

(*Paper No. 2015.*)

“The Old Water-Supply of Seville.”

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THE new Seville Waterworks, now in progress of construction by an English company, will destroy an ancient system of supply which has been in operation for more than seven hundred years.

Constructed in the year A.D. 1172 by the Moor Jucef Abu Jacub, whilst the City of Seville was still under the domination of the Saracens, it still exists in great part in the same original form in which it was first instituted—a standing monument to the conservative influences of the climate and people of the region where it is situated. Within a few short months all the most interesting features of this work of Moorish art will have disappeared.

The ancient Moors were always celebrated for their skill in dealing with water, and their application of it to irrigation, and many examples of their work in this respect still exist in Spain, in the primitive condition in which their constructors left them more than six hundred years ago; indeed it may safely be said that all the existing irrigation-works in Spain, now in active use, were originally designed and constructed by the enterprising Saracens.

The Author is not, however, aware of any existing system of town-distribution constructed by the Moors, so ancient and complete as that of Seville; and as this presents many points of interest to the engineer, a short account of it may be of use both in preserving an historical record of a work which is nowhere else recorded, and also as showing how, seven centuries ago, the then little understood principles of hydraulics were applied.

The old Seville water-supply may be divided into three parts.

First. The collection of the water.

Second. Its conduction to the city.

Third. Its distribution inside the city.

The first portion of the works, the collection of the water, is much older than the two latter portions, inasmuch as it is

believed to have been done by the Romans in the early part of the Christian era, whilst Spain was still under their domination, and was used as a supply for the ancient city of Ontivar, a city which has long disappeared, and left only its name to tell of its former existence. The water is collected by a tunnel constructed in a rock of tertiary formation which forms the basin of a small river called the Guadaira. This river rises in the Sierra de Moron, near the town of Moron in the province of Seville, and after a short course falls into the Guadalquivir close to the city of Seville. The valley of the river for some distance above Seville is composed of a very porous argillaceous limestone, resting on a bed of impermeable clay, and at the junction of the two strata numerous springs occur, the principal of these being in the neighbourhood of the town of Alcalà, which is situated on the river Guadaira, at a distance of 13 kilometres from Seville. The head or starting-point of the tunnel referred to is in a depression near the edge of the river and at some 600 metres above the last houses of the town. In this place, and at $8\frac{1}{2}$ metres below the ground, there is a circular chamber, excavated in the rock and communicating by a shaft with the surface, and from the bottom of this chamber numerous strong springs of clear water rise and flow away through a tunnel excavated in the rock. The height of the tunnel varies from about 4 feet to 5 feet 6 inches, it has a mean width of about 3 feet, but it is very irregular in shape and dimensions. The level of the water in this chamber is, in round numbers, about 22 metres above the streets of Seville.

From the first chamber the channel runs under the town of Alcalà, and almost in the centre of the town it is joined by a second tunnel, coming from another direction, and at a much higher level, the water of which is utilized to turn a most curious underground flour-mill, to which descent is made by means of a gallery leading down from the principal street of the town. The combined waters run on in a westerly direction under the town, and on emerging from it follow the course of the river for some little distance, till they arrive at the Arroyo de Zacatin. The tunnel makes a short detour at this point, keeping well under the bed of the stream, and afterwards continues on till it leaves the broken ground, and comes out into the open country at a distance of rather more than 3 kilometres from its origin. The depth of the tunnel below the surface of the ground varies according to the nature of the latter, but it is never less than 40 or 50 feet, and in some cases it is much more. Shafts communicate with the surface at every 50 or 60 metres, these being those probably used for the

construction of the work. During the whole course of its progress through the tunnel, the stream receives additions to its volume from the numerous little springs encountered in its route, and it also loses somewhat from filtrations in those points where the tunnel approaches more nearly to the edge of the hills. At the upper part of the depression down which the Arroyo de Zacatin flows, a tunnel has been perforated into the hills, probably at the same time as the original work was made, and a considerable stream so obtained is utilized to actuate five flour-mills. At the point where this stream crossed above the tunnel, arrangements were made by means of shafts and connecting-tunnels by which the waters from the Zacatin tunnel could be turned into the main tunnel in case of shortness of supply. The total volume of water collected by the tunnel in the course of the 3 kilometres of its length, varies according to the nature of the seasons from 4,000 to 6,000 and even 8,000 cubic metres per day, say 880,000 to 1,320,000 and 1,760,000 gallons per day. The water is of excellent quality, a little hard, having about 16 degrees of hardness, but entirely free from organic matter, and containing only a very moderate quantity of salts in solution; it may be described as a first-class water for dietetic purposes. The Zacatin tunnel produces an average supply of about 500,000 gallons per day.

Considering the date of the construction of the tunnel, that the use of powder was not then known, and that for the distance of 3 kilometres the tunnel was excavated in the solid rock at a depth below the surface sometimes exceeding 150 feet, the industry and engineering talent displayed by these early masters of the profession may well be admired.

CONDUCTION TO THE CITY.

During the time of the Romans the water after leaving the tunnel was probably led direct to the town of Ontivar, but after the destruction of this latter place and the occupation of the country by the Moors, the water was led by an open conduit down to a place called Torreblanca. Here it received an additional supply from another aqueduct and tunnel, the origin of which is lost, and from hence the united streams flowed on to a point now called the Cruz del Campo, 1,100 metres from Seville, giving power during their course to nine flour-mills.

From the Cruz del Campo the water was conducted by an aqueduct to the dividing house outside the old walls at the gate

known as the Puerta de Carmona. Both the aqueduct and the watercourse are said to have been the work of the Moor Jucef Abu Jacob, A.D. 1172.

At a much later period, in order to avoid the pollution of the waters in the open course, the Town Council of Seville abandoned the nine mills which were their property, covered in the upper part of the course, and constructed another aqueduct for the purpose of carrying the water by a shorter channel over a depression in the ground, between Torreblanca and the Cruz del Campo. The level of the water at the Cruz del Campo before entering the old aqueduct is $11\frac{1}{2}$ metres above the lowest part of the city, and at the dividing house outside the Carmona Gate it is nearly 9 metres.

DISTRIBUTION OF THE WATER WITHIN THE CITY.

On the conquest of the City of Seville by the Spanish king, commonly known as Saint Ferdinand, he, in accordance with the custom of those times, took possession of the aqueduct and water, and the people were only allowed by royal favour, whatever water remained after the wants of his palace were satisfied, in the words of the old charters, of the surplus which was left after the "real casa y cocina" (royal house and kitchen) were satisfied. Immediately after the conquest, the king of course made large grants of lands and houses to his faithful followers, and at the same time he allotted to them portions of the water. Grants of water were also made to the numerous convents, which were then and afterwards established in the city. These grants are for the most part still valid, and the descendants of these old warriors, such as the Duke of Medina Coeli, and others, still claim a large share of the waters.

As time advanced, however, and the powers of the aristocracy decreased, whilst that of the townsmen increased, the administration of the water gradually fell into the hands of the town council. Public fountains were erected for the poorer classes, and portions of the water were sold or let off to the inhabitants. By degrees the quantity left for his majesty's palace grew smaller and smaller, and of the portion now claimed, his administrator considers himself lucky if he receives one-fourth part, whilst many of the old grantees are compelled, against their will, to suffer a similar reduction.

The Author will now describe the system, by which the waters were divided and conducted to the house. Before doing so, however,

it will be advisable to describe the unit of measure used in the regulations for supply. This is the "paja," the Spanish word for straw, and was doubtless originally meant to be as much water as would flow through a pipe having an internal diameter similar to that of a straw. Even supposing the diameter of a straw to be unvarying, it is evident that the amount of water flowing through it would depend directly on the head, and it can scarcely be conceived that the old Moors were not cognisant of this; but neither tradition nor written evidence has handed down any definition as to the head that was assumed, as that necessary, and though doubtless popular custom assigned some more or less regular head, yet at the present day it is impossible to find any reliable data on which to base it.

As regards the dimensions of the "paja," this was fixed at a comparatively early date, and amongst the archives of the municipality of Seville there is preserved an ancient document on vellum, in which the dimensions of the orifices necessary for the various discharges are shown graphically. On Fig. 1, the Author has reproduced the sizes from $\frac{1}{4}$ paja up to 10 pajas.

The heading of the old document referred to says:—

"The ancient and modern measures used in the distribution of the waters of the Carmona aqueduct of this city of Seville, in the times of our lords the Catholic kings, and of their predecessors, such as our lord the king Don Juan of famous memory.

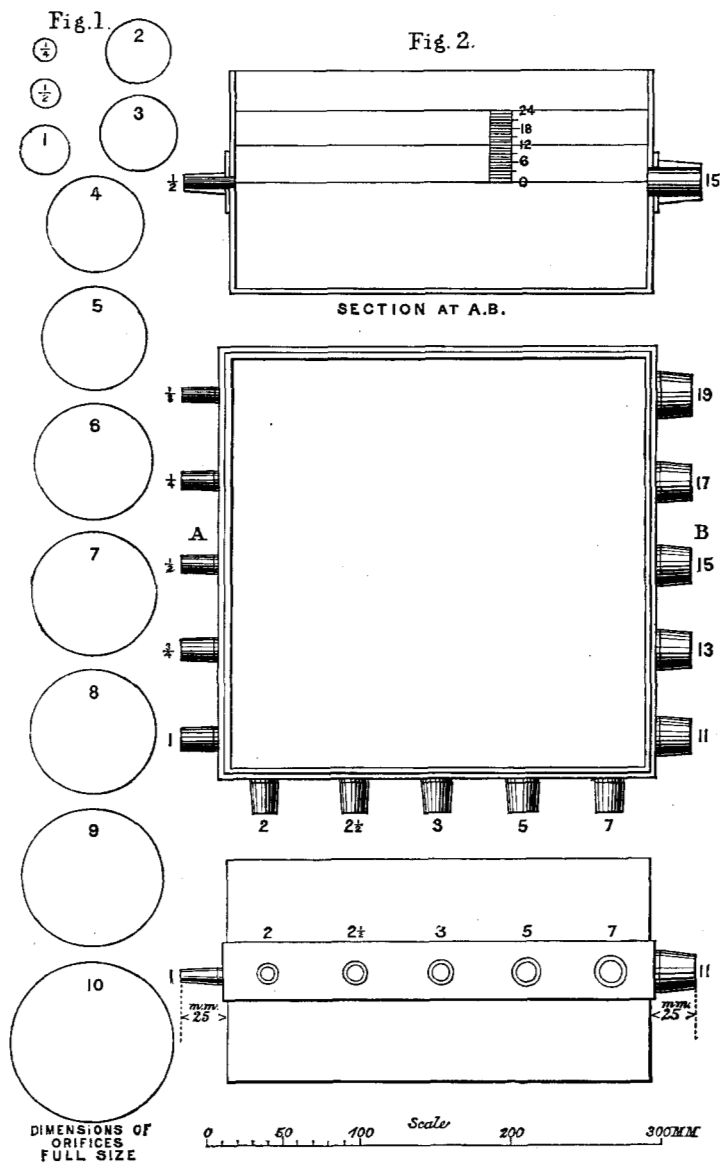
"By order of my lord Don Juan Francisco Navarette, of the council of H.M. and his judge of the royal tribunal of this city of Seville, and inspector of his royal palaces, and of the waters of the Carmona aqueduct.

"Made in the year, 1657.

SEBASTIAN DE RUESTA."

According to this document the diameter of the orifice for "one paja" is as nearly as possible 6 millimetres, or say $\frac{1}{30}$ th of a Spanish foot, and the discharge of the various orifices is shown to vary as the square of the diameter.

There exists also in the municipal archives a brass box, which is used, or was used, for measuring the water supplied to any house, in case of complaint. This box, shown by Fig. 2, is 10·82 inches square and 5·70 inches deep, and contains on three of its sides openings marked respectively from $\frac{1}{4}$ "paja" to 19 "pajas;" on the third side there is a scale, which, starting from the centre of the orifices, marks 2 Spanish inches, each inch being divided into 12



OLD WATER-SUPPLY OF SEVILLE.

Details of Metal Box for Measurement of Water, preserved in the Archives of the Town Council.

lines. It would appear from this box that the proper head should be 1 inch, as it is probable that the gauge was meant to ascertain whether any given pipe was discharging more or less than a "paja," and how much.

A series of very careful measurements made by the Author with this gauge, to determine the value of the "paja," gave with 1 inch head, the following results:—

Dimension of Orifice.	Discharge in 24 hours in Litres.
$\frac{1}{8}$ paja	270·84
$\frac{1}{4}$ "	434·17
$\frac{1}{2}$ "	604·19
$\frac{3}{4}$ "	1152·00
1 "	1661·53

According to these experiments, the value of 1 "paja" would be equal to about $365\frac{1}{2}$ gallons, and this is probably more than most of the old grantees receive, although there is a general idea prevalent in Seville, that the "paja" ought to be nearly double the amount mentioned above. The relation between the various quantities is as close as could be expected under the circumstances, as the constructors do not appear to have understood the influence of the adjutages, and these are all the same length, that for $\frac{1}{8}$ "paja" being the same as that for 19 "pajas."

The Author will now proceed to describe the system of distribution:—

The water on arriving at the city is delivered by the aqueduct into a covered reservoir, which is under the charge of an officer of the municipality, and to which no one has access without permission. The plan and section of this reservoir are shown on Plate 13, Figs. 4 and 5. The wall bounding the reservoir on one side, which is a half octagon, contains eight orifices, corresponding to eight principal mains serving the city. The first of these orifices, which is near the level of the floor, corresponds to the main supplying the royal palaces, and the opening communicates direct with an earthenware pipe. The remaining seven orifices communicate with a second chamber, from the bottom of which the pipes for the supply of each principal main lead off perpendicularly. These orifices are all provided with a bronze frame and diaphragm, pierced with holes of various dimensions. The orifice belonging to the royal palaces is 14 inches lower than the remaining seven, so that His Majesty has a decided advantage over his subjects.

The translation of the original document, preserved in the archives describing these various orifices, is as follows:—

No. 1. Pipe belonging to the royal palaces, which takes all the water of which it is capable. Its dimensions on the upper part is 14 inches, and on the lower part $9\frac{1}{2}$ inches; it does not possess its proper frame.

No. 2. Known as “Barca Rota,” in which is placed a bronze frame, having one opening, whose dimensions are equivalent to 23 “pajas” of water.

No. 3. Known as “Colegial del Salvador,” in which is found another frame of the same metal, with five openings. The first of 11 pajas; the second of 13; the third of 13; the fourth of 14; and the fifth also of 14, making together 65 “pajas” of water.

No. 4. Known as the City pipe, in which the water travels to the public fountains, the square of San Francisco, Calle Laguna, the Triana Gate, and the Square of La Magdalena, where is found another frame of the same metal as the former ones, having three orifices. The first of 24 “pajas”; the second of 30; and the third also of 30, making up 84 “pajas” of water.

No. 5. Known as “San Pablo,” is also of bronze. It consists of two orifices; the first of 18, and the second of 21 “pajas,” making together 39 “pajas” of water.

No. 6. Known as “Medina Sidonia,” of the same metal as the others, in which are six circular orifices, as are all of this principal main. They consist: the first of 36; the second of 16; the third of 13; the fourth of 13; the fifth of 11; and the sixth of 18; which added together make 107 “pajas” of water.

No. 7. Known as “Baños de San Juan de la Palma” consists of two orifices. The first of 22, and the second of 17, together 39 “pajas” of water.

No. 8. Known as that of the “Duke of Medina Coeli,” consists of one sole orifice of 18 “pajas” of water.

It will be noted that whilst many of the openings have a number of orifices of a specified size, the entire body of water delivered by them is carried off by one down pipe in the second chamber. The reason of this is to be sought in the historical antecedents of the system. As fresh grants were made by the king, or at a later period by the municipality, a new hole was bored in the frame, the size of which corresponded to the dimensions shown on the old documents, for the number of pajas granted. The main pipe was always supposed to be, and indeed was, large enough to convey all the water required; the measurement into

the main pipe was made at this chamber, and the measurement to the proprietors was made, as will be hereafter described, at the various distributing-boxes in the city.

The head of water over the orifices is that due to the difference of head between the two chambers, and is generally an inch or two. No means were provided for throttling the down pipe, but as the number of pajas admitted at the distributing chamber is, of course, exactly that distributed to the proprietors, the head of water is supposed to be balanced so as only to give the requisite discharge. Were the pipes sound and the distribution accurate, this would be so in practice. There is, however, a good deal of inequality in the distribution, and there is a large loss from leakage; but from long practice the distributors manage to make a pretty fair distribution to the various mains in chamber. The leakage is compensated for by a general discount on all the houses; and if, as often takes place, one proprietor gets more than his share, it is taken off some other proprietor, who has not had the astuteness to satisfy the official distributor. The principle of measurement is sound; it is virtually a discharge through a thin plate under a known head, and is the best and most efficient means of measuring. The openings in this main chamber have no adjutages; from which it is evident that the original constructors of this work knew more of the true principles of hydraulics than the constructors of the gauge-box.

The pipes for the conduction of the water through the streets were originally of earthenware surrounded by brickwork; many of these pipes, put down hundreds of years ago, are still doing service, but in some cases they have been superseded by cast iron. The smaller services are all of lead.

As there is occasionally a head of 25 or 30 feet on the pipes, it is evident that the leakage from the old class of pipes was, and is, considerable. It is wonderful, however, to see how well they have stood the pressure. As a matter of fact, however, out of the 4,000 metres of water per day brought into the city by the old aqueduct, not much more than one-half ever reaches its final destination.

Figs. 7 and 8, Plate 13, will explain how the distribution is made to the houses. Fig. 8 is an exact copy of one of the old plans kept in the municipality, and shows the mode of distribution in one of the small districts. The circles shown on the plan represent the dividing-boxes, the section and plan of which are shown on Fig. 7. The distribution is effected by means of a small metal box, placed in the outside wall of one of the houses, at such

a height that the level to which the water will rise at this portion of the city shall about one-half fill the box. A lead pipe about 4 inches in diameter inserted in the bottom of the box communicates with the main. The side of the box is perforated with as many holes as there are participants of the water flowing from this box, and the dimensions of the orifices correspond to the amount of *pajas* each one should receive. The water flowing from the orifices is caught in a small hollow made of cement, from which a lead pipe leads it down into the street and thence to the house of the owner. Many of these boxes serve for the division of the water from other boxes. In Fig. 8, Plate 13, it will be seen how this is done. The box G, at the corner of the Calle del Carpio, receives its water from a pipe coming down that street, and supplies five private houses and five secondary boxes, three of which are shown on this plan, lettered G', G'', G''', and the remaining two are in another district. This box therefore contains ten orifices of varying dimensions.

The large book preserved in the municipality contains plans of every district supplied similar to the one copied here, and also a series of plans or diagrams, of one of which Fig. 3 is a copy, showing the boxes situated on each main, and the houses supplied from each box. Thus the Christina box supplies eight houses, the number and street of each being written on the diagram. At the side of each diagram is a statement showing the street and the number of each house, and the amount of water it is to receive counted in fourth parts of "*pajas*."

The old boxes were mostly of iron or bronze, the metal being from $\frac{1}{8}$ to $\frac{1}{4}$ inch thick; they are of various shapes, some being oval and some square; as a rule they are about a foot square, and 9 inches deep. They are at varying heights above the street, according to the level of the latter.

It is evident that, theoretically, this system of measuring the water was good, and if a uniform head could be kept, there would be nothing to object to. Practically there were many drawbacks. There was no effectual way of controlling the head; the boxes were fixed in accordance with the height to which it was ascertained by actual experiment the water would rise; but once fixed, many causes combined to render the pressure a constantly varying one. The men in charge of the various districts manipulated the boxes in accordance with their hereditary practical instincts, and a kind of rough-and-ready justice was administered. Thus, in one box where there was too great a flow of water, either from the box having been fixed originally too low or a

greater pressure having been given by the laying of new and larger mains, the Author saw that a half brick had been placed on the inlet-pipe, and by this means the head was kept down to about 4 inches. The keys of all the boxes are kept by the head water-bailiff; and it is easy to understand what power this gave to a shrewd practical man who understood, in his own way, how to increase or diminish the supply to each house. His position thus became a lucrative one. To obtain one's full supply it was necessary to be on good terms with him, whilst those who had not thus provided for themselves found their supply daily growing smaller and smaller. At the same time a kind of practical balance was maintained in each district.

It will be easily understood that, after its numerous journeys, and the large amount of friction to which it was subjected, the water had not much power remaining when it arrived at the houses. In few houses, even in streets at the lowest level, did it rise many feet above the level of the floors; almost all, if not all, the houses which have water, collect it in a marble cistern, from whence it is pumped up by hand-power to the upper floors.

The new waterworks, now far advanced towards completion, will sweep away all the old system of distribution. They take the water at the conclusion of the tunnel and pump it up by steam-power to reservoirs constructed near the town of Alcalà, from whence it will be conducted by a 21-inch main to the city and distributed under a mean pressure of 25 metres head, so as to rise to the top floors of the highest houses.

Before all the data for doing so vanish, the Author thought that a description of these ancient works would probably interest the profession, as giving an account of perhaps one of the oldest systems of house-distribution known in connection with the water-supply of towns.

The communication is illustrated by four sheets of small scale drawings, from which Plate 13 and the woodcuts, Figs. 1, 2, and 3, have been prepared.

OLD SEVILLE WATER SUPPLY.

PLATE 13.

PLAN SHEWING COURSE OF TUNNEL AND AQUEDUCT.

Scale: $\frac{1}{50,000}$.

Fig: 1.

Fig: 2.

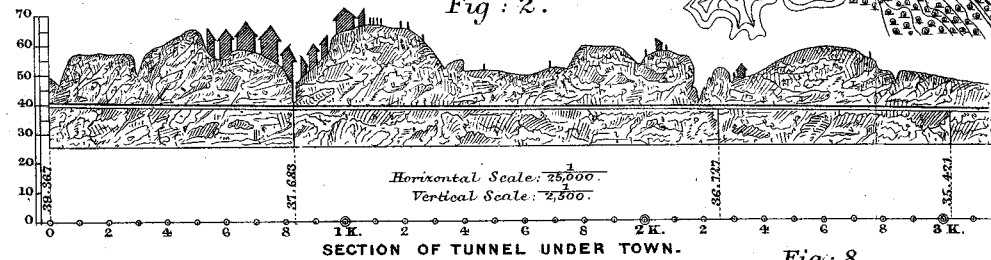
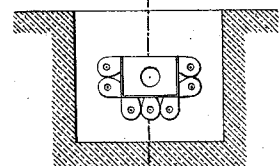
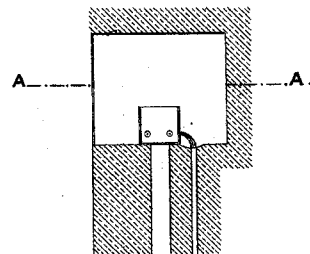


Fig: 7.

SUBSIDIARY DIVIDING BOX IN CITY.



HORIZONTAL SECTION A.A.

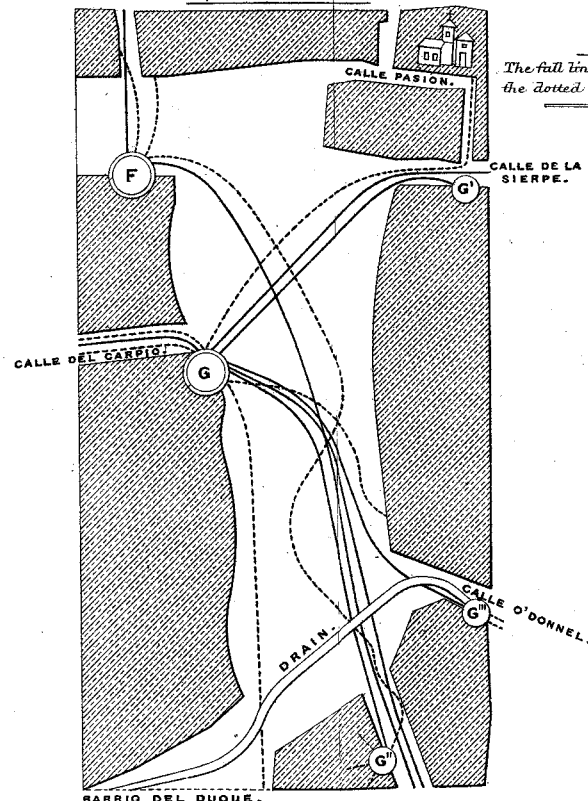


Level of Ground

VERTICAL SECTION B.B.

Fig: 8.

Copied from the Register Book in the Municipal Archives of Seville.

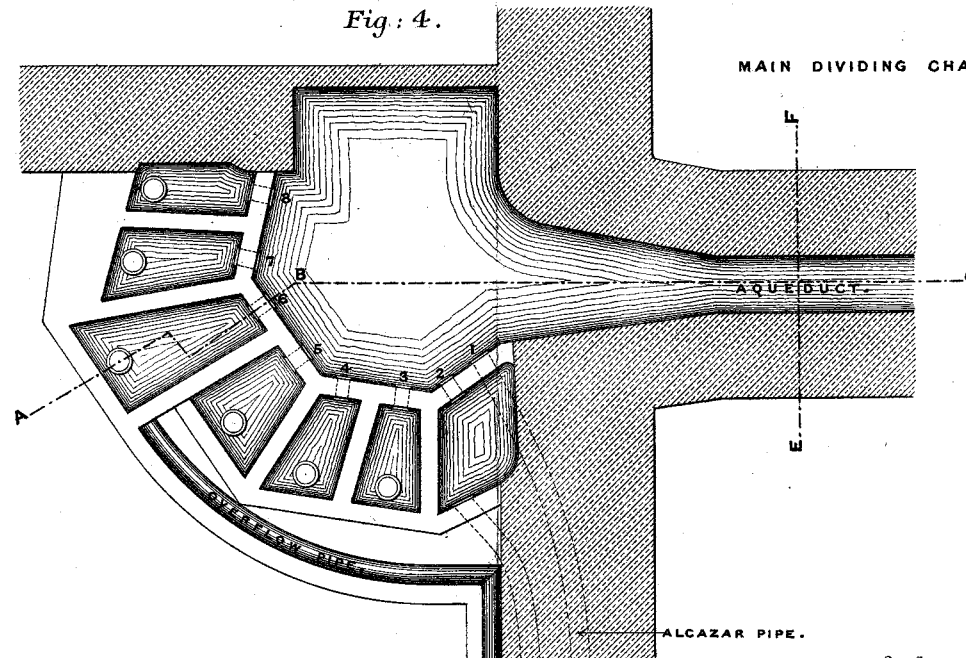


SITUATION OF ALL THE PIPES IN THE DISTRICT OF THE CAMPANA IN 1824.

NOTE:

The full lines are the principal pipes,
the dotted lines are private ones.

Fig: 4.



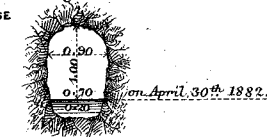
PLAN.

M.M. 1000 500 0

Scale.

2 Metres.

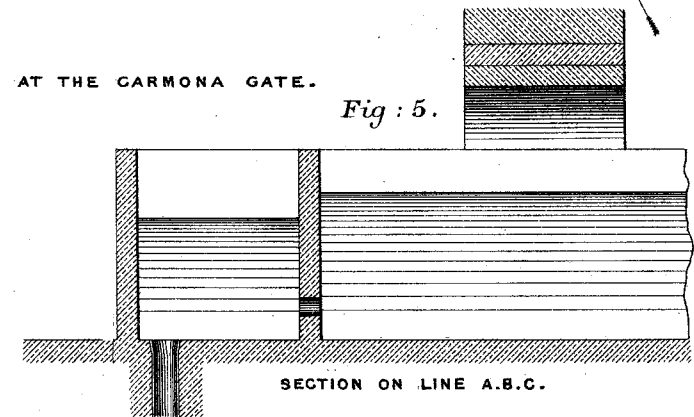
Fig: 3.



CROSS SECTION OF TUNNEL.

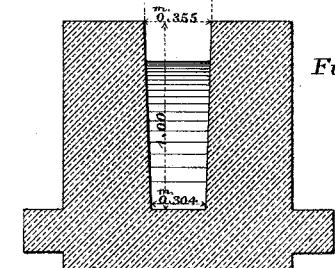
Scale: $\frac{1}{100}$.

Fig: 5.



SECTION ON LINE A.B.C.

Fig: 6.



SECTION AT E.F.