Mr. Pole, through the Secretary, communicated some extracts from notes partly collected during a recent visit to the locality, with Mr. Rendel (M. Inst. C. E.), and partly derived from information received from M. Pascal, the Engineer of the port of Marseilles.

After giving the general objects of the canal, he stated, that the principal aqueduct commenced at the *prise d'eau*, opposite the bridge of Pertuis, bore away in a westerly direction, and then turned directly southward to Les Beaumes St. Antoine, whence various branches diverged in different directions for the irrigation of the agricultural districts; one being carried onwards to Marseilles for the supply of water to the city.

The length of the principal aqueduct was $82\frac{2}{3}$ kilomètres, or about 51 English miles, and the heights above the Mediterranean were—

	Mètres.	English Feet.
At the commencement of the aqueduct	187·25	614·0
At the end of ditto	149·60	490·5
Total fall . .	37·65	123·5

Giving an average inclination of about 1 in 2,200, or 29 inches per mile.

The actual gradients were, in general—

For open channels, 1 in 3,333, or 19 inches per mile.
For tunnels, 1 in 1,000, or 63 inches per mile.
For bridge aqueducts, 1 in 1,428, or 44 inches per mile.
(Excepting the aqueduct of Roquefavour, which was 1 in 250, or 21 feet per mile.)

The quantity of water contemplated in the concession was about 12,000 cubic feet per minute; but the canal was made of such dimensions as to pass, if required, 21,000 cubic feet per minute.

The cost of the principal aqueduct, from its origin to its entrance into the territory of Marseilles, at St. Antoine, was—

	Francs.	£.
For preparations and superintendence	1,500,000	60,000
For land and compensations .	1,064,000	42,560
For works	17,436,000	697,440
Fr.	20,000,000	£800,000

Or £15,800 per mile.

The canal was commenced at the beginning of 1839, and was finished in June, 1847. The works were never entirely suspended, but, owing to political events, were considerably slackened in 1845 and 1846, for want of funds.

The following were the tunnels on the line of the principal aqueduct:—

Number of Tunnels.	Length.		Number of Shafts.	Greatest Depth from Surface.
	Miles.			Feet.
1	2·2	3,850 yards in length	13	320
1	2·25	3,950 yards	12	300
1	2·15	3,750 yards	12	400
6	1·65	varying from 330 to 730 yards in length.		
27	1·4	Short Tunnels.		
36	9·65			

There were also, in addition to the above, forty-eight smaller tunnels = $3\frac{1}{2}$ miles, on the chief branches, giving an aggregate of eighty-four tunnels, and a total length = $13\frac{1}{4}$ miles.

The tunnels had been formed generally through compact limestone, but argillaceous limestone and grey marl had also frequently been found, and in this last description of rock, it had been necessary to line the tunnels with masonry, as shown in Fig. 8, Plate 2. About one-half of the whole length of tunnelling had been so lined. The most difficult and costly tunnel was that of the Taillades, which occupied eight years in execution.

The general cost of the tunnels was—

	Francs per Mètre Courant.	Sterling per Yard forward.
	Fr.	£. s. d.
For small tunnels without shafts, and not lined	160 =	5 17 0
For large tunnels the cost had been very variable, but the following elements were tolerably well ascertained.		
For the tunnel proper, without shafts, or lining	260 =	9 10 0
For the tunnel when lined with masonry, exclusive of shafts	475 =	17 8 0
The most expensive tunnel (the Taillades), cost, including every expense, about 3,000,000 francs	816 =	30 0 0

The formula used by Mr. Pole for calculating the quantity of water which the canal would deliver, was—

Let h = fall, in a length = l, (both taken in the same unit,)
v = velocity in feet per second,
a = area of section of water, in feet,
c = wet perimeter, ,,

Then $v^2 = 10{,}000 \frac{h}{l} \frac{a}{c}$ nearly.

And $60\, v\, a$ = cubic feet discharge per minute.

This Rule gave for the sections in Plate 2, taking the water levels as there shown,—

Figs. 3, 4 and 5	= 14,400	cubic feet per minute.
„ 6, 7 and 10	= 16,700	„ „
„ 8	= 15,300	„ „
„ 9	= 21,700	„ „
„ 2	= 19,200	„ „

In the calculations the water levels were taken at a depth of $1\frac{1}{2}$ metre, as shown on the sections; but by supposing these to be somewhat raised, the corresponding discharge would of course be increased.

M. Mont Richer had stated, that, if he had now a canal to construct, he would line those portions in embankment with masonry 10 inches in thickness up the sides, to above the water line, and the bottom with béton (concrete) 8 inches thick. Revêtements thus made would not require any maintenance; this was not however the case with puddled banks and bottom, which were subject to slips and cracks. If, on account of any subsidence, small cracks did appear in revêtements of masonry, the filtrations, which were always trifling, finally disappeared. At present, nearly all the embankments of the canal in which there had been any considerable filtrations, were thus lined, as were also most of the open cuttings, whether in gravel, clay, or rock. In certain parts, however, puddle had been used, and it was on account of the inconveniences which it had presented, that M. Mont Richer regarded the use of a lining of masonry as decidedly preferable.

Mr. Rennie begged to explain, that the description of the Roquefavour Aqueduct now laid before the Institution, resulted from a sudden visit to the locality, made with M. C. Nepveu (M. Inst. C.E.), who was not more intimately informed of any particulars respecting this work, than Mr. Rennie himself. They were both so much struck with the general design and the execution of the works, that they had endeavoured to obtain some particulars of it; and after the lapse of about seven months, his travelling companion had transmitted to him a few particulars which he had embodied in the paper just read. It was remarkable that there was not any description of the canal to be found in the collection of the 'Annales des Ponts et Chaussées:' this arose, probably, from the extreme occupation of Monsieur Mont Richer, the Engineer, who had devoted to the work many years of unceasing labour, and had exhibited great skill and knowledge of the technical part of the subject.

The meeting would here, perhaps, permit Mr. Rennie to express the obligations he felt under to Mr. Manby,—the Secretary,—who had no sooner received the paper, than he set to work to procure documents bearing upon the subject, and the remarks by

Mr. Pole had resulted from his kind assistance; he also understood that M. Mont Richer had transmitted to the Secretary a fuller description of the works on the canal; the chief merit, therefore, that he could claim as the Author of the paper, was that of having brought forward a subject not hitherto well known to the Institution, and which it was hoped would prove the means of eliciting new matter from other sources.

He noticed, that the velocity of the water in the channel of the aqueduct of Roquefavour was very great;—perhaps there was an object in this, as it would prevent the deposit which was to be apprehended from water so highly charged with earthy matter; it was, in fact, almost of the colour of milk. In general the waters of the Durance were turbid and held in suspension a small quantity of carbonate of lime, as well as of alluvial matter, and for the purpose of arresting those substances, large settling reservoirs and filtering beds were established in connexion with the Marseilles Waterworks, which were now completed, and it was found that by the filtering process as much as 50,000 tons of water per day could be rendered perfectly limpid. The outlay for establishing the water-works and laying the distributing pipes in the town, amounted to about £200,000. About that amount had also been expended in the arrangements for irrigation. The prevalence of lime in the streams conveyed by the Romans for the use of their stations and cities, might account for their building such expensive stone structures as they had left, instead of employing pipes, with the use of which they were certainly acquainted. The channels of most of the Roman aqueducts, he had examined, were incrusted with carbonate of lime; in that of the Pont du Gard there was a deposit of nearly 7 inches in thickness, almost of the consistence of chalk. In the comparatively modern aqueduct of Alcantara,[1] there was a similar deposit, and the lead pipes, 5 inches in diameter, leading to the reservoir, were choked up by concentric rings of carbonate of lime.

At Lyons there were remains of two ancient aqueducts which conveyed the water by means of pipes down one side of the valley and up the other face of the hill; and it was evident the Romans understood and practised the use of pipes, as some which were intended to bear a heavy pressure were 8 inches in diameter, and 1 inch in thickness. A fragment of the lead pipe forming this reversed syphon was still in existence in the museum at Lyons. M. Gautier[2] mentioned a remarkable instance of the employment of lead pipes, by the Romans, for a purpose which

[1] Vide "Minutes of Proceedings, Inst. C.E.," Vol. I., 1841, p. 138.

[2] Vide "Traité de la Construction des Chemins," par H. Gautier, 1721 and 1778.

had been assumed to be essentially a modern contrivance; that of conveying water across and beneath the bed of a river.

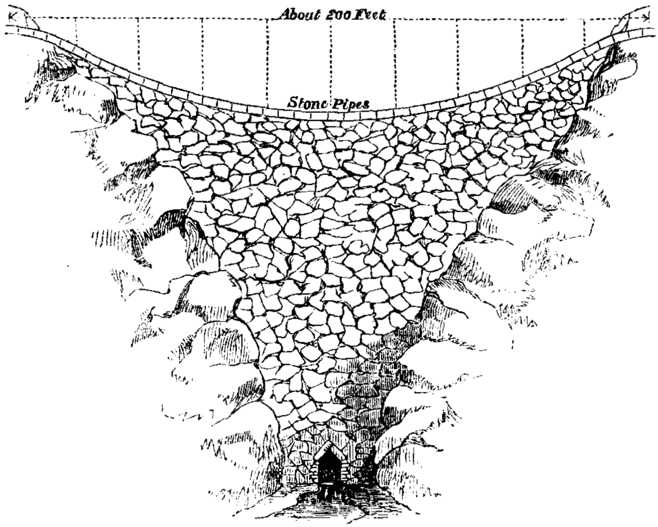
"Some years after," says Mr. Gautier, "when I had charge of the roads on the Rhone, and of many other works in the province of Languedoc, and while at Arles, I heard that a vessel had cast anchor on the Rhone, opposite the city, to take some loading; but when the commander wanted to sail again he could not raise the anchor. This fact attracted much attention, and many people went to witness the singular circumstance. The captain, unwilling to lose his anchor, sent down a man to find what was the matter; the diver reported that the anchor was hooked under something round, but he could not tell what it was. A capstan was applied to raise it, which succeeded.

"It brought up a leaden conduit pipe from the bottom of the Rhone, which crossed it from the city of Arles, towards Trinquetaillade, over a breadth of about 90 toises (576 feet) in a depth of 6 or 7 toises (about 40 feet), the deepest part of the Rhone. I saw some pieces of this conduit of lead, 5 or 6 inches in diameter, about four lines (one-third of an inch) thick, in joints of one toise each, soldered lengthwise and covered by a strip of lead of the same thickness, covering the first solder about 2 inches. The conduit was soldered at the joints, 6 feet apart, by the same material, which made a swell at that distance. On each joint were these words in relief C. Cantius Poihinus. F. which was apparently the name of the maker, or architect, who laid down the conduit-pipe in the time of the Romans. I delayed not to inform Mr. Begon, at Rochefort, of this discovery, because he had always favoured my project of conducting water along the bottom and across the Charente, which would not have been half so difficult as it had no doubt been, to lay one across the Rhone where this was found."

In further corroboration of the knowledge of the use of reversed syphon pipes by the ancients, Mr. Rennie mentioned the Greek aqueduct discovered near Patara, on the coast of Lycia, opposite to the island of Rhodes; it was situated about three miles to the east of the city, and near to the small port of Phœnicus, mentioned by Livy.

The valley, or ravine was about 250 feet deep and nearly 200 feet across; a wall, or embankment, of rough stone, "opus incertum" (Fig. 2), was built up, leaving a rough arch, for the passage of the stream. Upon the top of this was laid in a curved line a series of stone blocks, A A A, (Fig. 3,) each about 3 feet square, well cramped together, closely jointed, and laid in cement; with a circular hole (B), 13 inches diameter, bored through each, with a projecting collar of about 3 inches, round the hole, and a corresponding recess for receiving it in the next stone; thus forming rude spiggot and faucet pipes, jointed by cement. The joints appeared to have been worked with great accuracy, and

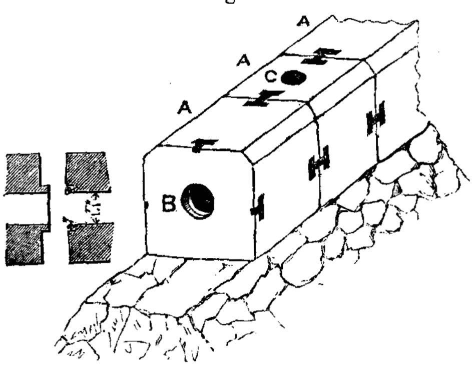
Fig. 2.



Ancient Greek Aqueduct, at Patara.

were secured by iron cramps run with lead. At intervals of about 20 feet apart (shown by dotted lines), throughout the aqueduct, were vents (C), about 7 inches in diameter, for the escape of the air. It was not stated what curve was given to this line of inverted syphon, but it was evidently considerable.

Fig. 3.



Details of Stone Pipes.

In Chap. VII. of the 8th Book, Vitruvius described three modes of conducting water;—by building a watercourse, or aqueduct,—by pipes of lead,—and by pipes of earthenware. In describing the mode of using lead pipes he said,—"If a long valley should be interposed in the course of the conduit, the inclination of the descent being followed, and arriving at the bottom, you should build a low wall, in order that as long a level as possible should be obtained. This is what the Greeks call *κοιλία*, or ventre (belly). When the pipes arrive at the opposite declivity the current of the stream of water will be slightly swollen, and will thus force itself to the top of the height. If this belly is not made in the valley, and there should occur an elbow, the force of the water would burst and disunite the joints of the pipes. In the belly you must make air-holes, so that the violence of the wind may escape, &c., &c. If, however, it should be necessary to economise, this is the mode.—Pipes of earthenware, not thinner than two fingers, should be so made that one end may enter into the other, the joints being closed and secured with lime mixed with oil, and in the bends, or elbows of the belly, instead of earthenware, blocks of red stone [probably red sandstone], should be bored and so formed as that one should connect with the other, from beginning to the end, so that the last earthenware pipe of the descent and the first of the belly may be inserted in the red stone pipe; and in the ascent in a similar manner. Forming the aqueducts thus, in their descent and ascent, they will never be disarranged; but such a wind is generated in aqueducts as is sufficient to burst even stone—so that it is customary to introduce the water by degrees at first, and to fortify the elbows and the bends with cramps and with a great weight—all the rest should be done like leaden pipes, &c., &c."

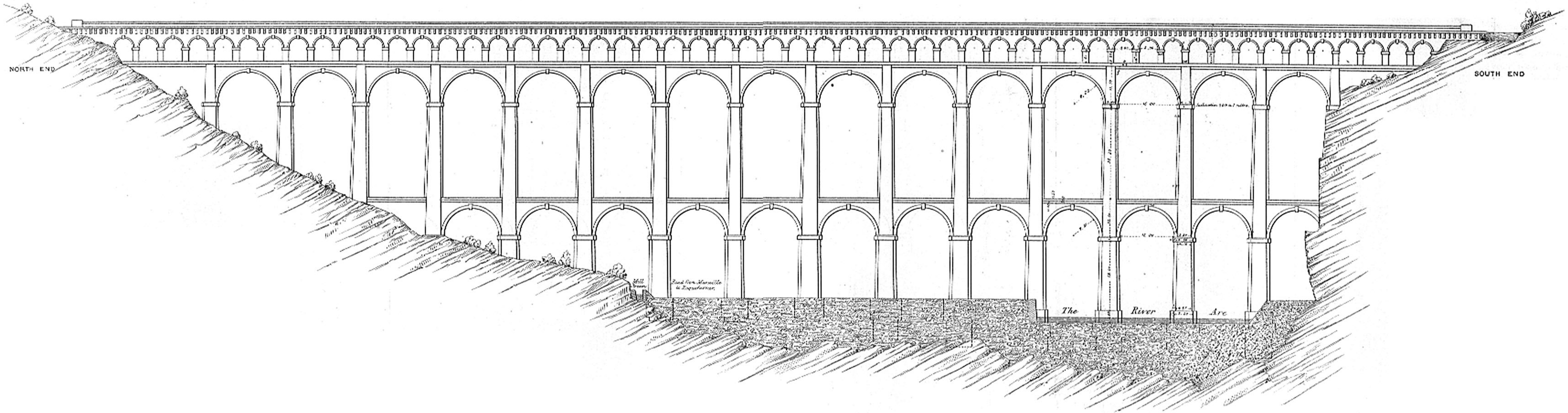
Mr. Rennie was indebted to Professor Cockerell for the sketches and description of this interesting work.

Mr. BIDDER, V.P., wished to direct the attention of Mr. Rennie and the Secretary, to the apparent discrepancies in the several statements of the dimensions and cost of the canal and aqueduct. It was of the utmost importance, that before the papers and discussions were published, they should undergo rigid supervision, as indeed should all the documents that went forth to the world in the volumes of the Minutes of Proceedings. He was sure that Mr. Rennie would excuse attention being directed to these discrepancies, as he would fully appreciate the importance of ascertaining the facts accurately, before the papers were published.

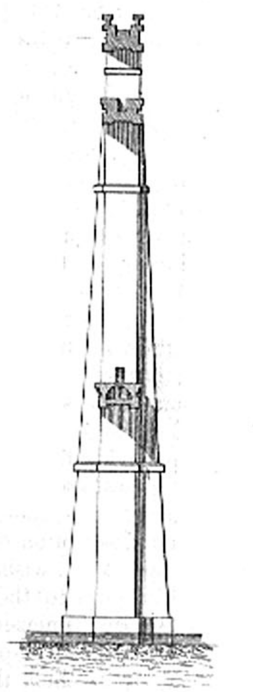
The Institution was much indebted to Mr. Rennie for calling attention to these magnificent works of ancient and modern times, and there were few engineers, who could not rejoice in having the opportunity of handing down their names to posterity by means of works of this character. But the efforts of modern engineering were generally restricted by the amount to be ex-

BRIDGE AQUEDUCT OF ROQUEFAVOUR.

ELEVATION



TRANSVERSE SECTION



From a drawing furnished by M. Lore

Day & Son, Lith.rs to the Queen.

Fig. 1.

TRANSVERSE SECTION THROUGH CENTRE OF ARCH.

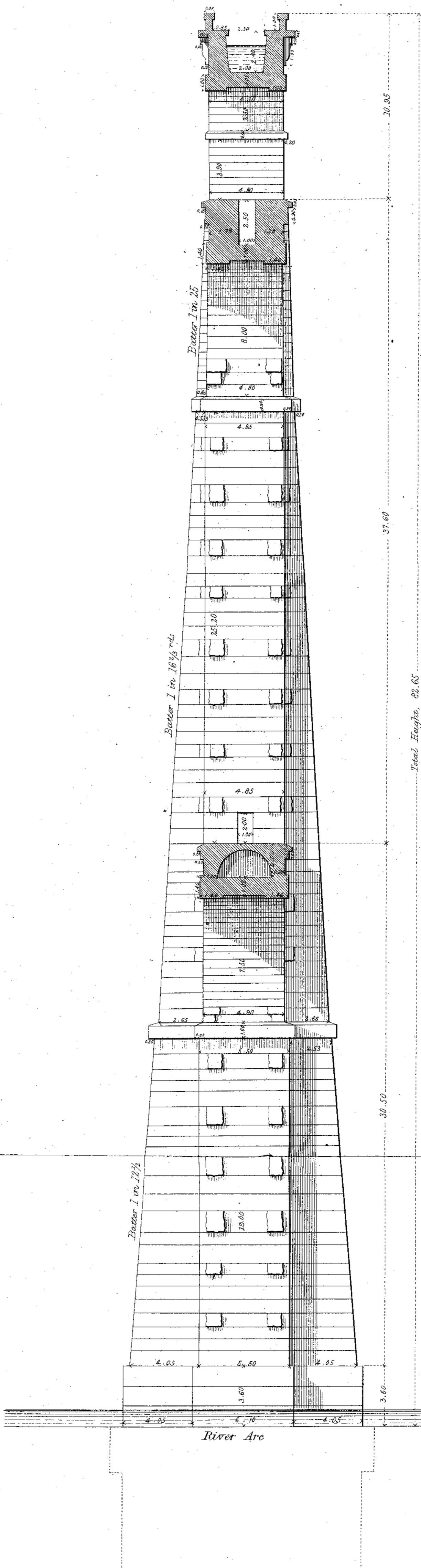


Fig. 2.

TRANSVERSE SECTION OF CHANNEL.

Fall 1 in 250

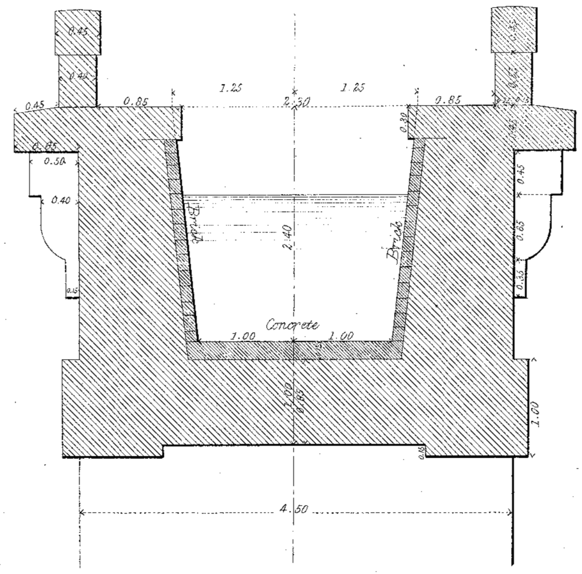


Fig. 3.

SECTION IN EARTH EMBANKMENT

Fall 1 in 3333

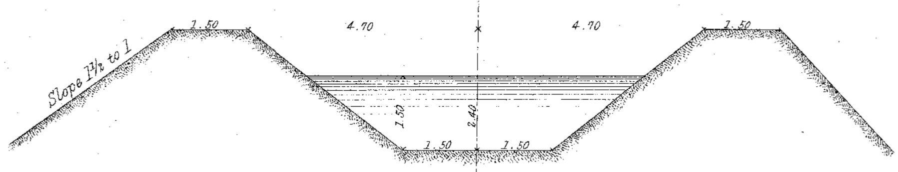


Fig. 4.

SECTION IN EARTH CUTTING.

Fall 1 in 3333

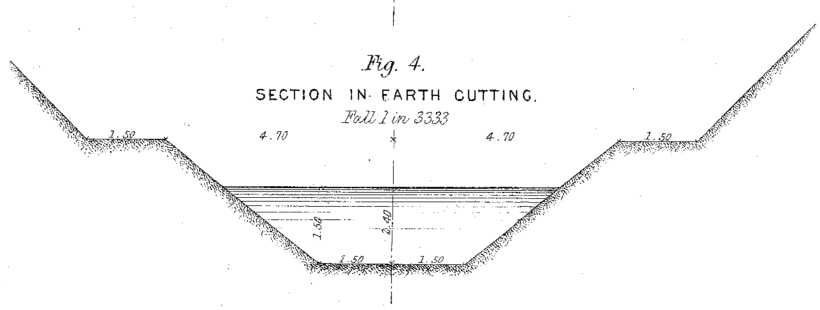


Fig. 5.

SECTION ON EARTH SLOPE.

Fall 1 in 3333

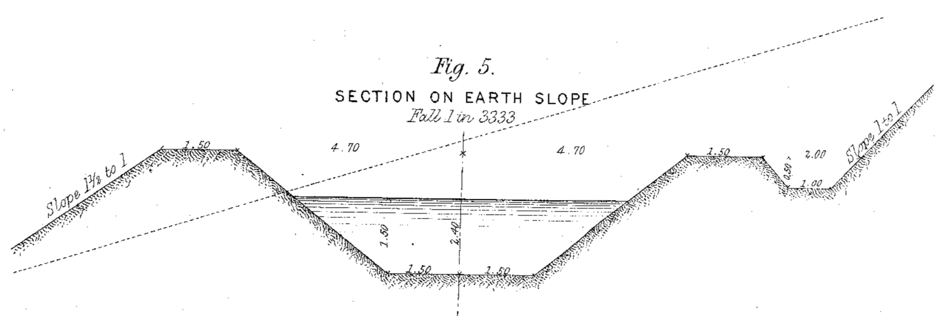


Fig. 6.

SECTION IN ROCK CUTTING.

Fall 1 in 3333

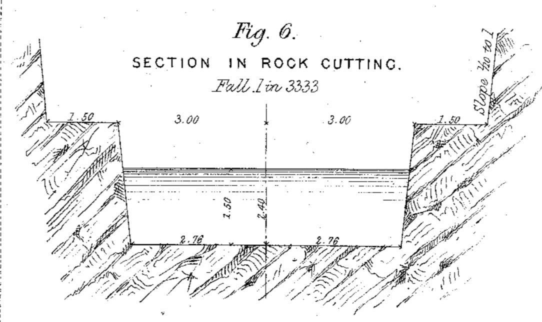


Fig. 7.

SECTION ON ROCK SLOPE.

Fall 1 in 3333

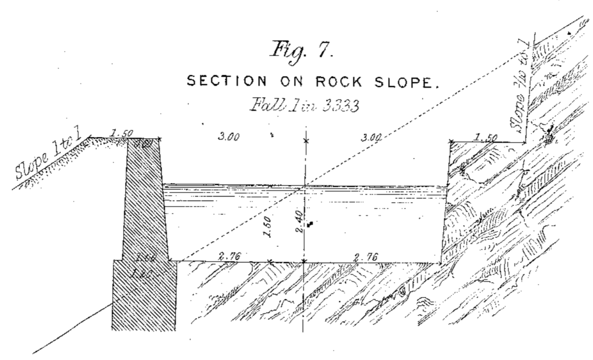


Fig. 8.

SECTION OF TUNNEL LINED.

Fall 1 in 1000

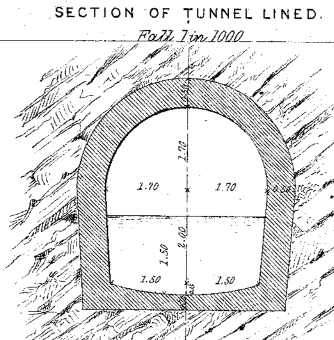


Fig. 9.

SECTION OF TUNNEL NOT LINED.

Fall 1 in 1000

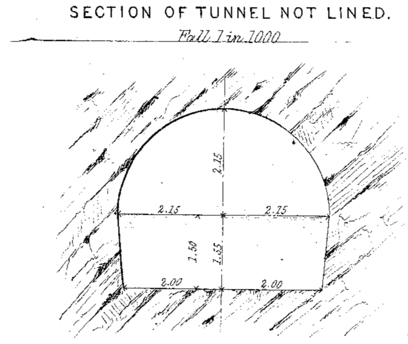
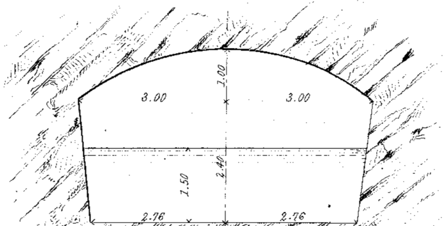


Fig. 10.

SECTION OF TUNNEL NOT LINED.

Fall 1 in 3333



Reduced from a drawing by M. Montricher.

Day & Son, Lithrs to the Queen.

The dimensions are all quoted in French mètres.

pended, and it now appeared that the engineer who obtained the greatest meed of fame, was he who executed the greatest work at the smallest cost. With reference to the work under consideration, the ordinary course of modern engineering would suggest the employment of cast-iron pipes, and it would be an interesting investigation to ascertain the difference of the cost of pipes of adequate dimensions, as compared with that of the stone structure,—he conceived there would be a material reduction of expenditure. Probably there would be a deposit of lime, but chemical knowledge now afforded the means of guarding against any very prejudicial effect arising from that cause.

Whilst alluding to the subject of cost of works, he would mention incidentally that of some railway viaducts, which were somewhat analogous structures to aqueducts. He had just completed a railway in Norway, for which the expenditure was restricted; the line passed through a difficult country, with heavy works, and a light estimate, not exceeding £10,000 per mile, including the stations, plant, and everything. There were several tunnels in clay and sand strata intermixed, and some high viaducts. To have constructed the latter in masonry, was out of the question, although it would have been more satisfactory; but the means could not be afforded, therefore he had caused them to be constructed of red pine, the produce of the country, used without any squaring, or other labour, beyond what was necessary to fix the pieces together. The cost of each of those viaducts, was about one shilling per square foot of the superficial elevation; of course the material was of a very perishable description and would not last more than about fifteen years; but the Railway Company were appropriating a sum out of revenue, to accumulate the means of filling up the valley with earth. In order to form some comparative opinion as to the cost of the Roquefavour Aqueduct, he would mention, that a brick viaduct cost about eight shillings per cubic yard. He was rather inclined to attribute the cracks, mentioned by Mr. Rennie, to some deficiency, or inequality in weighting the arches.

Mr. J. W. Papworth, speaking in corroboration of the previous statements as to comparative cost, quoted from the article 'Aqueduct,' in the Dictionary of Architecture,[1] the instance of the means adopted for conveying the supply of water for the city of New York. "To cross the Manhattan Valley, an aqueduct bridge 105 feet high, and 4,180 feet long, would have been required; this would have preserved 3 feet of head pressure for the conduit water, but at an expense of (1,200,000 dollars)

[1] Vide "Dictionary of Architecture"—article. Aqueduct; also "Illustrations of the Croton Aqueduct," by F. B. Tower, 4to, New York. Plates. 1843.

£240,000; while the passage by four pipes of 36 inches each, was calculated to cost one-fifth of that amount; it was therefore adopted. For the same reason it seemed desirable to carry the conduit water over the Haerlem river in a *souterazici* with iron pipes; but it was proposed to let them pass in the centre over an arch 120 feet wide, and 60 feet high. This was an object of popular disgust, and being compelled by the legislature either to carry it below the bottom of the river, or on a bridge, the latter course was adopted, although exceeding the tube system by, in cost (200,000 dollars), £40,000. With this arrangement the water crosses the bridge in pipes, with a depression of 12 feet." Only two lines of pipes had at present been laid across the Manhattan Valley.

With regard to the incrustation; the Greeks and the Romans were aware of it, and to provide against its bad effects they, in the first instance, constructed their water-courses of a much larger size than was necessary for the required supply. At Hieropolis, in Asia Minor, the channels for conveying the water through the streets were incrusted so rapidly, that it became necessary to devise means for correcting the increasing evil; this was accomplished by forming clay banks, upon which the incrustation took place; thus they not only got rid of the impurities of the water, but formed permanent channels for its conveyance.

Mr. Hawkshaw said the aqueduct of Roquefavour was a fine structure, and appeared to be well designed and proportioned and as well executed, but he must express his surprise at the apparent timidity of the Engineer, in having imitated the system of construction of the Roman aqueducts, rather than adopt the mode almost invariably employed, in the present day, for railway viaducts, which were subjected to much more injurious action, by the passage of heavy trains, at high speeds, than were the aqueducts which only supported a steady pressure, or weight. There was no necessity for several tiers of arches; it was a question whether they added to the beauty, or the symmetry of the structure; they were not essential to its stability, and they must considerably increase the cost. There was no difficulty in building an aqueduct with only one tier of arches of almost any height, within certain limits; there would be no hesitation in building a chimney 350 feet high, which had to withstand the action of the wind upon it, and there would be less difficulty in building the piers of arches 250 feet high, connected at the top and affording to each other mutual support. He could not, therefore, acquiesce in the adoption of an old style of construction, at a period when it was no longer necessary. He was not aware of any railway viaduct of so great a height as this aqueduct; but the Lockwood Viaduct, which he had built, with much lighter proportions than the aqueduct, had to carry trains of 300 or 400 tons weight, traversing it at a speed of from 30 to 40 miles an hour, which was more trying than the steady weight of a stream of water. With regard to comparative expense, this viaduct, which was 1,500 feet in length, and 136 feet high—about half the height of the aqueduct—cost £36,000; a very small sum as compared with £148,000, the cost of the aqueduct. As to the ancient aqueducts, it was a question whether, taking into consideration all the circumstances of construction, cost, rapidity of execution and adaptability for the service they had to perform, they had not been surpassed by many modern structures in connexion with railways.

Mr. S. CLEGG, Junior, said the aqueduct of Alcantara, near Lisbon, which was 250 feet in height, consisted of only one tier of arches.[1]

Mr. R. W. MYLNE said he had examined the canal and aqueduct of Marseilles, about a year and a half ago, and had collected some particulars relative to the work generally, which he would read from his notes made at the period of his visit, and derived from information obtained on the spot. The quantity of masonry in the aqueduct being about 50,000 cubic yards; the cost was about £3 per yard, the total expenditure on the structure being stated at £151,300.

"The Marseilles canal commenced at Pertuis, on the river Durance, and took a circuitous course, through a mountainous country, to the village of St. Antoine, within a few miles of Marseilles; its length was 50 miles, and 1,408 yards; the level of the canal at its junction with the river Durance was 614 feet above the sea, and at St. Antoine it was 490½ feet, making a mean fall of 29¼ inches per mile. Considerable variation in the falls occurred along the line, arising from a varied sectional area being given to the tunnels, open cuttings, and rock excavations.

"The tunnels were all executed to a width of 11 feet 2 inches, having a fall of 63·36 inches per mile, and a sectional area of 122·58 feet.

"Where the channel was excavated in the limestone rock, a width of 18¼ feet of water surface was given, and a sectional area of 99·45 feet.

"In the districts where a softer material existed, a fall of 18·99 inches per mile was adopted, having a width of 29 feet of water surface, and a sectional area of 134·28 feet.

"The aqueducts had a fall of 253·44 inches per mile.

"The quantity of water that was intended to be abstracted

[1] Vide "Minutes of Proceedings, Inst. C.E.," vol. 1, 1841, page 138.

from the Durance, was 15 cubic mètres per second, or 530 cubic feet per second; this was equal to 1¼ million tons in 24 hours.[1]

"The canal was commenced in 1838 and was finished as far as St. Antoine, in December 1846; the following year was chiefly occupied in constructing additional works, in rendering the channel water-tight, and in repairing the damages occasioned by a severe flood in the river Durance, in October 1846; when means were taken to preserve the mouth of the canal, by arching it over with stonework, so as to allow the waters of the Durance to flow over it, at times of extreme flood.

"The total cost of the canal as far as St. Antoine, amounted to £613,368 or £12,074 per mile; this was exclusive of land and superintendence.

"The cost might be classed in the following six divisions.

	Miles.	Yards.	£		£.	s.	
1st Division	17	1,079	= 87,108	or about	4,930	0	per mile.
2nd "	3	811	= 131,522	"	38,000	0	"
3rd "	14	1,213	= 73,760	"	5,012	0	"
4th "	8	1,077	= 151,394	aqueduct	352	18	per yard.
5th "			= 34,334	"	4,290	0	per mile.
6th "	6	748	= 135,254	"	21,047	0	"
	50	1,408	£613,368				

"It would be seen, by the enumeration of these divisions, that there existed very great variation in cost, which arose from the numerous tunnels, and aqueducts.

"There were no less than thirty-eight tunnels along the line, forming an aggregate length of 9¾ miles, the longest of which was that of Les Taillades: which was 4,008 yards in length; that of Assassin, was 3,798 yards and that of Notre Dame was 3,289 yards.

"The cost of the 'Assassin' Tunnel, was £39,799, or £10·9 per yard forward; and including the cost of twelve shafts was £11·10 per yard forward.

"The cost of the 'Notre Dame' Tunnel was £60,800, or £18·9 per yard forward; and including the cost of fifteen shafts was £20·1 per yard forward.

"The cost of the 'Taillades' Tunnel was £92,454, or £23·1

[1] M. Mont Richer states, that the law authorizing the construction of the canal only permitted to be taken from the Durance during the period of low water $5^{m}\cdot75^{c}$ cube of water per second; but during all other periods 10 cubic mètres were allowed to be taken, and the dimensions of the canal were such as to permit upwards of 12 cubic mètres to pass freely. The general fall was $0^{m}\cdot30^{c}$ per kilomètre, and the average sectional area was $14^{m}\cdot88^{c}$. Wherever large structures became necessary the fall was increased, in order to obtain the same quantity of water through a smaller sectional area. In the tunnels the fall was 1 mètre per kilomètre.—EDITOR.

per yard forward, and including the cost of fourteen shafts was £29·6 per yard forward. In sinking the shafts for this tunnel, the deepest of which was 269 feet, very serious obstacles were met with, from the large quantity of water found in the rock, which caused great expense, and in one instance it reached as high a cost as £14·18 for each foot in depth. The total produce of water, out of the Taillades Tunnel works, amounted to 294 cubic feet per minute, which flowed into the canal.

"There were several aqueducts along the line, but that of 'Roquefavour' was by far the most important. The length was 1,287 feet, and it contained 50,960 cubic yards of masonry; and the cost was £151,394, or £350 per yard forward. The following items comprised the total cost.

	£.	s.
Preparatory works	3,415	10
Construction and quarrying . .	111,751	5
Materials and carriage . .	33,578	0
Sundry expenses	2,649	5
	£151,394	0

"The fall in the length of the aqueduct was 4·89 feet; the width was 8 feet 2 inches, and its sectional area 51·11 square feet.

"From the termination of the main line of canal, at St. Antoine, the channel was reduced in dimensions and was carried along the slopes of the hilly districts, encircling in its course the town of Marseilles, and commanding a territory of about 20,000 acres, of an arid and sterile district, falling towards the sea. The length of this canal running round to Montredon, on the coast, was 25 miles and 616 yards; there were also two small branches near the Tunnel of Marionne, and two more branches at St. Antoine; making altogether a total length of 39 miles 1,214 yards, which were entirely devoted to the purposes of irrigation.

"A separate channel had been executed for the water-supply of Marseilles, branching out of the canal, near St. Marthe, 6 miles from St. Antoine, it traversed a distance of 3 miles and 598 yards, arriving at the basin of Longchamps, in the suburbs of the city, at an elevation of 242½ feet above the sea.

"The total length of the main canal, the irrigation channels and the branches, including the feeder for the waterworks, amounted to 94 miles.

"In reference to the flow of water in the canal, the quantity in the main channel, as previously stated, was 15 cubic mètres per second, and at St. Antoine 2 cubic mètres were allotted to each of the short branches, flowing towards the sea; from that village 11 mètres passed along the canal to St. Marthe; at that point 2 mètres were drawn off, for the supply of Marseilles; thus providing 9 mètres for the irrigation of the whole of the territory lying between St. Antoine and Montredon.

"The works designed for irrigation were very extensive, not being confined to the principal lines of canal, but including an intricate series of open channels, and closed conduits, for conveying the water to the lands of the several proprietors. Compulsory powers were accorded for passing the pipes across lands held by different proprietors; and the system had been found to work satisfactorily.

"The original intention had been to adopt the use of earthenware pipes, over those lands where a moderate pressure existed; but after the experience of the working of an aggregate length, of nearly 15 miles, they were found to be of so defective a material, though made with great care, by several manufacturers, that it was resolved, in 1851, to adopt iron for the future.

"Under the terms of the regulations, each proprietor could obtain a lease of a stipulated quantity of water, for a term of fifty years, or less, paying towards the expense of the distributing channels and for the water, at an average cost of about 17 shillings per acre, per annum.

"The total cost of the main canal and of the branches for irrigating and for the waterworks, as described, might be classed under the following heads.

The main canal	£613,368
The channels for irrigating and for the waterworks	48,559
Land direction, surveys, &c.	318,212
Extra works, lining canal, &c.	44,136
	£1,024,275

"The quantity of water destined for the domestic supply, the sanitary purposes, and the anticipated consumption of water-power for mechanical uses in the town of Marseilles, was 2 cubic mètres per second, or 38 million gallons per 24 hours.

"The water, on its arrival at the basin of Longchamps, at an elevation of 242½ feet, communicated with four other reservoirs, all of considerable height, and situated at commanding points; these reservoirs contained a large storage and were all covered; that at Longchamps was 26 feet in depth and contained 23 million gallons; the covering arches were constructed of béton, carried on stone pillars.

"The domestic supply was calculated at 12½ gallons per head, and as the population of Marseilles was, at present, about 200,000 souls (inclusive of 36,000—the assumed fluctuating number of strangers), the consumption would be 2½ million gallons per diem.

"The constant-supply system was proposed to be adopted, and the houses which were not in flats, but on the usual separate, or English plan, were not to be provided with cisterns.

"The cast-iron pipes used in the town and suburbs were obtained from the foundry at Marquise, situated between Calais and Boulogne; and they cost in 1852, delivered at Marseilles, about £9. 6*s.* per ton.

"The application of water for sanitary purposes, was intended to be very extensive, and several fountains were projected. A large consumption was also anticipated for water power, for which the price to be charged would be about 20*s.* per horse-power, per month. In 1852 the laying of the distributing pipes, forming the conduits and the construction of the reservoirs and of the channels for irrigation, were all in active progress and the expenditure was stated to be above three-quarters of a million sterling, irrespective of one million already spent on the canals.

"The works were designed by and executed under the able direction of M. Mont Richer, and his assistant M. Bouchart, through whose kindness, Mr. Mylne was enabled to obtain the information communicated to the meeting." [1]

Mr J. Murray said it had been stated by Mr. R. W. Mylne, that the quantity of water passing along the canal in 24 hours was $1\frac{1}{4}$ million tons = to 530 cubic feet per second, or 198,180 imperial gallons per minute; now as this quantity had to pass through the channel of the Roquefavour Aqueduct, which appeared to be of an inadequate section, doubts existed in his mind as to the accuracy of the statement. He had, therefore, been induced to examine the different sections given by Mr. Mylne, and to obtain from them an average section and fall, in a given length, for the purpose of calculating the discharge.

		Square Feet.
1. The sectional area in earth was . .		= 134·2859
2. Ditto ditto in rock . .		= 99·4504
3. Ditto in tunnel below springing	= 73·7672	
,, ,, above springing	= 48·8214	
	122·5886	
Adding 10 per cent. to the whole area of the section of the tunnel gave about the section in earth; viz. 134·875.		
And deducting 19 per cent. from it, gave nearly the section in rock; viz. 99·2968.		
On account of the water being wire-drawn through the tunnels, only that section occupied by water in the rock, could be calculated upon, viz.		99·4504
		3) 333·1867
Mean section of water		= 111·0622

[1] The dimensions and details of cost given by Mr. Mylne have been left as in his MS.—Editor.

Now dividing this by the depth of 7 feet

$$= \frac{111 \cdot 0622}{7} = 15 \cdot 866 \text{ mean width.}$$

Hence the wetted perimeter

$$= 9 \cdot 84 + 8 \cdot 9183 + 8 \cdot 9183 = 27 \cdot 6766 \text{ feet.}$$

Calling R the hydraulic mean depth } in inches.
F the fall in two English miles }

Then Prony's simple formula—

$$\sqrt{R\,F} \times 0 \cdot 909 = \text{velocity in inches per second.}$$

$$\text{Hence } \frac{111 \cdot 0622}{27 \cdot 6766} \times 12 = 48 \cdot 1536 = R$$

$$29 \cdot 1576 \times 2 = 58 \cdot 3152 = F$$

$$\sqrt{(48 \cdot 1536) \times (58 \cdot 3152)} \times 0 \cdot 909 = 48 \cdot 169$$

$$\frac{48 \cdot 1843}{12} = 4 \cdot 014 \text{ feet per second average velocity,}$$

= something less than 2¾ miles per hour.

Then $111 \cdot 0622 \times 4 \cdot 014 = 446$ cubic feet per second.

The difference between this calculated quantity and that first mentioned, viz. 530 cubic feet per second, amounted only to 16 per cent. It was probably, therefore, the correct discharge, and that a greater length of the canal than above assumed was constructed with the large section in earth.

Taking the quantity, therefore, to be 530 cubic feet per second, it was more than fourteen times the yield of the New River, which supplied that part of London north of the Thames, between Bishopsgate Street and Charing Cross. It was in fact 285,380,323 gallons per diem.

According to Frontinus the quantity of water supplied to ancient Rome was 50,378,955 cubic feet in 24 hours, giving an average to each of the nine aqueducts of upwards of 40,000,000 imperial gallons.

With so large a quantity of water passing through the Marseilles canal, it was interesting to investigate the matter further:—

Assuming the discharge to be 530 cubic feet per second; it was desirable to ascertain what would be the velocity of the stream through the maximum and minimum sections; as well as the fall which would generate those velocities, and the action of the current upon the bottom.

As to the greatest section when in earth:—

1. The velocity.—

$$\frac{530}{134 \cdot 2859} \times 12 = 47 \cdot 3616 = \text{mean velocity in inches per second.}$$

2. The fall necessary to produce this mean velocity.

$$\frac{\text{Sect. area}}{\text{Wetted perimeter}} = \text{the hydraulic mean depth}$$

$$= \frac{134 \cdot 2859}{33 \cdot 1898} \times 12 = 48 \cdot 552 \text{ inches.}$$

$$\text{Now } \frac{47 \cdot 3616}{0 \cdot 909} = 52 \cdot 103$$

$$\text{And } \frac{(52 \cdot 103)^2}{48 \cdot 552} \div 2 = 27 \cdot 9568 \text{ inches fall per mile.}$$

3. The action of the current.

$$\frac{47 \cdot 3616}{12} = 3 \cdot 9468 \text{ feet per second.}$$

$$\frac{3 \cdot 9468 \times 60 \times 60}{5280} = 2 \cdot 691 \text{ miles per hour mean rate.}$$

$$\frac{2 \cdot 691 \times 0 \cdot 6312}{0 \cdot 8156} = 2 \cdot 0828 \text{ miles per hour along the bottom.}$$

This velocity was capable of removing the bottom, if it were composed of fine gravel; but the scour was no doubt checked by a reduction of the area in the tunnels and in the sections through rock.

As to the less section when in rock.

1. The velocity.

$$\frac{530}{99 \cdot 4504} \times 12 = 63 \cdot 9516 \text{ mean velocity in inches per second.}$$

2. The fall.

$$\frac{99 \cdot 4504}{26 \cdot 3412} \times 12 = 45 \cdot 306 \text{ hydraulic mean depth in inches.}$$

$$\frac{63 \cdot 9516}{0 \cdot 909} = 70 \cdot 3538$$

$$\text{and } \frac{70 \cdot 3538}{45 \cdot 306} \div 2 = \left.\begin{array}{l} 54 \cdot 6247 \text{ inches} \\ = 4 \cdot 552 \text{ feet} \end{array}\right\} \text{fall per mile.}$$

3. The scouring action.

$$\frac{63 \cdot 9516}{12} = 5 \cdot 3293 \text{ feet per second.}$$

$$\frac{5 \cdot 3293 \times 60 \times 60}{5280} = 3 \cdot 6336 \text{ miles per hour mean rate.}$$

$$\frac{3 \cdot 6336 \times 0 \cdot 6312}{0 \cdot 8156} = 2 \cdot 812 \text{ miles per hour along the bottom.}$$

This rapid velocity was capable of acting upon large gravel and pebbles.

As to the Aqueduct of Roquefavour.

1°. The velocity of the water in the channel.

$$\frac{530}{51 \cdot 1144} \times 12 = 124 \cdot 4268 \text{ mean velocity in inches per second.}$$
$$= 7 \cdot 069 \text{ miles per hour.}$$

2°. The fall.

$$\frac{51 \cdot 1144}{20 \cdot 6334} \times 12 = 29 \cdot 7264 \text{ hydraulic mean depth in inches.}$$

$$\frac{124 \cdot 426}{0 \cdot 909} = 136 \cdot 883$$

$$\text{And } \frac{(136 \cdot 883)^2}{29 \cdot 157} \div 2 = 315 \cdot 7264 \text{ inches.}$$
$$= 26 \cdot 263 \text{ feet per mile.}$$

The length of the aqueduct being 1290 feet.

$$\text{Then } \frac{26 \cdot 263 \times 1290}{5280} = 6 \cdot 3597 \text{ feet fall throughout its length.}$$

According to the sections, the bottom of the channel actually fell 4·8885 feet in its length, which was at the rate of 20·0087 feet per mile ; consequently the mean velocity throughout the bridge-aqueduct must be between 7 and 8 miles per hour, or that of a torrent.

These calculations were based entirely upon the data given in the documents brought forward, but would be subject to revision if the data were erroneous.

Mr. R. W. Mylne said, the velocity of the water in the channel was so great, that it prevented any deposit on its passage, and it arrived in the storage reservoirs, at Marseilles, in apparently as turbid a state as it left the river Durance.

Mr. Simpson,—President,—said the cost of the aqueduct of Roquefavour appeared to be very great, for the purpose to which it was devoted, in fact it had always been his opinion that more economical, yet quite as effective means might be devised, for carrying water at a level across a valley.

In bringing the supply of water from the Mendip Hills for the use of the city of Bristol, it was necessary to cross several valleys, and as it was incumbent upon him to accomplish this in the simplest manner, he had adopted a system of wrought-iron tube aqueducts, of which he would give a brief description, even at the risk of placing before the Institution, prematurely, a portion of the description of the Bristol Water Works, which one of his assistants, an Associate Member, had promised to communicate, on a future occasion.

The three principal conditions by which he was guided in designing the Bristol Water Works, were—

1st. The subsidence of the water.

2nd. The sufficiency of the velocity of the water in the aqueduct.

3rd. The means of cleansing the aqueduct periodically, and of preventing accumulations of deposits.

With reference to the first condition, wherever it was possible, he determined to take the water direct from the springs, and to leave the existing channels and small streams as the natural drains, or sewers for the farms, or villages, as he observed, that they were subject to pollution, from the quantity of cattle, pigs, and poultry, kept by the inhabitants of the Mendip Hills.

He was well aware, that the deposit of lime by water from a limestone district, was a serious question to encounter, and that the deposit by the water from the Mendip Hills, was very large; but he arrived at the conclusion, that with a fall of 5 feet per mile, for the aqueducts, and 10 feet per mile for the pipes, he should create a self-acting aqueduct; and in order that no accident might happen in the passage of the water, he adopted the reverse of what was generally done. There were therefore no stop sluices, along the whole line. Tanks, with large sluices, were established at nearly every mile throughout, and if any accident occurred, these discharging sluices were opened, and all the water was intercepted. The plan had been perfectly successful, and he found, that by washing out the pipes every month, the deposit was almost entirely prevented from passing along the aqueduct.

Two men during the summer, and four men in the winter, at a cost of about £160 to £180 per annum, sufficed to manage the entire line of aqueduct, and even in case of carelessness on the part of these men, it was almost impossible that any injury could occur.

The chief source of supply for the Bristol waterworks, was at Chewton Mendip, a village about twelve miles in a direct line south of the city of Bristol, and five miles north of Wells, in Somersetshire.

The aqueduct was constructed on the eastern side of the Mendip Hills, extending from Chewton and Litton, through East Harptree, West Harptree, past Compton Marten, Breach Hill, Leigh Down, Chew Stoke, and Winford, to Barrow Gurney, where it terminated in a reservoir, formed in a natural dell, or depression of the slope of the west foot of Dundry Hill, which there rose to an elevation of about 900 feet above the river Avon.

The springs at Chewton and Litton were at an elevation of about 400 feet, above the level of the docks at Bristol, and were united below the ground level, by means of collecting tanks, open-jointed drains, and culverts; the water was then conveyed by the several branches, to the principal aqueduct, which proceeded towards East Harptree,—a length of 2¼ miles,—where it joined the tunnel driven through the high land above Harptree Village and

Court. The aqueduct was constructed of masonry, with an inclination towards Bristol of 5 feet per mile.

The Harptree Tunnel was about 1¼ mile in length, driven nearly all the way through solid magnesian limestone conglomerate rock, and the greater part was lined with masonry, corresponding in form and size with the other portions of the aqueduct. The tunnel had likewise an inclination towards Bristol of 5 feet per mile.

Proceeding onwards from the tunnel, the line crossed Harptree Coomb and was there joined by the branch aqueduct, conveying into the main line a considerable feeder from the springs and waters of that romantic and picturesque gorge of the Mendip Hills.

The aqueduct was continued across the Coomb, or ravine, by means of an oval wrought-iron tube 354 feet in length, supported at intervals of 50 feet on piers of masonry nearly 60 feet in height (Fig. 4). The internal dimensions of the tube accorded with those of the stone aqueduct and the ends were connected with it, by means of stone tanks and collars of clay puddling, 10 feet in thickness, in which the ends were embedded, so as to allow for any expansion, or contraction, and to prevent leakage. The tube rested on cast-iron saddles, fixed to the piers and abutments, and provision was made in the saddles, by means of friction balls, to allow of the tube expanding and contracting, with the variations of temperature, each way from the centre saddle, which rested on a pier of equilibrium. The balls of the centre saddle admitted of slight motion laterally, but prevented the tube from moving endways in either direction.

The following were the dimensions of the tube, of precisely similar construction, across the valley at Leigh Down (Fig. 4):—

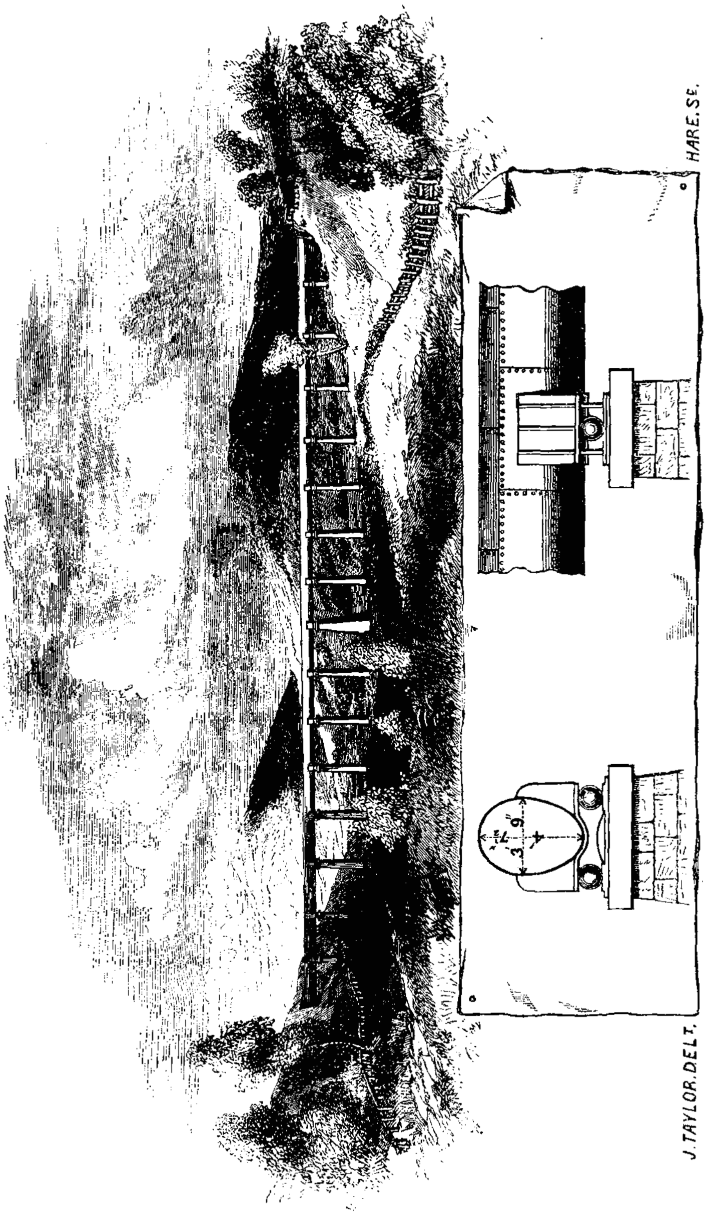
Length of wrought-iron tube . . .	834 feet
Length of aqueduct between abutments .	800 ,,
Span from pier to pier	50 ,,
Greatest height	40 ,,
Total cross-sectional area	13 sq. feet
Water area	10 ,,

Fall 1 in 1,056, or 5 feet in a mile.

Capability of the aqueduct for conveying water—
(10 square feet sectional area) 2,200 cubic feet per minute; or 20 million gallons per day.

	Tons.
Weight of iron tube	84
Weight of cast-iron saddles, &c. . .	26
Weight of water	230
Total weight on piers . . .	340

Fig. 4.



Wrought-iron Tubular Aqueduct, spanning a Valley near Leigh Down, on the line of the Aqueduct for the Bristol Water-Works.

Pressure on the masonry, about 1¼ ton per square foot.

	£.
Cost of tube, saddles, bolts, &c., fixed .	2,617
Cost of masonry, &c.	2,000
Total cost of aqueduct . .	£4,617

Cost per lineal yard £16. 10*s*.

The wrought-iron plates, of which the tubes were composed, were three-eighths of an inch thick at the bottom, and seven-sixteenths of an inch thick at the top. The section was oval, the transverse diameter being 3 feet 9 inches, and the conjugate diameter 4 feet 7 inches.

Very light and efficient aqueducts were thus formed, spanning these wide valleys at a cost not exceeding £14 to £16 per lineal foot, including all expenses.

The aqueduct and tubes were of sufficient capacity to convey a larger quantity of water, than the cast-iron pipes of 30 inches diameter; the dimensions of the former having been in some degree decided by the area in which the men could most conveniently work. The cast-iron pipes were calculated to convey eight millions of gallons of water per diem, and the land purchased for the pipe track was of sufficient width to admit of another line of pipes; the intention being to collect large quantities of water, at those periods of the year when the springs and streams of the Mendip Hills yielded the most abundant supplies, and to convey the water to the large store reservoir at Barrow Gurney, —a deep artificial basin of about 25 acres.

At a distance of about 250 yards beyond the iron-tube at Harptree and near to West Harptree, the stone aqueduct terminated in a tank, and a line of cast-iron pipes 30 inches in diameter, and 4¼ miles in length, was laid across the valley, nearly on the summit of the ridge, at the head of the river Yeo, and the westerly branches of the river Chew, between West Harptree and Chew Stoke, and thence over Breach Hill, up to the tunnel through North Hill. The line of pipes was undulatory, with a total fall of 42½ feet, or 10 feet per mile, and was so arranged, that the escape of air from the pipes, whilst they were being charged with water, took place at each extremity, and at a high point on Breach Hill, where an open upright tube, or stand-pipe was placed, at a sufficient elevation to prevent any overflow of water. This stand-pipe was screened, by being placed within a stone obelisk 50 feet in height.

The remainder of the line of works from the termination of the 30-inch pipes, to the store reservoir at Barrow, consisted of a tunnel through North Hill (in indurated red marl) three-quarters of a mile in length; then a line of aqueduct built with masonry, and similar to that already described—a portion of it being formed as an embankment, where the level of the land was deficient; following this, a wrought-iron tube, or aqueduct, of the same kind as before described, 834 feet long; then another length of stone aqueduct, followed by a third wrought-iron tube, also 834 feet long; these tubes conveying the water across Leigh Down and Winford valleys respectively; and lastly the Winford Tunnel, one mile in length, chiefly pierced through a confused and upheaved mass, consisting of mountain and blue lias limestones, red sandstone and gypsum.

The works comprised a length of nearly eleven miles of aqueduct, tunnels, and tubes, from Chewton Mendip to the store reservoir at Barrow Gurney.

The SECRETARY said, he had entered into correspondence with several authorities, on the subject of ancient and modern aqueducts, and had, with the assent of Mr. Rennie, incorporated a portion of the results of his inquiries into the body of the paper. He would also collate the apparent discrepancies in the several accounts, and would as far as was possible correct them, and give the conversion of the dimensions, from French into English measures, before publishing the paper.

M. Mont Richer, the Engineer and designer of the Canal of Marseilles and of the Bridge-Aqueduct of Roquefavour, had kindly transmitted some valuable memoranda, which he had translated; part of this information had been used in the original paper, and the remainder would be laid before the meeting. He was requested by M. Mont Richer to apologize for the incompleteness of the document, and to state that it arose from the extreme occupation of his time, which had hitherto prevented his drawing up an account of the work, even for the 'Annales des Ponts et Chaussées.'

The Secretary then read the following translation of part of the document.

"Description of the Bridge Aqueduct, on the line of the Canal of Marseilles."

The Bridge Aqueduct of Roquefavour (Plates 1 and 2) presents a front elevation of 83 mètres (272·31 feet) from the standard-level of the river Are, to the summit of the parapet, and from that point down to the lowest part of the foundation of the tallest pier in the river, is a depth of about 93 mètres (305·12 feet); the total length, upon the parapet, may be taken at 393 mètres (1289·39 feet), and it is composed of three ranges of superposed arcades of semicircular arches. The first, or lowest range is 34^{m} 10^{c} (111·87 feet) high, from the standard-level of the river; the second range 37^{m} 60^{c} mètres (123·36 feet), and the third range 10^{m} 95^{c} (35·92 feet) up to the summit of the parapet.

The structure is on a straight line, and is supported by piers, strengthened by counterforts, rising up as far as the string-course of the second range of arches. The eleven piers in the first range of arches, are at their bases, 5^m 50^c (18·04 feet) in width, measuring perpendicularly to the longitudinal axis of the structure, and 6^m 50^c (21·32 feet) in thickness, measuring on the line of the axis. The piers diminish upwards, at an uniform batter of 15 millimètres per mètre (1 in 66), so that their thickness, at the line of the springing of the first row of arches, is reduced to 6 mètres (19·68 feet). The counterforts have a batter of 8 centimètres per mètre (1 in $12\frac{1}{2}$) on the perpendicular axis, between the base-line, and the line of the springing of the first arches, at which height their breadth is 4^m 30^c (14·10 feet).

The twelve arches of the first range, have a span of 15 mètres (49·21 feet) and a breadth between the faces, of 4^m 90^c (16·07 feet).

In order to diminish the weight of the structure, there has been left from end to end, over the haunches of the arches, a semicircular arched way of a span of 3^m 30^c (10·82 feet), upon the top of which, there is a foot-passage throughout the length of the first arcade. This passage traverses the piers by openings of 1 mètre wide by 2 mètres high (3·28 feet by 6·56 feet); each covered by a single block of stone of $0{\cdot}80^c$ to 1^m (2·62 to 3·28 feet) thick, and cubing about 3 mètres each = 106 cubic feet.

The fourteen piers of the second range are 4^m 85^c in breadth and 5^m 30^c in thickness (15·91 feet by 17·38 feet). The counterforts, at the springing of the first range of arches, have a width of 3^m 80^c (12·46 feet) and a projection of 2^m 65^c (8·69 feet) with a uniform batter of $0{\cdot}06^c$ per mètre (1 in 16 $\frac{2}{3}$) up to the springing of the second range.

The string-course, at the top of the second range of arches, is $0{\cdot}90^c$ (2·95 feet) wide, and has a gradual fall of $0{\cdot}004^{mil.}$ (1 in 250) per mètre, which is identical with that of the channel of the Aqueduct.

The fifteen arches of the second range have a span of 16 mètres (52·49 feet) and are 1 mètre (3·28 feet) thick at the key-stone. The face-walls are 2^m 50^c (8·20 feet) in height, and pierced throughout with a passage 1 mètre (3·28 feet) wide, forming a corridor along the whole of the top of the second range.

The projection of the counterforts, at the springing of these arches, is reduced to $0{\cdot}65^c$ (2·13 feet) and the batter to $0{\cdot}04^c$ (1 in 25) per mètre, and at the line of the top of the key-stone, where they terminate, the projection is only $0{\cdot}25^c$ (0·82 foot).

The third range is composed of fifty-two small piers 2 mètres (6·56 feet) thick and 4^m 50^c (14·76 feet) wide; resting in sets of three on the large arches, with one set of four arches in each abutment, and supporting fifty-three semicircular arches having each a span of 5 mètres (16·40 feet) and a width of 4^m 50^c (14·76 feet) over the face walls. These arches carry the channel of the aqueduct, which is 2 mètres (6·56 feet) wide at the base and 2^m 30^c (7·54 feet) at the top, with a depth of 2^m 40^c (7·87 feet). The average thickness of the face-walls is 1^m 10^c (3·60 feet). At the top of the structure is a cornice, $0{\cdot}45^c$ (1·47 foot) in height, with a projection of $0{\cdot}65^c$ (2·13 feet), supported by brackets 1^m 50^c (4·92 feet) high. Upon this cornice is a parapet 1 mètre (3·28 feet) high, which forms a passage on either side of the channel. The parapets abut at both ends against cubical blocks, each composed of a single stone of 3 mètres (9·84 feet) long, 1^m 60^c (5·24 feet) thick, and 1^m 20^c (3·93 feet) high.

The foundations of the piers were all sunk down to the solid rock. For the four nearest the north end, where the face of the valley has a gentle acclivity, a solid foundation was obtained at a short depth beneath the surface, but for the rest, a greater depth was required; even as much as 10 mètres (32·80 feet) below the low-water level of the river, for the piers nearest to the south end, which consequently attain a height of 93 mètres (305·12 feet) from their foundations, in the bed of the river, up to the summit of the parapet. The works were frequently interrupted by floods during the course of their execution.

The simplest mechanical means were adopted for the construction of this great work. Each pier was surrounded by a moveable scaffolding, composed of four vertical balks supporting two trussed beams, carrying iron rails, and placed perpendicularly to the axis of the bridge on each side of the pier. The balks were joined together by horizontal bearers at the level of the rails. The horizontal beams were themselves morticed together at their ends, so as to obtain the greatest possible amount of rigidity.

On the rails was placed a travelling-winch, worked by four men, and by means of two parallel drums and four cranks the stones were raised vertically, and transported to the right and left of the building, to any point required.

The scaffolding was generally carried upon four corbels, forming projecting brackets, left in carrying up the masonry of the piers; upon which were laid horizontal cills with cast-iron shoes at their extremities, into which the scaffolding-balks were inserted.

It was thus only requisite to bring the materials within reach of the crane placed on each pier, and the stones, etc., were raised with such facility, that the masonry proceeded with great rapidity. In order to facilitate this, a single line of railway worked by horses, was laid from the quarries, situated at a distance of about 6 kilomètres ($3\frac{3}{4}$ miles), to the site of the aqueduct. On arriving at that point the waggons, loaded with stones of all dimensions to 6 mètres (202 feet) cube, were raised upon an inclined plane of rails laid down on the right bank of the Are, the whole length of the piers, and worked by a rope of 450 mètres (1,476 feet) in length, to which motion was given by a water-wheel erected near the aqueduct, whence the motive power was supplied.

Thus by means of a series of spur-gearing, working a drum, round which the rope was coiled, and a snatch-block fixed on the top of the bank, the waggons were drawn up to the various points required, where their progress was arrested by lowering the sluice-gate, so as suddenly to cut off the supply of water, and by applying a break of great power to the axis of the wheel.

A crane placed at the requisite height, lifted the stones from the waggons and transported them to another line of rails, laid at the various levels along the aqueduct, as the building proceeded. Each unloaded waggon then descended the inclined plane by its own weight, carrying with it the rope as it uncoiled itself from the drum, which had been previously disengaged from the machinery of the water-wheel and was allowed to revolve freely. The stones were thus brought up to the level of the masonry and easily transported upon a waggon, along the line of the works, at the various and proper heights on the right bank of the Are. In order to convey the materials to the piers for which they were destined, a continuous line of rails was laid down, connecting the whole of the piers together. The railway was formed by fifteen sets of trussed service bridges 18^{m} 90^{c} (62 feet) in length, and 2 mètres (6·56 feet) in external width, each bridge being completely independent of the others, with its ends resting on two contiguous piers. The passage was continued over the piers, by plain timbers, carrying rails, placed against the ends of the bridges. The stones, brought to their destination along the line of rails previously mentioned, were immediately lifted off the waggon by the crane on the pier, and the empty waggon returned to fetch other loads, which the water-wheel was continually raising.

It has been stated, that a drum was employed to draw the stones up the inclined plane: when it was not thus employed it was uncoupled from the machinery of the water-wheel, and another was thrown into gear, by means of which and a rope running over a pulley fixed to the scaffolding of the ninth pier, the mortar and water necessary for the masonry, were raised vertically on to the work, in corves each containing about 300 litres (10·59 cubic feet). When at the proper level, these corves were placed, by means of the travelling-winch of the ninth pier, upon the waggons of the service-bridges, for distribution along the whole length of the aqueduct.

It is evident, from the above description, that the height to which the masonry could be raised was limited by the height of the cross-timbers of the scaffolding under which the loaded waggons had to pass. The next step therefore was to raise the scaffolding, and on that account the parts were so constructed as to be moveable, when once the masonry had attained to within a short distance of the winches.

Very simple, but efficient means were employed to accomplish this. Between the foundation beam, which supported the scaffolding, and the line of rails, on which the travelling-winch rested, there was a height of $8^m\ 20^c$ (26·90 feet), so that when the masonry was carried up about 6 mètres (19·68 feet) there only remained a space of $1^m\ 80^c$ (5·90 feet) free between the beds of the stones and the rails, for the passage of the workmen and the waggons, and for manœuvring the stones upon the piers. When therefore that point was attained, four screw-jacks, each 5 mètres (16·40 feet) high, were brought along the service-bridges and placed, by means of a travelling-winch at the four angles of the pier, inside the counterforts, where they were secured vertically by means of cords and guy-ropes attached to the upper beams of the scaffolding. Cast-iron nuts with a projection of $0{\cdot}30^c$ (0·98 foot) received a movement lengthways of the jacks from a screw of $0{\cdot}08^c$ (0·26 foot) diameter, turning in brasses. Each screw was worked by two men, by means of bevel-gearing and a four-branch crank. The cast-iron nuts in rising, took a bearing beneath the rails of the scaffolding, and then the whole was raised by eight men working simultaneously at the screw-jacks. Each operation occupied from two to four hours, and men, well accustomed to the work, were thus enabled to raise without difficulty and in a short space of time, the scaffolding and their winches, weighing together 16,000 kilogrammes (about 16 tons) a height of 3 mètres (9·84 feet) at each change.

The foundation beams, which were removed the moment the scaffolding began to rise, were replaced upon the projecting stone corbels, left in building the piers, and which were weighted down by a course of masonry 3 mètres (9·84 feet) in thickness; then by turning the screws in a contrary direction, the scaffolding descended a short distance and rested, as previously, on the foundation beams. The travelling winches which had thus been raised $4^m{\cdot}80^c$ (15·74 feet) above the masonry, laid hold of each screw-jack successively and deposited it in one of the waggons on the service bridge, by which it was carried to another pier, there to repeat the same operation.

All the scaffoldings being thus successively raised, there only remained the service bridges to be lifted, and they were generally only raised 1 mètre (3·28 feet) at a time, so that they might rest directly upon the masonry. This required very little time and few preparations, as by driving out of their bearings the oak wedges which held the joists together, each bridge became independent of the others. The winches of the two contiguous piers then seized each end and working together lifted the service-bridge as high as was required. The same operation being performed with all the bridges then the winches took up the joists and placed them in their positions, the oak wedges were replaced in their bearings, and the line of rails was again re-established along the whole length of the aqueduct.

By these consecutive operations all the piers of the aqueduct were raised to a height of 75 mètres (246·06 feet) above the river.

It was however necessary to employ different means for turning the arches.

The sphere of action of the cranes being almost entirely confined to the area of the piers, it was not possible to use them in the construction of the arches; it was, therefore, resolved to carry up the piers without reference to the arches, and when the scaffolding had been raised to above the line of the top of the keystone of the arches, then to fix the centres. The centres for each arch consisted of four principals; the two outside principals being each formed of three angular trusses, held together by wrought-iron plates and screws. These outside principals were raised in parts and placed in position by means of the travelling winches of the piers. They were thus raised with ease, and economy, without the least danger.

The placing of the internal centres was similarly effected, and then the laggings were placed, thus forming at the same time a convenient and solid scaffolding.

The fixing of the centres being effected, a beam was passed through each opening in the first range of arches. These beams were 17 mètres (55·77 feet) in length, and supported a railway for conveying the necessary materials for the construction of the arches. Upon the projecting corbel stones left in the piers, at 13 mètres (42·65 feet) above the line of the springing, there were placed two beams, 19 mètres (62·34 feet) long, and $4^{m}\cdot 90^{c}$ (16·07 feet) apart, supported by beams and struts abutting on the centres. On these beams rails were laid down in the direction of the longitudinal axis of the aqueduct, on which was a traveller $5^{m}\cdot 20^{c}$ (17·06 feet) in length, carrying another set of rails at right angles with the axis. A winch upon four wheels, placed upon this last set of rails, distributed to all parts of the centres the materials brought through the openings between the piers. In this manner, the works of the first range of arches were executed with such facility, that five days sufficed to complete an arch, each of whose keystones did not weigh less than 1200 kilogr. (nearly 24 cwt.)

It is hardly necessary to add, that the materials were brought by the same inclined plane as had been used for the piers, which were then being carried upwards another stage.

In the construction of all the arches of the first arcade, only four sets of centres were used, which were taken down as soon as an arch was completed, to be consecutively employed in the others. By the time this range of arches was finished, the piers had reached the height of the second range of arches, which were then constructed by the same means, a slight modification only being made in the span of the centering, which was increased from 15 to 16 mètres (49·21 feet to 52·49 feet).

Similar means to those used for the construction of the first range of arches, were employed in finishing the masonry and placing the keystones of the second; the only difference being, that instead of the beams bearing upon the centres, the trussed beams of the service-bridges, which were no longer required for the masonry of the piers, were used for supporting the line of rails and the travelling winches.

The piers and arches of the third range, were afterwards constructed without difficulty, by means of small travelling cranes working upon the second range of arches.

All the face walls of the aqueduct and of the piers are built of hard cut stone, in courses varying from 0·60^{c} (1·96 foot) to 1^{m}·50^{c} (4·92) in height. Some of the blocks were as much as 6 mètres (202 feet) cube, and weighed 15,000 kilogr (15 tons) each. The total cubic content of the cut stone employed in the construction of the bridge-aqueduct of Roquefavour being about 50,000 mètres (1,765,000 cubic feet). Besides this, there were used, in the body of the arches, the backing of the haunches, and in forming the channel of the aqueduct, about 15,000 cubic mètres (530,000 cubic feet) of rubble masonry.

The stone was obtained from two quarries which were discovered, almost facing one another, on the two banks of the Are, at about 6 kilomètres (3¾ miles) below Roquefavour. A year had been occupied in fruitless research all around the site of the aqueduct and within a radius of several leagues, when at last the quarry of Mont Ribas was discovered on the left bank of the Are, and then that of the Collet de Bourret, on the right bank. The first was opened on the north face of the hill and in a length of 1,800 mètres (1,968 yards), and at an average height of 10 mètres (32·80 feet) four beds of hard facing stone, varying in thickness from 0·60^{c} (1·96 foot) to 1^{m}·50^{c} (4·92 feet) and separated from each other by beds of argillaceous limestone, were developed. This quarry was worked by five inclined planes, at a considerable angle,—separated from each other by horizontal landings,—with three other less rapid inclined planes, at the top of the quarry. A single line of railway was used for conveying away the stone when quarried. The inclination of the upper planes was just sufficient to allow the waggons to descend without breaks, to the point where the lowest inclined planes branched off. These last were self-acting, with a single line of rails, the empty waggons running upon the surface of the ground in their ascent, and by their friction helping the breaks to moderate the velocity of descent of those loaded with stone.

The face opening of the quarry of the Collet de Bourret, was 600 mètres (656 yards) long, and was worked by three inclined planes, in the same manner as the other.

In working these quarries nearly twelve hundred men were employed, for whom it was necessary to provide temporary habitations on the spot, with offices, quarters for the police, a prison, &c., which were required for the wants of the new colony.

About 50 cubic mètres (1,765 cubic feet) of the cut stone were worked per diem.

The time occupied in the construction of the bridge-aqueduct was nearly seven years; but during two years of this time, the work was intrusted to Contractors who proved unequal to the task. After much time had been thus lost, the contract was rescinded, and at the beginning of 1843, the work was undertaken by the Government. Some considerable time was still required for getting together the necessary plant, such as cranes, winches, scaffolding, &c., but notwithstanding these difficulties, the water flowed over the bridge aqueduct on the 30th June, 1847. It may, therefore, be fairly said to have been actually executed in about five years.[1]

The total cost of the aqueduct was in round numbers 3,700,000 francs = £148,000.

The proportions for the various parts of the work would be nearly thus—

Preliminary works,		fr. c.	£.
Materials raised from the quarries . .		85,390 45	
Contract works per M. Mouren. . .		208,958 36	
Task work under the Government engineers—			
	fr. c.		
Excavation, filling and levelling . . .	19,259 15		
Masonry	656,966 94		
Rubble stone, lime, Pozzolana, &c.. .	110,827 45		
Horses, keep, superintendence, &c.. .	132,656 64		
General expenses .	33,504 74		
Carried forward	953,214 92	294,348 81	

[1] The Editor would take advantage of this opportunity to express his thanks to M. Mont Richer for the documents and sketches supplied by him—to M. Love for the drawing of the elevation of the aqueduct—to M. Cavallier, for permission to take the photograph view—and to Mr. Pole for his assistance in the conversion of the measures and checking the calculations.

	fr.	c.	fr.	c.	£.
Brought forward	953,214	92	294,348	81	
Quarries—					
Preliminary expenses of opening, extracting stone, carrying spoil and haulage of stone	1,156,002	90			
Dressing stones ready for laying . . .	409,739	62			
			2,599,957	44	
Materials—					
Timber	68,938	44			
Carpenters' labour on ditto	60,452	47			
Waggons, &c. . . .	51,912	02			
Cranes, winches, and iron-work . . .	392,272	87			
Cables. &c. . . .	63,956	97			
Haulage of materials .	23,544	61			
Horses	2,950	00			
Railway	175,428	41			
			839,455	79	
Sundry expenses—					
Preliminary expenses of establishment .	47,825	01			
Experiments, &c.. .	890	19			
Unexpected expenses in consequence of the floods in the river	6,758	19			
Overfall weir at the aqueduct . . .	2,236	91			
Pulling down and carrying away the work-yards, &c. .	8,827	66			
			66,237	96	
Total			3,800,000	00 =	£152,000
Value of old materials sold after the termination of the work .			100,000	00 =	£4,000
Total . . Francs			3,700,000	00 =	£148,000

The quantities may be taken in round numbers, as—

Cut stone	50,000	cub. mèt.	=	1,765,000 cub. ft.
Rubble stone	16,600	,,	=	586,000 ,,
Rock excavation	9,000	,,	=	318,000 ,,
Earth ditto	24,000	,,	=	847,000 ,,
Iron dowells for stonework	90,000	kilogr.	=	90 tons.

The general expense may also be thus divided, including the cost of material.

	francs.	
50,000 cubic mètres of cut stone, raised to a maximum height of 83 mètres = (272 feet) at 66 francs per cubic mètre	3,300,000	
16,600 cubic mètres of rubble masonry with hydraulic lime, at 16 francs	265,600	
9,000 cubic mètres of rock excavated for foundations, at 3fr. 50c.	31,500	
24,000 cubic mètres of earth excavated for ditto, at 0·70c.	16,800	
90,250 kilogrammes of iron, at 0·40c.	36,100	
Pumping out foundations, &c.	50,000	
Total . . Francs	3,700,000	= £148,000

Mr. POLE stated, that the Secretary had recently placed in his hands M. Mont Richer's determinations of the quantities of water, which the various sections of the canal would deliver at different depths; it would be interesting to compare these with the other calculations that had been given in the course of the discussion.

M. Mont Richer had used the following formulæ, which he ascribed to Prony:—

Let S = section of water,
P = wet perimeter,
R = "hydraulic mean depth" = $\frac{S}{P}$,
I = fall per mètre,
V = mean velocity per second,
Q = quantity delivered per second,
(All in French mètres)

Then, $V = 56 \cdot 86 \sqrt{R\,I} - 0 \cdot 072$,
and $Q = S\,V$.

The resulting quantities of water which the various sections would deliver were:—

Section.	Depth of Water in Mètres.	Delivery in Cubic Feet per Minute.
Plate 2.		
Figs. 3, 4, and 5 . . .	1·00	6,822
	1·50	*14,017
	2·00	23,888
Figs. 6, 7, and 10 . .	1·00	9,280
	1·50	*16,426
	2·00	24,410
Fig. 8	1·00	8,480
	1·50	*14,860
	2·10	23,750
Fig. 9	1·00	12,280
	1·50	*21,400
	1·60	23,460
Fig. 2 . . . . (Channel of Roquefavour Bridge-Aqueduct.)	1·00	11,300
	1·50	*19,310
	1·80	24,530

It thus appeared, that although the quantity of water to be drawn during dry seasons was only about 12,000 cubic feet per minute, yet by raising the water in the channels to certain higher levels, which the works were purposely constructed to allow with safety, the delivery could be increased to 24,000 cubic feet.

The quantities marked thus * referred to the same depths of water as those calculated independently by Mr. Pole, and stated on page 204; from which it would be seen, that the results of the simple rule there given, to which his investigations had led him, did not differ more than about 2 per cent. from those of the more complicated formula adopted by M. Mont Richer.

Mr. A. POYNTER exhibited a diagram of the Ponte Maddalone, by which the waters of the aqueduct of Caserta were conveyed across a deep valley, to the Royal Palace of Caserta, near Naples. The aqueduct was designed and executed under the direction of Vanvitelli, in 1753; it brought the water a distance of twelve miles, through a difficult country, having in its course to traverse the mountains by five tunnels, for the construction of which some of the shafts required to be upwards of 200 feet in depth. In other places the channel was carried along the sides of the mountains in cuttings of from 15 to 20 feet deep.

The bridge-aqueduct, Ponte Maddelone, had three superposed tiers of arches.

The lower tier of	19 arches,	of 20 ft. 10 in. span,	and 54 ft. 1 in.	high.
,, second	,, 27	,, ,,	,, 59 ft. 6 in.	,,
,, upper	,, 43	,, ,,	,, 73 ft. 1 in.	,,

The extreme height to the top of the parapet was 179 ft. 7 in.

It was built of "Tufa," bonded with brick, and from its solidity and correct proportions was a very important structure.

Mr. POLE, through the SECRETARY, remarked that he could corroborate the account of the Maddalone aqueduct, as he had visited it and taken its principal dimensions. The total length of the top of the aqueduct was upwards of 1,700 feet, the extreme breadth at the base over the buttresses, was about 34 feet, and the width of the top tier of arches 12 feet 6 inches. The water channel was covered, and had a road 9 feet wide over it, establishing a foot communication between the high lands on either side of the valley. The situation was very picturesque, and from the centre of the bridge a fine view was obtained, extending as far as the Bay of Naples and the Island of Capri.

The water was brought from a spring in the Monte d'Aburno, called the "Aqua Julia," which had been anciently used by Cæsar Augustus to supply the colony of Capua; and which, Mr. Pole believed, was at a greater distance than had been stated by Mr. Poynter. A Latin inscription on the Ponte Maddalone, gave the length of the conduit as 26 "millia," but it was not quite clear what length of mile was alluded to. A very large quantity of water was brought to Caserta by the aqueduct; it was delivered, at a high level, on a hill in the grounds of the Palace, and thence descended for about 250 feet through a series of ornamental cascades, like those established at Chatsworth, in Derbyshire, for which they were stated to have served as models.

Mr. PENTLAND, through the SECRETARY, exhibited a drawing of the Viaduct of Ariccia, recently built by the Roman Government, from the designs of the late Cavalière Bertolini, of Rome, for carrying the public road between Albano and Ariccia across a deep valley intersecting the line of the Via Appia. It consisted of three superposed tiers of semicircular arches.

The lower tier of	6 arches,	of 30 ft. span,	67 ft. extreme height.
,, middle ,,	12	,,	,,	63 ft.	,,
,, upper ,,	18	,,	,,	70 ft.	,,

The width of the piers, or depth through the arches, was—

	Feet.	Inches.
Lower piers	58	3
Middle ,, ...	36	0
Upper ,, ...	32	0
Roadway	21	0
Length of lower tier of arches .	351	0
,, middle ,, .	604	0
,, upper ,. (roadway)	1020	0

The greatest height above the bottom of the ravine was about 200 feet. The mass of masonry, 118,240 cubic metres = 4,175,882 cubic feet. The cost of construction, including the approaches, was under £30,000 sterling.

The structure was entirely of stone, the "Lapis Albanus" of the ancients, and in mass and solidity surpassed almost all the modern works of a similar nature.

A short description of the viaduct had been given in the "Comptes Rendus" of the Académie des Sciences at Paris, but in the course of the next Session Mr. Pentland hoped to be able to present a more detailed account to the Institution.

Mr. RENNIE said, that after examining the aqueduct of Roquefavour, he determined to visit the remains of the "Pont du Gard," in order to establish, in his own mind, the points of resemblance between the two structures; and, on his return, he had embodied his observations in a few short memoranda, which had been submitted to the Council, and which he would request the SECRETARY to read.

The SECRETARY, with the permission of the PRESIDENT, read the following paper:—

"Description of the Pont du Gard." By GEORGE RENNIE, M. Inst. C. E.

The Pont du Gard, or Aqueduct of Nismes, as it is sometimes called, has been described by Daviler and De Lannoy, in 1700; by Jean Jacques Rousseau, in 1741; by Pitot, in 1743; Nizard and Delon, in 1787; Grange and Durand; J. Rondelet, in 1821, and by so many English and other travellers, that further description would appear almost superfluous. Nevertheless, having visited the structure, shortly after that of Roquefavour, the Author thought it desirable to place the ancient and modern buildings in contrast.

The Pont du Gard is, in all probability, one of the most ancient aqueducts constructed by the Romans out of Rome, as it is attributed to Agrippa, son-in-law of the Emperor Augustus, who, on his return from Egypt, in the annals of Rome 735, seventeen years B. C., commissioned him to quell the disturbances in Gaul, when, flattered with his reception from the inhabitants of Nismes, he fixed his residence in that city. The insufficient supply furnished by the fountains of Nismes doubtless suggested the idea of conducting thither the waters of the Eure and the Airan, rivulets situated near the city of Uzès, about seven leagues distant, from whence the water was led eastward, through several hills, and over many arches, in a devious course, to the village of Castillon du Gard, and thence southward, across the valley and river of the Gardon, over which was built this celebrated bridge-aqueduct. After crossing by this structure, the channel passes through the hills, by tunnelling, and where it crosses the valleys it is supported by small arches, in a southerly direction, towards Sarnhoe, whence it diverges suddenly in a south-western direction, and after having traversed, for a distance of a quarter of a league, the chain of mountains to the north, the aqueduct shows itself near Sarnhoe, after which it can only be traced by imaginary levels near the villages of Bezousse, St. Gervais, Marguerite, and Courbessac, to Nismes, the total length being estimated at 41,000 mètres, or $25\frac{1}{4}$ miles.

M. J. Rondelet, from whom this description of the locality is derived states, that although he had measured the Pont du Gard himself, he considered the measurements of MM. Grange and Durand, and published by those engineers in the "Description of the Ancient Monuments of France," so much more accurate, that he preferred to give them in place of his own. The following are the details:—

The Pont du Gard consists of three rows of superposed arches.

The first, or lower series, under which the River Gardon passes, consists of seven arches.

The second, or middle tier, of eleven arches.

The third, or upper tier, of thirty-five arches.

All these arches are semicircular, and rest on imposts of greater, or less elevation.

It is the third, or upper range of arches, which carries the water channel, and that at an elevation of about 160 feet.

The middle arch of the lower series is 24^m 52^c or 80·142 feet span.

The three arches on each side of the centre are 19^m 20^c each, or 63· feet span.

The smallest, 15^m 55^c, or 51· feet.

The arches in the second series are the same as those below. The upper series has its arches alike, viz., 4^m 80^c, or 15·74 feet span.

The piers of the first and second series are all 4^m 55^c, or 14·92 feet thick.

The piers of the upper series vary according to the diameters of the arches below, four arches of this upper series corresponding with one arch of the lower.

As the two sides of the mountains which form the valley of the Gardon are not of equal height, that of the left bank being lower than the level of the aqueduct, while the right bank is higher, the aqueduct was sustained by a long series of arches similar to those of the upper series, and on the opposite side these arches were continued on the mountain itself.

The length of the aqueduct across the valley is 269^m 10^c, or 882 feet.

The Pont du Gard is entirely constructed of cut masonry from top to bottom, and all the beds so closely jointed, and without mortar, or cement, that it was generally difficult to insert the blade of a pen-knife between them—in many cases it was not possible.

The channel which carries the water is the only part which is not of cut stone. It is constructed with rubble on the two sides, and with ordinary masonry in the interior, and covered with a cement 0^m 05^c, or 2 inches thick, of broken brick, or tiles, mixed with lime and gravel. The width of the channel was originally 1^m 22^c, or 4 feet, and its depth 1^m 62^c, or $5\frac{1}{3}$ feet English. This width has, however, been diminished, by a deposit from the water, of 0^m 29^c, or nearly 1 foot in thickness. This deposit proves that the usual depth of the water in the channel was about 1 mètre, or 3·2809 English feet, and that the quantity of water which passed latterly was only one-half of what it was originally.

The channel over the aqueduct was originally covered with flagstones, few of which now remain.

The Pont du Gard appears to have been broken at both ends, at some distant but uncertain period, but which is dated about 406, or near the commencement of the fifth century, so that it is probable that the water flowed through the channel for four centuries, after which it ceased to flow for fourteen centuries. Numerous stalactites, or calcareous deposits, now observable in great quantities underneath the arches, show that the water percolated through them, notwithstanding the boasted tightness of the cemented bottom.

The foundations of the Pont du Gard presented no difficulty; they were cut into the rock, about 2 mètres, or 6½ feet. The bed-stones are about $0^m\ 10^c$, or 4 inches in thickness. The voussoirs of the large arches are about $1^m\ 60^c$, or 5¼ feet in length; in the second series of arches the voussoirs are about $1^m\ 55^c$, or 5 feet, and in those of the upper series they are about $0^m\ 80^c$, or 2½ feet.

It is to be remarked also, that the third, fourth, and seventh first courses of the voussoirs of the first and second series are connected in three pieces throughout the whole thickness of the bridge; it is only above these arches that the counter arches begin.

The three first voussoirs of the arches of the top series are connected in two lengths.

The stone of which this bridge is built came from a quarry in the neighbourhood, on the right bank of the river.

At the beginning of the eighteenth century the Duc de Rohan, to facilitate the passage of his artillery, caused one side of the foot of the piers to be cut away, one-third of the thickness of the arches of the second rank, and otherwise mutilated the bridge, so as to weaken the whole superstructure. This was, however, subsequently repaired, and in addition, a road-bridge was constructed, on the eastern face of the aqueduct, in 1743, by M. Pitot, who also repaired the aqueduct in many parts. This fine structure has been frequently repaired from time to time; and it now stands, considering its great antiquity, a splendid monument of architectural skill.

The projecting stones under the soffit of the arches, and on their faces, left, doubtless, for fixing the scaffolding, have a picturesque effect.