another tube. The water is forced upward with great velocity into

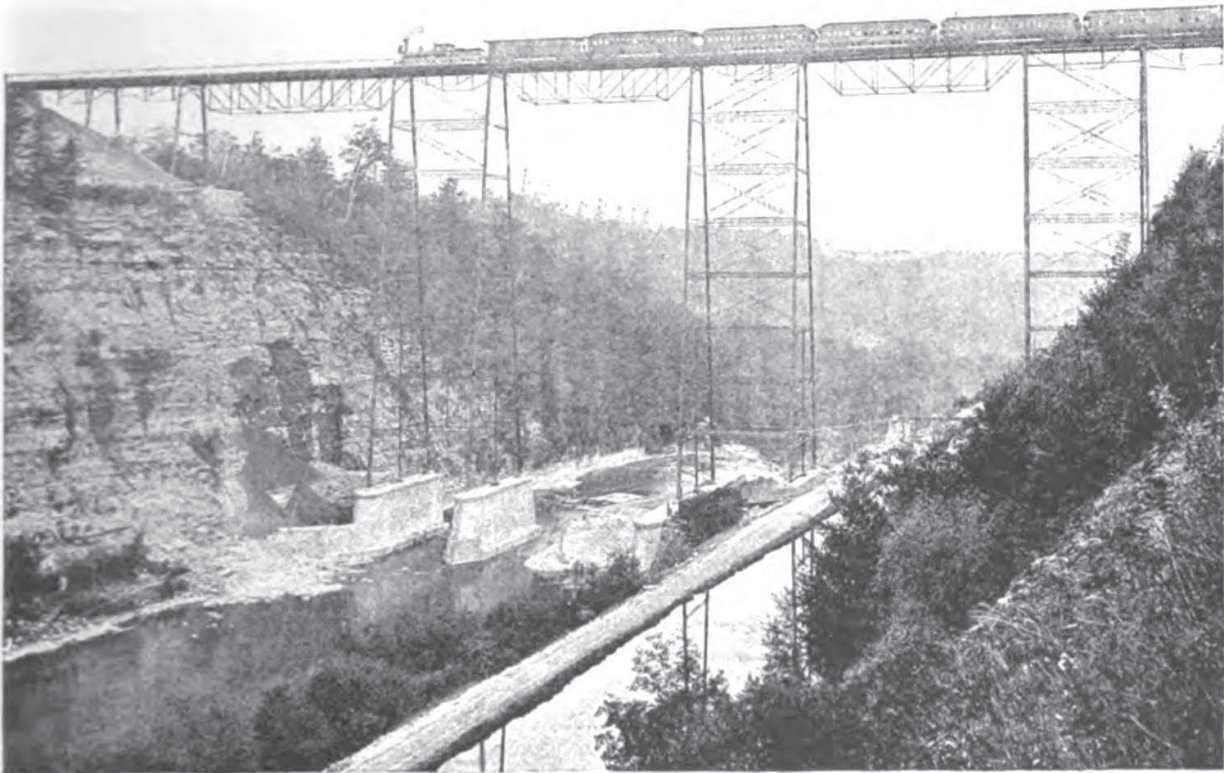
the second tube, through a conical annular opening, and, expelling the atmosphere, carries with it to the surface a continuous stream of sand and water from the bottom of the excavation.

This system has been used successfully in the foundations of piers and abutments of bridges in all parts of the world. The rapidity of the descent of the caisson varies with the material through which it has to pass. The speed with which such foundations are executed is remarkable, when one remembers with what delicacy and intelligent supervision they have to be balanced and controlled. In some instances it has been necessary to carry them to great depths, one at St. Louis being 107 feet below ordinary water level in the river.

The Old Portage Viaduct, Erie Railway, N. Y.

The pressure of air in caissons at these depths is very great ; at 110 feet below the surface of the water it would be 50 pounds to the square inch. Its effect upon the men entering and working in the caisson has been carefully noted in various works, and these effects are sometimes very serious ; the frequency of respiration is increased, the action of the

below. Occasionally a stream of sand and water issues with such velocity from the discharge pipe that, in the night, the friction of the particles causes it to look like a stream of living fire. Far below is another busy force. Under the great pressure and abnormal supply of oxygen they work with an energy which makes it impossible to remain there



The New Portage Viaduct.

heart becomes excited, and many persons become affected by what is known as the "caisson disease," which is accompanied by extreme pain and in many cases results in more or less complete paralysis. The careful observations of eminent physicians who have given this disease special attention have resulted in the formulation of rules which have reduced the danger to a minimum.

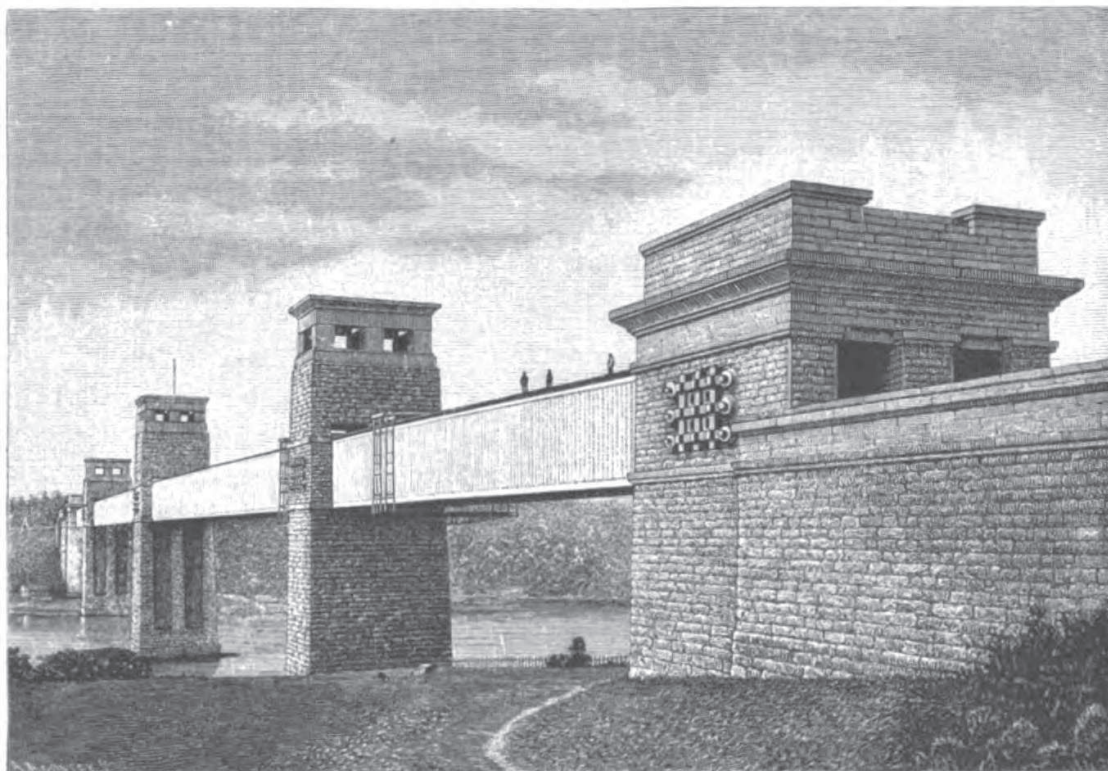
The execution of work within a deep pneumatic caisson is worth a moment's consideration. Just above the surface of the water is a busy force engaged in laying the solid blocks of masonry which are to support the structure. Great derricks lift the stones and lay them in their proper position. Powerful pumps are forcing air, regularly and at uniform pressure, through tubes to the chamber

more than a few hours. The water from without is only kept from entering by the steady action of the pumps far above and beyond their control. An irregular settlement might overturn the structure. Should the descent of the caisson be arrested by any solid under its edge, immediate and judicious action must be taken. If the obstruction be a log, it must be cut off outside the edge and pulled into the chamber. Boulders must be undermined and often must be broken up by blasting. The excavation must be systematic and regular. A constant danger menaces the lives of these workers, and the wonderful success with which they have accomplished what they have undertaken is entitled to notice and admiration.

Another process, which has succeed-

ed in carrying a foundation to greater depths than is possible with compressed air, is by building a crib or caisson, with chambers entirely open at the top, but having the alternate ones closed at the bottom and furnished with cut-

shall descend evenly and always maintain its upright position. The dredge is handled and operated entirely from the surface. The very idea is startling, of managing an excavation more than a hundred feet below the operator, en-



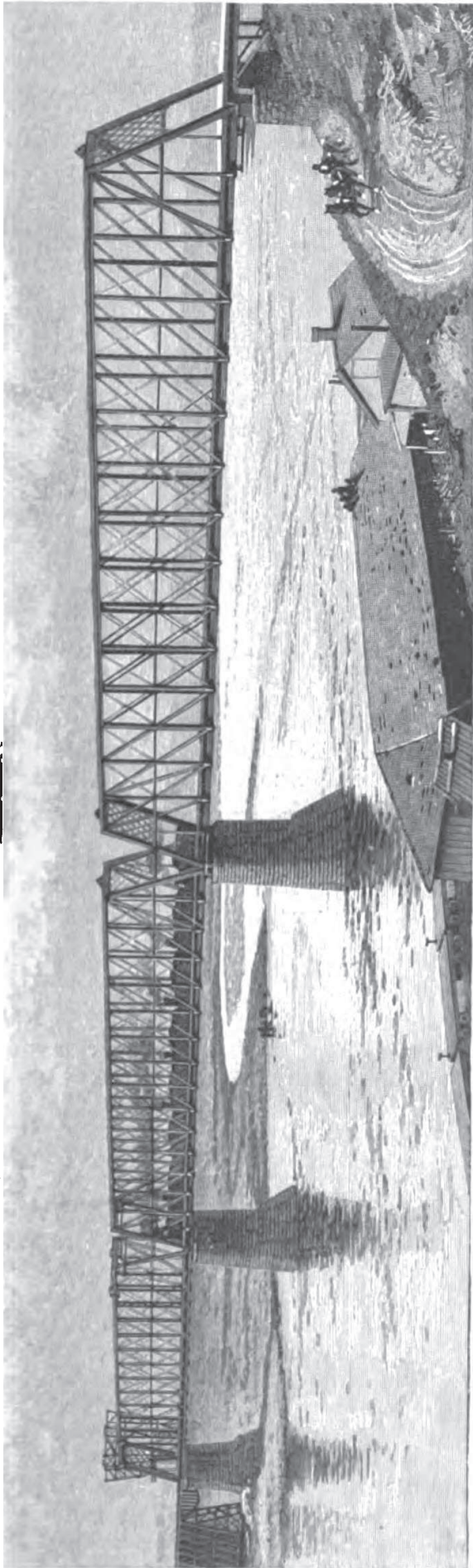
The Britannia Tubular Bridge over the Menai Straits, Wales.

ting edges. These closed chambers are weighted with stone or gravel until the structure rests upon the bottom of the river; the material is then excavated from the bottom through the open chambers, by means of dredges, thus permitting the structure to sink by its weight to the desired depth. When that depth is reached, the chambers which have been used for dredging are filled with concrete, and the masonry is constructed upon the top of this structure. The use of this system has enabled the engineer to place foundations deeper than has been accomplished by any other device, one recently built in Australia being 175 feet below the surface of the water. Illustrations on page 15 show this method of construction.

Even more remarkable than the pneumatic caisson is this method of sinking these great foundations. The removal of material must be made with such systematic regularity that the structure

tirely by means of the ropes which connect with the dredge, and doing it with such delicacy that the movement of an enormous structure, weighing many tons, is absolutely controlled. This is one of the latest and most interesting advances of engineering skill.

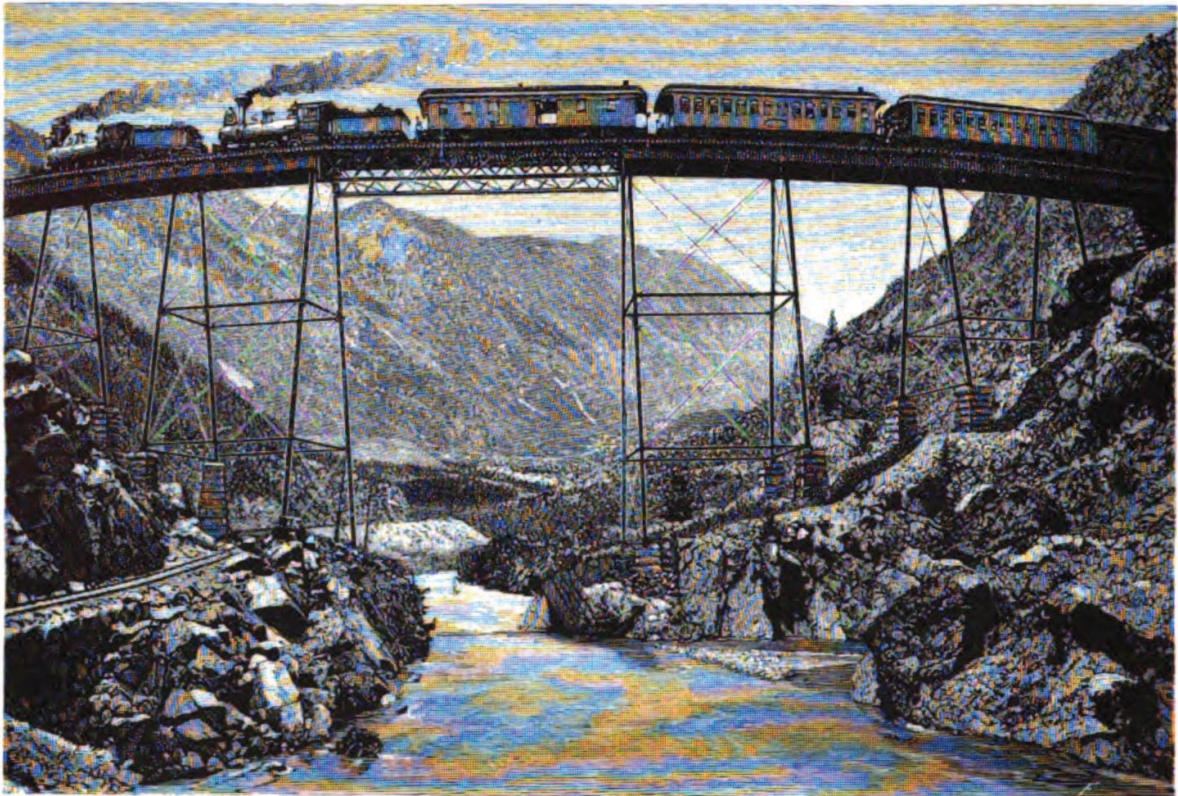
While it is true that the avoidance of large expenditure, when possible, is a mark of the best engineering, yet great structures often become absolutely necessary in the development of railway communication. Wide rivers must be crossed, deep valleys must be spanned, and much study has been given to the best methods of accomplishing these results. In the early history of railways in Europe substantial viaducts of brick and stone masonry were generally built; and in this country there are notable instances of such constructions. The approach to the depot of the Pennsylvania Railroad, in the city of Philadelphia,



Truss Bridge of the Northern Pacific Railway over the Missouri River at Bismarck, Dakota.—Testing the central span.

is an excellent example. Each street crossed by the viaduct is spanned by a bold arch of brick. Upon a number of our railways there are heavy masonry arches and culverts, and at some places these are of a very interesting character. The arches in the approach to the bridge over the Harlem Valley, now in construction, are shown on page 19. These are arches of granite, of a span of 60 feet. The illustration shows also the method of supporting the stone work of such arches during construction. Braced timbers form what is called the centre, and support the curved frame of plank upon which the masonry is built, which, of course, cannot be self-supporting until the keystone is in place; then the centre is lowered by a loosening of the wedges which support it, and the stone work of the arch is permitted to assume its final bearing. It is generally considered that where it is practicable to construct masonry arches under railways there is a fair assurance of their permanency, but some engineers of great experience in railway construction advance the theory that the constant jar and tremor produced by passing railway trains is really more destructive to masonry work than has been supposed, and that it may be true that the elements of the best economy will be found in metal structures rather than in masonry. It is true that repairs and renewals of metal bridges are much more easily accomplished than of masonry constructions.

In this country the wooden bridge has been an important, in fact an essential element in the successful building of our railways. At this moment the length of wooden bridges on the railway lines is very much greater than of metal. There have been a number of forms of wooden structure, but the Howe truss is, in many respects, the most per-



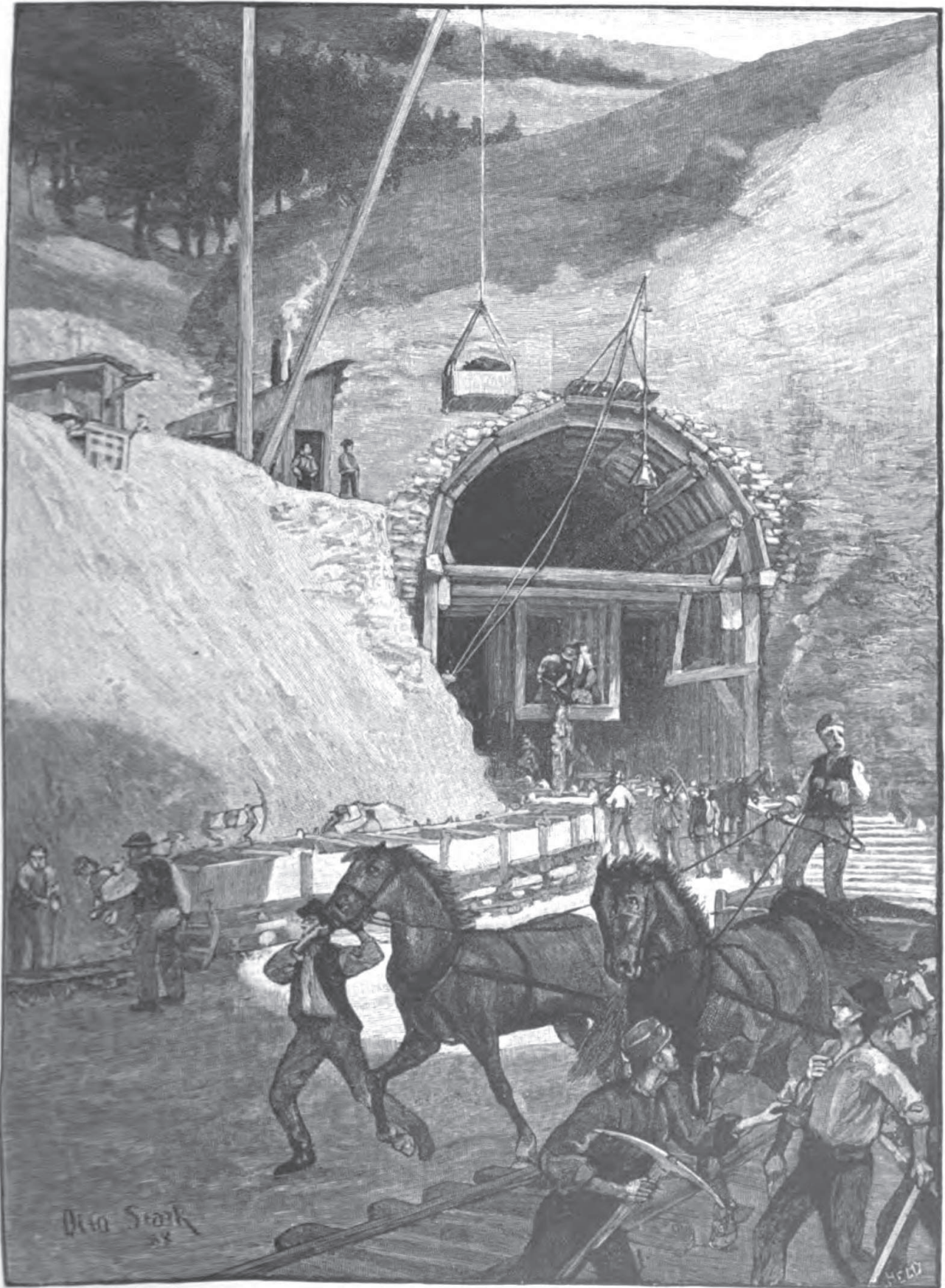
Curved Viaduct, Georgetown, Colorado ; the Union Pacific crossing its own line.

fect ; its construction is simple. it has the minimum amount of metal, the vertical rods being of iron, the rest of the structure, with the exception of some of the angle blocks, bolts, nuts, etc., being entirely of wood. A bridge built by Mr. Howe in 1840, across the Connecticut River at Springfield, with seven spans of 180 feet each, was one of his first works. It lasted until 1853, when it was replaced by a Howe truss of more modern design, which was in good condition when, in 1874, it was replaced by a double-track iron bridge. This improved form of truss has held its place in public favor, and, where timber is convenient, is an economical bridge.

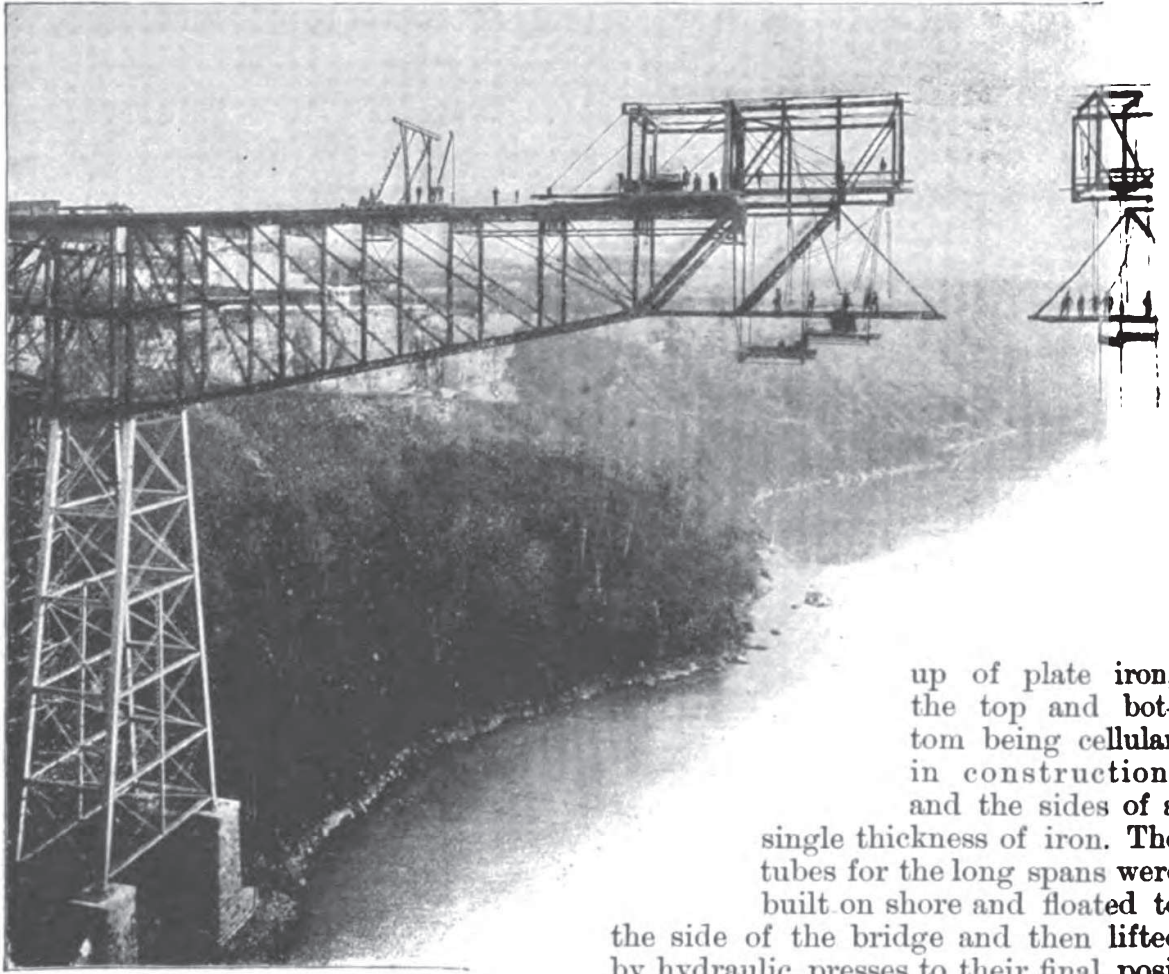
Timber is also used extensively in railroad construction in the form of trestles ; one example of which has been alluded to on page 7. There were also constructed, years ago, some very bold viaducts in wood. One of the most interesting is shown on page 20, being the viaduct at Portage, N. Y. This construction was over 800 feet long, and 234 feet high from the bed of the river to the rail. The masonry foundations were 30 feet high, the trestles 190 feet, and the truss 14 feet ; it contained more than a

million and a half feet, board measure, of timber. The timber piers, which were 50 feet apart, are formed by three trestles, grouped together. It was framed so that defective pieces could be taken out and replaced at any time. This bridge was finished in 1852 and was completely destroyed by fire in 1875. The new metal structure which took its place is shown on page 21, and is an interesting example of the American method of metal viaduct construction, an essential feature of that construction being the concentration of the material into the least possible number of parts. This bridge has ten spans of 50 feet, two of 100 feet, and one of 118 feet. The trusses are of what is called the Pratt pattern, and are supported by wrought-iron columns, two pairs of columns forming a skeleton tower 20 feet wide and 50 feet long on the top. There are six of these towers, one of which has a total height from the masonry to the rail of 203 feet 8 inches. There are over 1,300,000 pounds of iron in this structure.

The fundamental idea of a bridge is a simple beam of wood. If metal is substituted it is still a beam with all superfluous parts cut away. This re-



Portal of a Tunnel in Process of Construction.



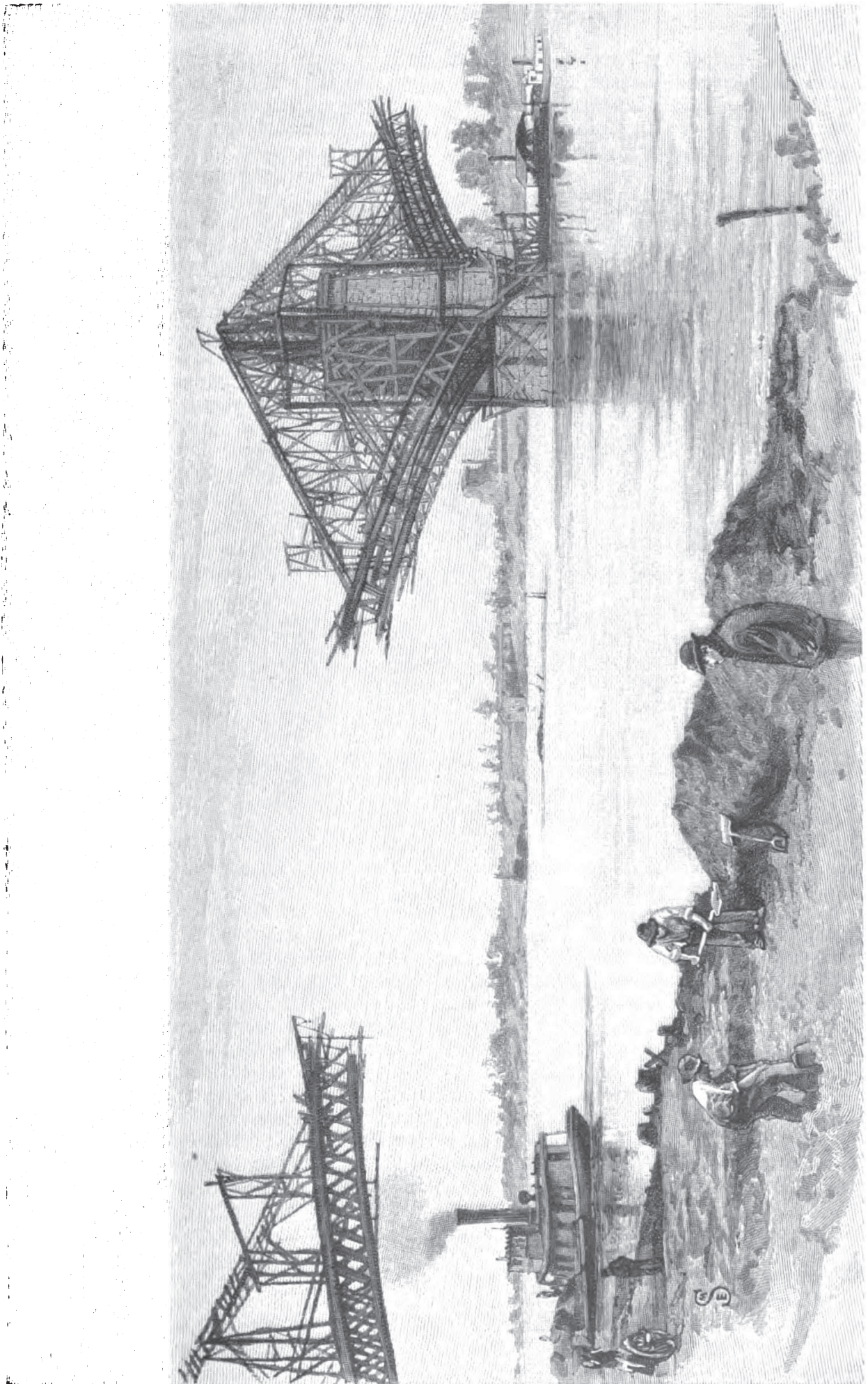
The Niagara Cantilever Bridge in Progress.

sults in what is called an I beam. When greater loads have to be carried, the I beam is enlarged and built up of metal plates rivetted together and thus becomes a plate girder. These are used for all short railway spans. For greater spans the truss must be employed.

Before referring, however, to examples of truss bridges, a description should be given of the Britannia Bridge, built by Robert Stephenson in 1850, over the Menai Straits. This construction carries two lines of rails and is built of two square tubes, side by side, each being continuous, 1,511 feet long, supported at each extremity and at three intermediate points, and having two spans of 460 feet each and two spans of 230 feet each. [P. 22.] The towers which support this structure are of very massive masonry, and rise considerably above the top of the tubes. These tubes are each 27 feet high and 14 feet 8 inches wide; they are built

up of plate iron, the top and bottom being cellular in construction, and the sides of a single thickness of iron. The tubes for the long spans were built on shore and floated to the side of the bridge and then lifted by hydraulic presses to their final position. The rapid current, and other considerations, made the erection of false works for these spans impracticable. The beautiful suspension bridge, built by Telford in 1820, over the Menai Straits, is only a mile away from this Britannia Bridge, but, at the time of the construction of the latter, it was not deemed possible by English engineers to erect a suspension bridge of sufficient strength and stability to accommodate railway traffic.

The Victoria Bridge at Montreal is of the same general character of construction as the Britannia Bridge, but is built only for a single line of rails; this bridge also was built by Mr. Stephenson, in 1859. These two structures were enormous works; their strength is undoubted, but they lacked that element of permanent economy which has been spoken of in this article; their cost was very great and the expense of maintenance is also very great. A very large amount of rust is taken from these tubes every year; they require very frequent painting, and their



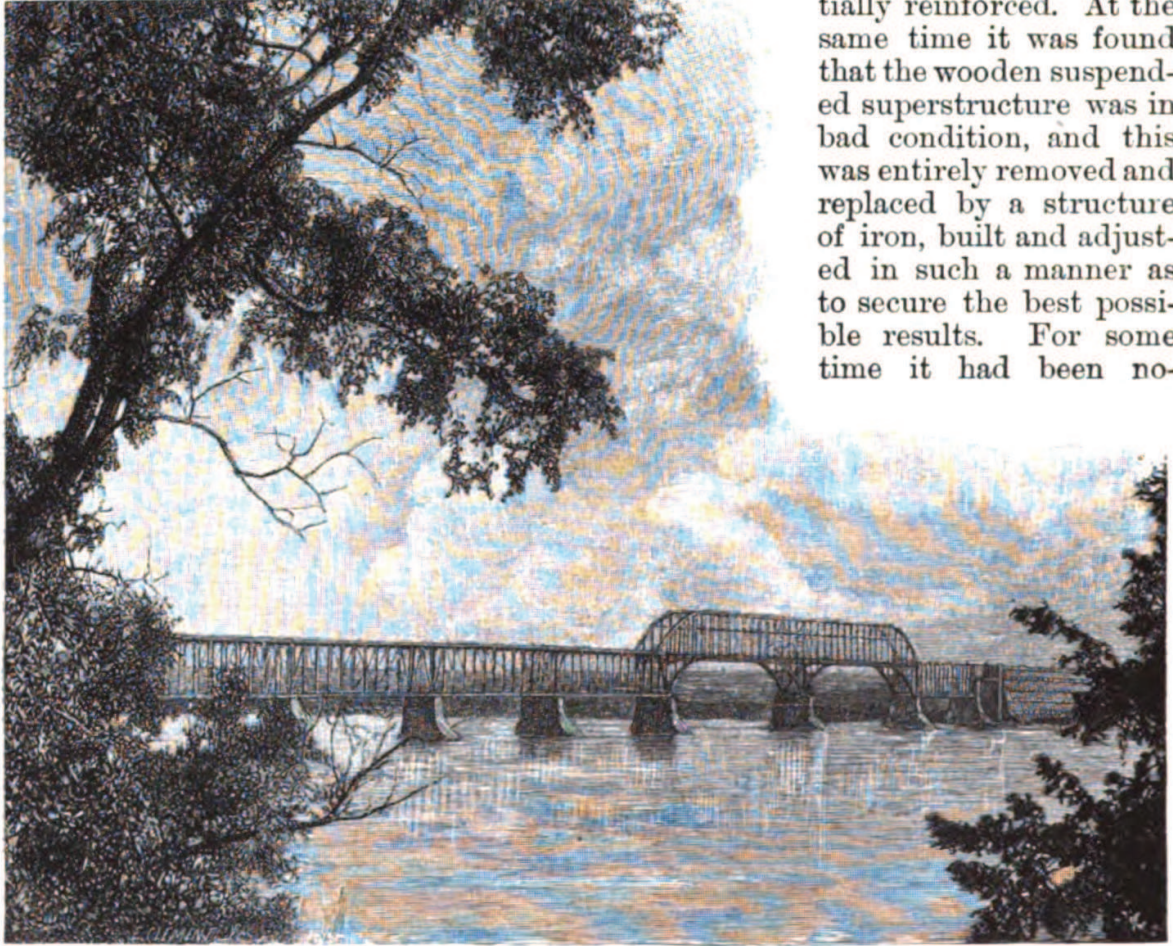
The St. Louis Bridge during Construction.

are on the Victoria Bridge 30 acres of iron surface to be painted.

A remarkable and interesting contrast to these heavy tubes of iron is the Niagara Falls railway suspension bridge,

years; it was then found that some repairs to the cable were required at the anchorage, the portions of the cables exposed to the air being in excellent condition. These repairs were made, and the

anchorage was substantially reinforced. At the same time it was found that the wooden suspended superstructure was in bad condition, and this was entirely removed and replaced by a structure of iron, built and adjusted in such a manner as to secure the best possible results. For some time it had been no-



The Lachine Bridge, on the Canadian Pacific Railway, near Montreal, Canada.

completed in March, 1855. The span of this bridge is 821 feet, and the track is 245 feet above the water surface. It is supported by 4 cables which rested on the tops of two masonry towers at each end of the central span, the ends of the cables being carried to and anchored in the solid rock. The suspended superstructure has two floors, one above the other, connected together at each side by posts and truss rods, inclined in such a manner as to form an open trussed tube, not intended to support the load, but to prevent excessive undulations. The floors are suspended from the cables by wire ropes, the upper floor carrying the railroad track, and the lower forming a foot and carriage way. Each cable has 3,640 iron wires. This bridge carried successfully a heavy traffic for 26

ticed that the stone towers which supported the great cables of the bridge showed evidences of disintegration at the surface, and a careful engineering examination in 1885 showed that these towers were in a really dangerous condition. The reason for this was that the saddles over which the cables pass on the top of the towers had not the freedom of motion which was required for the action of the cables, caused by differences of temperature and by passing loads. These saddles had been placed upon rollers but, at some period, cement had been allowed to be put between these rollers, thus preventing their free motion. The result was a bending strain upon the towers which was too great for the strength and cohesion of the stone. A most interesting

and successful feat was accomplished in the substitution of iron towers for these stone towers, without interrupting the traffic across the bridge. This has been accomplished very recently by building a skeleton iron tower outside of the stone tower, and transferring the cables from the stone to the iron tower by a most ingenious arrangement of hydraulic jacks. The stone towers were then removed. Thus, by the renewal of its suspended structure and the replacing of its towers, the bridge has been given a new lease of life and is in excellent condition to-day. [P. 33.]

This Niagara railway suspension bridge has been so long in successful operation that it is difficult now to appreciate the general disbelief in the possibility of its success as a railway bridge, when it was undertaken. It was projected and executed by the late John A. Roebling. Before it was finished, Robert Stephenson said to him, "If your bridge succeeds, mine is a magnificent blunder." The Niagara bridge did succeed.

We are so familiar with the great suspension bridge between New York and Brooklyn [frontispiece], that only a simple statement of some of its characteristic features will be given. Its clear span is 1,595½ feet. With its approaches its length is 3,455 feet. The clear waterway is 135 feet high. The towers rise 272 feet above high water and extend on the New York side down to rock 78 feet below. The four suspension cables are of steel wire and support six parallel steel trusses, thus providing two carriage ways, two lines of railway, and one elevated footway. The cables are carried to bearing anchorages in New York and in Brooklyn. The cars on the bridge are propelled by cables, and the amount of travel is now so great as to demand some radical changes in the methods for its accommodation, which a few years ago were supposed to be ample.

Except under special circumstances of location or length of span, the truss bridge is a more economical and suitable structure for railway traffic than a suspension bridge. Reference has been made to the excellent wooden trusses which have for so many years done good service in every part of the country. The material of course is perishable, al-

though the life of some of these well-built wooden trusses is wonderfully long. The great danger is from fire—and as the traffic on a road increases that danger becomes greater.

The advance from the wood truss to the modern steel structure has been through a number of stages. Excellent bridges were built in combinations of wood and iron, and are still advocated where wood is inexpensive. Then came the use of cast iron for those portions of the truss subject only to compressive strains, wrought iron being used for all members liable to tension. Many bridges of notable spans were built in this way and are still in use. The form of this combination truss varied with the designs of different engineers, and the spans extended to over three hundred feet. The forms bore the names of the designers, and the Fink, the Bollman, the Pratt, the Whipple, the Post, the Warren, and others had each their advocates. The substitution of wrought for cast iron followed, and until quite recently trusses built entirely of wrought iron have been used for all structures of great span. The latest step has been made in the use of steel, at first for special members of a truss and latterly for the whole structure. The art of railway bridge building has thus, in a comparatively few years, passed through its age of wood, and then of iron, and now rests in the application of steel in all its parts.

Two distinct ways of connecting the different parts of a structure are in common use, riveting and pin connections.

In riveted connections the various parts of the bridge are fastened at all junctions by overlapping the plates of iron or steel and inserting rivets into holes punched through all the plates to be connected. The rivets are so spaced as to insure the best result as to strength. The pieces of metal are brought together, either in the shop or at the structure during erection, and the rivets, which are round pieces of metal with a head formed on one end, are heated and inserted from one side, being made long enough to project sufficiently to give the proper amount of metal for forming the other head. This is done while the rivet is still hot, either by hammering or by the application of a

riveting machine, operated by steam or hydraulic pressure. Ingenious portable machines are now manufactured which are hung from the structure during erection and connected by flexible hose with the steam power, by the use of which the rivet heads can be formed in place with great celerity. The connections of plates by rivets of proper dimensions and properly spaced give great strength and stiffness to such joints.

In pin connections the members of a structure are assembled at points of junction and a large iron or steel pin inserted in a pin-hole running through all the members. This pin is made of such diameter as to withstand and properly transmit all the strains brought upon it. Joints made with such pin connections have flexibility, and the strains and stresses can be calculated with great precision. Eye-bars are forged pieces of iron or steel, generally flat, and enlarged at the ends so as to give a proper amount of metal around the pin-hole or eye, formed in those ends.

Structures connected by pins at their principal junctions have, of course, many parts in which riveting must be used.

The elements which are distinctively American in our railway bridges are the concentration of material in few members and the use of eye-bars and pin connections in place of riveted connections. The riveted methods are, however, largely used in connection with the American forms of truss construction.

An excellent example of an American railway truss bridge is shown on page 23. This structure spans the Missouri River at its crossing by the Northern Pacific Railroad. It has three through spans of 400 feet each and two deck spans of 113 feet each. The bottom chords of the long spans are 50 feet above high water, which at this place is 1,636 feet above the level of the sea. The foundations of the masonry piers were pneumatic caissons. The trusses of the through spans, 400 feet long, are 50 feet deep and 22 feet between centres. They are divided into 16 panels of 25 feet each. The truss is of the double system Whipple type with inclined end posts. The bridge is proportioned to carry a train weighing 2,000 pounds per

lineal foot, preceded by two locomotives weighing 150,000 pounds in a length of 50 feet. The pins connecting the members of the main truss are 5 inches in diameter.

This bridge is a characteristic illustration of the latest type of American methods. The extreme simplicity of its lines of construction, the direct transfer of the strains arising from loads, through the members, to and from the points where those strains are concentrated in the pin connections at the ends of each member, are apparent even to the untechnical eye. The apparent lightness of construction arising from the concentration of the material in so small a number of members, and the necessarily great height of the truss, give a grace and elegance to the structure and suggest bold and fine development of the theories of mechanics.

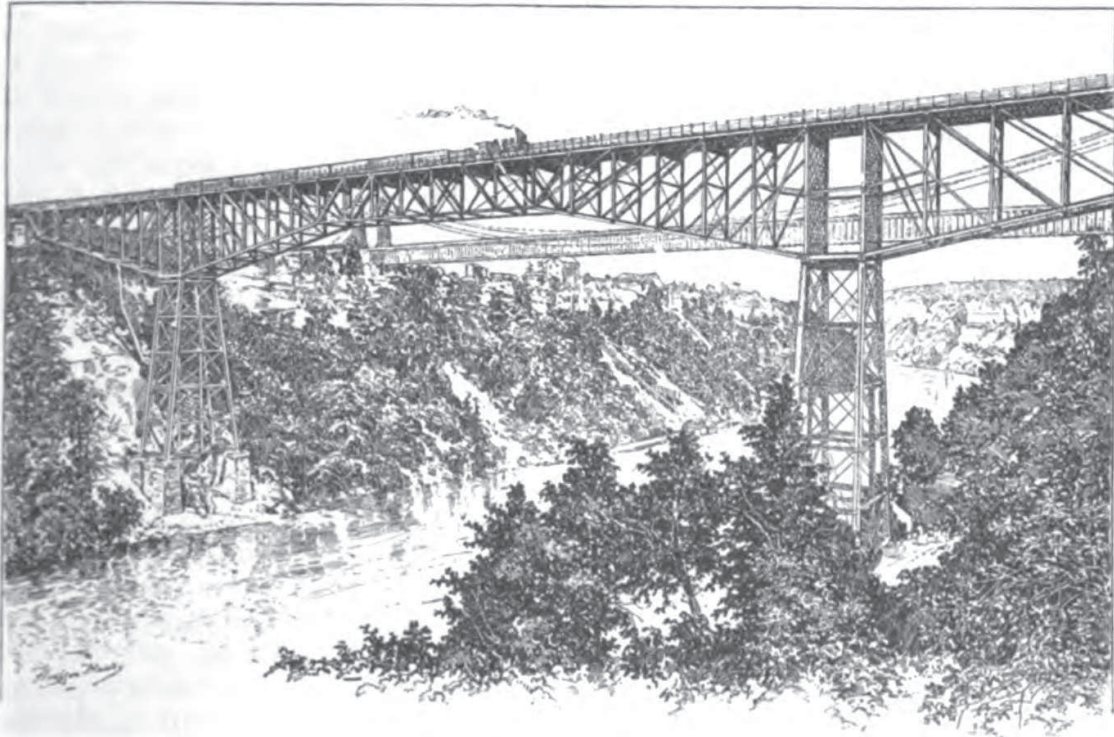
An interesting structure is that shown on page 24, where the railway crosses its own line on a curved truss.

The truss bridges which have been mentioned as types of the modern railway bridge are erected by the use of false works of timber, placed generally upon piling or other suitable foundation, between the piers or abutments, and made of sufficient strength to carry each span of the permanent structure until it is completed and all its parts connected, or, as is technically said, until the span is swung. Then the false works are removed and the span is left without intermediate support. But there are places where it would be impossible or exceedingly expensive to erect any false works. A structure over a valley of great depth, or over a river with very rapid current, are instances of such a situation.

A suspension bridge would solve the problem, but in many cases not satisfactorily. The method adopted by Colonel C. Shaler Smith at the Kentucky River Bridge [p. 9] shows ingenuity and boldness worthy of special remark. The Cincinnati Southern Railroad was here to cross a cañon 1,200 feet wide and 275 feet deep. The river is subject to freshets every two months, with a range of 55 feet and a known rise of 40 feet in a single night. Twenty years before, the towers for a sus-

pension bridge had been erected at this point. The design adopted for the railroad bridge was based upon the cantilever principle. The structure has three spans of 375 feet each, carrying a railway track at a height of 276 feet above the bed of the river. At the time of its construction this was the highest railway bridge in the world, and it is

half the length of the side spans, and at this point rested upon temporary wooden supports. From thence they were again extended as cantilevers until the side spans were completed and rested upon the iron piers. This cantilever principle is simply the balancing of a portion of the structure on one side of a support by the portion on the opposite



The Niagara Cantilever Bridge.

still the highest structure of the kind with spans of over 60 feet in length. The bridge is supported by the bluffs at its ends and by two intermediate iron piers resting upon bases of stone masonry. Each iron pier is 177 feet high, and consists of four legs, having a base of $71\frac{1}{2} \times 28$ feet, and terminating at its top in a turned pin 12 inches in diameter under each of the two trusses. Each iron pier is a structure complete in itself, with provision for expansion and contraction in each direction through double roller beds interposed between it and the masonry, and is braced to withstand a gale of wind that would blow a loaded freight-train bodily from the bridge.

The trusses were commenced by anchoring them back to the old towers, and were then built out as cantilevers from each bluff to a distance of one-

side of the same support. Similarly the halves of the middle span were built out from the piers, meeting with exactness in mid-air. The temporary support used first at the centre of one side span and then at the other, was the only scaffolding used in erecting the structure, none whatever being used for the middle span.

When the junction was made at the centre of the middle span, the trusses were continuous from bluff to bluff, and, had they been left in this condition, would have been subjected to constantly varying strains resulting from the rise and fall of the iron piers due to thermal changes. This liability was obviated by cutting the bottom chords of the side spans and converting them into sliding joints at points 75 feet distant from the iron piers. This done, the bridge consists of a continuous girder 525 feet

long, covering the middle span of 375 feet, and projecting as cantilevers for 75 feet beyond each pier, each cantilever supporting one end of a 300-foot span, which completes the distance to the bluff on each side.

A most interesting example of cantilever construction is the railway bridge recently built at Niagara, only a few rods from the suspension bridge and a short distance below the great falls. It is shown in the illustrations on pages 26 and 31. The floor of the bridge is 239 feet above the surface of the water, which at that point has a velocity in the centre of $16\frac{1}{2}$ miles per hour and forms constant whirlpools and eddies near the shores. The total length of the structure is 910 feet, and the clear span over the river between the towers is 470 feet. The shore arms of the cantilever, that is to say, those portions of the structure which extend from the top of the bank to the top of the tower built from the foot of the bank, are firmly anchored at their shore ends to a pier built upon the solid rock. These shore arms were constructed on wooden false works, and serve as balancing weights to the other or river arms of the lever, which project out over the stream. These river arms were built by the addition of metal, piece by piece, the weight being always more than balanced by the shore arms. The separate members of the river arms were run out on the top of the completed part and then lowered from the end by an overhanging traveling derrick and fastened in place by men working upon a platform suspended below [see p. 26]. This work was continued, piece by piece, until the river arm of each cantilever was complete, and the structure was then finished by connecting these river arms by a short truss suspended from them directly over the centre of the stream. This whole structure was built in eight months, and is an example both of a bold engineering work and of the facility with which a pin-connected structure can be erected. The materials are steel and iron. The prosecution of this work by men suspended on a platform, hung by ropes from a skeleton structure projecting, without apparent support, over the rushing Niagara torrent, was always

an interesting and really thrilling spectacle.

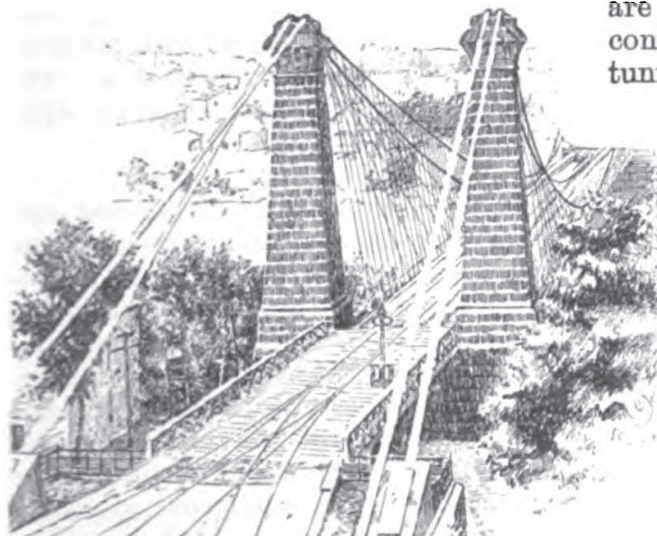
The Lachine Bridge just built over the St. Lawrence near Montreal [p. 28] has certain peculiar features. It has a total length of 3,514 feet. The two channel spans are each 408 feet in length and are through spans. The others are deck spans. Through spans are those where the train passes between the side trusses. Deck spans are those where the train passes over the top of the structure. These two channel spans and the two spans next them form cantilevers, and the channel spans were built out from the central pier and from the adjacent flanking spans without the use of false works in either channel. A novel method of passing from the deck to the through spans has been used, by curving the top and bottom chords of the channel spans to connect with the chords of the flanking spans. The material is steel.

This structure, light, airy, and graceful, forms a strong contrast to the dark, heavy tube of the Victoria Bridge just below.

The enormous proposed cantilever Forth Bridge, with its two spans of 1,710 feet each, is in steady progress of construction and will when completed mark a long step in advance in the science of bridge construction.

Of entirely different design and principle from all these trusses are the beautiful steel arches of the St. Louis Bridge [p. 27], the great work of that remarkable genius, James B. Eads. This structure spans the Mississippi at St. Louis. Difficult problems were presented in the study of the design for a permanent bridge at that point. The river is subject to great changes. The variation between extreme low and high water has been over 41 feet. The current runs from $2\frac{3}{4}$ to $8\frac{1}{2}$ miles per hour. It holds always much matter in suspension, but the amount so held varies greatly with the velocity. The very bed of the river is really in constant motion. Examination by Captain Eads in a diving bell showed that there was a moving current of sand at the bottom, of at least three feet in depth. At low water, the velocity of the stream is small and the

bottom rises. When the velocity increases, a "scour" results and the river-bed is deepened, sometimes with amazing rapidity. In winter the river is



Old Stone Towers of the Niagara Suspension Bridge.

closed by huge cakes of ice from the north, which freeze together and form great fields of ice.

It was decided to be necessary that the foundations should go to rock, and they were so built. The general plan of the superstructure, with all its details, was elaborated gradually and carefully, and the result is a real feat of engineering.

There are three steel arches, the centre one having a span of 520 feet and each side arch a span of 502 feet. Each span has four parallel arches or ribs, and each arch is composed of two cylindrical steel tubes, 18 inches in exterior diameter, one acting as the upper and the other as the lower chord of the arch. The tubes are in sections, each about twelve feet long, and connected by screw joints. The thickness of the steel forming the tubes runs from $1\frac{3}{8}$ to $2\frac{1}{8}$ inches. These upper and lower tubes are parallel and are 12 feet apart, connected by a single system of diagonal bracing. The double tracks of the railroad run through the bridge adjacent to the side arches at the elevation of the highest point of the lower tube. The carriage road and footpaths extend the full width of the

bridge and are carried, by braced vertical posts, at an elevation of twenty-three feet above the railroad. The clear headway is 55 feet above ordinary high water. The approaches on each side are masonry viaducts, and the railway connects with the City Station by a tunnel nearly a mile in length. The illustration shows vividly the method of erection of these great tubular ribs. They were built out from each side of a pier, the weight on one side acting as a counterpoise for the construction on the other side of the pier. They were thus gradually and systematically projected over the river, without support from below, till they met at the middle of the span, when the last central connecting tube was put in place by an ingenious mechanical arrangement, and the arch became self-supporting.

The double arch steel viaduct now in process of erection over the Harlem Valley in the city of New York [p. 18] has a marked difference from the St. Louis arches in the method of construction of the ribs. These are made up of immense voussoirs of plate steel, forming sections somewhat analogous to the ring stones of a masonry arch. These



The New Iron Towers of the Same

sections are built up in the form of great I beams, the top and bottom of the I being made by a number of parallel steel plates connected by angle pieces with

the upright web, which is a single piece of steel. The vertical height of the **I** is 13 feet. The span of each of these arches is 510 feet. There are six such parallel ribs in each span, connected with each other by bracing. These great ribs rest upon steel pins of 18 inches diameter, placed at the springing of the arch. The arches rise from massive masonry piers, which extend up to the level of the floor of the bridge. This floor is supported by vertical posts from the arches and is a little above the highest point of the rib. It is 152 feet above the surface of the river—having an elevation fifty feet greater than the well-known High Bridge, which spans the same valley within a quarter of a mile. The approaches to these steel arches on each side are granite viaducts carried over a series of stone arches. The whole structure will form a notable example of engineering construction. It will be finished within two years from the beginning of work upon its foundations, the energy of its builders being worthy of special commendation.

In providing for the rapid transit of passengers in great cities the two types of construction successfully adopted are represented by the New York Elevated and the London Underground railways. The New York Elevated is a continuous metal viaduct, supported on columns varying in height so as to secure easy grades. The details of construction differ greatly at various parts of the elevated lines, those more recently built being able to carry much heavier trains than the earlier portions. The roads have been very successful in providing the facilities for transit so absolutely necessary in New York. The citizens of that city are alive to the present necessity of adding very soon to those facilities, and it is now only a question of the best method to be adopted to secure the largest results in a permanent manner.

The London Underground road has

also been very successful. Its construction was a formidable undertaking. Its tunnels are not only under streets but under heavy buildings. Its daily traffic is enormous. The difficult question in its management is, as in all long tunnels, that of ventilation, but modern science will surely solve that, as it does so many other problems connected with the active life of man.

Many broad questions of general policy, and innumerable matters of detail are involved in the development of railway engineering. In the determination, for instance, of the location, the relations of cost and construction to future business, the possibilities of extensions and connections, the best points for settlements and industrial enterprises, the merits and defects of alternative routes must be weighed and decided.

Where structures are to be built, the amount and delicacy of detail requisite in their design and execution can hardly be described. Final pressures upon foundations must be ascertained and provided for. Accurate calculations of strains and stresses, involving the application of difficult processes and mechanical theories, must be made. The adjustment of every part must be secured with reference to its future duty. Strength and safety must be assured and economy not forgotten. Every contingency must, if possible, be anticipated, while the emergencies which arise during every great construction demand constant watchfulness and prompt and accurate decision.

The financial success of the largest enterprises rests upon such practical application of theory and experience. Even more weighty still is the fact that the safety of thousands of human lives depends daily upon the permanency and stability of railway structures. Such are some of the deep responsibilities which are involved in the active work of the Civil Engineer.

