ANCIENT ENGINEERING, ITS METHOD AND APPLIANCES.

No. I.

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The arched aqueduct popularly called the Pont du Gard is the grandest monument of ancient Roman skill in bridge construction which remains in France, and can scarcely be said to find a rival in the modern aqueduct of Roquefavour, which supplies Marseilles with water. The general character of the Pont du Gard may be seen in side elevation and transverse sections in Figs. 1 and 2, 3, 4, and 5. It consists of three tiers of superimposed semicircular arches, crossing the river and the valley of the Gardon at about thirteen miles from the city of Nismes, which it anciently supplied with water derived from two natural sources at the northern side of the valley. The name of its designer is unknown, and the exact date of its construction can only be guessed at. It is believed to have been commenced about eighteen years B.C., while Agrippa, the son-in-law of Augustus, was governor of Gaul and resident at Nismes. The foundation of the structure is laid on the solid rock, which extends in flat beds with but slight inclination over the entire breadth of the valley. The river channel ordinarily runs in a very deep course which it has excavated for itself, at the northern side of the valley. In high floods, however, the water occasionally covers nearly the whole bottom of the valley, and runs through nearly all the lower arches. The entire structure, with the exception of the channel which conveyed the water across the valley, which is placed above the third tier of arches, consists of cut ashlar masonry in large blocks, and laid dry or without mortar, the material being hard cretaceous limestone. The arches of the lower tier vary in span from about 52 feet to 80 feet, which is that of the arch which crosses over the river channel, and the spans of the second tier of arches coincide with these, so that the piers of the first and second tiers are superposed. In the third tier of arches the spans are about 15 feet, and superimposed upon these is the water conduit, consisting of two side walls of rubble masonry, laid in hydraulic mortar and lined to the thickness of about two inches with beton, consisting of hydraulic lime and coarse sand mixed with fragments of red tiles, whose colour is still fresh on fracturing the cement. It is probable that the watercourse was broken during the civil wars that convulsed France about the end of the fourth century, and during the four hundred years or thereabouts in which water ran through the channel, which has been now dry for about fourteen hundred years, a deposit upon both bottom and sides had been formed from the water of rather less than a foot in thickness, which is still visible, and is shown in Figs. 3, 4, and 5. This deposit is but slightly coherent, and consists of clayey mixed with calcareous matter. The water channel is covered with large slabs of stone, most of which remain, so that it is possible to walk at this elevation from one side of the valley to the other. The rectangular piers, from which all three tiers of arches spring, are constructed of ashlar masonry laid dry, the joints of which are broken in the usual manner in the successive courses, and this is also the character of the masonry forming both the lateral faces of the arch spandrils. The arches are also constructed of large ashlar voussoirs, but these present the remarkable characteristic that they are not laid in "break joint," but with joints transverse to the courses of voussoirs which run continuously from one springing of an arch to the other, thus dividing the arch into so many separate arch rings abutting against each other. Thus, in the first tier of arches, Fig. 4, the entire breadth measured along the soffit being 21ft., the entire arch is divided into four abutting arch rings, each ring consisting of single voussoirs of about 5ft. 3in. in length. In the second tier, likewise, each arch consists of three such abutting rings, and the upper tier of two such rings. This very peculiar construction is shown on the transverse section, Fig. 4, in which is also shown the modern common road bridge which was constructed in 1743 by the estates —or Parliament of Languedoc, and which, though close to the aqueduct at the down-stream side, forms no part of the ancient structure, though it is probable that this bridge originated the modern popular name of Pont du Gard, by which the aqueduct is known. We have been indebted for these sections to the Commission des Monuments Français, inaugurated during the late empire to obtain complete and authentic drawings and details of the great historic monuments of France; they may, therefore, be looked upon as exact, which cannot be said of any of the sections which have been elsewhere published; none of which that we have ever seen take any notice of this singular disposition of the thorough or continuous cross joints of the voussoirs. We might expect to find it noticed by Gauthey in his "Traité sur la Construction des Ponts," which comprises details of all the remarkable bridges structures of the world, and also in Labord's "Monuments de la France," but neither say a word as to the arch jointing. The late Mr. George Rennie, in the discussion of his paper descriptive of Roquefavour aqueduct—"Minutes of Proceedings, Inst. C. E." vol. 54, page 236—gives a long list of authors that have more or less generally described this structure, and appears to notice some peculiarity in the jointing of the voussoirs—but in terms which, whether from a manuscript misread by the printers or otherwise, are to us at least perfectly unintelligible.

None of these authors, however, offer the slightest reasons for the adoption of this peculiar mode of arch jointing; nor appear to have asked themselves the question why an architect competent to design the grand structure should have so far departed from the established practice of breaking joint in the arched courses, and adopted one in its stead which certainly diminishes the general stability of the structure, and that without any adequate reason being apparent for the departure. It is not until after we have examined some of the other minuter features of the building and seen what reference they may bear to this peculiarity in the arch jointing, that we are enabled to see some points of connection between them from which we can infer, in the writer's opinion, the reasons for the peculiarity, and the sound judgment with which they were adopted. On examining carefully the external faces of the several tiers of arches at both sides of the structure as it now stands, we find a large number of stones projecting from twelve to fifteen inches from the general face of the work. These are in various stages of preservation, and some are altogether decayed away, but enough remain to enable us to see, both on the ends of the piers and the spandrils of the arches, that a certain determinate arrangement both in the horizontal and vertical directions was observed in the placing of these projecting stones, and that they were obviously intended to support ledgers or other longitudinal timbers, and as footings for struts and braces to be employed in constructing the work above. On the faces of the piers beneath the arches, as well as projecting from the intrados of the arches themselves up to a certain height, we find other similar stones. Examining further the intrados or soffits of the arches, we find this singular feature, that in all the lower tier of arches, except the two extreme and land arches at the north and south sides of the valley, three successive courses of voussoirs project several inches below the level of the intrados of the arch, and these projections run continuously from one side to the other of the aqueduct.

These projecting courses are found to be situated at such a height above the springing of the arch that a line drawn radially through the middle of the three projecting courses, makes an angle of from 28 deg. to 32 deg. with a horizontal line passing through the springing of the arch. Examining the second tier of arches we find similar projecting courses, except in the two land arches. Now, what was the use of these singular projections, and why placed as we have described? As ornament they could not have been intended, for they are rather a deformity, and why are they absent in the land arches? When we mentally connect these projecting courses and the single stones projecting also from the arches with the through cross-joints, we shall arrive at the key to the whole mystery, and be able to discern that the reason was a thoroughly practical one, and had for its purpose the economising of time, labour, and material, and especially in the timber, and construction of the centering whereon the arches were turned. If the cross joints of the courses of voussoirs were arranged in the usual break joint style, it is obvious that centering must have been provided extending to the entire width of one or more arches, and for arches of this magnitude the centering would require much timber, and most of it in very long lengths, and we may reasonably presume that such timber was not easily obtained at or near the site of the aqueduct.

For although at the commencement of our æra France was much more largely afforested than it is now, the indigenous trees were not generally of a sort producing long, straight timber, nor, probably, were there pine forests such as those which still adorn Dauphine and other hilly regions in the south-east of France existing in the neighbourhood of the intended work. Roads also, with the exception of the great Roman military ways, fitted for the easy transport of heavy timber, scarcely existed, every inducement therefore existed to economise the mass of timber required for the centering, as well as to economise the amount of carpentry and of iron fastenings required in the centering. Limiting our view for the moment to the lower tier of arches, it is manifest that if each single ring of arched voussoirs of 5ft. in length could be turned separately and in succession until the whole width, consisting of four such rings, was reached, the amount of timber and of centering required, though not perhaps reduced to one-